Overview on FST

26 April 2021 @ F2F Meeting

National Cheng Kung University
Yi Yang

The Forward Silicon Tracker

Flexible hybrid PCB: **SDU/IU**

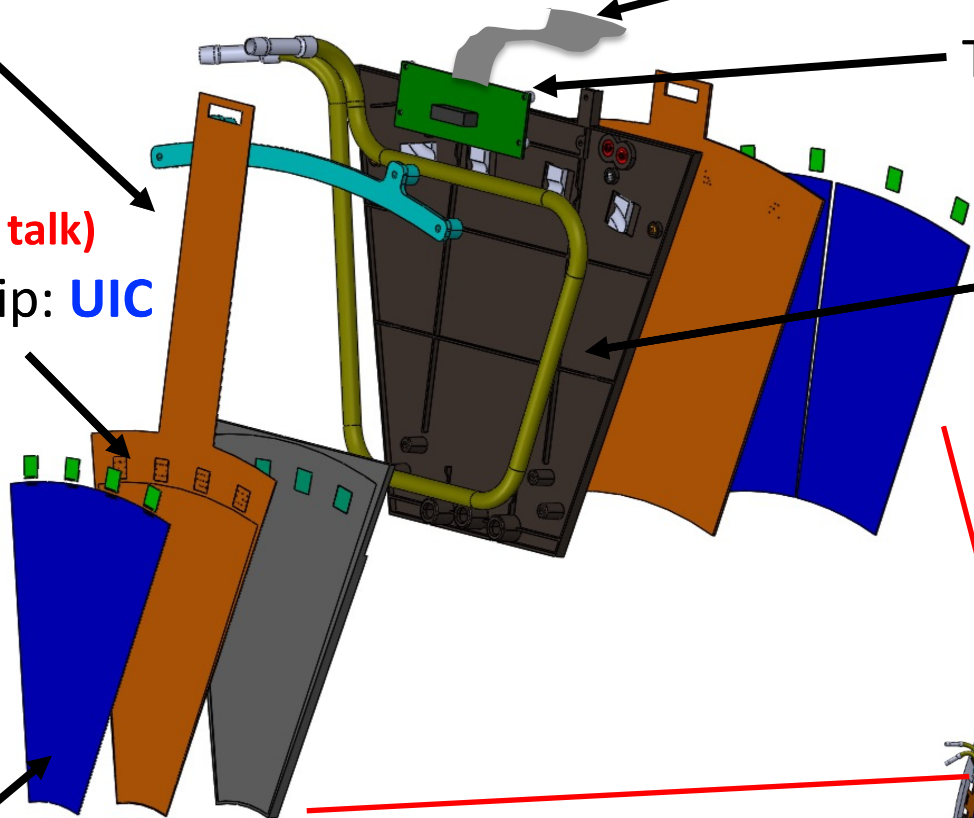
Inner Signal Cable: **BNL/IU**

T-Board: **SDU/IU**

(Shenghui's talk)

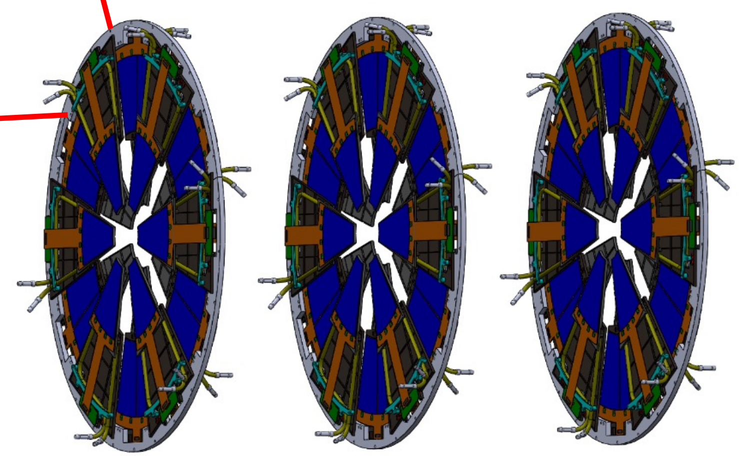
APV25 Chip: **UIC**

Mechanical Structure
(+ cooling pipe): **NCKU/AIDC**



(Xu, Rahul, and Flemming's talks)

Supporting Structure &
Integration: **BNL**



Silicon sensor: **UIC/BNL** (Shenghui's talk)

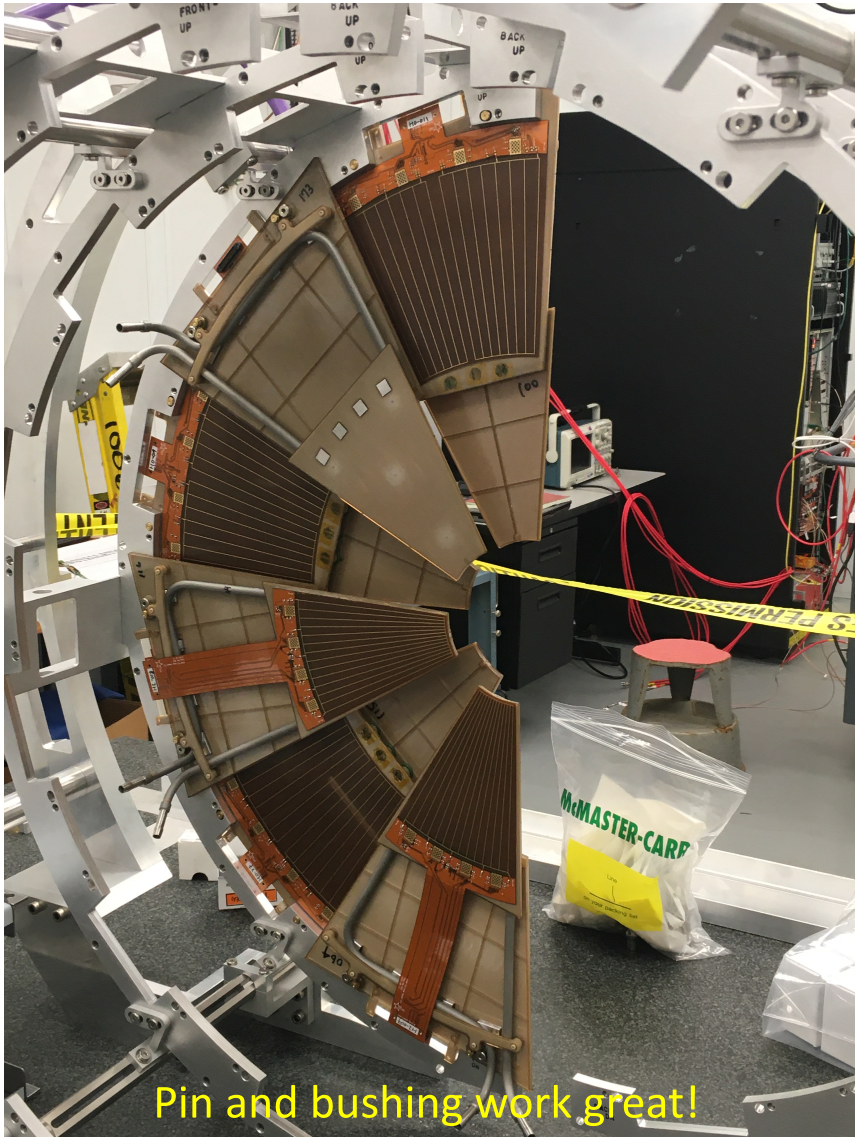
Cooling: **BNL/NCKU** (Rahul's talk)

