DUNE-APA PCB Tolerance Change Request

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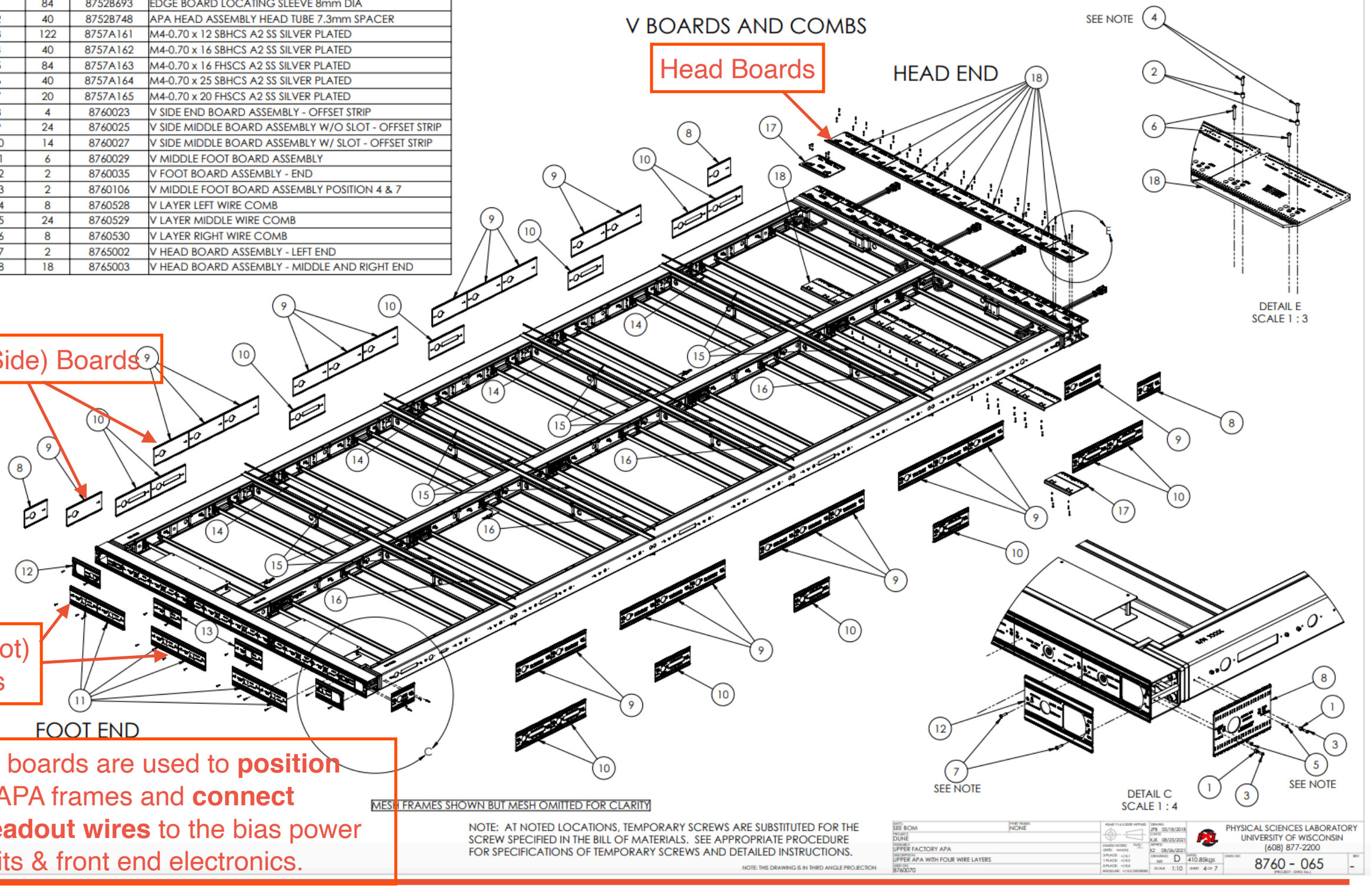
for the DUNE APA PCB Team

DUNE APA Technical Board Meeting, 21st August 2023.

University of Sheffield

What are Geometry Boards?

ITEM NO.	QTY.	PART NUMBER	DESCRIPTION
1	84	8752B693	EDGE BOARD LOCATING SLEEVE 8mm DIA
2	40	8752B748	APA HEAD ASSEMBLY HEAD TUBE 7.3mm SPACER
3	122	8757A161	M4-0.70 x 12 SBHCS A2 SS SILVER PLATED
4	40	8757A162	M4-0.70 x 16 SBHCS A2 SS SILVER PLATED
5	84	8757A163	M4-0.70 x 16 FHSCS A2 SS SILVER PLATED
6	40	8757A164	M4-0.70 x 25 SBHCS A2 SS SILVER PLATED
7	20	8757A165	M4-0.70 x 20 FHSCS A2 SS SILVER PLATED
8	4	8760023	V SIDE END BOARD ASSEMBLY - OFFSET STRIP
9	24	8760025	V SIDE MIDDLE BOARD ASSEMBLY W/O SLOT - OFFSET STRIP
10	14	8760027	V SIDE MIDDLE BOARD ASSEMBLY W/ SLOT - OFFSET STRIP
11	6	8760029	V MIDDLE FOOT BOARD ASSEMBLY
12	2	8760035	V FOOT BOARD ASSEMBLY - END
13	2	8760106	V MIDDLE FOOT BOARD ASSEMBLY POSITION 4 & 7
14	8	8760528	V LAYER LEFT WIRE COMB
15	24	8760529	V LAYER MIDDLE WIRE COMB
16	8	8760530	V LAYER RIGHT WIRE COMB
17	2	8765002	V HEAD BOARD ASSEMBLY - LEFT END
18	18	8765003	V HEAD BOARD ASSEMBLY - MIDDLE AND RIGHT END



Geometry boards are used to **position wires** on APA frames and **connect charge readout wires** to the bias power supply units & front end electronics.

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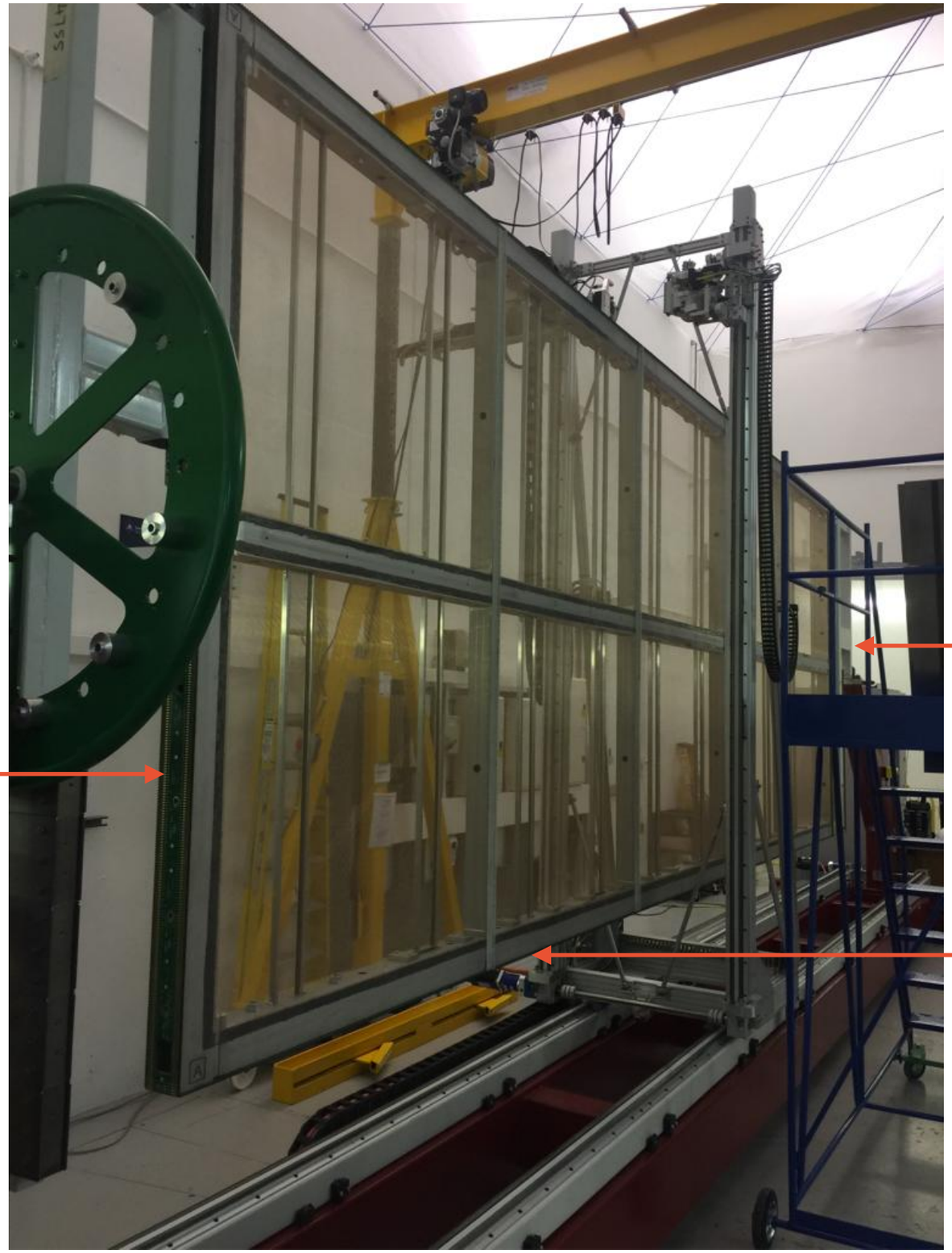
Geometry Boards on an APA



