DUNE-APA PCB Production Status

Anthony Ezeribe
for the DUNE APA PCB Team

LBNF/DUNE-UK Project Meeting

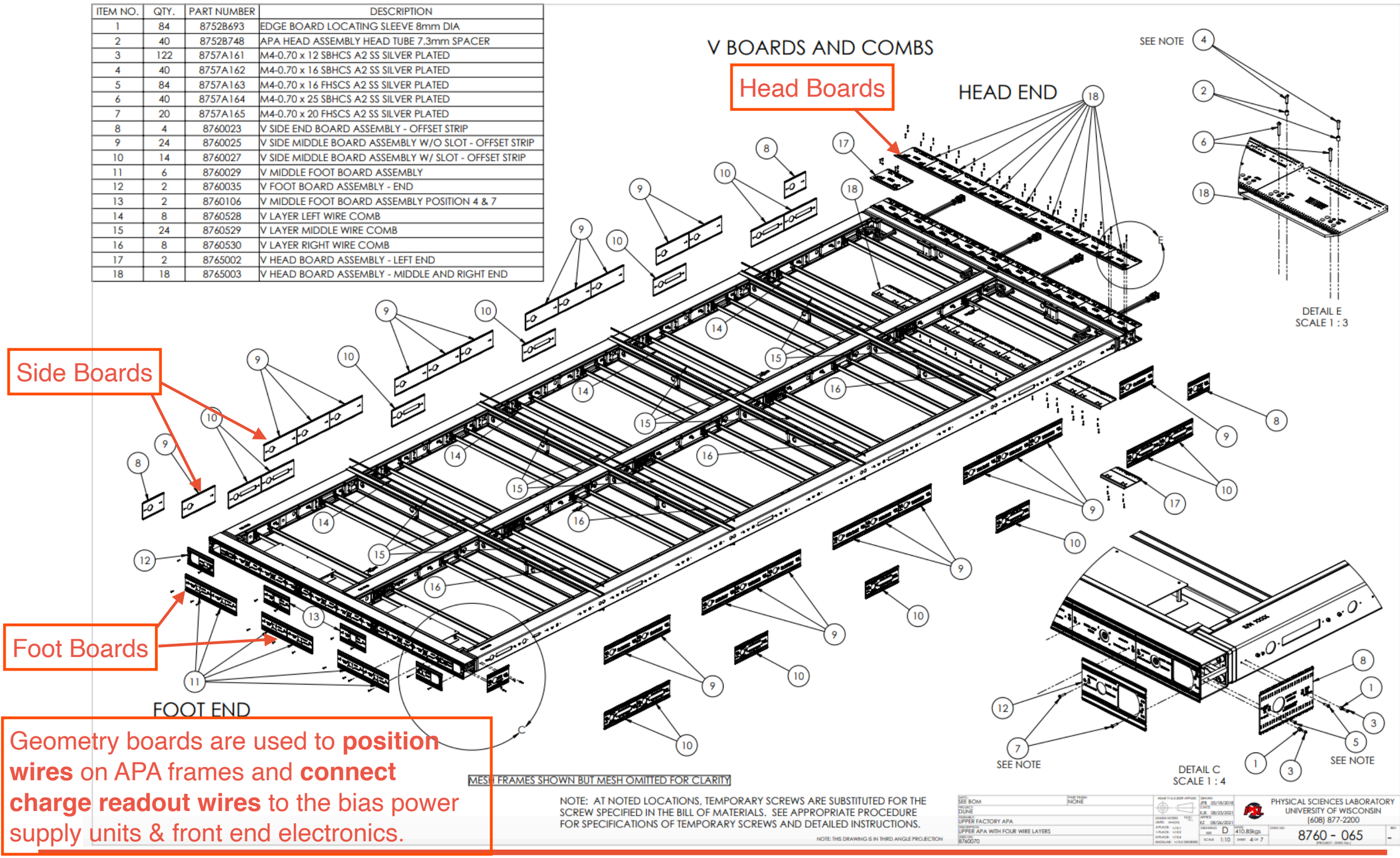
The University Of Sheffield.

DUNE-UK APA PCB Team

- **CAMBRIDGE**
  - Melissa Uchida
  - Jingyuan Shi
- **SUSSEX**
  - Clark Griffith
- **LANCASTER**
  - Jaroslaw Nowak
  - Tom Walsh
  - Matt Handy
  - Agnieszka Nowak
  - Gwenn Mouster
- **UKRI**
  - Andra Pirvu
  - Antonis Papanestis
- **MANCHESTER**
  - Justin Evans
  - Pawel Guzowski
  - Graham Miller
  - Humzah Iqbal
- **SHEFFIELD**
  - Vitaly Kudryavtsev
  - Shaun Smith
  - Anthony Ezeribe