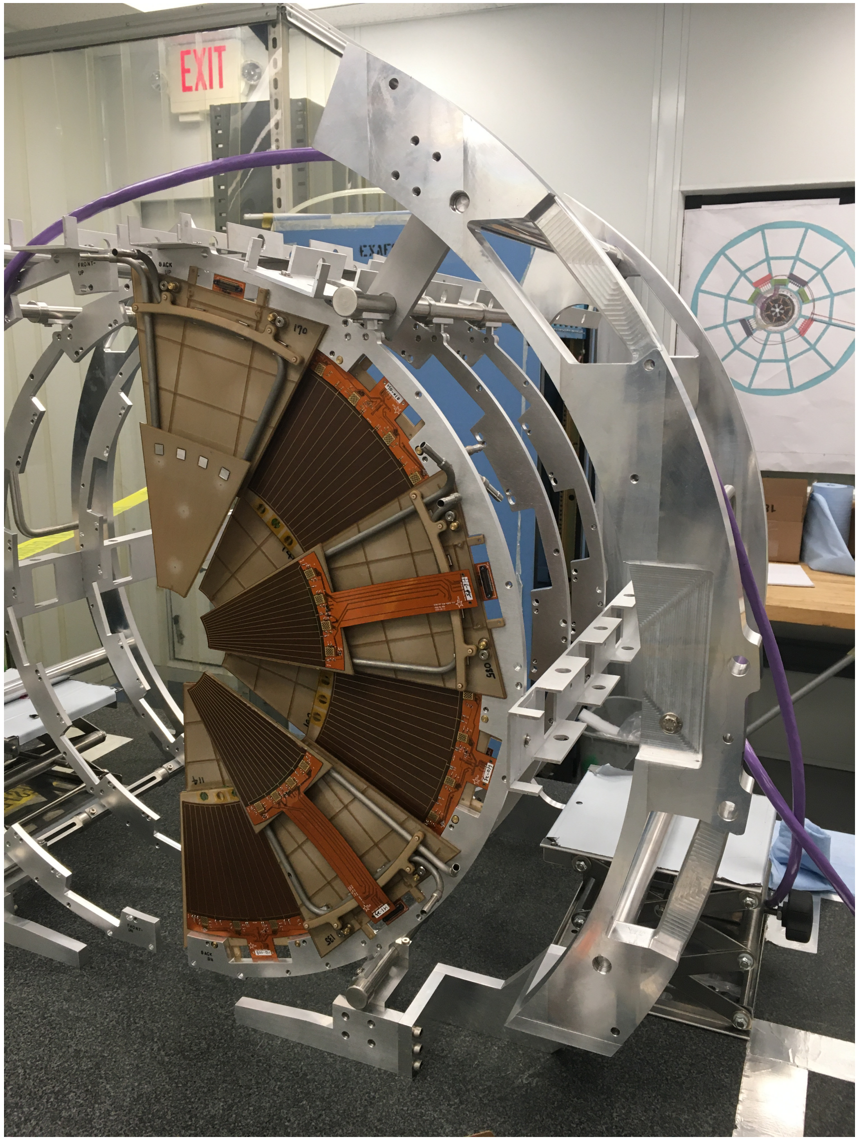
Simulation: **UIC/BNL/IISER/NCKU**

Production of MS

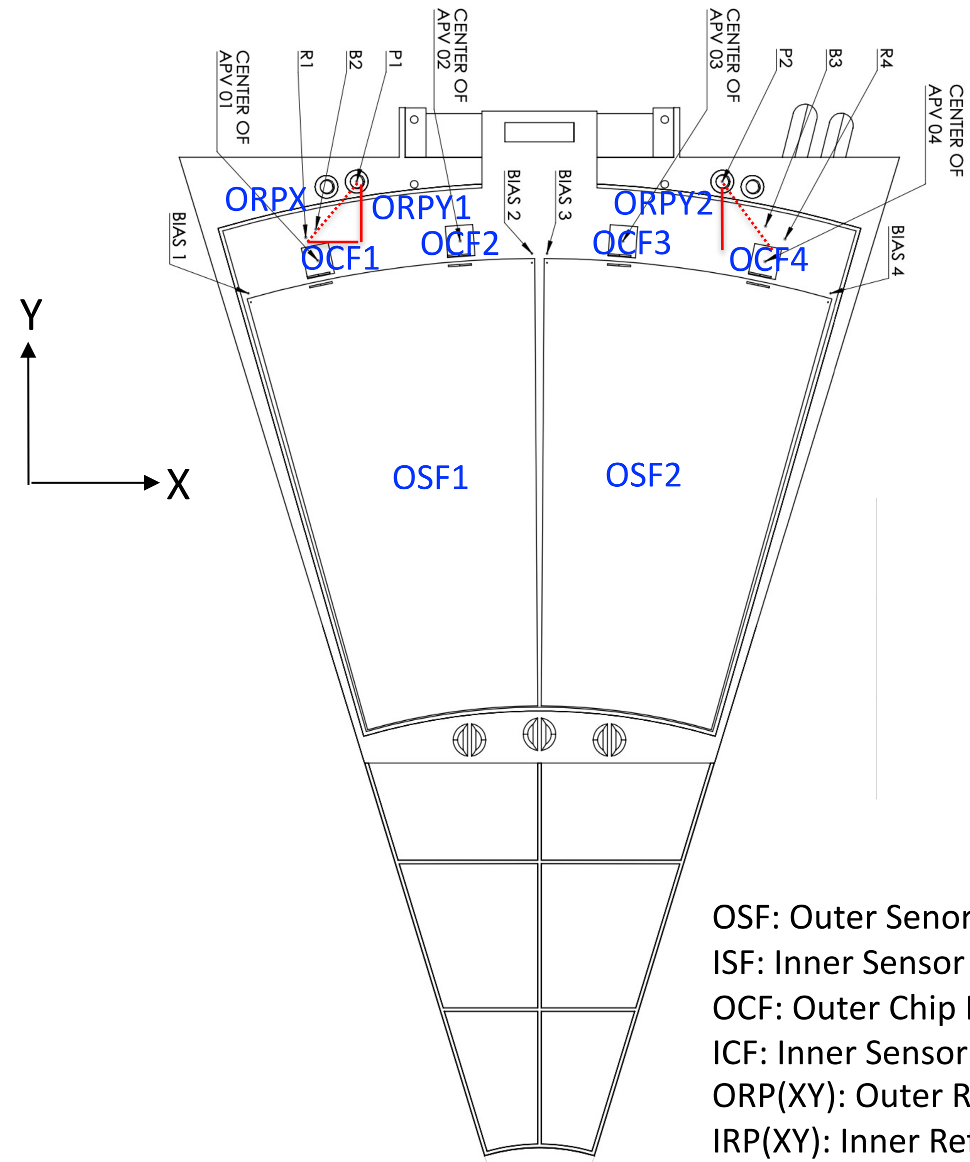
- The production phase: October, 2020 - March 23, 2021
- Produced FST model: **FST-06 – FST-79**

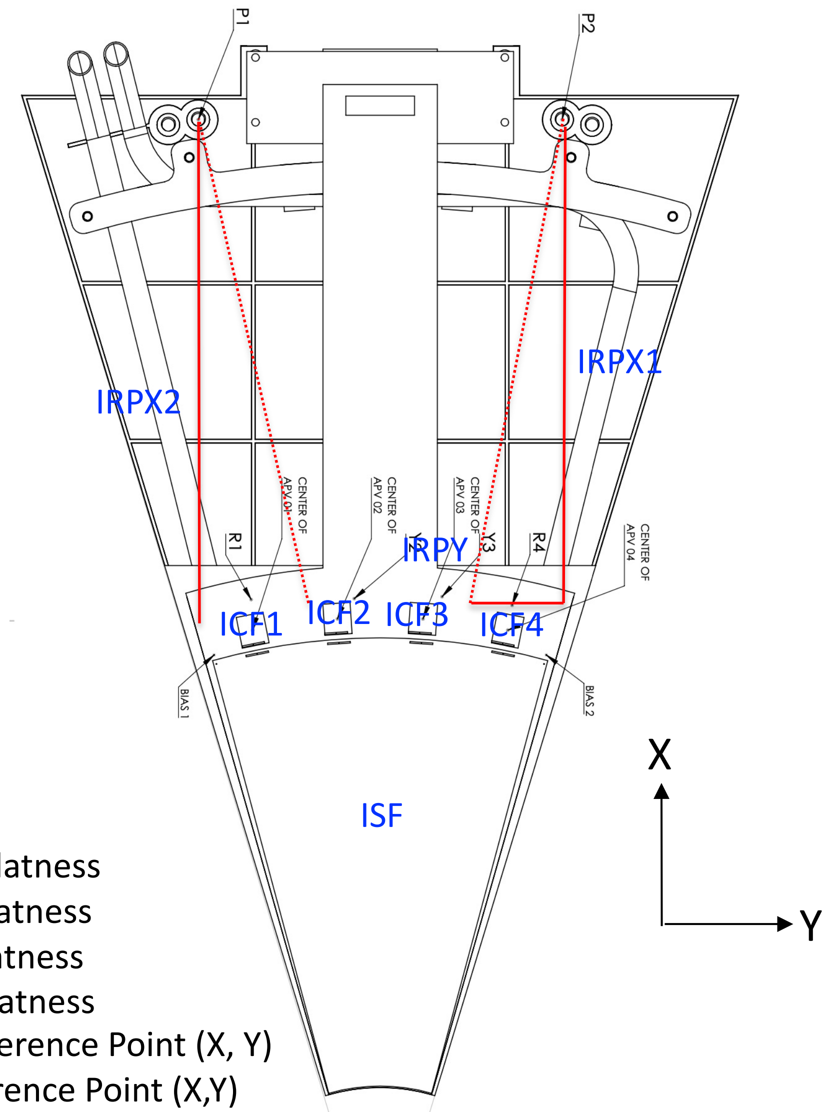
Pre-Installation





QA for Production





OSF: Outer Senor Flatness
ISF: Inner Sensor Flatness
OCF: Outer Chip Flatness
ICF: Inner Sensor Flatness
ORP(XY): Outer Reference Point (X, Y)
IRP(XY): Inner Reference Point (X,Y)

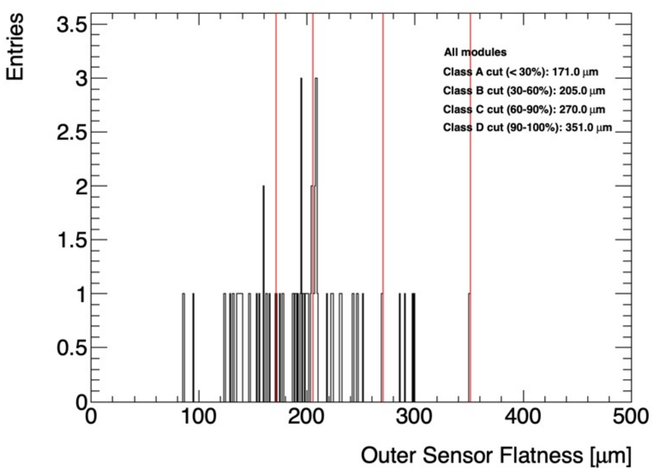
Production Statistics

- All the measurements are recorded on Google Sheet: https://docs.google.com/spreadsheets/d/1YLm95aj0zIxxCnsfy0XVoxeI9FWD4RHUv-Pe4qCOfSc/edit?usp=sharing

Module ID	OSF1	OSF2	ISF	OCF1	OCF2	OCF3	OCF4	ICF1	ICF2	ICF3	ICF4	ORPX1	ORPY	ORPY2
FST-11	207.36	194.35	286.39	97.19	59.43	31.42	73.15	60.58	98.73	133.33	89.85	41.12	6.08	6.75
FST-12	285.54	230.17	329.6	110.12	56.26	131.73	55.3	17.22	85.92	83.71	32.61	59.59	29.96	30.56
FST-13	246.73	165.61	387.82	58.05	113.73	57.96	25.07	188.06	173.58	197.44	124.9	47.81	9.13	40.68
FST-14	350.48	191.1	207.8	91.41	120.57	183.44	18.95	10.41	12.99	53.68	18.26	20.67	26	17.49
FST-15	299.74	231.05	247.37	26.59	66.23	60.56	60.68	87.93	96.57	112.93	93.02	7.39	17.95	1.62
FST-16	223.66	208.09	347.64	41.48	122.14	24.98	65.22	45.09	99.86	111.18	69.67	52.96	71.88	40.93
FST-17	193.94	177.52	148.62	83.07	48.64	62.03	69.88	106.19	109.41	121	76.97	99.08	45.04	26.45
FST-18	194.51	186.23	217.09	45.59	24.77	73.35	55.62	48.08	52.21	95.42	53.15	50.77	6.57	17.26
FST-19	194.63	222.71	308.47	58.62	49.05	34.73	54.15	28.03	99.43	103.29	66.71	98.54	6.99	92.65
FST-20	290.91	199.34	40.22	59.38	55.12	76.72	57.72	56.33	113.15	135.63	98.1	6.96	47.86	14.4
FST-21	131.72	94.04	100.09	65.97	110.06	33.42	72.89	69.01	132.39	162.31	87.64	108.11	14.89	20.75
FST-22	136.28	128.44	152.55	92.76	135.82	68.95	54.76	116.37	164.88	205.1	146.78	35.08	20.65	16.85
FST-23	85.3	159.93	37.5	107.18	120.74	92.29	110.59	12.1	46.48	40.75	36.32	84.1	6.51	18.17
FST-24	204.53	200.03	88.62	45.62	92.2	116.51	94.46	24.68	70.43	96.06	65.1	53.19	18.53	30.46
FST-25	251.82	135.2	96.23	44.96	123.47	61.34	78.09	56.97	107.33	106.81	64.3	36.01	0.44	57.84
FST-26	208.01	138.57	375.38	49.37	83.94	19.86	46.75	27.04	35.2	51.12	30.02	51.12	21.89	8.24
FST-27	170.18	206.67	145.83	63.82	82.6	94.26	107.16	68.93	140.57	145.54	109.35	66.91	82.6	18.16
FST-28	146.378	153.47	91.27	63.71	87.16	57.88	46.47	38.71	69.65	92.77	61.35	15.53	9.79	40.45