Head Boards

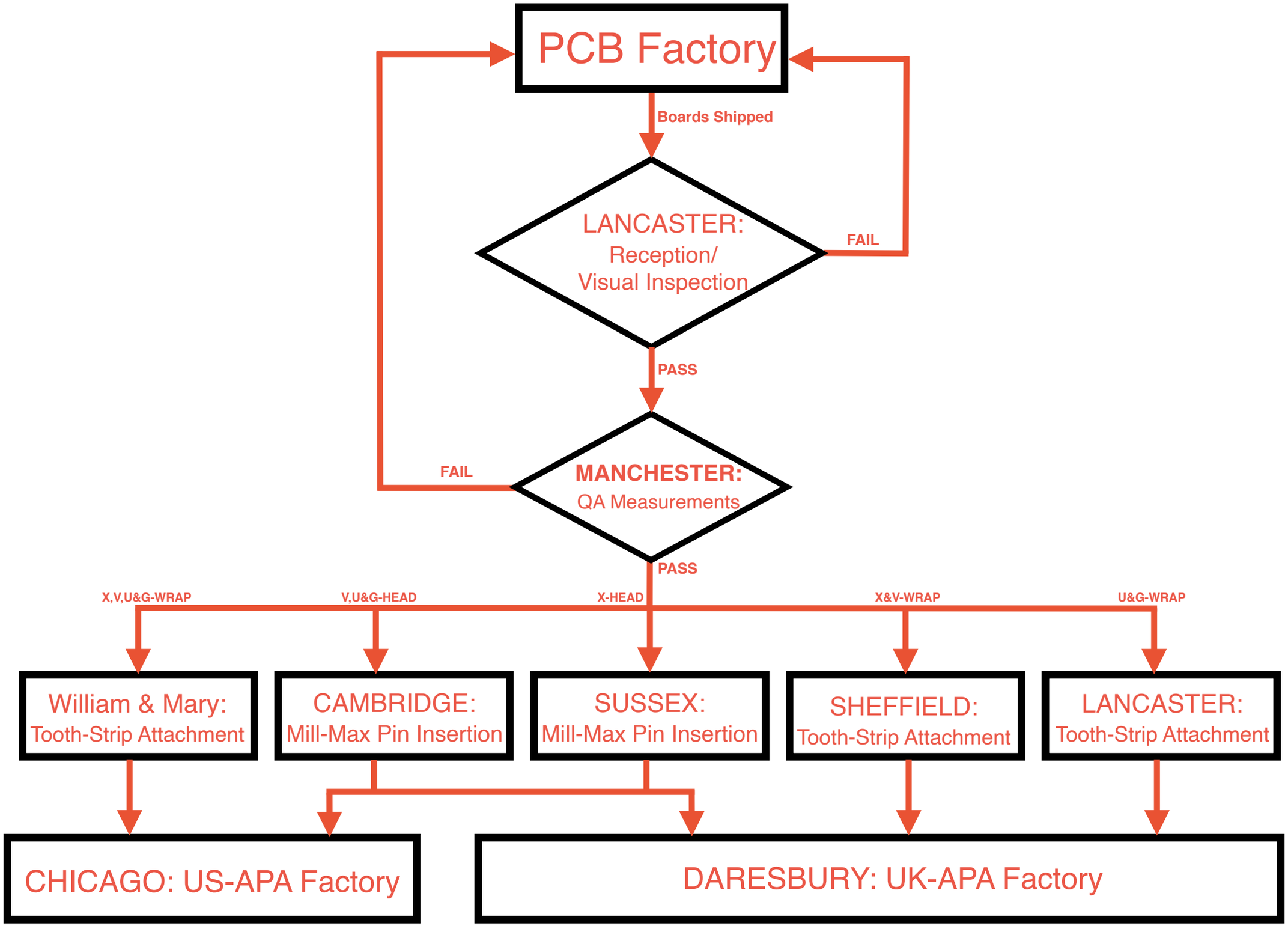
Wrap (Foot) Boards

Wrap (Side) Boards

APA PCB Production Requirements

- Required number of UK-APAs: 134
- Required number of US-APAs: 14
- Total APA worth of geometry boards: 148
- **UK** to produce **148 APAs** worth of **geometry boards** (i.e. a total of **32,436** pieces of geometry boards).
- Geometry boards are:
  - Head and wrap (side and foot) boards that come in **29** flavours.
- **US** to produce **148 APAs** worth of **filter boards** (i.e. a total of **9,176** boards).
- Filter boards are:
  - CR, G-bias filter, CE-CR Adapter and SHV header boards that come in **5** flavours.

APA PCB Processing Work Flow



Board Shipments To APA Factories

APA No	Date Required	Date shipped to Daresbury, Chicago & W&M									
		X-Head (Sus)	V-Head (Cam)	U-Head	G-Head	X-Wrap	V-Wrap	U-Wrap (Lan)	G-Wrap (Lan)	Cover (Shef)	Etched cover
4	1-Sep-2022	1-Jul-2022	1-Jul-2022	1-Jul-2022	1-Jul-2022	1-Jul-2022	1-Jul-2022	30-Sept-2022	30-Sept-2022	1-Jul-2022	25-Nov-2022
5	1-Sep-2022	28-	24-Oct-2022	24-Oct-2022	22-Aug-2022	15-Aug-2022	15-Aug-2022	16-Nov-2022	16-Nov-2022	28-Aug-2022	25-Nov-2022
6	1-Sep-2022	27-Jul-2022	24-Oct-2022	24-Oct-2022	7-Sept-2022	6-Oct-2022	6-Oct-2022	31-Oct-2022	31-Oct-2022	28-Aug-2022	25-Nov-2022
7	1-Sep-2022	23-Nov-2022	31-Oct-2022	6-Jan-2023	7-Sept-2022	18-Oct-2022	18-Oct-2022	25-Nov-2022	25-Nov-2022	28-Aug-2022	25-Nov-2022
8	1-Nov-2022	1-Dec-2022	6-Jan-2023	6-Jan-2023	27-Sept-2022	28-Oct-2022	28-Oct-2022	15-Dec-2022	15-Dec-2022	28-Aug-2022	13-Jun-2023
US 1	1-Feb-2023	17-	28-Feb-2023	24-Feb-2023	28-Feb-2023	25-Jan-2023	25-Jan-2023	25-Jan-2023	25-Jan-2023	28-Apr-2023	
9	1-Nov-2022	13-Dec-2022	6-Jan-2023	13-Jan-2023	27-Sept-2022	7-Nov-2022	7-Nov-2022	19-Jan-2023	19-Jan-2023	19-Jun-2023	13-Jun-2023
10	1-Nov-2022	6-Jan-2023	6-Jan-2023	7-Feb-2023	27-Sept-2022	16-Nov-2022	16-Nov-2022	10-Mar-2023	10-Mar-2023	19-Jun-2023	
11	1-Nov-2022	17-Jan-2023	10-Jan-2023	22-Feb-2023	27-Sept-2022	28-Nov-2022	28-Nov-2022	4-Apr-2023	4-Apr-2023	10-Jul-2023	
12	12-May-2023	24-Jan-2023	9-Feb-2023	23-Feb-2023	27-Sept-2022	5-Dec-2022	5-Dec-2022	25-Apr-2023	25-Apr-2023	10-Jul-2023	
US 2	31-May-2023	17-	21-Apr-2023	27-Apr-2023	27-Apr-2023	28-Apr-2023	28-Apr-2023	28-Apr-2023	28-Apr-2023	6-Jul-2023	
13	22-Jun-2023	30-Jan-2023	27-Apr-2023	14-Mar-2023	14-Nov-2022	15-Dec-2022	15-Dec-2022	9-May-2023	9-May-2023	10-Jul-2023	
14	24-Jul-2023	22-Feb-2023	9-May-2023	31-Jul-2023	8-Feb-2023	5-Jan-2023	5-Jan-2023	18-May-2023	18-May-2023	10-Jul-2023	
15	1-Jan-2023	5-Apr-2023		3-Aug-2023	2-Aug-2023	13-Jan-2023	13-Jan-2023	1-Jun-2023	1-Jun-2023	10-Jul-2023	
16	1-Jan-2023	21-Apr-2023			11-Aug-2023	15-May-2023	15-May-2023	13-Jun-2023	13-Jun-2023	10-Jul-2023	
17	26-May-2023	2-May-2023				19-May-2023	19-May-2023	22-Jun-2023	22-Jun-2023	26-Jul-2023	
US 3	17-May-2023	6-Jun-2023	22-Jun-2023	29-Jun-2023	05-Jul-2023	20-Jun-2023	20-Jun-2023	16-Jun-2023	16-Jun-2023	6-Jul-2023	
18	15-Feb-2023	12-				25-May-2023	25-May-2023	6-Jul-2023	6-Jul-2023	26-Jul-2023	
19	15-Feb-2023	12-Jul-2023				1-Jun-2023	1-Jun-2023	Ready -7x 8760042 boards		27-Jul-2023	
20	15-Feb-2023					19-Jun-2023	19-Jun-2023			27-Jul-2023	
21	15-Feb-2023					19-Jun-2023	19-Jun-2023			31-Jul-2023	
22	15-Feb-2023					4-Jul-2023	4-Jul-2023			17-Aug-2023	
US 4	15-Jun-2023	3-Jul-2023		28-Jul-2023	28-Jul-2023	ship from	ship from	ship from	ship from Man	6-Jul-2023	
23	1-Apr-2023					2-Aug-2023	2-Aug-2023			17-Aug-2023	
24	1-Apr-2023									21-Aug-2023	
25	1-Apr-2023									21-Aug-2023	
26	1-Apr-2023										
27	1-Apr-2023										
US 5	20-Jul-2023					ship from	ship from	ship from	ship from Man	6-Jul-2023	

- Highlighted in red are **scrapped UK-APA 6 boards**.
- **Solid blue line** in the table above shows the current position of **Daresbury APA factory** in utilising the delivered geometry boards. The US APA factory is yet to start production.
- So, the **APA board production/assembly** is ahead of **both the UK and US APA factories** as required.

Geometry Board Production Status

S/N	Board Ref No	Description	No Per APA	No passed QA	APAs Passed	No Ordered	% order passed
1	8760119	U Head Board Left End	2	86	43	318	27.0%
2	8760030	V Foot Board Middle	6	344	57.3	954	36.1%
3	8760057	U-Foot Board Middle	6	294	49	954	30.8%
4	8760116	V Head Board Left End	2	165	82.5	318	51.9%
5	8760044	U-Foot Board High Slot End	1	126	126	159	79.2%
6	8760123	U Head Board Right End	2	51	25.5	318	16.0%
7	8760054	G Edge Board Middle	6	212	35.3	954	22.2%
8	8760026	V Side Board Middle Without Slot	24	620	25.8	3816	16.2%
9	8760040	U-Side Board Without Slot Middle	24	729	30.4	3816	19.1%
10	8760038	U-Side Board End	4	305	76.3	636	48.0%
11	8760121	G Head Board Middle	16	800	50	2544	31.4%
12	8760108	V Head Board Right End	18	275	15.3	2862	9.6%
13	8760122	G Head Board Left-End	2	90	45	318	28.3%
14	8760104	X Board Head	20	630	31.5	3180	19.8%
15	8760034	X Edge Board Middle	6	326	54.3	954	34.2%
16	8760024	V Side Board End	4	301	75.3	636	47.3%
17	8760109	X Edge Board Position 4 And 7	2	202	101	318	63.5%
18	8760036	V Foot Board End	2	227	113.5	318	71.4%
19	8760107	V Foot Board Middle Position 4 And 7	2	188	94	318	59.1%
20	8760111	U-Foot Board Position 4 And 7	2	223	111.5	318	70.1%
21	8760059	U-Foot Board Low Slot End	1	86	86	159	54.1%
22	8760032	X Edge Board End	2	237	118.5	318	74.5%
23	8760051	G Edge Board Low Slot End	1	90	90	159	56.6%
24	8760113	G Edge Board Position 4 and 7	2	78	39	318	24.5%
25	8760062	G Edge Board High Slot End	1	55	55	159	34.6%
26	8760115	U Head Board Middle	16	567	35.4	2544	22.3%
27	8760120	G Head Board Right-End	2	144	72	318	45.3%
28	8760028	V Side Board Middle With Slot	14	369	26.4	2226	16.6%
29	8760042	U-Side Board With Slot Middle	14	256	18.3	2226	11.5%
		Total	204	8076		32436	
				24.9%			

- **Red: less than 20 APAs** worth of the board type have passed visual inspection and metrology measurements (top production priority). **14%.**
- **Yellow: only 20 - 49 APAs** worth of the board type have passed visual inspection and metrology measurements (medium production priority). **45%.**
- **Green:** the December 2023 target of **50 APAs** worth of a given board type have already passed visual inspection and metrology measurements. **41%.**

University of Sheffield DUNE

Are There Boards We Can Accept On Concession?