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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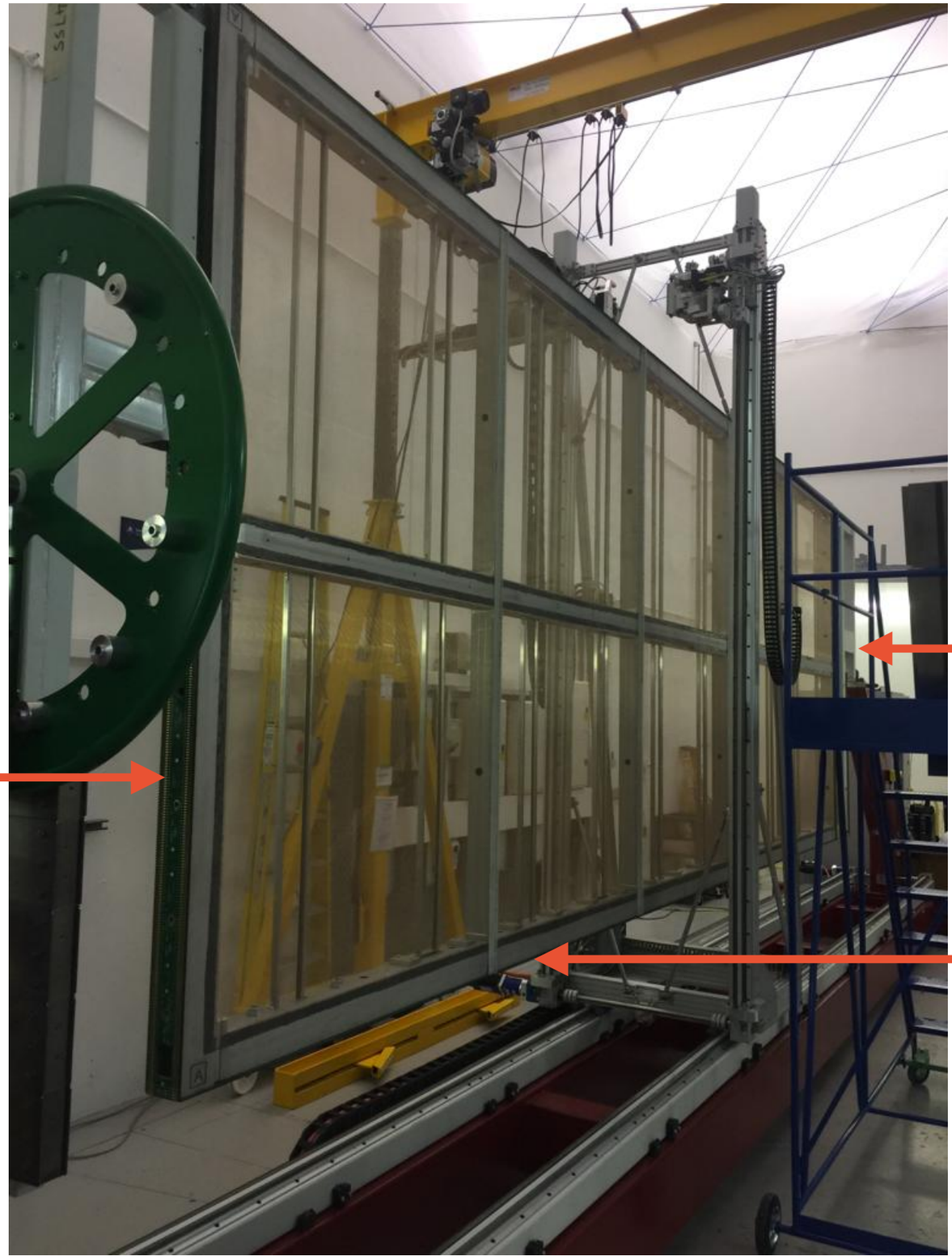
Geometry Boards on an APA



Head Boards

Foot Boards

Side Boards

APA PCB Production Requirements

- Required number of UK-APAs: 128
- Required number of US-APAs: 20
- 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, 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.