Grading Matrix

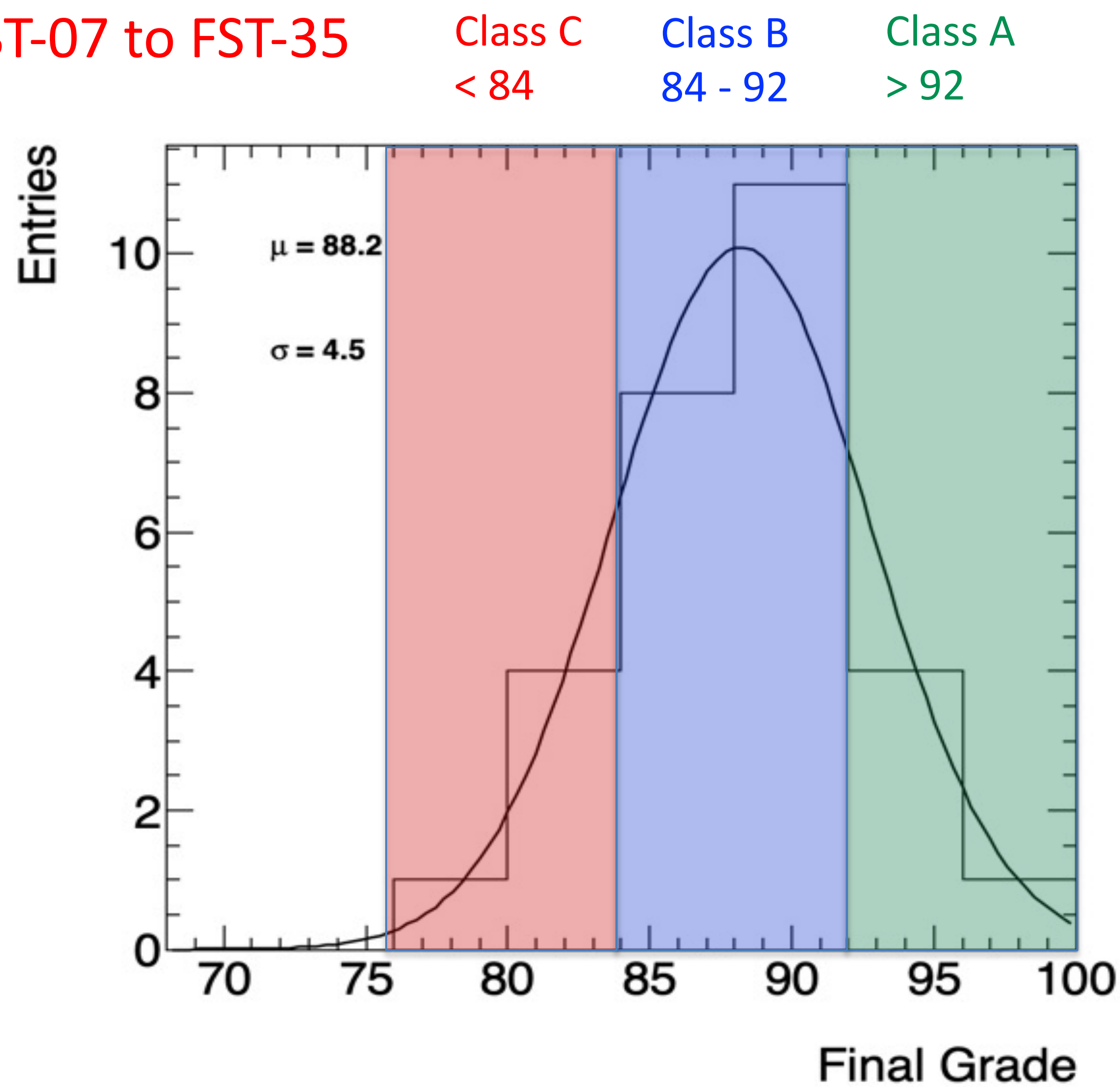
- Assumption: all modules are good unless it encounters some technical issue, e.g. overflow glue…
- Apply a hard cut on flatness at 250 mm



		A: < 30 % (100 pts)	B: 30 – 60% (90 pts)	C: 60 – 90% (80 pts)	D: > 90 % (60 pts)
OSF x 2 (25%)		< 171 μm	171 – 205 μm	205 – 270 μm	270 – 351 μm
ISF (25%)		< 94 μm	94 – 218 μm	218 – 276 μm	376 – 388 μm
OCF x 4 (10%)		< 55 μm	55 – 70 μm	70 – 114 μm	114 – 184 μm
ICF x 4(10%)		< 52 μm	52 – 88 μm	88 – 141 μm	141 – 206 μm
ORP (15%)	X	< 40 μm	40 – 53 μm	53 – 99 μm	99 – 109 μm
	Y x 2	< 15 μm	15 – 26 μm	26 – 58 μm	58 – 153 μm
IRP (15%)	Y	< 11 μm	11 – 51 μm	51 – 132 μm	132 – 165 μm
	X x 2	< 22 μm	22 – 44 μm	44 – 100 μm	100 – 349 μm

Final Classes

Based on FST-07 to FST-35

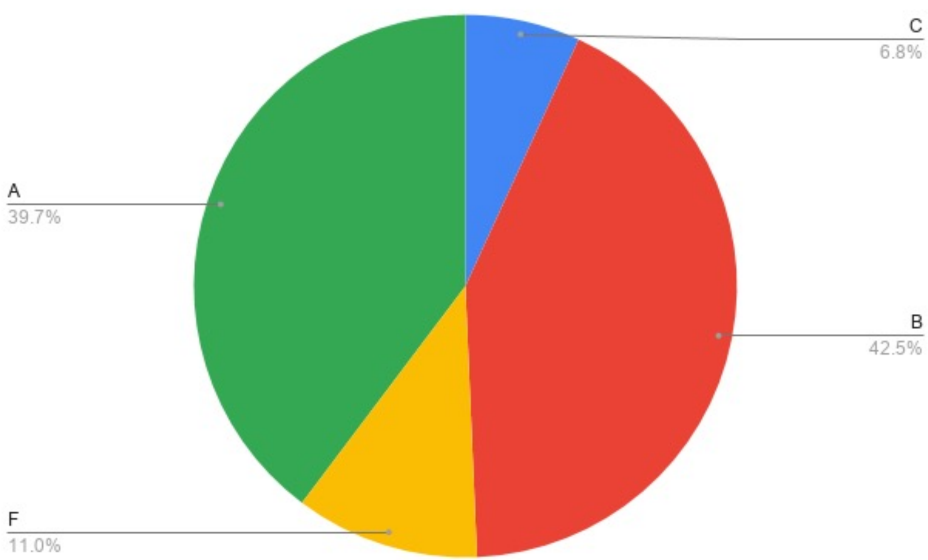


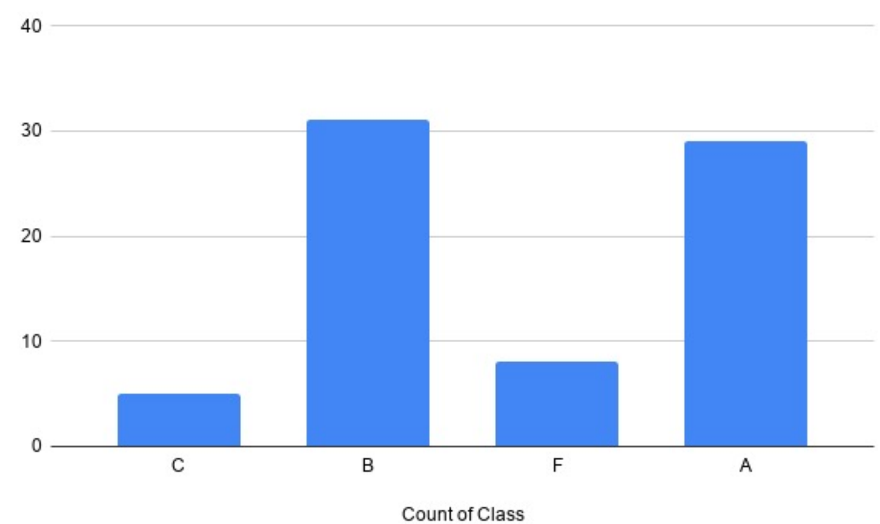
Overall Statistics

- Production modules: FST-07 to FST-79 (total 73)
  - Class A: 29 (passed 250 nm cut: 29)
  - Class B: 31 (passed 250 nm cut: 20)
  - Class C: 5
  - Class F: 8