DUNE-APA PCB Tolerance Review Meeting

- To check if there are board feature tolerances we could relax on **concession** to improve the board QA pass rate, we had a DUNE PCB feature tolerance review meeting on the **1st day of March 2023 at the Daresbury APA factory**.

- The following people attended the meeting:

  - **Justin Evans** (Manchester): DUNE APA Management
  - **Vitaly Kudryavtsev** (Sheffield): DUNE PCB Management
  - **Dan Salisbury** (STFC-Daresbury): APA Factory Expert
  - **Graham Miller** (Manchester): Electrical Engineer
  - **Pawel Guzowski** (Manchester): Postdoc on DUNE APAs
  - **Anthony Ezeribe** (Sheffield): Postdoc on DUNE APAs

Features Failing On Head Boards

All tested boards		
(total tested boards) 2964	# Failed QA	%tage
SLOT_H	228	7.69%
RMOUNT_SLOTH	151	5.09%
RMOUNT_TR_DIA	117	3.95%
LMOUNT_TL_DIA	113	3.81%
LMOUNT_BR_DIA	113	3.81%
LMOUNT_TR_DIA	111	3.74%
RMOUNT_BR_DIA	108	3.64%
RMOUNT_TL_DIA	106	3.58%
REDGE_B	94	3.17%
TH_R_TR_DIA	91	3.07%
THICK_GROOVE	89	3.00%
TH_L_BL_DIA	64	2.16%
TH_L_TL_DIA	52	1.75%
TH_R_BL_DIA	52	1.75%
TH_L_TR_DIA	50	1.69%
TH_R_TL_DIA	49	1.65%
THICK_RELIEF	47	1.59%
LMOUNT_C_DIA	44	1.48%
RMOUNT_C_DIA	44	1.48%
DIA001	42	1.42%
LEDGE_B	41	1.38%
DIA002	38	1.28%
DIA004	38	1.28%
DIA003	37	1.25%
TH_R_BR_DIA	36	1.21%
DIA041	35	1.18%
TH_L_BR_DIA	32	1.08%
DIA042	29	0.98%
TEDGE_R	28	0.94%
BEDGE_R	27	0.91%
DIA043	27	0.91%

After 1 Oct 2022			
(total tested boards) 2283	# Failed QA	%tage	Board Feature
RMOUNT_SLOTH	129	5.65%	Slot height (all 8760108 boards)
SLOT_H	119	5.21%	Slot height
RMOUNT_TR_DIA	117	5.12%	Mounting hole diameter
LMOUNT_TL_DIA	113	4.95%	Mounting hole diameter
LMOUNT_BR_DIA	113	4.95%	Mounting hole diameter
LMOUNT_TR_DIA	111	4.86%	Mounting hole diameter
RMOUNT_BR_DIA	108	4.73%	Mounting hole diameter
RMOUNT_TL_DIA	106	4.64%	Mounting hole diameter
TH_R_TR_DIA	85	3.72%	Mounting hole diameter
REDGE_B	74	3.24%	Edge position
THICK_GROOVE	70	3.07%	Groove thickness
TH_L_BL_DIA	55	2.41%	Mounting hole diameter
TH_R_BL_DIA	47	2.06%	Mounting hole diameter
TH_L_TR_DIA	45	1.97%	Mounting hole diameter
LMOUNT_C_DIA	44	1.93%	Mounting hole diameter
RMOUNT_C_DIA	44	1.93%	Mounting hole diameter
TH_L_TL_DIA	43	1.88%	Mounting hole diameter
TH_R_TL_DIA	41	1.80%	Mounting hole diameter
DIA001	38	1.66%	MM pin hole diameter
LEDGE_B	33	1.45%	Edge position
DIA003	32	1.40%	MM pin hole diameter
DIA004	32	1.40%	MM pin hole diameter
DIA002	31	1.36%	MM pin hole diameter
DIA041	30	1.31%	MM pin hole diameter
THICK_RELIEF	29	1.27%	Relief thickness
DIA043	26	1.14%	MM pin hole diameter
TH_R_BR_DIA	25	1.10%	Mounting hole diameter
DIA042	25	1.10%	MM pin hole diameter
TH_L_BR_DIA	24	1.05%	Mounting hole diameter
BEDGE_R	23	1.01%	Edge position
DIA044	22	0.96%	

- All Head Boards (HB) tested from inception: **2964**
- Head boards tested from 01/10/2022: **2283**
- Failed HB points since 01/10/2022: **3220**
- HB we can accept under concession: **1512**
- Head board failure reduction rate: **~46.96%**

- Green: **Features not critical**. Proposed to relax tolerances at the meeting - see the first change request.
- Red: **Tolerances proposed to be relaxed** but needed more work to determine limits - see the second request.
- Blue: **Very critical features**, so current tolerances **cannot be changed**.

Procedure Change Requests On EDMS

Geometry Board Tolerances And Metrology Procedure Change Request

Requester: Justin Evans, Vitaly Kudryavtsev, Graham Miller, Pawel Guzowski & Anthony Ezeribe	Date: 31/03/2023
	Number: APA-PCB-09

Description of requested change:	Reason for change:
We had a meeting at the Daresbury factory with the APA winding experts to understand the board features that are critical to produce a functional APA. Considering their requests and the physics requirements of the DUNE detector, we propose as follows: **FOR HEAD BOARDS:** **(1) Mounting Slot Heights/Hole Sizes:** slots that are on head boards are needed for positioning boards for winding a given wire layer. So we propose to measure only the **relevant slot** for any given wire layer. The slots/holes that are relevant to each of the wire layers are: "10,11" for the X-layer "16,17" for the V-layer "12,18" for the U-layer "12,21" for the G-layer These proposed changes does not apply to the centre "12" mounting holes. **(2) Board Widths:** Tolerance on the board widths is currently ±150 µm. We are proposing to change the tolerance of the datum to solder pad head board edge widths to **±250 µm** while the datum to Mill-Max pin hole edge widths remains unchanged at **±150 µm**, see the picture below for details.	PCR-1 This change is necessary as slots and slot heights that are needed for positioning the X-layer boards (for instance) will not be needed or make any difference to the following V, U and G wire layers. The distance between solder pads and width-edge of head boards is currently 13 -15 mm so removing or adding an extra ±250 µm will not affect the functioning or IPC power ratings of the head boards. So we propose to move the tolerance of the datum to solder pad head board edge widths from the current ±150 µm to ±250 µm.

Geometry Board Tolerances And Metrology Procedure Change Request

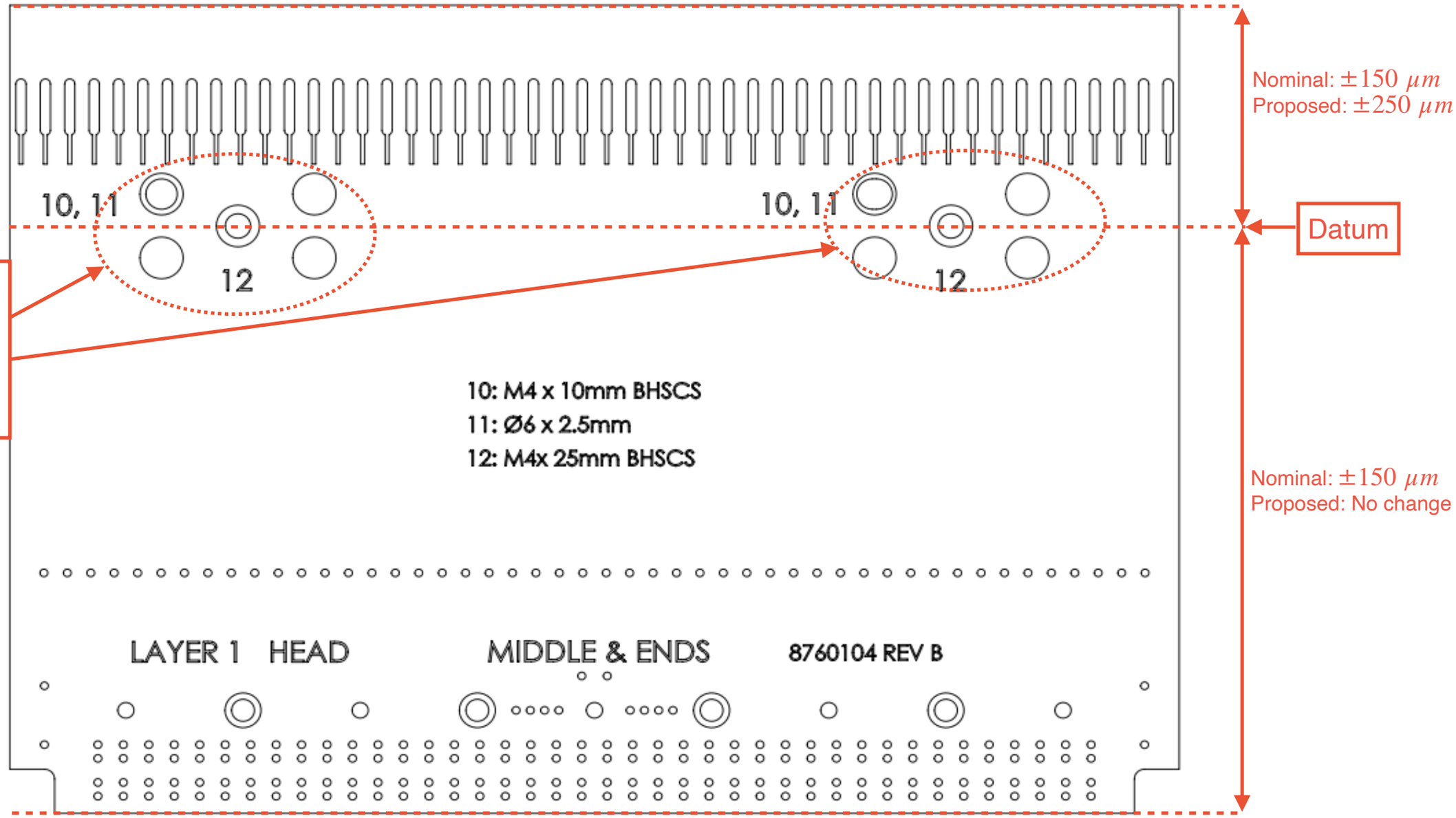
Requester: Justin Evans, Vitaly Kudryavtsev, Graham Miller, Pawel Guzowski & Anthony Ezeribe	Date: 24/05/2023
	Number: APA-PCB-10