Geometry Board Procurement Status

Currently here **Should be here**

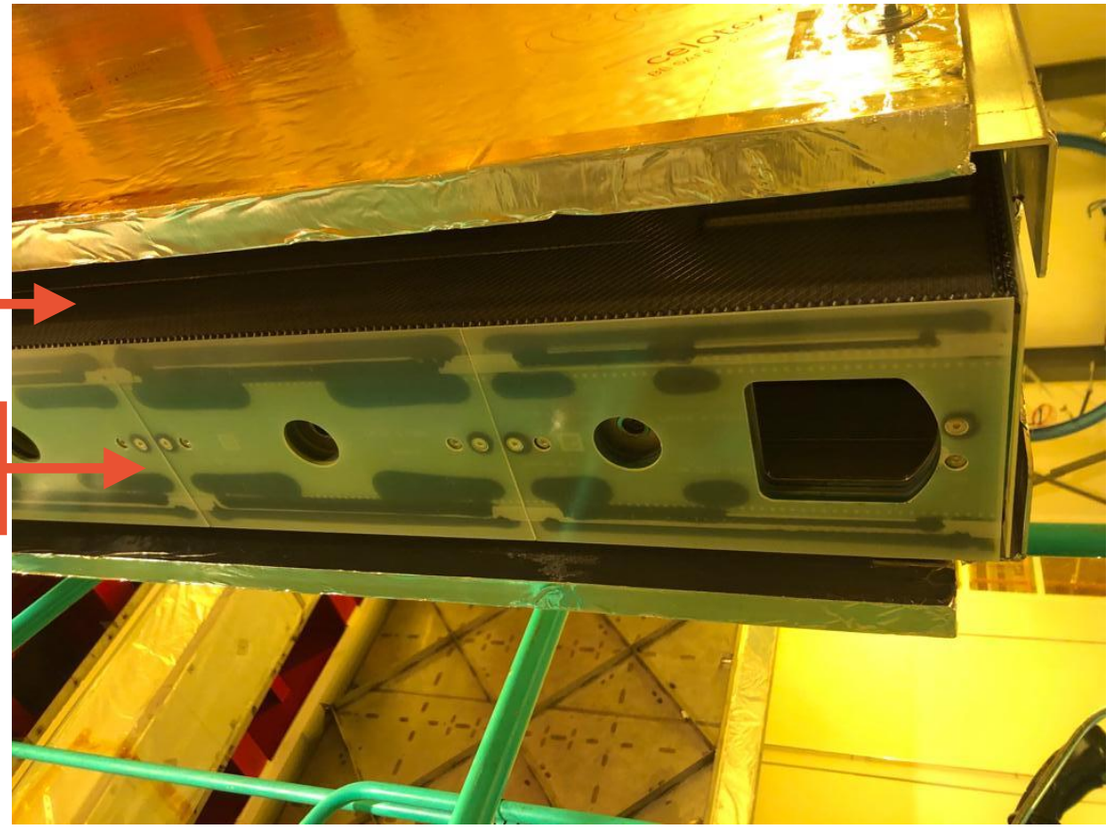
		23rd Feb. 2022	15th June 2022		5th October 2022		25th January 2023		17th May 2023		6th September 2023		4th January 2024		25th April 2024		15th August 2024		5th December 2024		27th March 2025	
Name	Ref on EDMS	Min No Rqd	Min No Rqd	Cumulative	Min No Rqd	Cumulative	Min No Rqd	Cumulative	Min No Rqd	Cumulative	Min No Rqd	Cumulative	Min No Rqd	Cumulative	Min No Rqd	Cumulative	Min No Rqd	Cumulative	Min No Rqd	Cumulative	Min No Rqd	Cumulative
G Head Board Middle	8760121	192	384	576	384	960	384	1344	384	1728	384	2112	432	2544	x	x	x	x	x	x	x	x
G Head Board Right-End	8760120	44	44	88	44	132	44	176	44	220	44	264	54	318	x	x	x	x	x	x	x	x
G Head Board Left-End	8760122	90	44	134	44	178	44	222	44	266	52	318	x	x	x	x	x	x	x	x	x	x
G Edge Board Low Slot End	8760051	90	22	112	22	134	25	159	x	x	x	x	x	x	x	x	x	x	x	x	x	x
G Edge Board Middle	8760054	120	120	240	120	360	120	480	120	600	120	720	120	840	114	954	x	x	x	x	x	x
G Edge Board High Slot End	8760062	22	22	44	22	66	22	88	22	110	22	132	27	159	x	x	x	x	x	x	x	x
G Edge Board Position 4 and 7	8760113	44	44	88	44	132	44	176	44	220	44	264	54	318	x	x	x	x	x	x	x	x
U Head Board Middle	8760115	95	380	475	380	855	380	1235	380	1615	380	1995	380	2375	169	2544	x	x	x	x	x	x
U Head Board Left End	8760119	44	44	88	44	132	44	176	44	220	44	264	54	318	x	x	x	x	x	x	x	x
U Head Board Right End	8760123	44	44	88	44	132	44	176	44	220	44	264	54	318	x	x	x	x	x	x	x	x
U-Side Board End	8760038	144	144	288	144	432	144	576	60	636	x	x	x	x	x	x	x	x	x	x	x	x
U-Side Board Without Slot Middle	8760040	100	400	500	400	900	400	1300	400	1700	400	2100	400	2500	400	2900	400	3300	400	3700	116	3816
U-Side Board With Slot Middle	8760042	78	312	390	312	702	312	1014	312	1326	312	1638	312	1950	276	2226	x	x	x	x	x	x
U-Foot Board High Slot End	8760044	90	44	134	25	159	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
U-Foot Board Middle	8760057	72	144	216	144	360	144	504	144	648	144	792	162	954	x	x	x	x	x	x	x	x
U-Foot Board Low Slot End	8760059	90	44	134	25	159	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
U-Foot Board Position 4 And 7	8760111	120	120	240	78	318	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
V Head Board Right End	8760108	100	300	400	300	700	300	1000	300	1300	300	1600	300	1900	300	2200	300	2500	362	2862	x	x
V Head Board Left End	8760116	90	90	180	90	270	48	318	x	x	x	x	x	x	x	x	x	x	x	x	x	x
V Side Board End	8760024	180	180	360	180	540	96	636	x	x	x	x	x	x	x	x	x	x	x	x	x	x
V Side Board Middle Without Slot	8760026	100	400	500	400	900	400	1300	400	1700	400	2100	400	2500	400	2900	400	3300	400	3700	116	3816
V Side Board Middle With Slot	8760028	76	304	380	304	684	304	988	304	1292	304	1596	304	1900	304	2204	22	2226	x	x	x	x
V Foot Board Middle	8760030	120	120	240	120	360	120	480	120	600	120	720	120	840	114	954	x	x	x	x	x	x
V Foot Board End	8760036	90	90	180	90	270	48	318	x	x	x	x	x	x	x	x	x	x	x	x	x	x
V Foot Board Middle Position 4 An	8760107	90	90	180	90	270	48	318	x	x	x	x	x	x	x	x	x	x	x	x	x	x
X Board Head	8760104	100	400	500	400	900	400	1300	400	1700	400	2100	400	2500	400	2900	280	3180	x	x	x	x
X Edge Board End	8760032	120	120	240	78	318	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
X Edge Board Middle	8760034	120	120	240	120	360	120	480	120	600	120	720	120	840	114	954	x	x	x	x	x	x
X Edge Board Position 4 And 7	8760109	120	120	240	78	318	x	ˇ	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Total	2785	4690	7475	4526	12001	4035	14764	3686	16701	3634	19699	3693	23074	2591	17748	1402	17748	1162	17748	232	17748

- Bid for the production of all the required **32,436** DUNE-APA geometry boards for the 148 FD-1 detector APAs have been awarded to a UK company.
- Delays shown in the above board delivery schedule are due to:
  - time lost in reworking/retesting initial board batches that failed our visual inspection/QA tests.
  - effects of the pandemic.
- We have worked with the PCB company to reduce most of the identified issues.

APA Cover Boards

APA Frame

Cover boards on an APA



- Cover boards are used to **cover/protect wires** soldered on the **geometry boards**.
- Cover boards come in **10** flavours.
- There are **72** cover boards per APA.