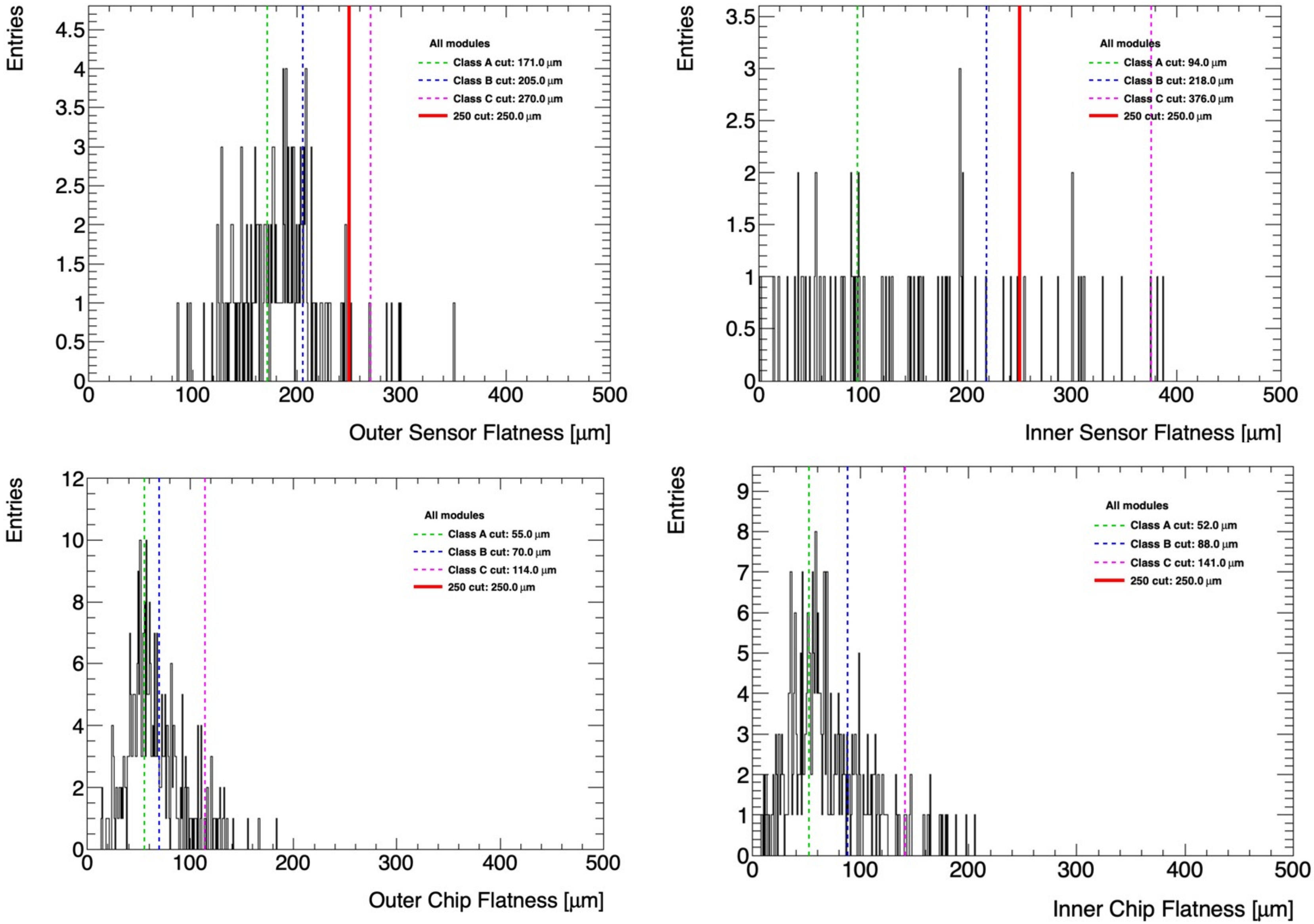
} 49 very good ones

- 3 out of 49 have some issues (soldering on bonding pad and connector lost)
- Will use 2 modules has flatness slightly over 250 μm

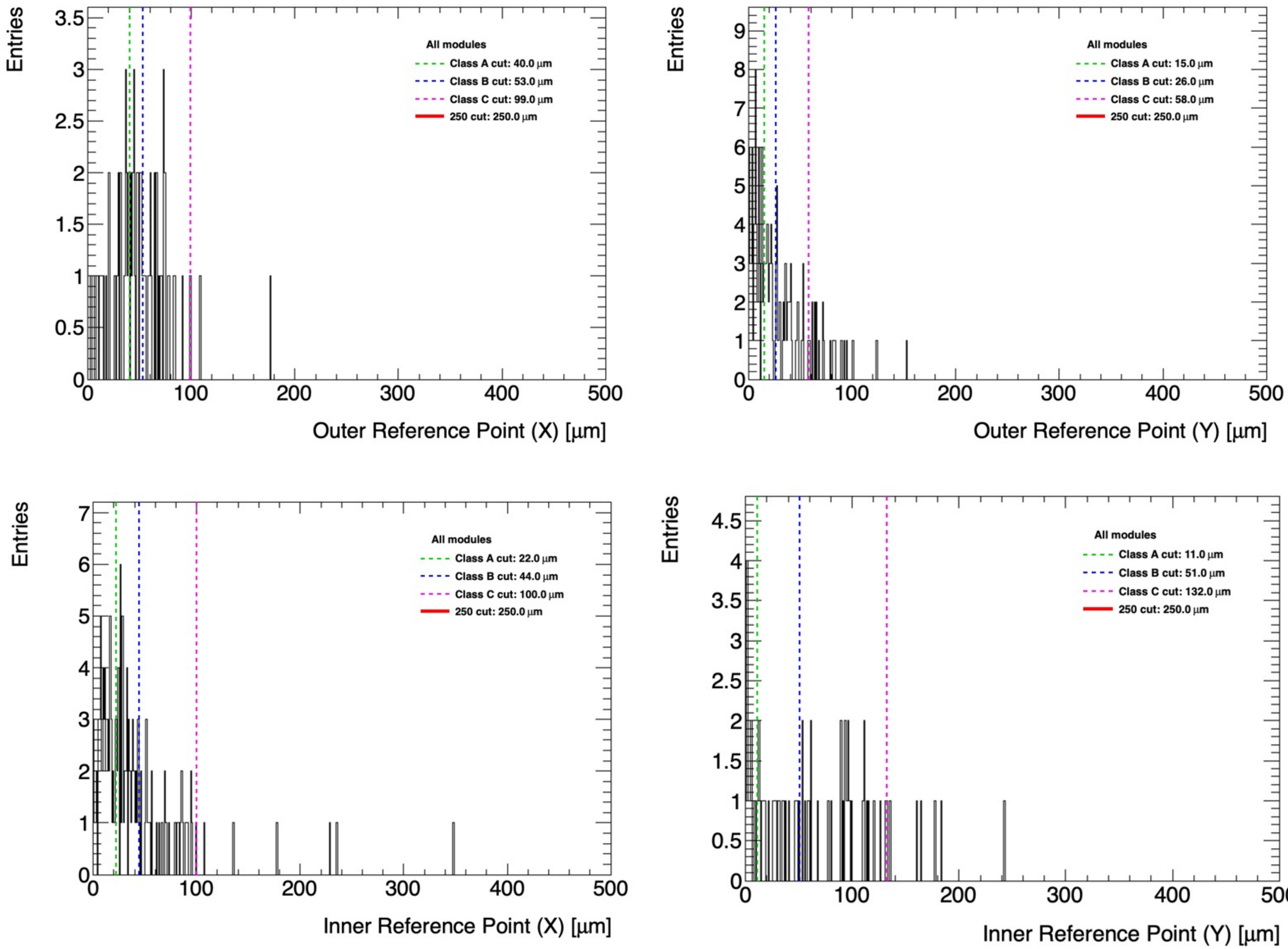




Outer/Inner Sensor/Chip Flatness

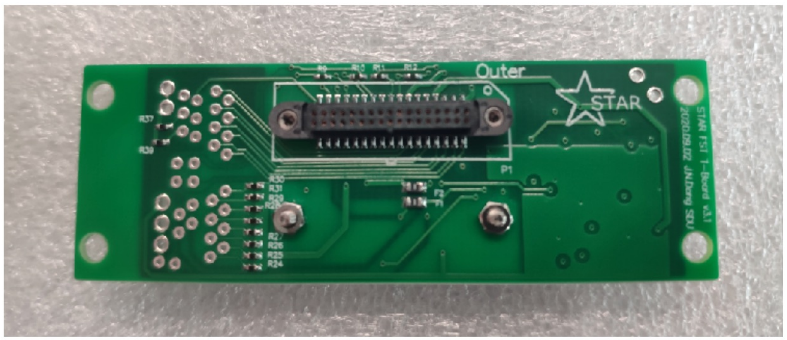


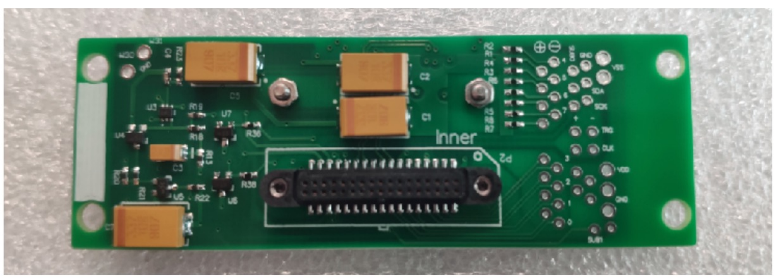
Outer/Inner Reference Point – X/Y direction