Description of requested change:	Reason for change:
We had a meeting at the Daresbury factory with the APA winding experts to understand the board features that are critical to produce a functional APA. Considering their requests and the physics requirements of the DUNE detector, we propose as follows: **FOR HEAD BOARDS:** (1) **Groove Thickness:** To change epoxy groove thickness tolerances on V, U and G head boards which are used to collect/stop DP-2216 epoxy from flowing into the Mill-Max press-fit connector pin holes. The major constraining issues on these head board groove thickness design are whether (a) the thickness of FR4 materials beneath the epoxy groove could break after tensioned wires are soldered on the head board and (b) the groove size will be enough to collect all the epoxy. Considering these issues, we propose to change the tolerances of the head board grooves from the current $1.05^{+0.25}_{-0.20}$ mm to $1.05^{+0.45}_{-0.25}$ mm. (2) **Central Counter-bore Mounting Hole Diameter:** To change the central counterbored hole diameter tolerances. These holes are marked "12" on each head board. The major constraining issues on these head board central counterbored hole diameter design are whether (a) the M4 screws in such holes will have enough FR4 materials to rest on when locked and (b) the screws will have enough clearance to pass through if the holes	PCR-2 The proposed head board groove tolerances will ensure that each of the V, U and G head boards will have a minimum of **230 x 5 x 0.8 mm³** groove and a maximum of **230 x 5 x 1.5 mm³** groove which will be enough to stop epoxy from flowing to the Mill-Max pin holes. The maximum expected tension on any of the head boards is **~350N** (i.e. 48 wires x 7N) which is well below the expected **2,760 N** flexural strength of a head board with the **230 x 5 x 1.5 mm³** (worst case) epoxy groove so the head boards can still carry the tensioned wires with the proposed tolerances. To ensure that there are enough FR4 materials to hold the head of the locked M4 screws, we have not made the hole bigger by not changing the maximum allowed counterbored hole diameter. The minimum allowed counterbored hole diameter for a given M4 screw is 4.3 mm. However, the proposed tolerance here allows a minimum counterbored hole diameter of 4.5 mm to ensure that the screws have enough

- The first procedure change request (PCR) was uploaded on EDMS on the 31st day of March while the second PCR went live on EDMS on the 24th day of May 2023.
  - **EDMS Link to the first PCR:** https://edms.cern.ch/ui/file/2881026/1/APA_PCB_Metrology_Procedure_Change_Request.pdf
  - **EDMS link to the second PCR:** https://edms.cern.ch/ui/file/2898080/1/APA_PCB_Metrology_Procedure_Change_Request2.pdf

Head Board Slot Hole & Edge Dimensions

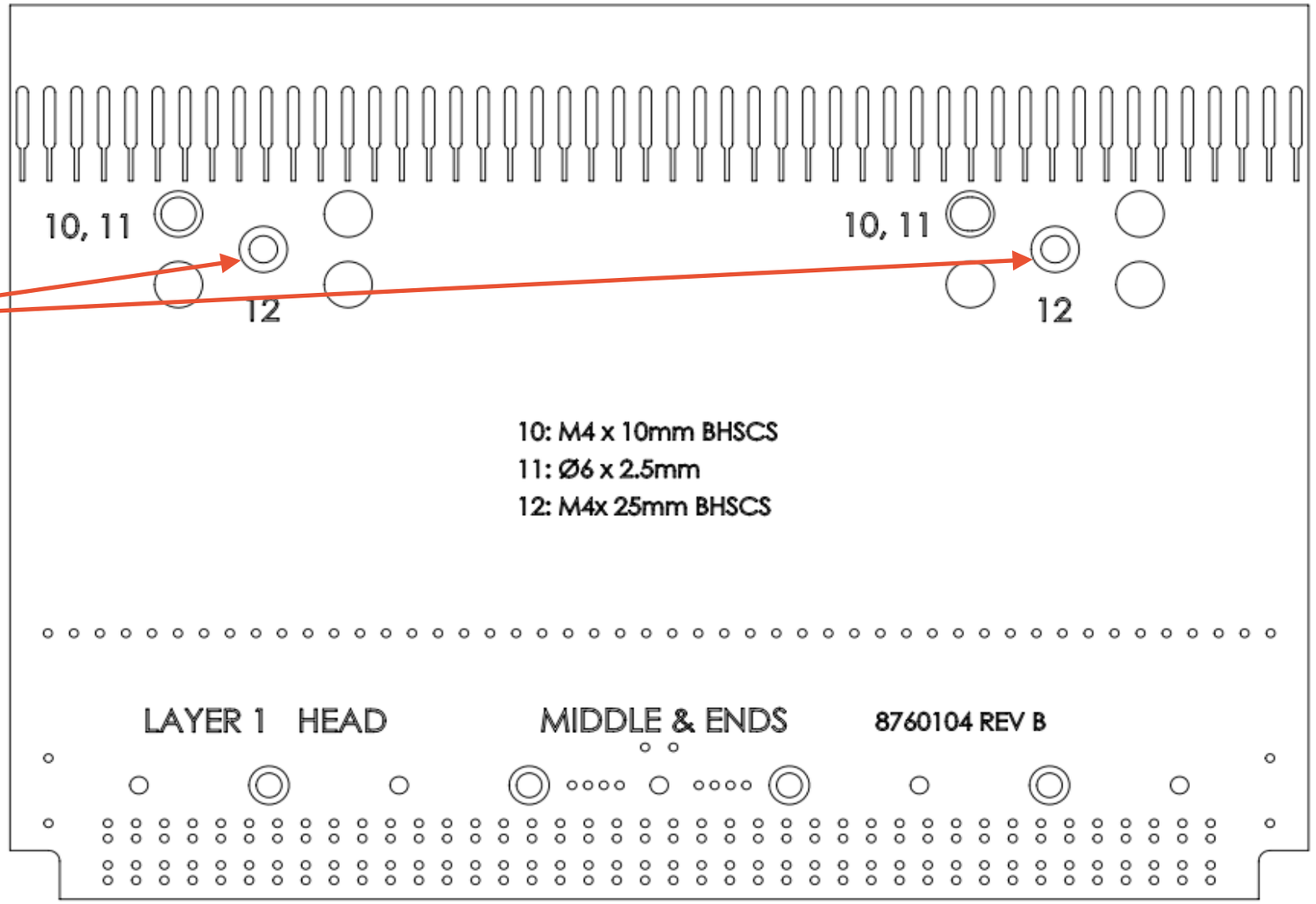
Mounting Slot Holes (Slot heights widths) in **PCR-1**. and



- **MT Slot holes** “10,11” relevant for only the X-layer boards. Slots, “16,17”; “12,18”; “12, 21” are all relaxed on X-layer boards.
- **MT Slot Holes** “16,17” relevant for only the V-layer boards. Slots, “10,11”; “12,18”; “12, 21” are all relaxed on V-layer boards.
- **MT Slot Holes** “12,18” relevant for only the U-layer boards. Slots, “10,11”; “16,17”; “12, 21” are all relaxed on U-layer boards.
- **Slots/MT holes** “12, 21” relevant for only the G-layer boards. Slots, “10,11”; “16,17”; “12, 18” are all relaxed on G-layer boards.

Head Board Central Counterbore Holes

Central Mounting Counterbored Hole Diameter in PCR-2.

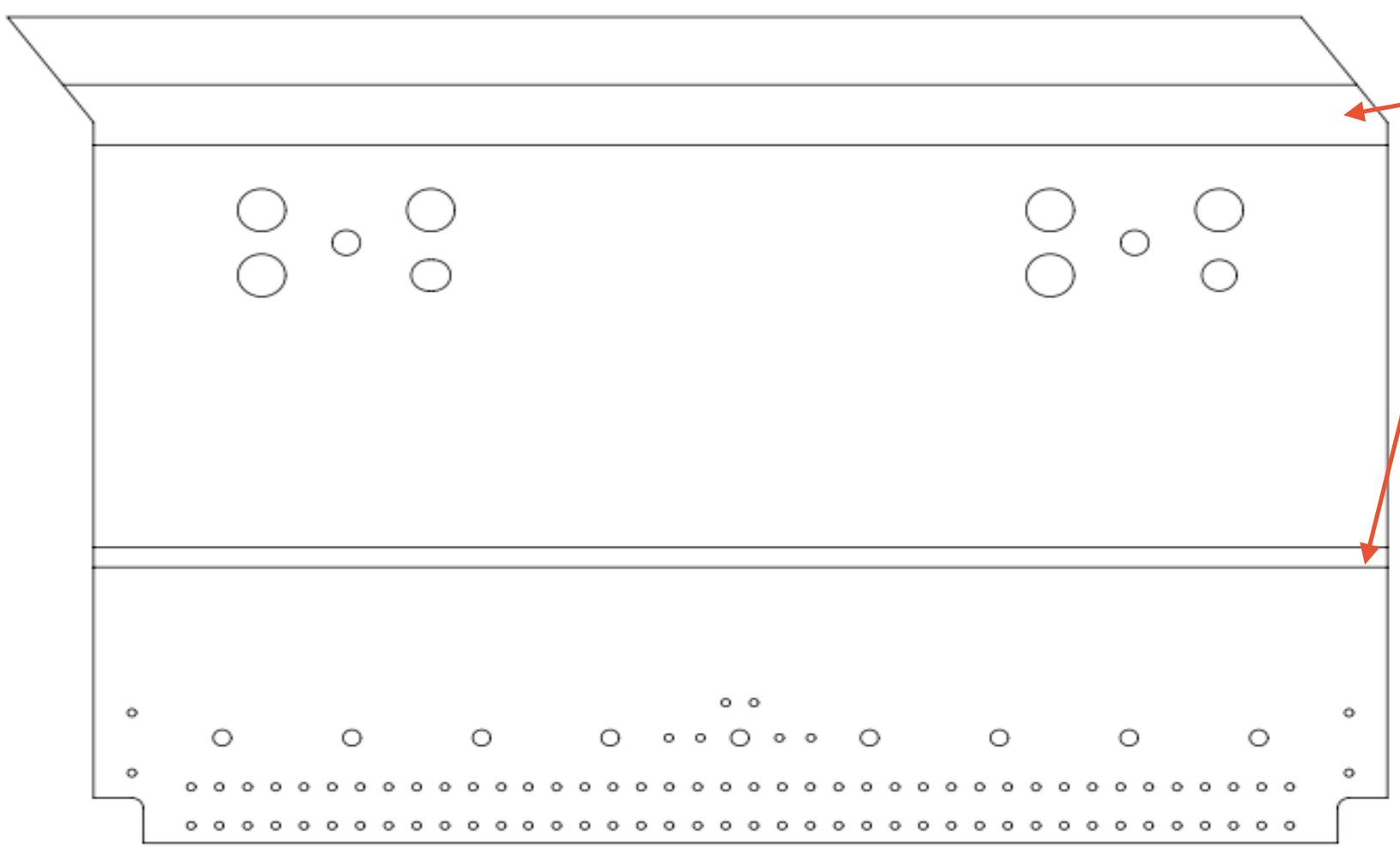


- Nominal head board central counterbore hole diameter is 5.000 ± 0.115 mm, proposed for change to $\mathbf{5.000^{+0.115}_{-0.500}}$ **mm**. See **PCR-2** for details.

- The counterbore hole has not been made bigger to ensure that the head of the M4 screw locks the head board with enough FR4 material.

- The minimum possible clearance for an M4 screw is 4.3 mm but the minimum counterbore diameter is 4.5 mm.