Part Number	Description	Qty per APA	Qty Ordered	Qty Delivered	Qty To Deliver 12/01/2023
8760064	Cover, foot, low slot end	1	152	10	142
8760067	Cover, foot, middle	6	906	54	852
8760069	Cover, foot, high slot end	1	152	10	142
8760071	Cover, side, foot end	2	302	18	284
8760072	Cover, side, head end	2	302	18	284
8760073	Cover, side, w/o slot	24	3620	212	3408
8760074	Cover, side w/slot	14	2112	124	1988
8760182	Cover, foot, middle position 4 & 7	2	302	18	284
8757267	Cover - head - left end	2	302	18	284
8757268	Cover - head middle & right end	18	2716	160	2556

Geometry Board Assembly Components

Press-Fit Mill-Max Contacts

0921-1-15-20-75-14-11-0
Type-3: Spring loaded without tail

S/N	Part Number	Description	Per APA	Qty Ordered	Qty Delivered
1	4617-0-15-15-32-27-34-0	Receptacle with tail	5,600	830,000	830,000
2	5817-0-15-15-32-27-40-0	Receptacle without tail	4,440	660,000	660,000
3	0921-1-15-20-75-14-11-0	Spring loaded without tail	1,100	163,000	163,000

- Mill-Max press fit contacts are inserted on head boards to connect each APA wire layer to the bias power supply unit and to the readout FEMBs.
- All the required Mill-Max press-fit contacts needed to produce the 148 DUNE-APAs (i.e. UK + USA) have been purchased through an approved UKRI **SSA**.

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APA Board Tooth-Strips

Tooth-Strips Before Assembly

Tooth-Strip Assembly Jigs

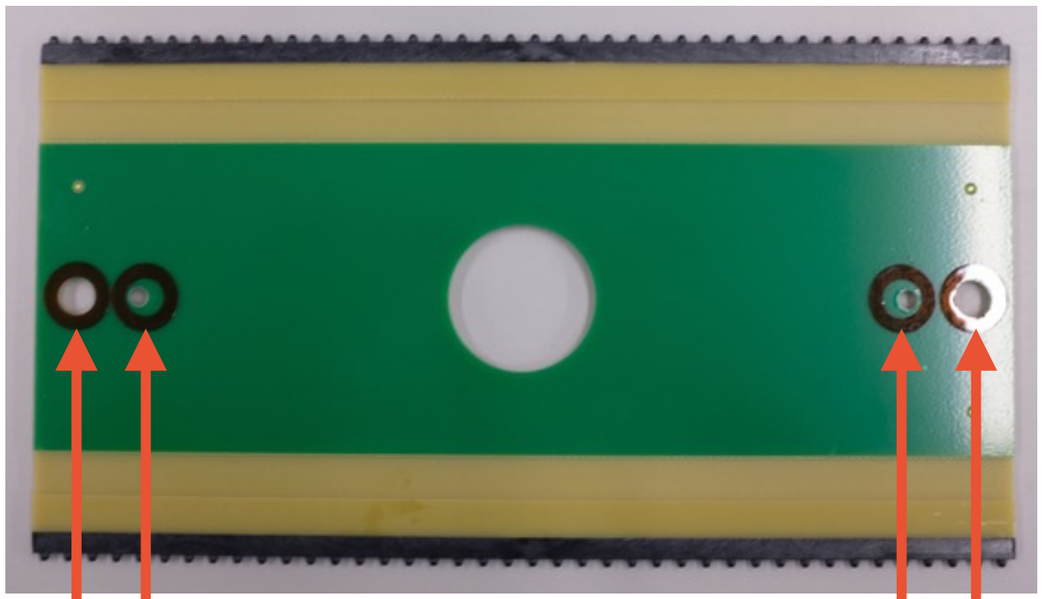
Wrap board after Tooth-Strip Assembly

S/N	Part Number	Description	Per APA	Qty Ordered	Qty Delivered
1	8752827	U & V-Side	168	25,620	25,620
2	8752828	U & V-Foot	40	6,100	6,100
3	8752829	G & X-Foot	40	6,100	6,100

- Glass fibre reinforced vectra polymer tooth-strips are **glued to the foot and side boards** to maintain the required ~5 mm wire spacing on an APA.
- All the required tooth-strips for needed to produce the 148 DUNE-APAs (i.e. UK + USA) have been purchased through an approved UKRI **SSA**.