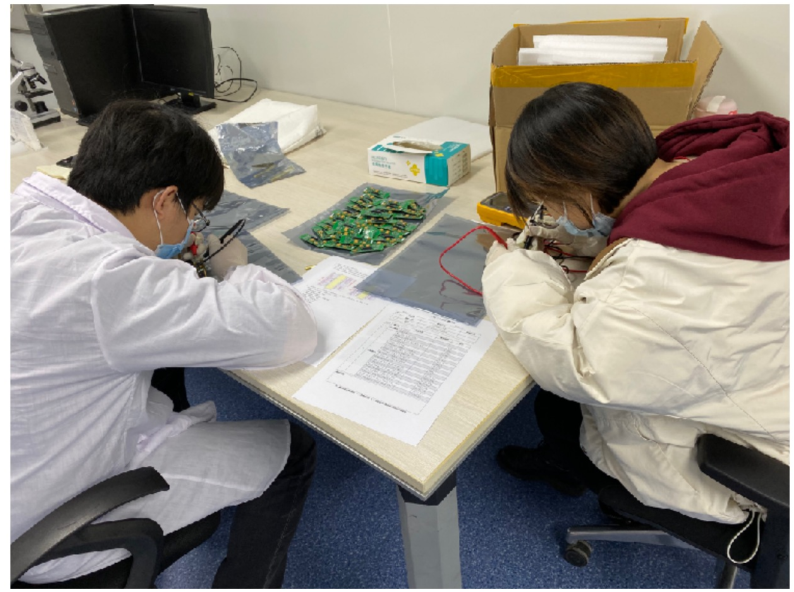


T-Board Production

From Maowu Nie







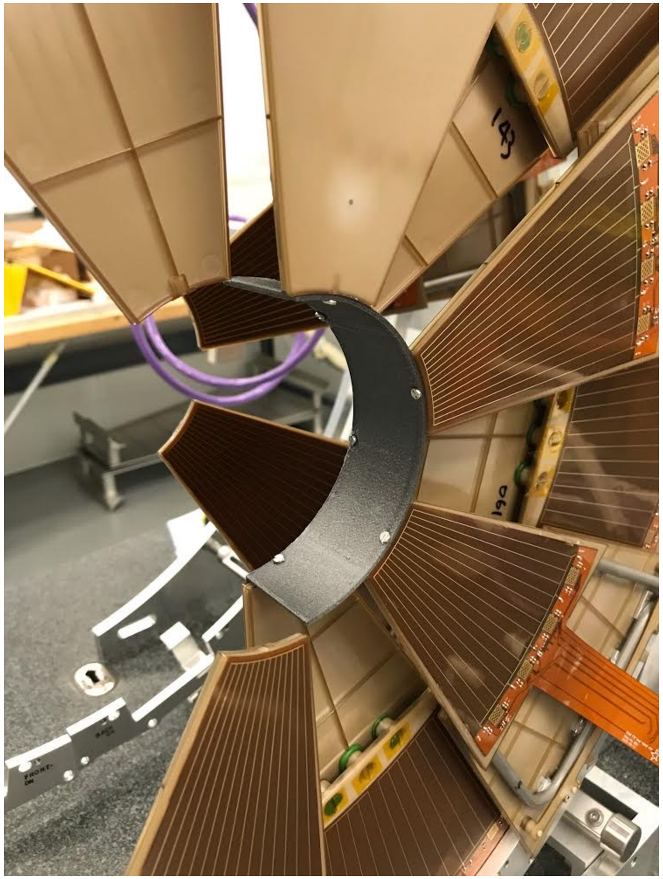
QC table: https://drupal.star.bnl.gov/STAR/system/files/QC%20of%20T-board%20v3_1%20for%20FST.pd

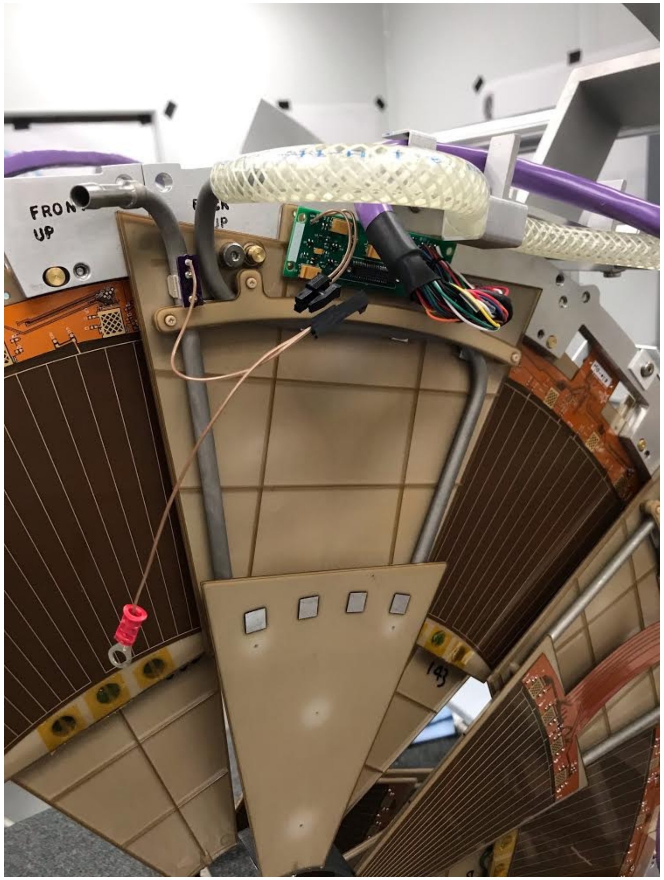
- **T-Board production and assembly were all done.**
- **After QC test, they were shipped to BNL, and Mike already received all of them on Apr. 13, 2021.**

Cables

- The grounding/bonding are figured out (thanks to Mike)
- Lengths are almost determined (thanks to Xu and others)

➔ By early next week we can sign off on it and get the quotes.





Summary

- Production and assembly of FST MS were finished on March 23, 2021 (by NCKU)
- Production and assembly of FST T-Boards were finished on April 13, 2021 (by SDU)
- Cable is almost ready to get quotes and place the order
- Sensor and chip assembly is ongoing at Fermilab (UIC), expected to be finished in 2-3 weeks
- Testing and preparation of installation are ongoing (BNL/UIC)

Backup

Design of Mechanical Structure

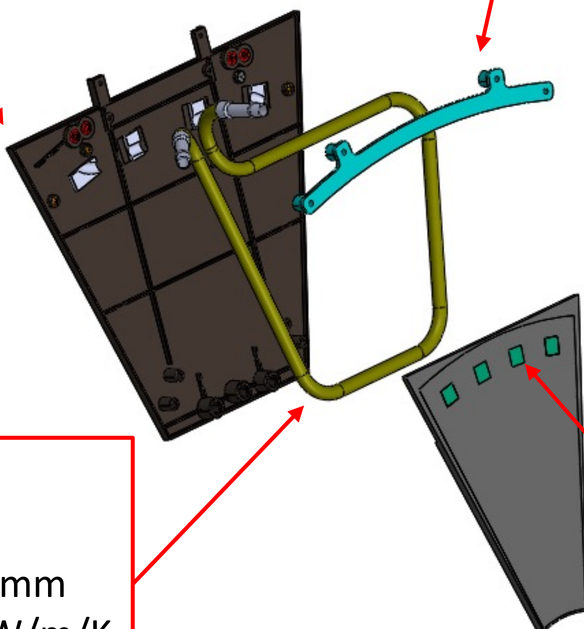
Main structure:
- Material: PEEK
- Thermal Conductivity: 0.24 W/m/K
- ES&H: **Good**
- Rad.: **Good**

Tube fixture:
- Material: PEEK
- ES&H: **Good**
- Rad.: **Good**

Thermal grease:
- Material: Thermalrigh TF8 2G
- ES&H: **Good**
- Rad.: **Good**

Glue (inner MS+outer MS):
- Material: Loctite EA 9359.3 AERO
- ES&H: **Good**
- Rad.: **Good**

Glue (hybrid+MS):
- Material: Araldite 2011
- ES&H: **Good**
- Rad.: **Good**



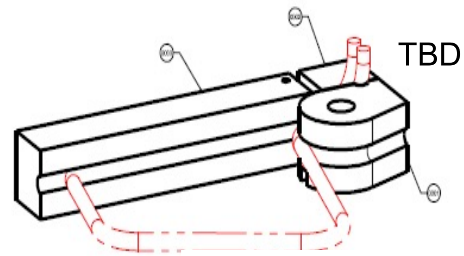
Tube:
- Material: Stainless 316
- Size: OD 6.35 mm, ID 5.54 mm
- Thermal Conductivity: 14 W/m/K
- ES&H: **Good**
- Rad.: **Good**

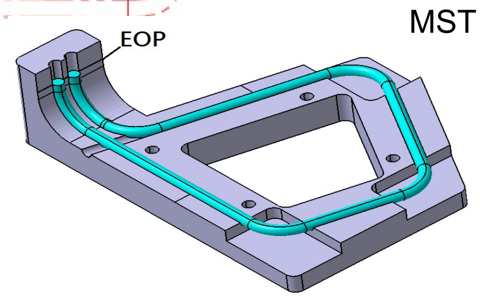
Heat sink:
- Material: Al 6061
- Size: ~8.2 x 8.0 x 3 mm^2
- ES&H: **Good**
- Rad.: **Good**

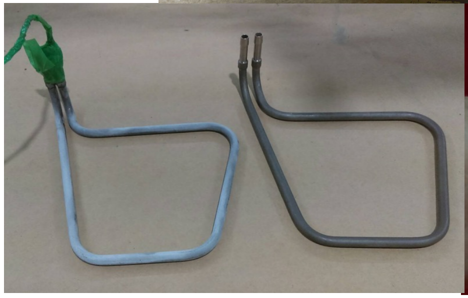
*PEEK has been used in collider experiments: e.g. STAR HFT

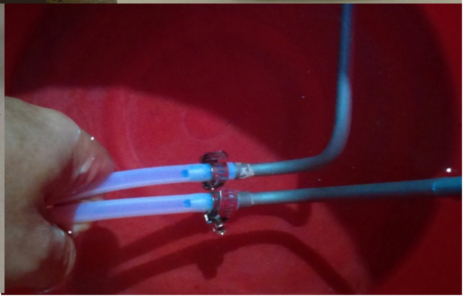
Manufacture of Cooling Tube

1) Passivation treatment on the raw 316 stainless steel tube
2) Use Tube Bending Die (TBD) to bend the tube
3) Use 3D printed Miscellaneous Service Tool (MST) to check the dimensions.
4) Braze the connectors to the tube
5) Leakage test
6) Clean the cooling tube