Head Board Epoxy Groove Depth



- The nominal **head board epoxy groove depth** is $1.05^{+0.25}_{-0.20}$ mm, proposed for change to $\mathbf{1.05^{+0.45}_{-0.25}}$ **mm**.
- The nominal **head board epoxy relief depth** is 0.25 ± 0.15 mm, proposed for change to $\mathbf{0.25^{+0.3}_{-0.18}}$ **mm**.
- The proposed tolerances will allow a minimum head board epoxy groove volume of **230 x 5 x 0.8 mm³** with a maximum groove volume of **230 x 10 x 1.5 mm³** expected to be enough to stop epoxy from reaching the MM pins.
- The maximum expected tension on each head board is **~336 N** (7N x 48 wires) which is well below the expected ~**1190 N** limit of a head board with the **230 x 10 x 1.5 mm³** epoxy groove (worst case).

Features Failing On Wrap Boards

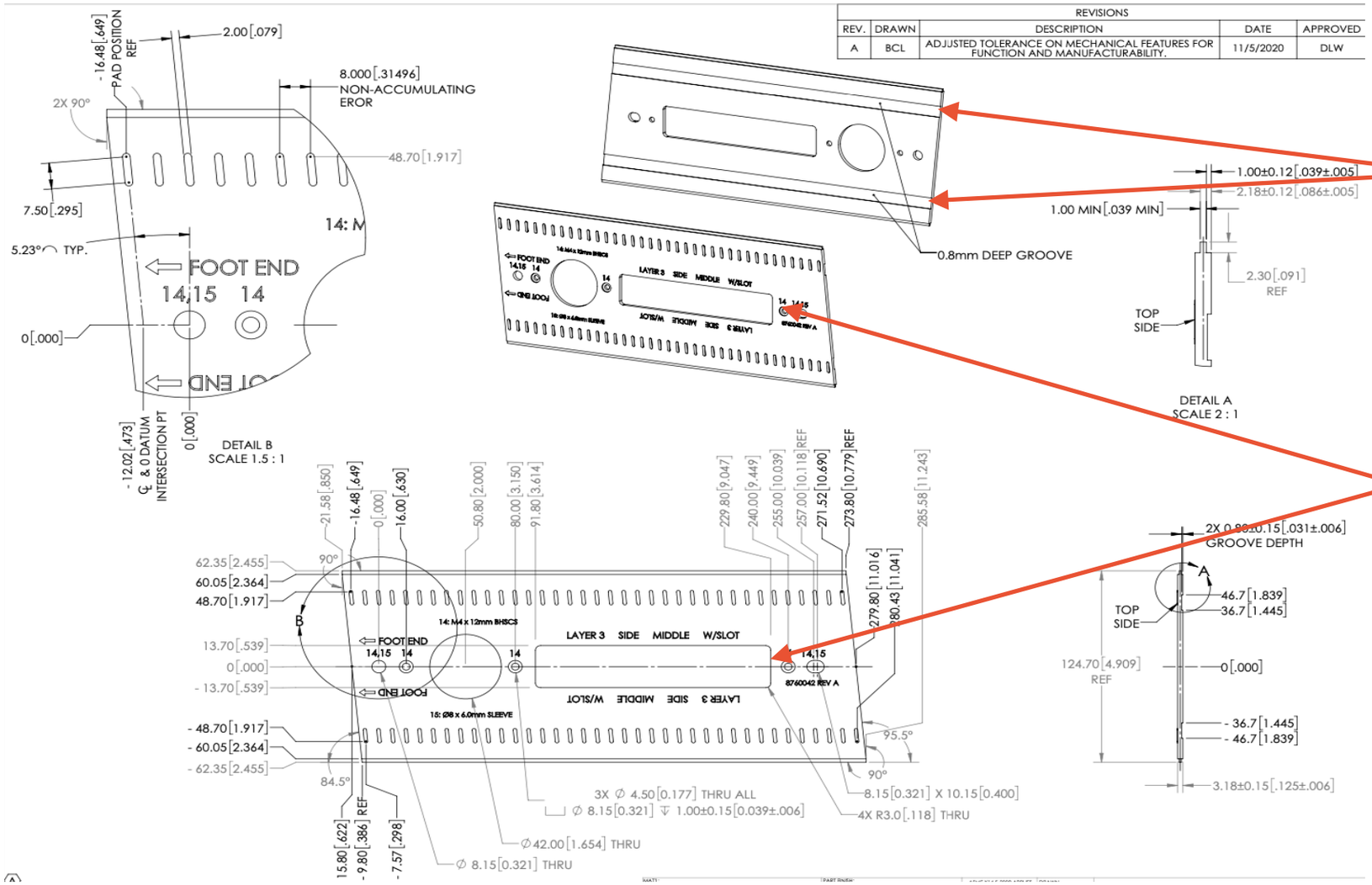
All tested boards				After 1 Oct 2022			
(total tested boards) 5771	# Failed QA	%tage		(total tested boards) 3891	# Failed QA	%tage	Board Feature
THICK_TOP_TONGUE	601	10.41%		SLOT_W	266	6.84%	Slot width (163 from 040 boards)
THICK_BOT_TONGUE	499	8.65%		TONGUE_TR	258	6.63%	Tongue height (top right)
SLOT_W	348	6.03%		THICK_TOP_TONGUE	227	5.83%	Tongue Thickness
TONGUE_TR	329	5.70%		THICK_BOT_TONGUE	196	5.04%	Tongue Thickness
TONGUE_BL	195	3.38%		TONGUE_TL	138	3.55%	Tongue height (top right)
TONGUE_TL	184	3.19%		THICK_TOP_THICK_1	122	3.14%	Board Thickness
SHOULDER_BR	177	3.07%		THICK_BOT_THICK_1	111	2.85%	Board Thickness
SHOULDER_TL	158	2.74%		TONGUE_BL	108	2.78%	Tongue height (bottom left)
TONGUE_BR	147	2.55%		SHOULDER_TL	95	2.44%	Shoulder Height
TH_L_DIA	137	2.37%		PDS_BR_RAD	87	2.24%	Rectangular slot radius (bottom)
THICK_TOP_THICK_1	131	2.27%		TH_L_DIA	81	2.08%	Hole diameter (left)
THICK_BOT_THICK_1	114	1.98%		TONGUE_BR	79	2.03%	Tongue height (bottom right)
SHOULDER_BL	113	1.96%		THICK_BOT_GROOVE	78	2.00%	Groove thickness
THICK_BOT_GROOVE	112	1.94%		DCUT_TR_RAD	56	1.44%	Radius of wire conduit cut
TEDGE_R	110	1.91%		SHOULDER_BR	54	1.39%	Shoulder height
PDS_BR_RAD	99	1.72%		BEDGE_L	49	1.26%	Left edge position (from bottom)
SLOT_R_X	86	1.49%		TEDGE_R	45	1.16%	Left edge position (from top)
SLOT_L_X	76	1.32%		SLOT_H	38	0.98%	Slot height
TGROOVE_T	62	1.07%		SHOULDER_TR	37	0.95%	Shoulder height
SHOULDER_TR	58	1.01%		DCUT_BL_RAD	32	0.82%	
DCUT_TR_RAD	56	0.97%		TH_R_DIA	27	0.69%	

- All Wrap Boards (WB) tested From Inception: **5771**
- Wrap boards tested from 01/10/2022: **3891**
- Failed WB points since 01/10/2022: **2516**
- WBs we can accept under concession: **1784**
- Wrap board failure reduction rate: **~70.91%**

- Green: **Features not critical**. Proposed to relax tolerances at the meeting - see the PCR-1.
- Red: **Tolerances proposed to be relaxed** but needed more work to determine limits - see the PCR-2.
- Blue: **Very critical features** and so current tolerances **cannot be changed**.

University of Sheffield

WB Epoxy Grooves & PDS Hole Edge Radius

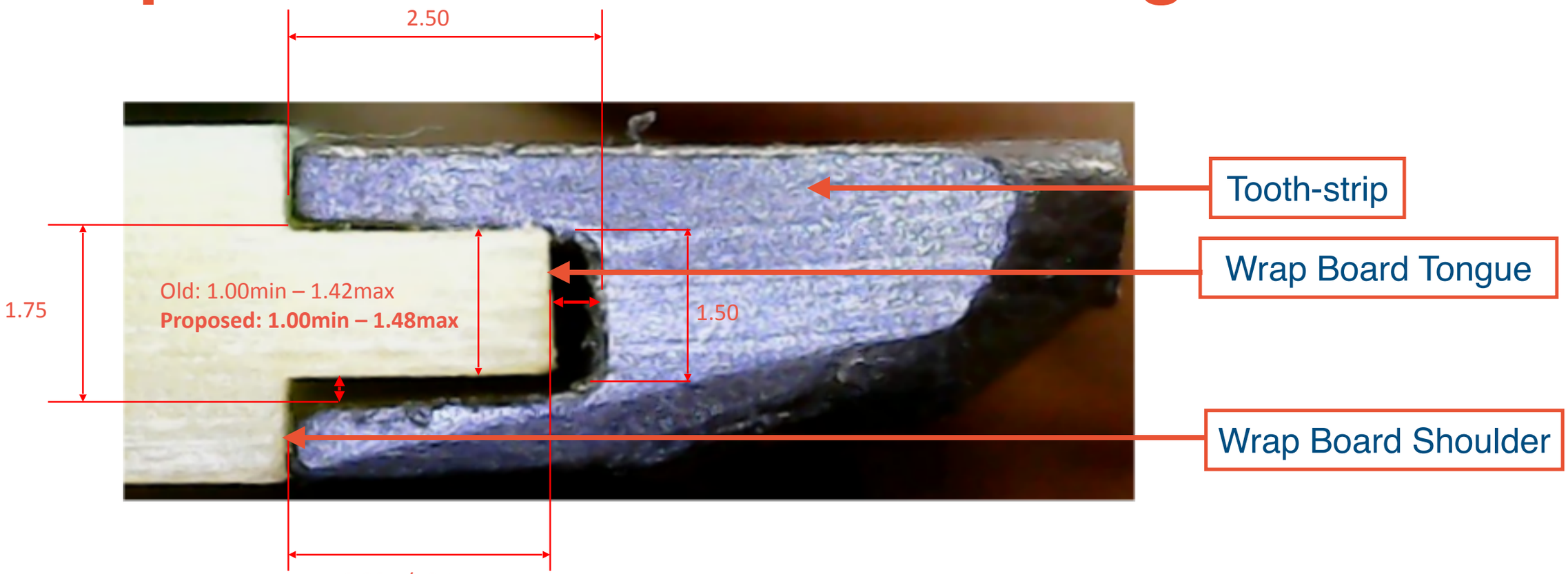


Wrap board **Epoxy Groove Depth** tolerances proposed to change from $0.8^{+0.25}_{-0.20}$ mm to $\mathbf{0.8^{+0.35}_{-0.23}}$ mm. See PCR-2 for more details.

Wrap board **Photon Detector System (PDS)** rectangular cut-out **edge radius** tolerances proposed to change from 3.00 ± 0.45 mm to $\mathbf{3.00^{+0.50}_{-0.75}}$ mm. See PCR-2 for details.