Broach Nuts and Shims

Stainless Steel Broach-Nuts: KFS2-M3

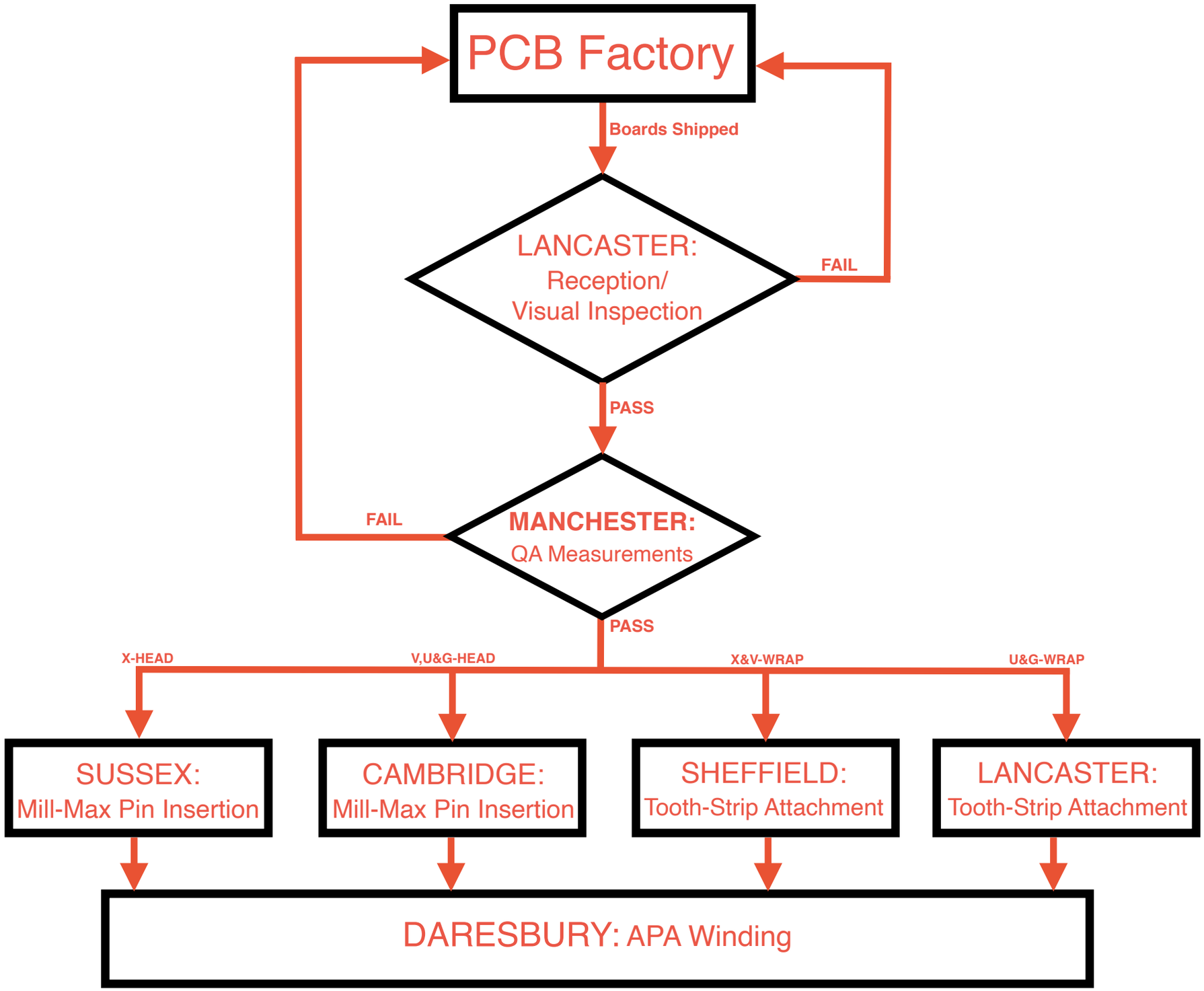


Shim: 5 mil polyimide film baked with 1.5 mil silicone adhesive

S/N	Part Number	Description	Per APA	Qty Ordered	Qty Delivered
1	KFS2-M3	Broach Nuts	220	32,900	32,900
2	5B-5Mil Polyimide	Shims	566 (max)	90,000	90,000

- **Broach nuts** are attached to the **X and G-head boards** for locking the X, V, U and G wire layer head boards into position.
- The **6.5 mil Polyimide shims** maintain even level across sandwiched board assemblies that have **~6 mil wires** soldered on them.
- All the required **Broach nuts** and **Shims** for production of the 148 DUNE-APAs (i.e. UK + USA) have been purchased.

PCB Processing Work Flow



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Geometry Board Production Status

S/N	Board Ref No	Description	No Per APA	No passed QA	APAs Passed	No Ordered	% QA Passed	Yet To QA
1	8760119	U Head Board Left End	2	36	18	318	11.3%	0
2	8760030	V Foot Board Middle	6	229	38.2	954	24.0%	0
3	8760057	U-Foot Board Middle	6	160	26.7	954	16.8%	1
4	8760116	V Head Board Left End	2	103	51.5	318	32.4%	0
5	8760044	U-Foot Board High Slot End	1	74	74	159	46.5%	56
6	8760123	U Head Board Right End	2	35	17.5	318	11.0%	1
7	8760054	G Edge Board Middle	6	134	22.3	954	14.0%	8
8	8760026	V Side Board Middle Without Slot	24	244	10.2	3816	6.4%	101
9	8760040	U-Side Board Without Slot Middle	24	218	9.1	3816	5.7%	10
10	8760038	U-Side Board End	4	81	20.3	636	12.7%	113
11	8760121	G Head Board Middle	16	305	19.1	2544	12.0%	82
12	8760108	V Head Board Right End	18	173	9.6	2862	6.0%	0
13	8760122	G Head Board Left-End	2	43	21.5	318	13.5%	0
14	8760104	X Board Head	20	219	11	3180	6.9%	112
15	8760034	X Edge Board Middle	6	220	36.7	954	23.1%	0
16	8760024	V Side Board End	4	72	18	636	11.3%	116
17	8760109	X Edge Board Position 4 And 7	2	74	37	318	23.3%	32
18	8760036	V Foot Board End	2	52	26	318	16.4%	20
19	8760107	V Foot Board Middle Position 4 And 7	2	117	58.5	318	36.8%	19
20	8760111	U-Foot Board Position 4 And 7	2	49	24.5	318	15.4%	95
21	8760059	U-Foot Board Low Slot End	1	69	69	159	43.4%	35
22	8760032	X Edge Board End	2	79	39.5	318	24.8%	0
23	8760051	G Edge Board Low Slot End	1	61	61	159	38.4%	14
24	8760113	G Edge Board Position 4 and 7	2	41	20.5	318	12.9%	2
25	8760062	G Edge Board High Slot End	1	38	38	159	23.9%	17
26	8760115	U Head Board Middle	16	284	17.8	2544	11.2%	2
27	8760120	G Head Board Right-End	2	20	10	318	6.3%	11
28	8760028	V Side Board Middle With Slot	14	179	12.8	2226	8.0%	124
29	8760042	U-Side Board With Slot Middle	14	68	4.9	2226	3.1%	218
		Total	204	3477		32436		1189
				10.7%				