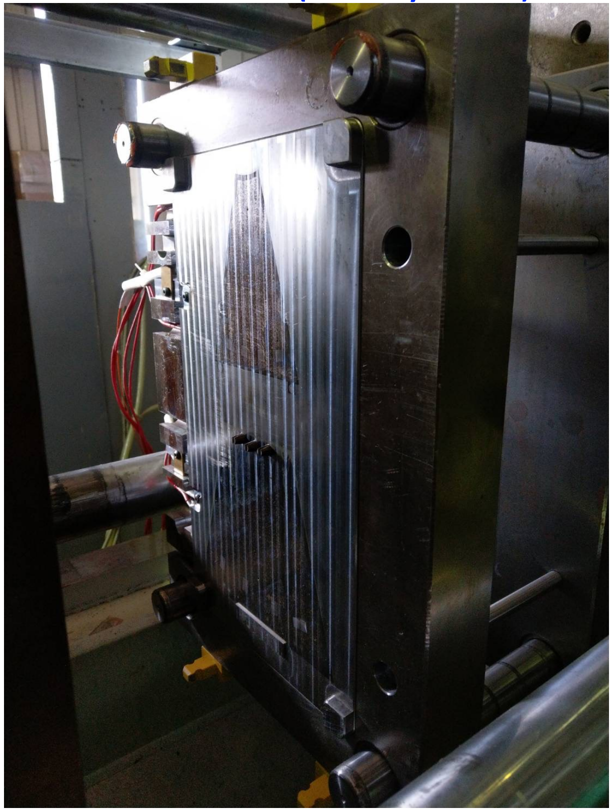


Injection Molding for MS

- The mechanical structure are made using injection molding method
- ***Very challenging:*** thin + large + complex structure
  many components embedded

Moving Half (Core Side)

Fixed Half (Cavity Side)

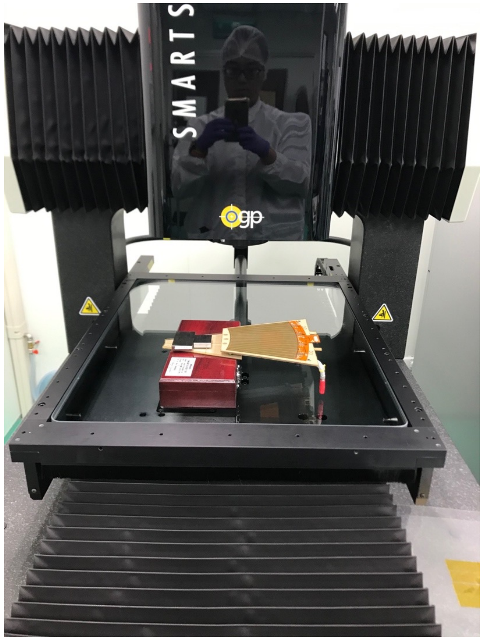


Assembly Procedure: Facilities

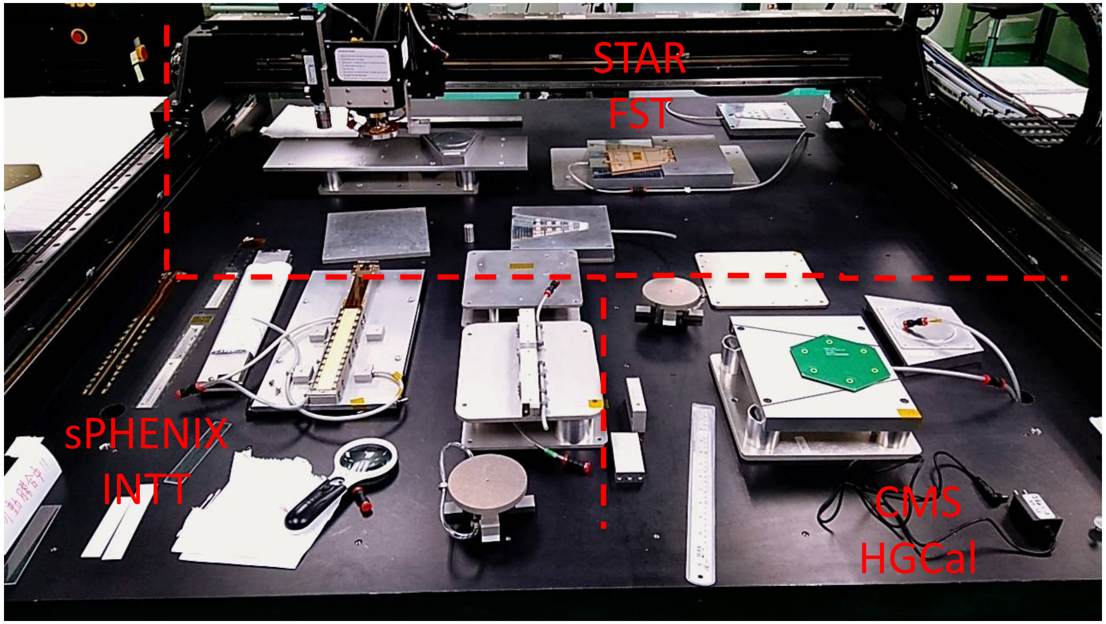
- Use the robotic machine at **Taiwan instrumentation Detector Consortium** (TiDC, https://www.taiwan-tidc.org) to assemble
  1) Hybrid PCBs to inner and outer structures
  2) Inner wedge and outer wedge

  → Moving smoothly at TiDC

Optical Gauging Products (OGP)

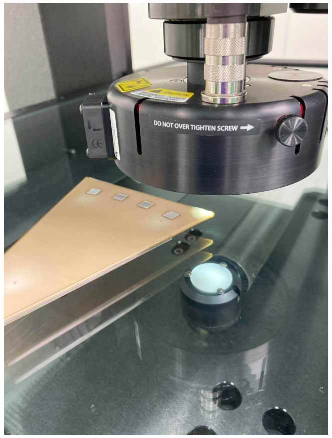


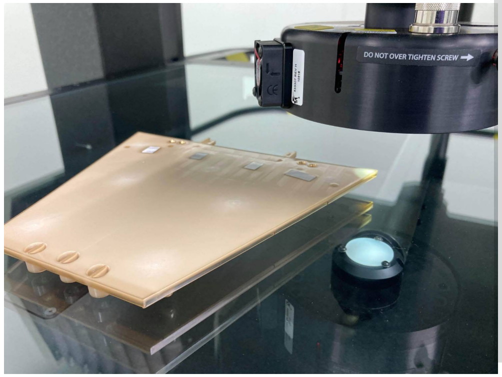
Assembly table and gantry



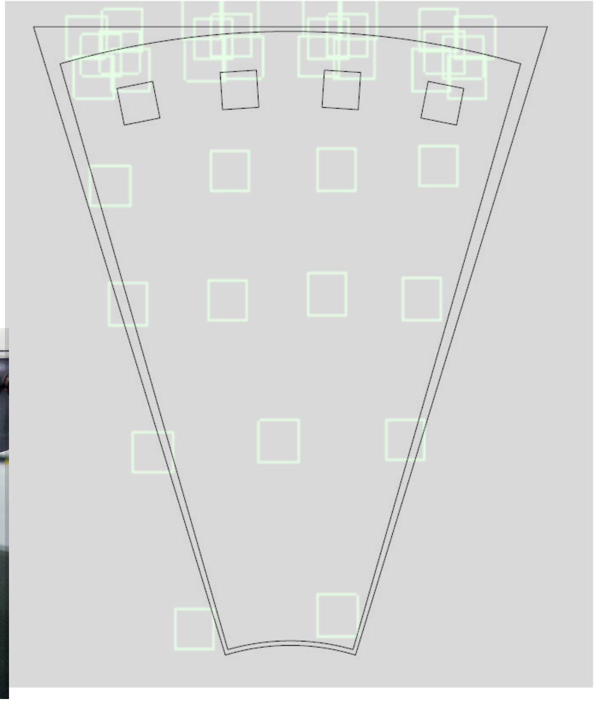
Quality Control

- Use OGP to measure the **flatness** (maximum difference between measured points)
- 5 points at chip areas and 13 (9) points at sensor area
- Acceptance: < 500 μm