- The maximum expected tension on each wrap board is **~672 N** (2 x 7N x 48 wires) which is well below the expected **~912 N** limit of a wrap board with the **230 x 10 x 1.15 mm³** epoxy groove (worst case).
- The proposed PDS rectangular hole edge radius tolerance leaves a clearance of at least $\mathbf{250}$ μm between the APA's frame and wrap board PDS edge radius (in the worst case).

Wrap Board Thickness And Tongue Thickness



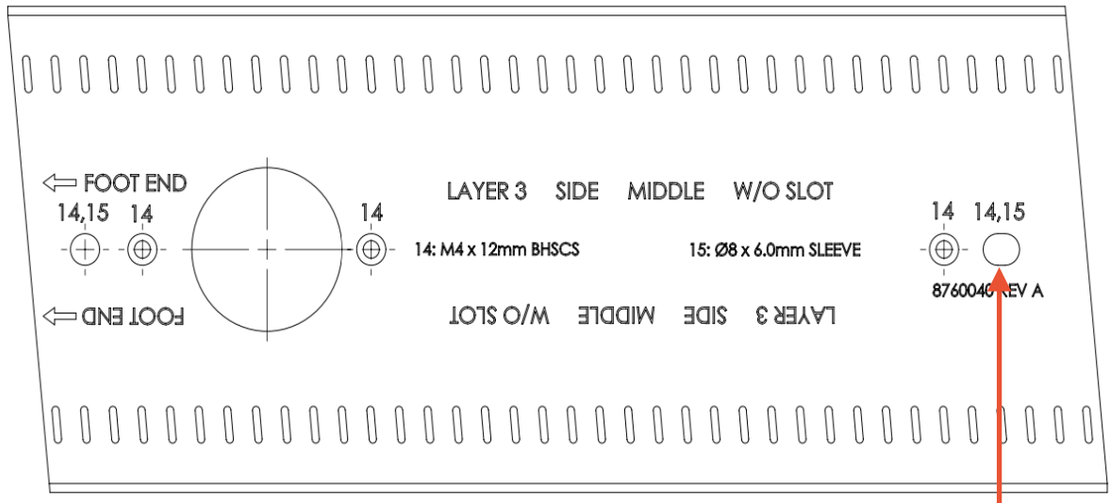
- The proposal is to change the current wrap board thickness tolerance from 3.18 ± 0.159 mm (5%) to $\mathbf{3.18^{+0.160}_{-0.318}}$ mm $\begin{matrix}\text{(i.e. +5\%)}\\\text{(i.e. -10\%)}\end{matrix}$. See **PCR-2** for details.

- The +5% upper thickness range was need to ensure that gaps between adjacent APAs in the cryostat are maintained.

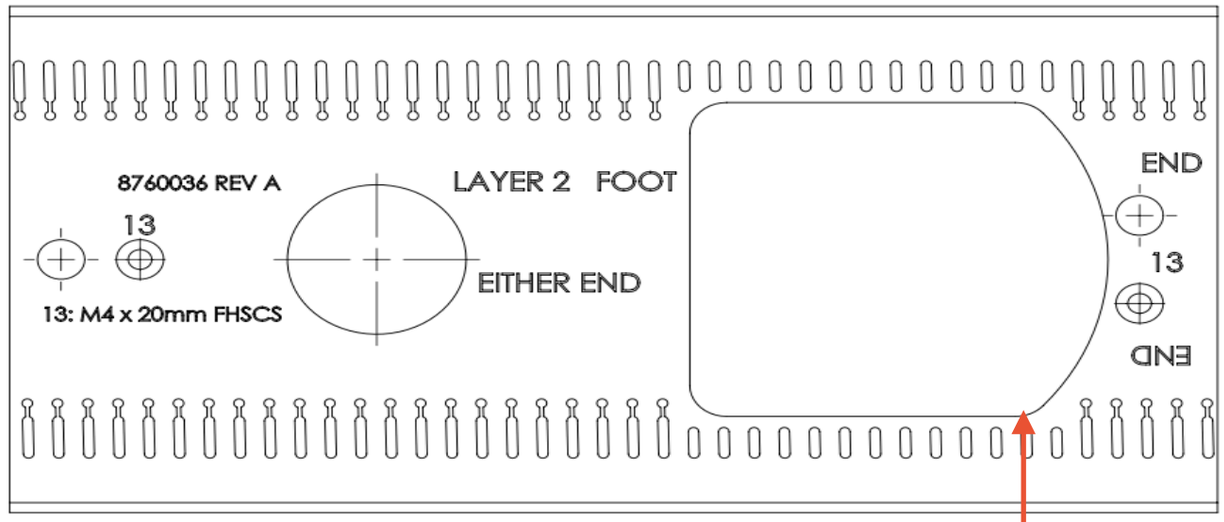
- The proposed -10% lower thickness range will not affect the position as the wire layer as this is determined by the wrap board tongue shoulder position and the finished height of an assembled wrap board.

- The proposal is to change the current **wrap board tongue thickness** tolerance from $1.18^{+0.24}_{-0.18}$ mm to $\mathbf{1.18^{+0.30}_{-0.18}}$ mm. The proposed upper tongue thickness ensures a clearance of at least 20 μm from the maximum tooth-strip top-end groove. See **PCR-2** for details.

Wrap Board Slot Widths & D-Cut Edge Radius



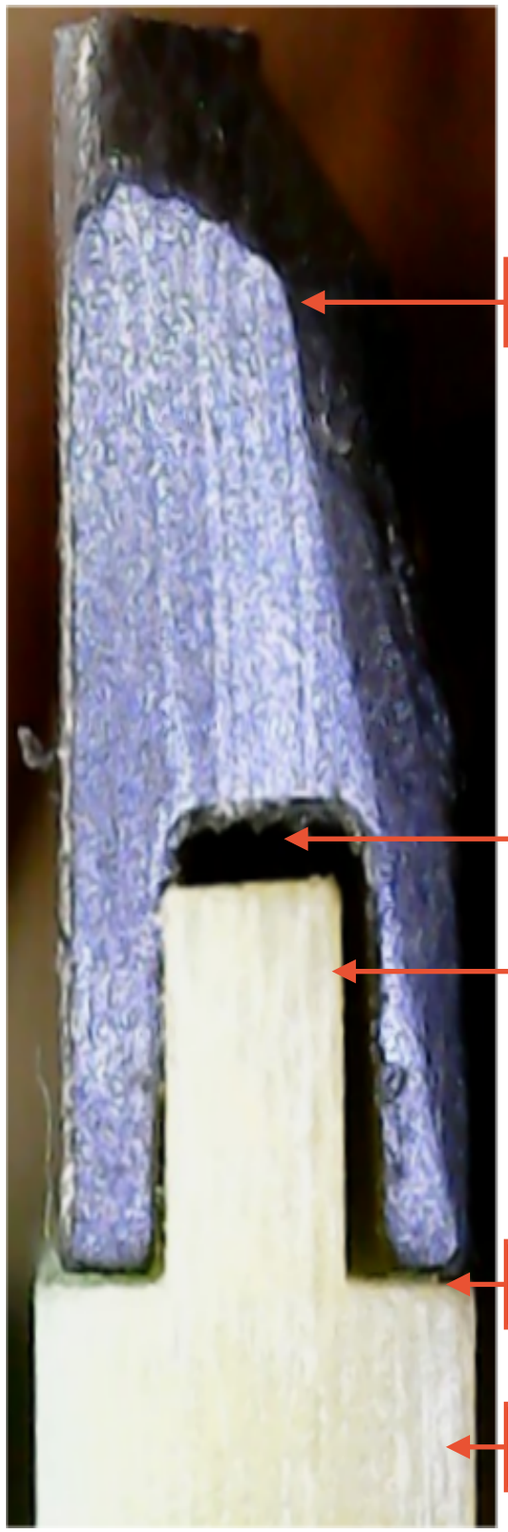
Wrap Board Mounting Slot Hole

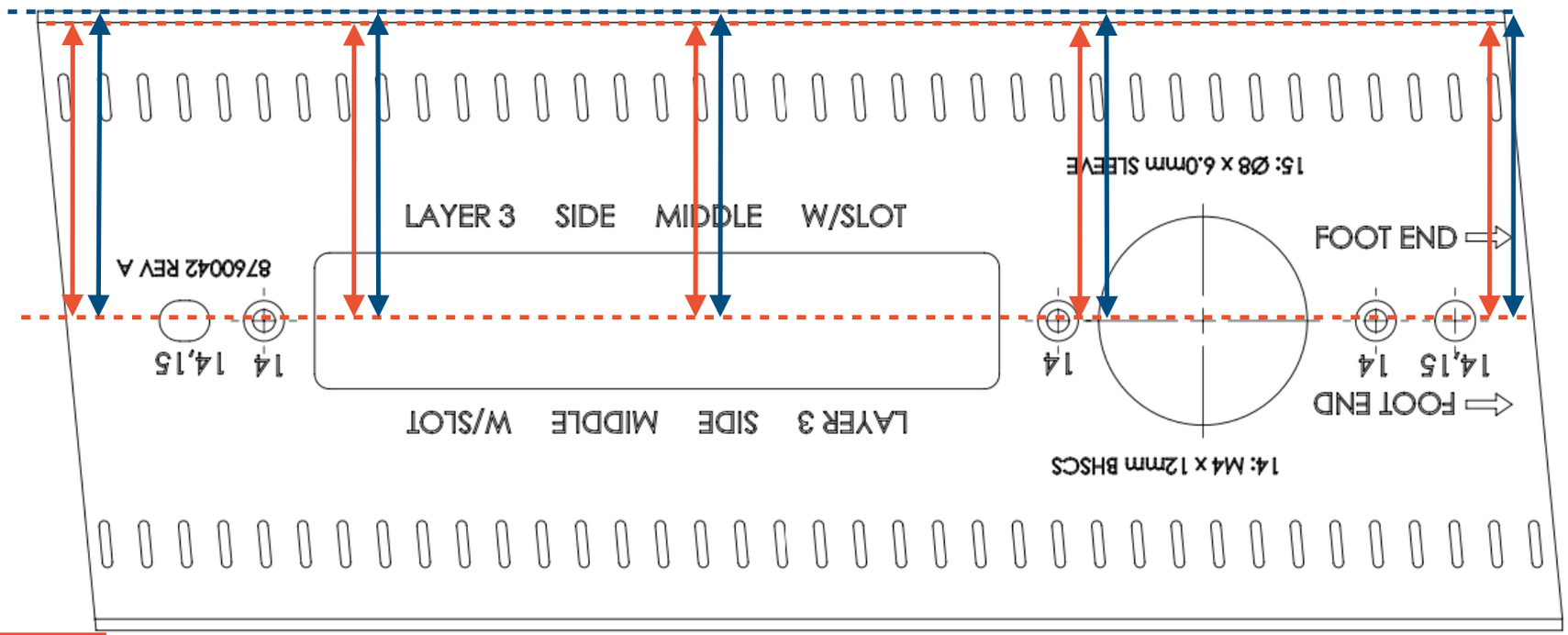


Wrap Board D-Cut Cable Conduit Hole

- The proposal is to change the current wrap board mounting slot width tolerance from $10.15^{+0.20}_{-0.11}$ mm to $\mathbf{10.15 \pm 0.25}$ mm. See **PCR-1** for more details.
- Wrap board **slot height** affects the wire layer position and not the **slot widths!** Slot widths are needed to position the wrap boards in the horizontal direction so no issue is expected from the $50 - 140$ μm change.
- The proposal is to change the current wrap board cable conduit D-cut edge radius from 7.00 ± 0.45 mm to $\mathbf{7.00 \pm 0.70}$ mm. See **PCR-2** for more details.
- The proposed wrap board cable conduit D-cut edge radius tolerance will leave **at least a clearance of $\mathbf{300}$ μm** (in the worst case) between the main APA wire conduit hole and edge of the wrap board D-cut hole.