Board Shipments to Daresbury

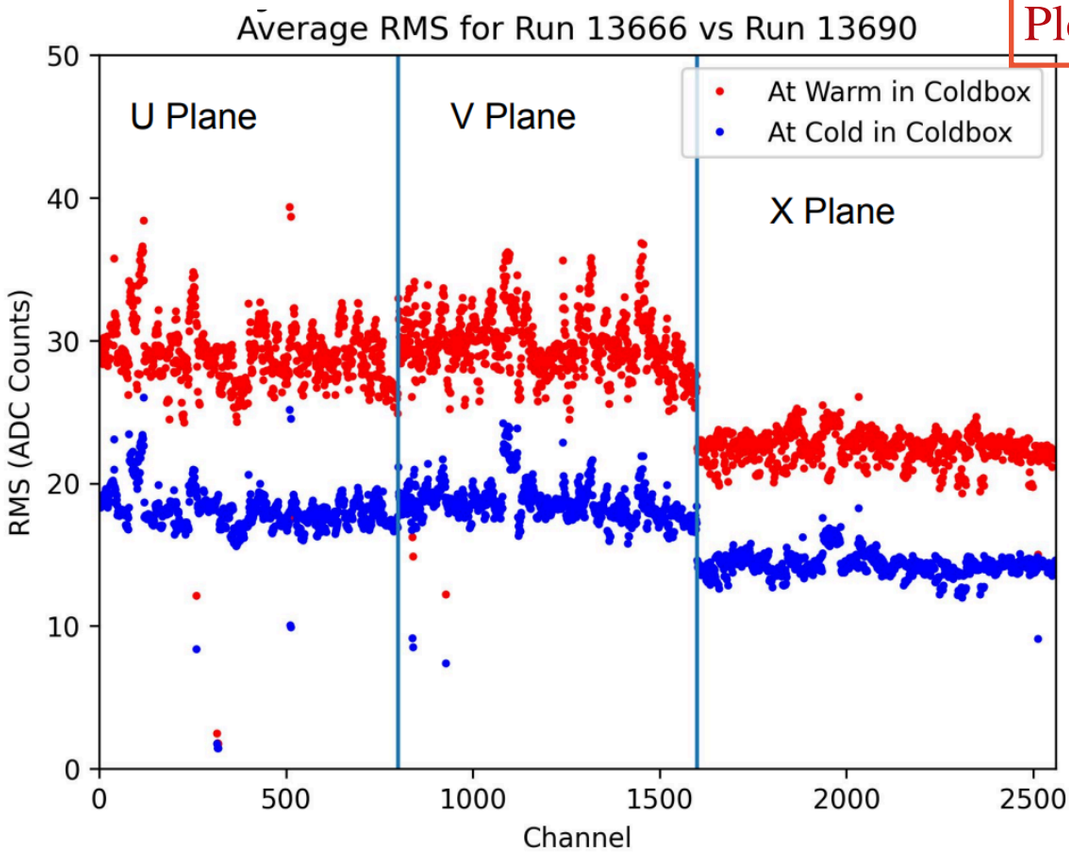
APA Number	Date required at Daresbury / W&M	Date delivered to Daresbury									
		X-Head (SUS)	V-Head (CAM)	U-Head (CAM)	G-Head (CAM)	X-Wrap (SHEF)	V-Wrap (SHEF)	U-Wrap (LAN)	G-Wrap (LAN)	Cover (MAN)	Etched cover (LAN)
4	1-Sep-2022	1-Jul-2022	1-Jul-2022	1-Jul-2022	1-Jul-2022	1-Jul-2022	1-Jul-2022	30-Sept-2022	30-Sept-2022	1-Jul-2022	25-Nov-2022
5	1-Sep-2022	28-Sept-2022	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-2022	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-202	6-Jan-2022	27-Sept-2022	28-Oct-2022	28-Oct-2022	15-Dec-2022	15-Dec-2022	28-Aug-2022	
US 1	1-Feb-2023					From MAN	From MAN	From MAN	From MAN		
9	1-Nov-2022	13-Dec-2022	6-Jan-202		27-Sept-2022	7-Nov-2022	7-Nov-2022				
10	1-Nov-2022	6-Jan-2023	6-Jan-202		27-Sept-2022	16-Nov-2022	16-Nov-2022				
11	1-Nov-2022				27-Sept-2022	28-Nov-2022	28-Nov-2022				
12	1-Nov-2022				27-Sept-2022	5-Dec-2022	5-Dec-2022				
US 2	1-Mar-2023										
13	1-Jan-2023				14-Nov-2022	15-Dec-2022	15-Dec-2022				
14	1-Jan-2023					5-Jan-2023	5-Jan-2023				