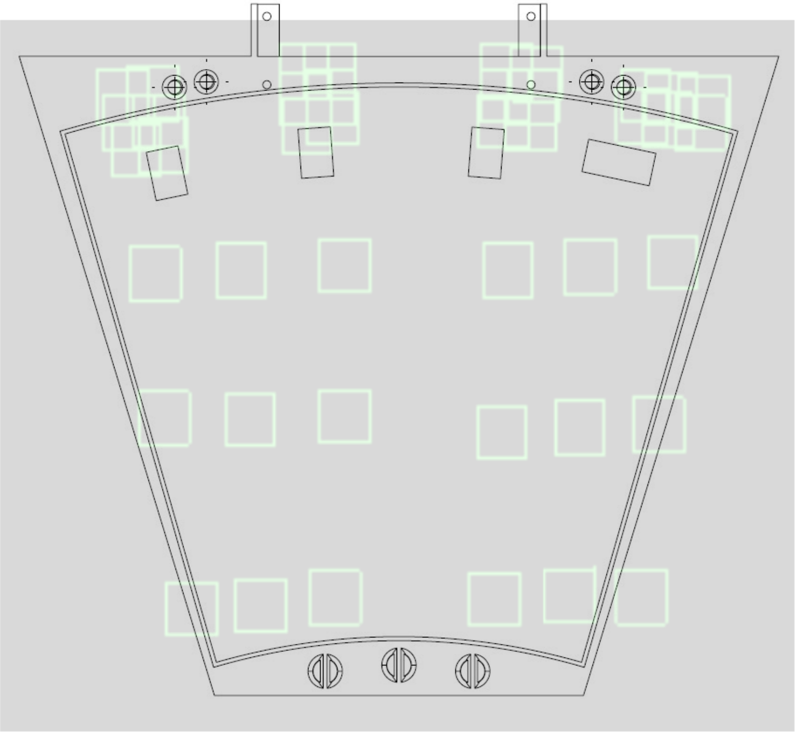




Inner

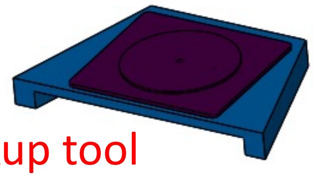


Outer



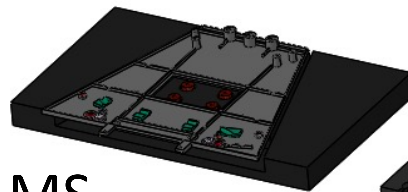
Assembly Procedure: Outer MS

1) Place the pickup tool, outer MS + tray, outer Hybrid + tray on table

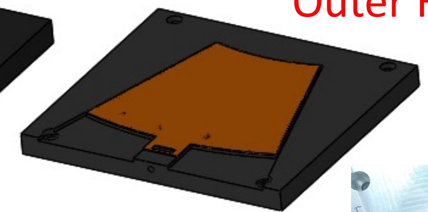


pickup tool

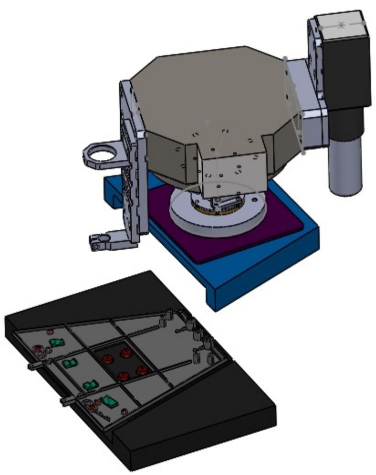
Outer MS + tray

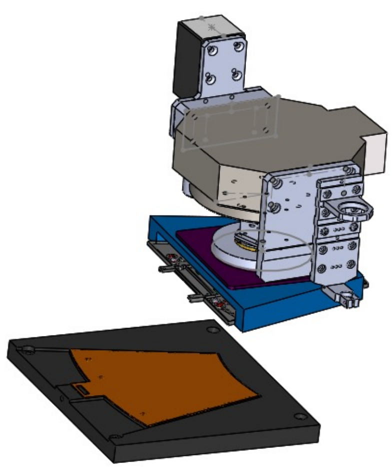


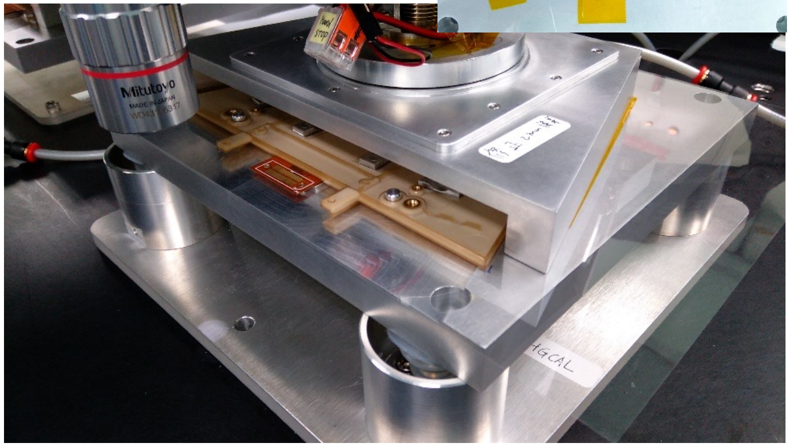
Outer Hybrid + tray



2) Place guide pin on outer MS
3) Apply glue on outer Hybrid
4) Use camera to locate the reference points
5) Glue





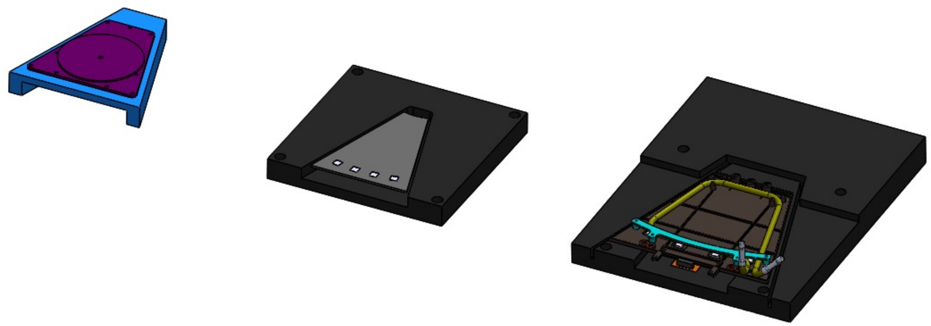


Modified Gluing Procedure for Inner Hybrid

* Manufacturing new fixtures now

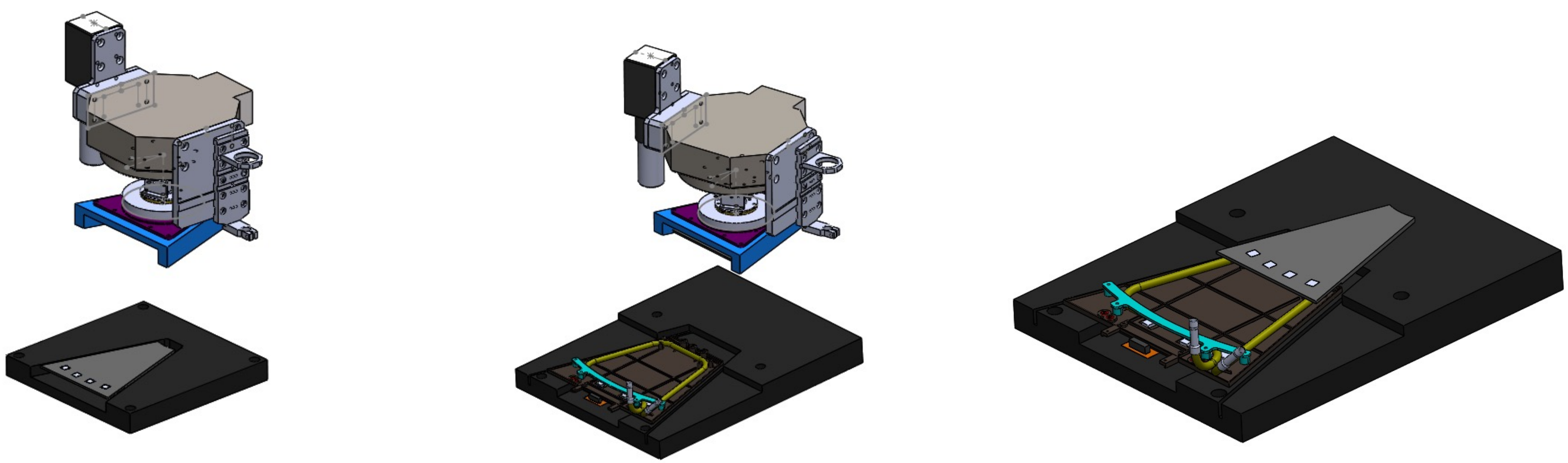
❑ Glue the inner MS first

1) Place pickup tool, inner MS + tray, outer wedge + tray on table



2) Use camera to locate reference points

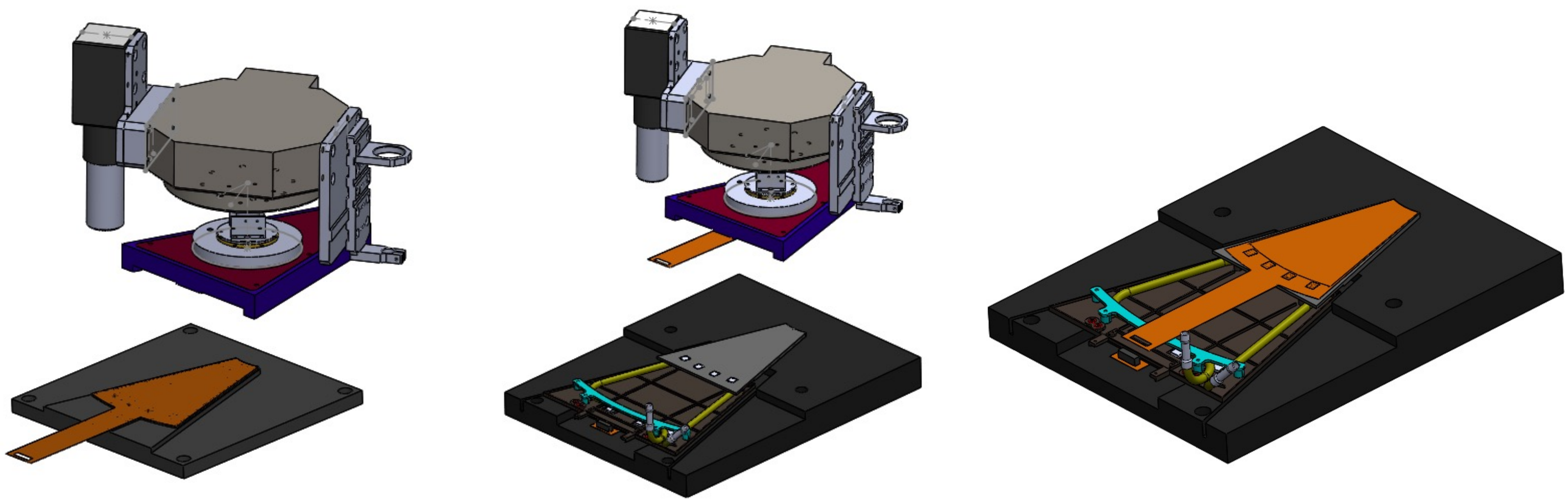
3) Pick up inner MS and glue it on the outer wedge



Modified Gluing Procedure for Inner Hybrid

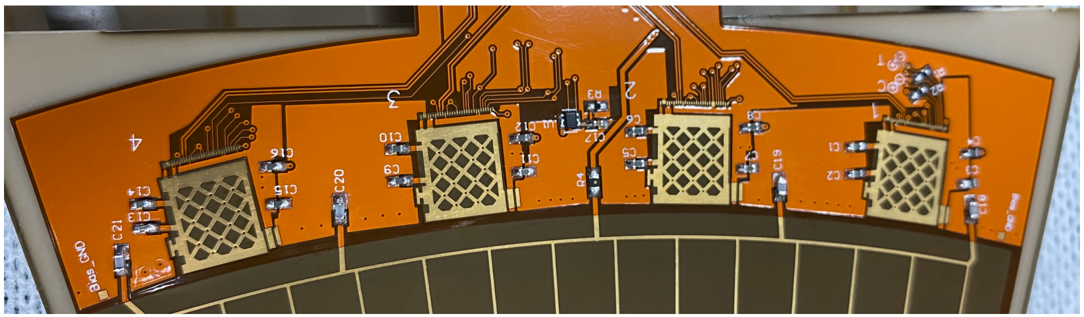
- Follow the "same" procedure as the outer Hybrid