Wrap Board Tongue & Shoulder Heights





- Tongue and should heights are currently measured from the edges of a given wrap boards resulting in 2 data points.
- The proposal is to increase the measurement points from 2 to 5 and then base the decision on the average of the the 5 data points.

Review Comments on PCR-1

PCR 1: Review Comments

Requester: Justin Evans, Vitaly Kudryavtsev, Graham Miller, Pawel Guzowski & Anthony Ezeribe	Date: 31/03/2023
	Number: APA-PCB-09

Description of requested change:	Reason for change:
We had a meeting at the Daresbury factory with the APA winding experts to understand the board features that are critical to produce a functional APA. Considering their requests and the physics requirements of the DUNE detector, we propose as follows:	
FOR HEAD BOARDS: **(1) Mounting Slot Heights/Hole Sizes:** slots that are on head boards are needed for positioning boards for winding a given wire layer. So we propose to measure only the **relevant slot** for any given wire layer. The slots/holes that are relevant to each of the wire layers are: "10,11" for the X-layer "16,17" for the V-layer "12,18" for the U-layer "12,21" for the G-layer These proposed changes does not apply to the central mounting holes labeled "12". **(2) Board Widths:**	This change is necessary as slots and slot heights that are needed for positioning the X-layer boards (for instance) will not be needed or make any difference to the following V, U and G wire layers.

Please follow the naming and numbering convention defined in the instructions at EDMS 2709827

Reference number changed

2.3mm diametral clearance exists between the hole (which the request asks to not inspect) and sleeve. As long as the holes not being inspected aren't significantly out of tolerance this is okay. i.e. it is reasonable to assume there will not be interference in these holes.

There has not been issues based on the unused hole clearances from Daresbury so we consider this as **Approved.**

PCR 1: Review Comments

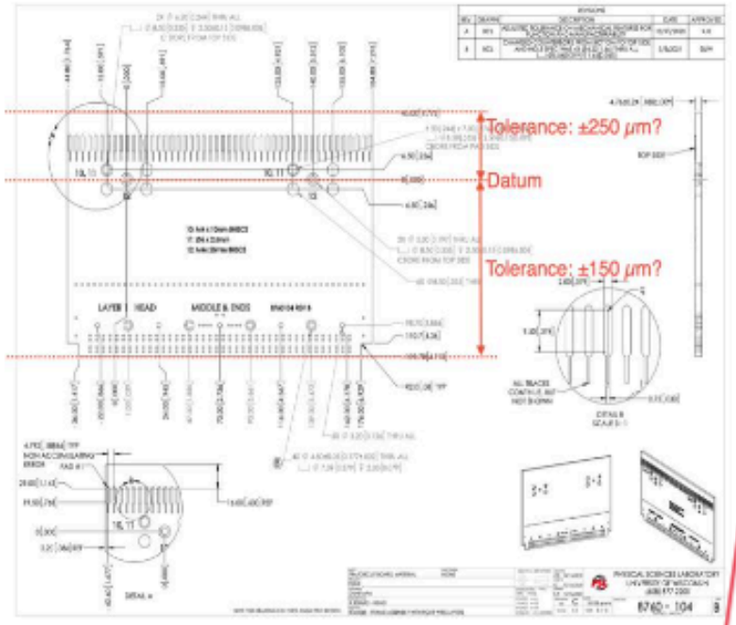
(2) Board Widths:
Tolerance on the board widths is currently ±150 µm. We are proposing to change the tolerance of the datum to solder pad head board edge widths to **±250 µm** while the datum to Mill-Max pin hole edge widths remains unchanged at **±150 µm**, see the picture below for details.

The distance between solder pads and width-edge of head boards is currently 13 -15 mm so removing or adding an extra ±250 µm will not affect the functioning or IPC power ratings of the head boards. So we propose to move the tolerance of the datum to solder pad head board edge widths from the current ±150 µm to ±250 µm.

The edge closest to the solder pads does not affect form, fit or function. The request is okay.

Approved.

PCR 1: Review Comments



(3) Epoxy Relief Depth:
Epoxy relief cut-outs were introduced in the head board designs to stop/collect epoxy so they do not cover any of the Mill-Ma pin holes. The current tolerance of the relief thickness is ±150 μm. We propose to change the tolerance on all the relief dimensions to $0.25^{+0.3}_{-0.18}$ mm.

The relief mentioned here is not used to provide a reservoir to stop/collect epoxy before it can spread to the mill-max pins. The relief is filled with epoxy to bond the wires to the board surfaces above and below. The amount of epoxy needed to fill the gap was carefully studied. Current volume to fill has a depth of 0.25+/-0.15 (+/-60%).

The change requested is 0.25+0.3/-0.18 (+120%/-72%). With this wider range it is uncertain if the epoxy will completely fill and fully cover the wire length thus affecting the bond.

There is another request similar to this one on a different document.

Adding an extra 300 μm or removing 180 μm from the 250 μm relief depth will not affect the performance of the boards in any way as most part of the relief will be filled with the DP 2216 grey epoxy during the APA assembly.

The requested change does not affect

Considered as Not Approved:

Can PSL test the proposed dimensions and advise us?

PCR 1: Review Comments

mm.

FOR WRAP BOARDS:

(1) Mounting Slot Widths:

The current tolerance on wrap board mounting holes is +200 µm and -110 µm. We propose to change this to ±250 µm as what matters most to the APA assembly team is the slot heights and not the width of the slots.

The requested change does not affect the location of the board. The change is okay as long as the distance minimum distance between the slot edge and board traces meets requirements.

Slot widths are required to allow for the positioning of wrap boards so a slot width that is 250 µm less or greater than the nominal values will not affect the board position or the strength of the board locking screws.

Hole to trace clearance meets IPC 2221 requirement so we consider this as **Approved.**

PCR 1: Review Comments

(2) Tongue/Shoulder Heights:
Currently we measure the wrap board tongue/shoulder heights from the edge side of a given wrap board. The tongue height is the distance between a wrap board shoulder and the top end of the wrap board tongue while the shoulder height is the distance between the board datum line and the base of the tongue. To ensure that good wrap boards with a negligible dip (for instance) on the edge side of the tongues or shoulder heights are not rejected in QA, we propose to increase the tongue/shoulder height measurement points from the current 2 to 5. This way, we can average the tongue height results from the 5 measurement points to

A single point negligible dip on any part of a wrap board tongue/shoulder heights will not affect the given wrap board assembly or performance. The finished height of wrap boards are measured after the wrap board assembly to ensure that each wire layer is within the design specifications.

If the current procedure calls for measuring two points and by doing so "good" boards are rejected (non-conformance)... measuring five points and taking an average brings them back into conformance?
The change cannot be made because this is not how inspection is done. For example, if the tongue is 1mm thin on one end and 1mm thick on the other end the average thickness is within tolerance (which gives an erroneous result).

- The comment seem to consider tongue thicknesses.
- The request was for tongue/shoulder **heights** only.
- Point failures were considered by the team but we thought that point failures that are in spec when averaged should not affect the strength of an epoxied tooth-strip.

Review Comments on PCR-2

PCR 2: Review Comments

	Number: APA-PCB-10
Description of requested change:	Reason for change:
We had a meeting at the Daresbury factory with the APA winding experts to understand the board features that are critical to produce a functional APA. Considering their requests and the physics requirements of the DUNE detector, we propose as follows: **FOR HEAD BOARDS**: (1) **Groove Depth:** To change epoxy groove depth tolerances on V, U and G head boards which are used to collect/stop DP-2216 epoxy from flowing into the Mill-Max press-fit co The major constraining i board groove thickness (a) the thickness of FR4 the epoxy groove could wires are soldered on th the groove size will be e the epoxy. Considering propose to change the t board groove depth fron $1.05^{+0.25}_{-0.20}$ mm to $1.05^{+}_{-0.25}$	The proposed head board groove depth tolerances will ensure that each of the V, U and G head boards will have a minimum of **230 x 5 x** n of **230 x 10 x** nough to stop lax pin holes. The any of the head 7N) which is **N** flexural e **230 x 10 x 1.5** so the head ned wires with

Please follow the naming and numbering convention defined in the instructions at EDMS 2709827

Reference number changed

Is there a typo in here?

Shear strength?

Minimum width from grooves on V-head boards.

Similar to the other request on a different document: The relief mentioned here is not used to provide a reservoir to stop/collect epoxy before it can spread to the mill-max pins. The relief is filled with epoxy to encapsulate the solder and solder flux to keep LAr clean. Some of the epoxy is intended to spread into the gap that bonds the wire. The amount of epoxy needed to fill the gap was carefully studied.

The change requested has a wider range it is uncertain if the epoxy will completely fill and fully cover solder pads and spread into the wire bond area properly.

Flexural strength: resistance to bend deformation

Shear strength: resistance to shear deformation

Considered as Not Approved: Can PSL test the proposed dimensions and advise us?

PCR 2: Review Comments

(2) **Central Counter-bore Mounting Hole Diameter:** To change the central counterbored hole diameter tolerances. These holes are marked "12" on each head board. The major constraining issues on these head board central counterbored hole diameter design are whether (a) the M4 screws in such holes will have enough FR4 materials to rest on when locked and (b) the screws will have enough clearance to pass through if the holes are made too small? Considering these	To ensure that there are enough FR4 materials to hold the head of the locked M4 screws, we have not made the hole bigger by not changing the maximum allowed counterbored hole diameter. The minimum allowed counterbored hole diameter for a given M4 screw is 4.3 mm. However, the proposed tolerance here allows a minimum counterbored hole diameter of 4.5 mm to ensure that the screws have enough clearance.
issues, we propose to change the head board central counterbored hole diameter tolerances from the current 5.00 ± 0.115 mm to $5^{+0.115}_{-0.500}$ mm.	Are you certain the max material condition (proposed here to be changed from 4.9 to 4.5) is enough clearance? Keep in mind the position tolerance of hole(s) is also factor. Minimum lock material has not been changed so we consider this as **approved.**

PCR 2: Review Comments

FOR WRAP BOARDS:

(1) Wrap Board Tongue Thickness:

To change the tolerance on wrap board tongue thicknesses. Tooth-strips are glued on wrap board tongues. These glued tooth-strips are then used to position the wires on an APA to maintain the required wire pitch. Hence, the major constraining issues on this wrap board tongue thickness design are whether (a) they will fit the tooth-strip grooves during assembly and (b) they could break after the assembly - when exposed to the tensioned wires. Considering these issues, we propose to change the tolerances of the wrap board tongue thicknesses from the current $1.18^{+0.24}_{-0.18}$ mm to $\mathbf{1.18^{+0.30}_{-0.18}}$ mm.