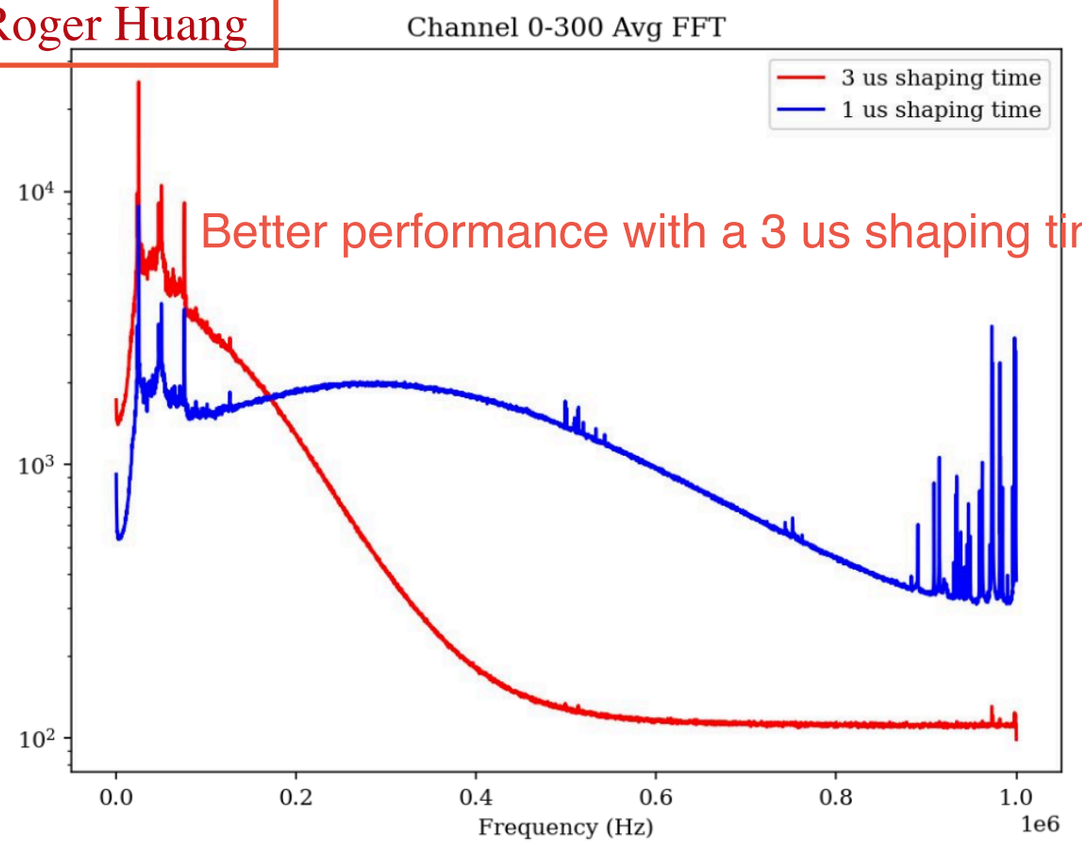
- Blue line in the table above shows the current position of the APA factory in utilising the delivered geometry boards.
- So, the APA board production/assembly are currently ahead of the factory as required.

Geometry Boards Production Challenges

UK-APA -2 Cold Box Test Issues

Plots from: Roger Huang



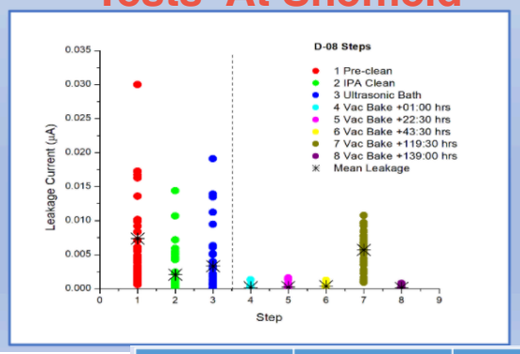


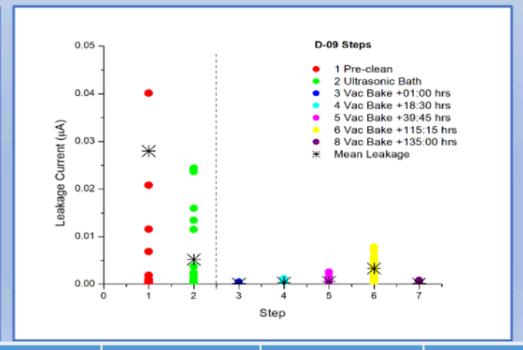
Better performance with a 3 us shaping time.

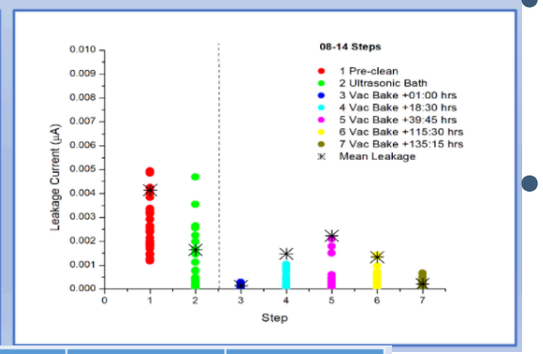
- Observed ~30 ADC Noise RMS spread. There are efforts by the cold electronics consortium to develop a coherent noise filter which is expected to improve the baseline noise further.
- The ~25 kHz noise peaks were also observed from the UK-APA-2 FFT results.
- Initially, 3 channels were dead, the affected FEMBs were replaced which solved this issue. However, 7 other channels were reported to look open. These potentially open channels were consistent with the recorded APA non-conformances.
- However, during the APA warn up, FEMB 10 and 11 showed ~180 ADC continuous noise/current spikes.