The proposed tongue thickness tolerance still allows the required minimum tongue thickness of 1 mm and a maximum tongue thickness of 1.48 mm which gives a 20 μm clearance from the expected maximum tooth-strip groove top-end width.

Some tooth strip grooves fit the tongue with very little clearance. Increasing the thickness may leave the epoxy bond too thin and not strong enough to resist the wire tension forces.

- Minimum design clearance between the tongue and tooth-strip is ~$\pm 50\ \mu m$
- There is $\pm 50\ \mu m$ tolerance on tooth-strip groove widths and depth.
- We dry fit the tooth-strips on wrap board tongues before assembly so can safely consider this as **approved.**

PCR 2: Review Comments

(2) Wrap Board Thickness: To change the tolerance on wrap board thicknesses. Wrap boards are attached on the side and foot end of an APA frame to maintain the wire pitch all through an APA. Thicker wrap boards are expected to close up the clearance between adjacent APAs in the Cryostat. Hence, we propose to change the current tolerance on wrap board thickness from 3.18 ± 0.159 mm to $\mathbf{3.18^{+0.160}_{-0.318}}$ **mm**. This implies that we are maintaining a 5% board thickness tolerance on the upper limit while relaxing the lower limit to the conventional 10% thickness tolerance.	tension forces. The proposed -10% wrap board lower-thickness range will not affect the position of the wire layers on an APA as this is determined by the finished height of a given wrap board and the head board thickness. In a worst case scenario, this proposed change in tolerance can only add an extra <10 cm gap which could have been a negligible dead region relative to the 58 m x 14 m x 12 m FD1 detector volume.
(3) Wrap Board PDS Rectangular Cut-Out Hole Edge Radius: To change the tolerance on the wrap board PDS rectangular cut-out edge radius. These are the edge radius of the rectangular cut-out holes for installation of photon detector systems (PDS). The major constraining issues in the PDS cut-out edge radius design is whether any changes in the tolerances will obstruct the PDS box installation process?	The proposed wrap board PDS rectangular cut-out edge radius tolerances will leave a clearance of at least 250 μm (in the worst case) between the edge of the main APA PDS rectangular cut-out hole and edge of the wrap board PDS rectangular cut-out hole. So the proposed tolerance changes will still allow a smooth installation of the PDS system without any

Edges of the wrap boards are cantilevered beyond the width of the tube. The support is only that of the flat surface and does not include the tube radius. The strength and stiffness of the board (with cantilevered wire load) must be checked before allowing thinner boards.

- Minimum Flexural strength of FR4: $345 \times 10^6 \frac{N}{m^3}$,
- for 8760024 boards of dimension: 191.6 mm x 115.2 mm x 2.862 mm (proposed lower limit) = $6.317 \times 10^{-5}\ m^3$
- With 24 x 2 wires at 8N = 384N
- So the force that can break the 8760024 board will be: $2.179 \times 10^4\ N$.

PCR 2: Review Comments

(3) Wrap Board PDS Rectangular Cut-Out Hole Edge Radius: To change the tolerance on the wrap board PDS rectangular cut-out edge radius. These are the edge radius of the rectangular cut-out holes for installation of photon detector systems (PDS). The major constraining issues in the PDS cut-out edge radius design is whether any changes in the tolerances will obstruct the PDS box installation process?	load) must be checked before allowing thinner boards. The proposed wrap board PDS rectangular cut-out edge radius tolerances will leave a clearance of at least 250 μm (in the worst case) between the edge of the main APA PDS rectangular cut-out hole and edge of the wrap board PDS rectangular cut-out hole. So the proposed tolerance changes will still allow a smooth installation of the PDS system without any
The current tolerance on these wrap board PDS rectangular cut-out edge radius is 3 ± 0.45 mm which allows a clearance of ~ 1 mm from the main PDS holes on an APA frame and the edge of the wrap board PDS rectangular cut-out hole. Hence, we propose to change these PDS rectangular cut-out edge radius tolerance to $\mathbf{3.0}^{+0.50}_{-0.75}$ mm.	expected interference. Okay, the proposed change does not violate minimum distance from edge to traces.

Approved.

PCR 2: Review Comments

(4) Wrap Board Epoxy Groove Depth:
To change the wrap board epoxy groove thickness tolerances. Epoxy grooves on some V, U and G wrap boards are used to collect/stop DP-2216 epoxy from flowing to the wire solder pads. The major constraining issues on these wrap board groove design are whether (a) the thickness of FR4 materials beneath the epoxy groove could break after tensioned wires are soldered on the wrap board and (b) the epoxy groove size will be enough to collect all the epoxy. Considering these issues, we propose to change the tolerances of the wrap board epoxy grooves from the current $0.8^{+0.25}_{-0.20}$ mm to $\mathbf{0.8^{+0.35}_{-0.23}}$ mm.

(5) **Wrap Board Cable Conduit D-Cut Edge**

The proposed wrap board epoxy groove tolerances will ensure that each of the affected V, U and G wrap boards will have a minimum of **230 x 10 x 0.57 mm^3** groove and a maximum of **230 x 10 x 1.15 mm^3** groove which will be en
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The relief mentioned here is not used to provide a reservoir to stop/collect epoxy from flowing to wire solder pads. The relief is filled with epoxy to encapsulate the solder and solder flux to keep LAr clean. Some of the epoxy is intended to spread into the gap that bonds the wire. The amount of epoxy needed to fill the gap was carefully studied.

The change requested has a wider range it is uncertain if the epoxy will completely fill and fully cover solder pads and spread into the wire bond area properly.

Further, more details on how the flexural strength of the wrap boards was determined would be useful.

Considered as Not Approved: Can PSL test the proposed dimensions and advise us?

PCR 2: Review Comments

(5) **Wrap Board Cable Conduit D-Cut Edge Radius:** To change the wrap board cable conduit D-cut edge radius tolerances. These are the edge radius of the D-cut holes for the installation of cable conduit pipes on an APA. The major constraining issues on these cable conduit D-cut edge radius design are whether any changes in tolerances will obstruct the cable conduit pipe installation process? The current tolerance on these wrap board cable conduit D-cut edge radius is 7 ± 0.45 mm which allows a clearance of ~ 1 mm from the main APA cable conduit D-cut hole and the edge of the wrap board cable conduit D-cut hole. Hence, we propose to change these wrap board cable conduit D-cut edge radius tolerance to $\mathbf{7 \pm 0.70}$ mm.	Further, more details on how the flexural strength of the wrap boards was determined would be useful. The proposed wrap board cable conduit D-cut edge radius tolerances will leave a clearance of at least 300 μm (in the worst case) between the edge of the main APA cable conduit D-cut hole and edge of the wrap board cable conduit D-cut hole. So the proposed changes will still allow for a smooth installation of the cable conduit pipes without any expected interference. Okay, the proposed change does not violate minimum distance from edge to traces.
Affected procedures (include EDMS links):	Names of affected parts and procedures:

Approved.

Current PCR-1 & PC-2

Geometry Board Tolerances And Metrology Procedure Change Request

Requester: Justin Evans, Vitaly Kudryavtsev, Graham Miller, Pawel Guzowski & Anthony Ezeribe	Date: 02/08/2023
	Number: PCR0013

Description of requested change:	Reason for change:
We had a meeting at the Daresbury factory with the APA winding experts to understand the board features that are critical to produce a functional APA. Considering their requests and the physics requirements of the DUNE detector, we propose as follows: **FOR HEAD BOARDS**: **(1) Mounting Slot Heights/Hole Sizes:** slots that are on head boards are needed for positioning boards for winding a given wire layer. So we propose to measure only the **relevant slot** for any given wire layer. The slots/holes that are relevant to each of the wire layers are: "10,11" for the X-layer "16,17" for the V-layer "12,18" for the U-layer "12,21" for the G-layer These proposed changes does not apply to the central mounting holes labeled "12". **(2) Board Widths:** Tolerance on the board widths is currently ±150 µm. We are proposing to change the tolerance of the datum to solder pad head board edge widths to **±250 µm** while the datum to Mill-Max pin hole edge widths remains unchanged at **±150 µm**, see the picture below for details.	This change is necessary as slots and slot heights that are needed for positioning the X-layer boards (for instance) will not be needed or make any difference to the following V, U and G wire layers. The distance between solder pads and width-edge of head boards is currently 13 -15 mm so removing or adding an extra ±250 µm will not affect the functioning or IPC power ratings of the head boards. So we propose to move the tolerance of the datum to solder pad head board edge widths from the current ±150 µm to ±250 µm.

Approved Requests are now on PCR0013

Geometry Board Tolerances And Metrology Procedure Change Request

Requester: Justin Evans, Vitaly Kudryavtsev, Graham Miller, Pawel Guzowski & Anthony Ezeribe	Date: 02/08/2023
	Number: PCR0017

Description of requested change:	Reason for change:
We had a meeting at the Daresbury factory with the APA winding experts to understand the board features that are critical to produce a functional APA. Considering their requests and the physics requirements of the DUNE detector, we propose as follows: **FOR HEAD BOARDS**: (1) **Groove Depth:** To change epoxy groove depth tolerances on V, U and G head boards which are used to collect/stop DP-2216 epoxy from flowing into the Mill-Max press-fit connector pin holes. The major constraining issues on these head board groove thickness design are whether (a) the thickness of FR4 materials beneath the epoxy groove could break after tensioned wires are soldered on the head board and (b) the groove size will be enough to collect all the epoxy. Considering these issues, we propose to change the tolerances of the head board groove depth from the current $\mathbf{1.05^{+0.25}_{-0.20}\ mm}$ to $\mathbf{1.05^{+0.45}_{-0.25}\ mm}$. **(2) Epoxy Relief Depth:** Epoxy relief cut-outs were introduced in the head board designs to stop/collect epoxy so they do not cover any of the Mill-Ma pin holes. The current tolerance of the relief thickness is ±150 µm. We propose to change the tolerance on all the relief dimensions to $0.25^{+0.3}_{-0.18}$ mm.	The proposed head board groove depth tolerances will ensure that each of the V, U and G head boards will have a minimum of **230 x 5 x 0.8 mm^3** groove and a maximum of **230 x 10 x 1.5 mm^3** groove which will be enough to stop epoxy from flowing to the Mill-Max pin holes. The maximum expected tension on any of the head boards is **~350N** (i.e. 48 wires x 7N) which is well below the expected **~1190 N** flexural strength of a head board with the **230 x 10 x 1.5 mm^3** (worst case) epoxy groove so the head boards can still carry the tensioned wires with the proposed tolerances. Adding an extra 300 µm or removing 180 µm from the 250 µm relief depth will not affect the performance of the boards in any way as most part of the relief will be filled with the DP 2216 grey epoxy during the APA assembly.

Non Approved Requests are now on PCR0017

Thanks for listening!