Geometry Boards Before APA Assembly

Tests At Sheffield



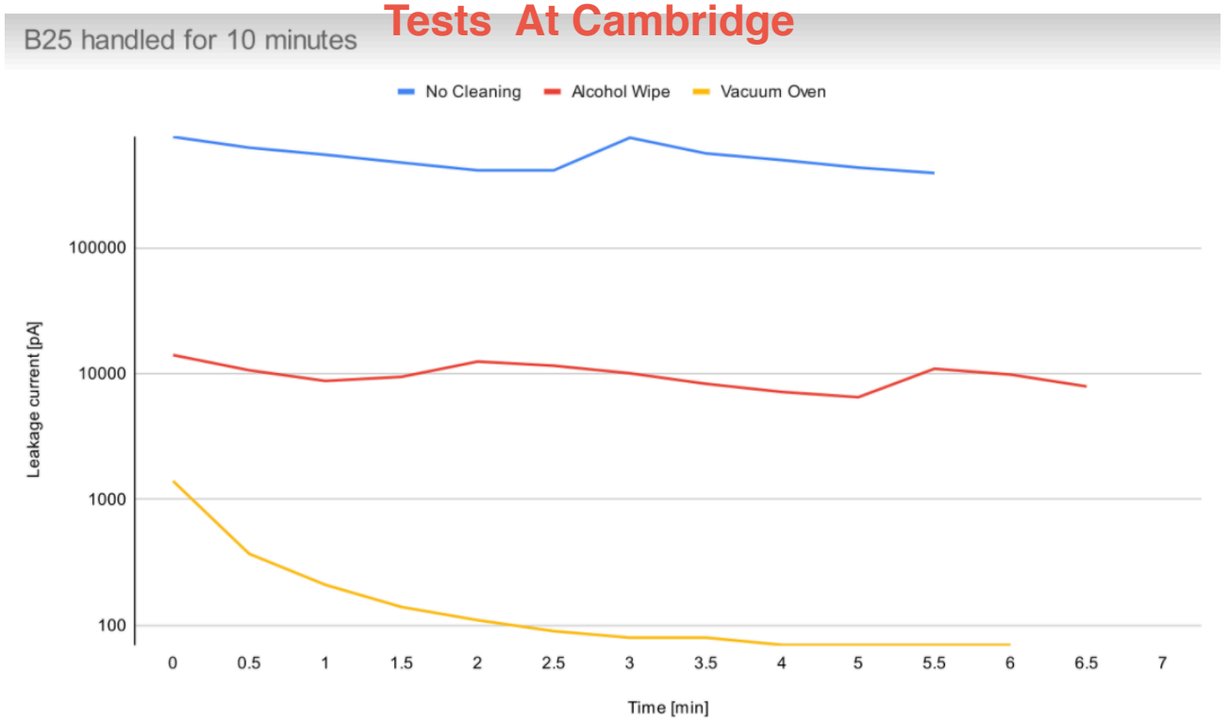




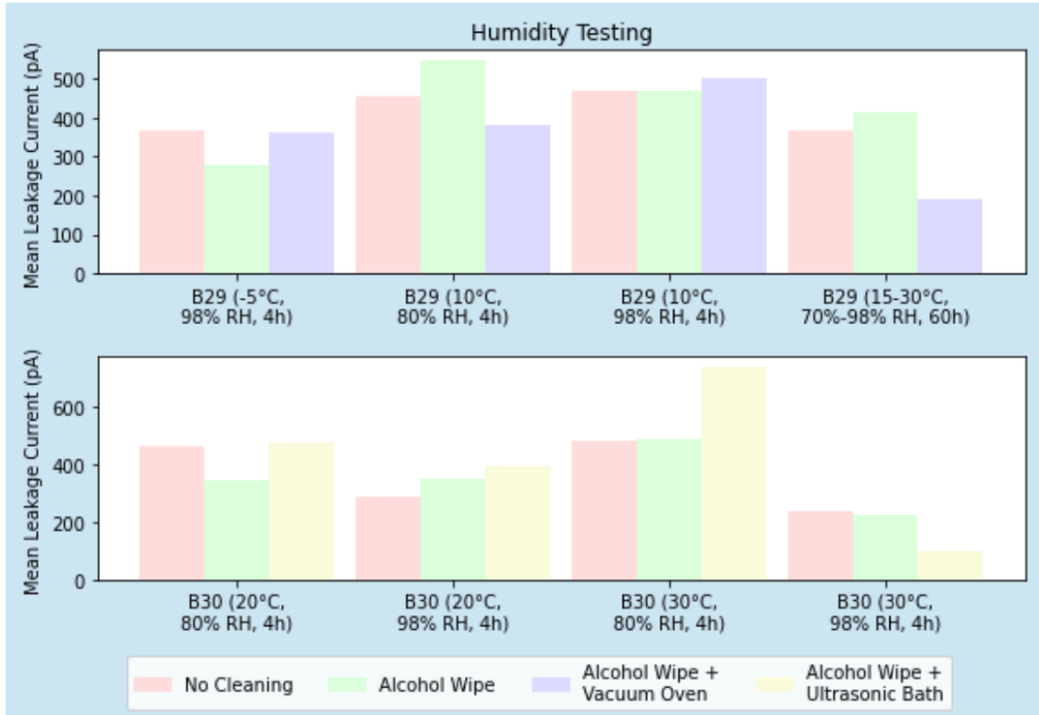
Board	Pre-Clean	+US Bath	+Vac Bake	+18hrs	+40hrs	+122hrs	+146hrs
D-07	4.9nA		0.4nA	0.2nA			
D-08	7.4nA	3.3nA	0.2nA	0.3nA	0.4nA	5.7nA	0.2nA
D-09	28.0nA	5.2nA	0.1nA	0.3nA	0.5nA	3.3nA	0.2nA
08-14	4.1nA	1.6nA	0.1nA	1.5nA	2.2nA	1.3nA	0.2nA

- **Handling, increase in temperature** and **humidity** increases leakage current.
- Observed leakage current on board from the factory is **<30 nA**.
- **Washing boards** with either **demonised water** or **liquid soap** reduces leakage current by **an order of magnitude**.
- About an additional **order of magnitude reduction** in leakage current was gained when the boards **are vacuum baked**.

Tests At Cambridge



Board handled for 10 minutes, wiped with IPA and baked.



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Mitigating Warm APA Baseline Noise Spikes

- Potential causes of the observed APA noise response include:
  - Dirts on boards due to poor handling which can create unnecessary current loops?
    - ✓PCB and wire winding procedures have been reviewed to ensure that gloves are used to handle boards at all times.
    - ✓Boards are shipped and stored in sealed anti-static bags.
  - Free unglued grounded mesh wires distorting the expected uniform electric field around the affected wires?
    - ✓Free APA ground mesh wires are now checked and glued to the mesh frame.
  - Test lab humidity?
    - ✓Boards are shipped and stored with desiccants in anti-static bags.
    - We plan to build an APA (may be APA 9?) using only washed + baked boards.
    - Similar FEMB noise tests will be performed to check if baking minimises the effects of humidity.

Summary

- DUNE-APA geometry board production contract has been awarded to a UK company.

- The production, QA tests, assembly and delivery of these geometry boards at the APA factory are ongoing.

- Assembly components for all the required geometry boards have been purchased and delivered.

- There are a few challenges which we are working to resolve.

Thanks for listening!