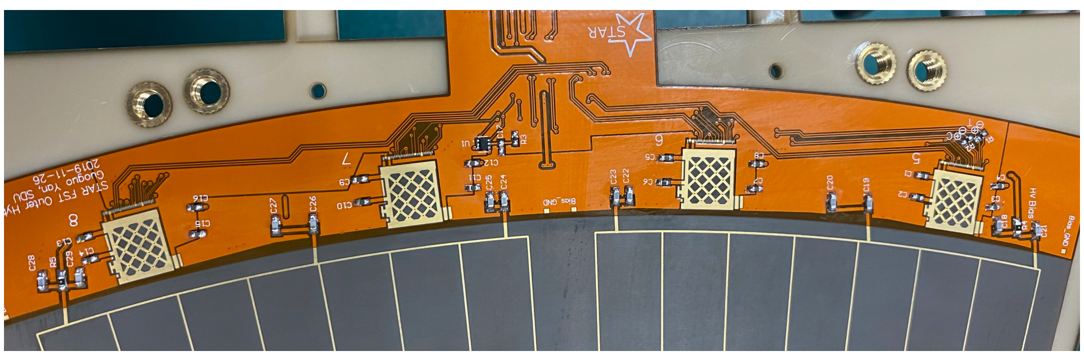
1) Place pickup tool, inner Hybrid + tray, outer wedge + inner MS + tray on table
2) Use camera to locate the reference points
3) Pick up inner Hybrid and glue it on the inner MS



Assembly Procedure: Components on Hybrid

1) Solder components manually
2) Electrical open connection test





Prototypes: FST-003, FST-004, FST-005

Not used

FST-003

FST-004

FST-005

QC: FST-003, FST-004, FST-005

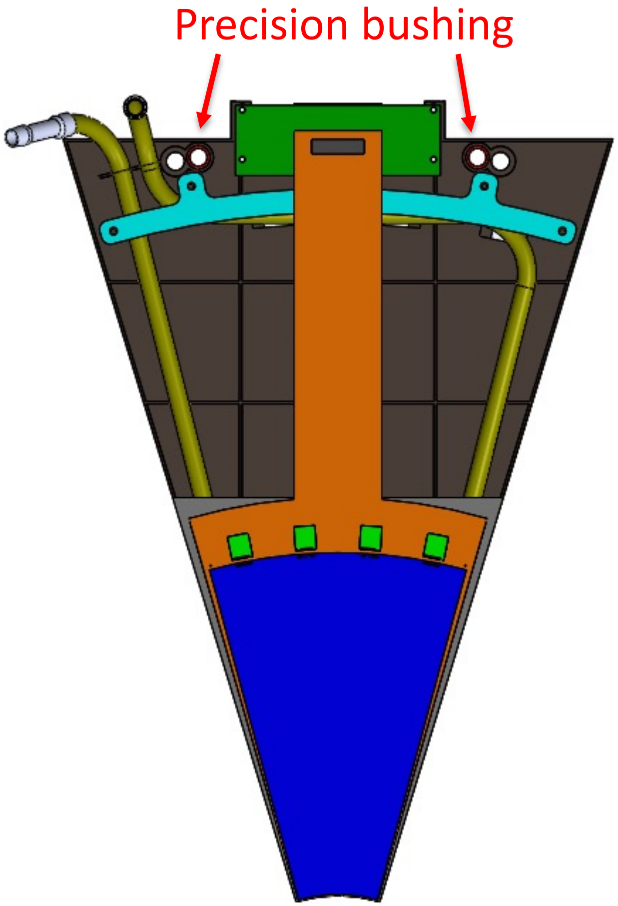
Not used

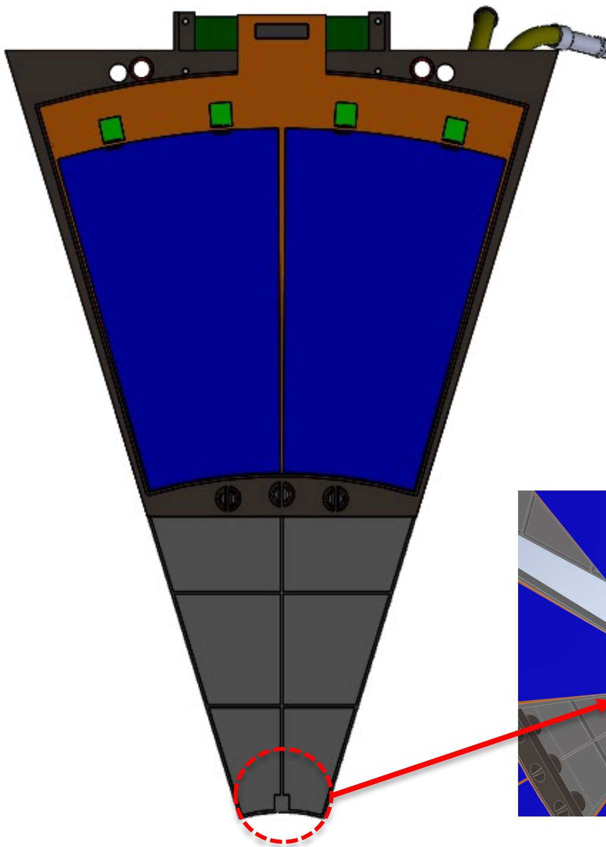
[μm]	FST-003		FST-004		FST-005 (No components soldered)	
	Inner	Outer	Inner	Outer	Inner	Outer
Flatness sensor 1	155	233	196	130	237	145
Flatness Sensor 2		221		158		100
Flatness Chip 1	62	34	31	38	31	38
Flatness Chip 2	25	43	76	41	17	34
Flatness Chip 3	32	31	121	63	43	29
Flatness Chip 4	3	30	52	39	38	54
δD1	98	61	98	83	105	1
δD2	86	174	86	58	151	67

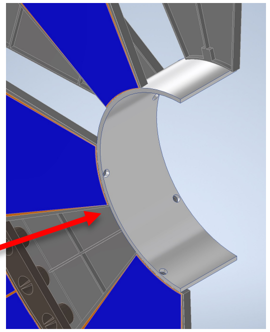
*Flatness measurements are on Hybrids

Modified Mechanical Structure

- Implemented the suggestions from Rahul's team
  - Precision bushings and pins (inner holes), larger through holes (outer holes)
  - Add inner supporting part (screw hole)

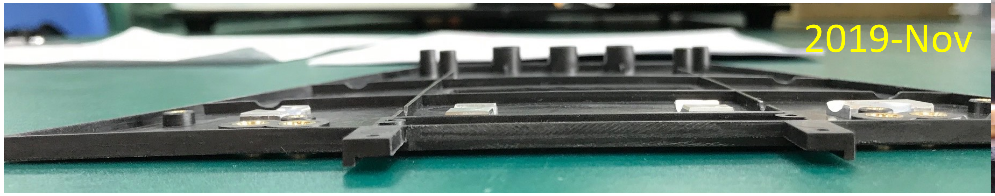


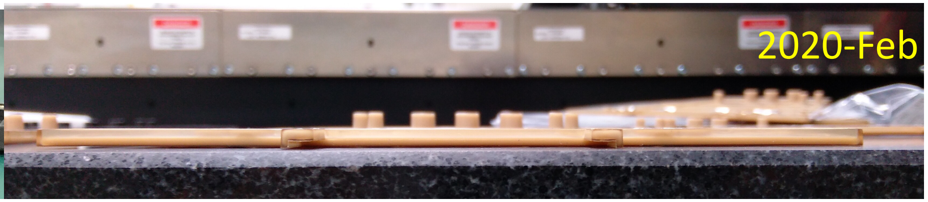




Flatness Issue on Main Structure

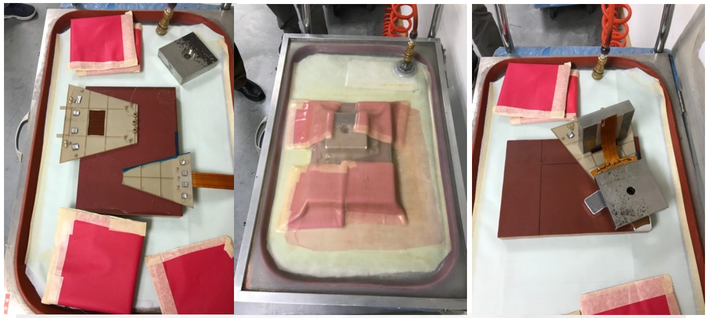
- Timeline:
  - **2019-Nov**: produced 1st (PEEK+30% CF) and 2nd (PEEK+30% GF) prototype
    - → Obvious flatness issue
  - **2019-Dec**: modified the design due to the change of the positions of APV chips and produce 3rd prototype
    - → Flatness issue is not solved
  - **2020-Jan**: increased the thickness from 1.5 mm to 2.0 mm + changed the injection points from side to center
    - → Flatness issue is not solved
  - **2020-Feb**: use pure PEEK + extra cooling on molds
    - → Flatness is significantly improved, but not 100% solved
  - **2020-May**: use rigid quality control selections
    - → Flatness improved (solved)

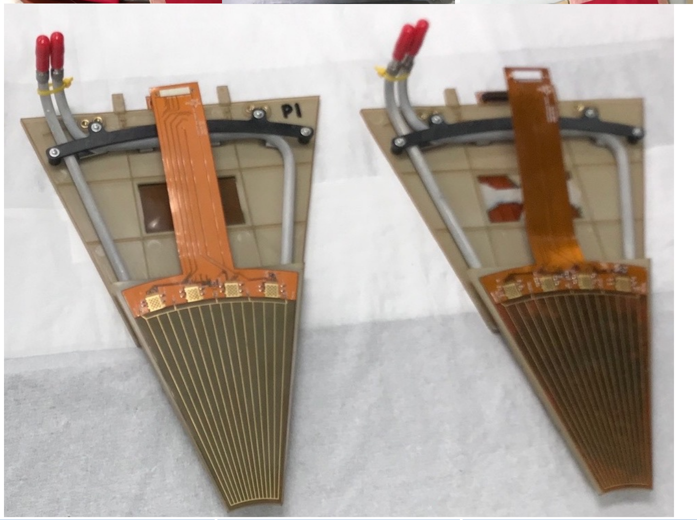




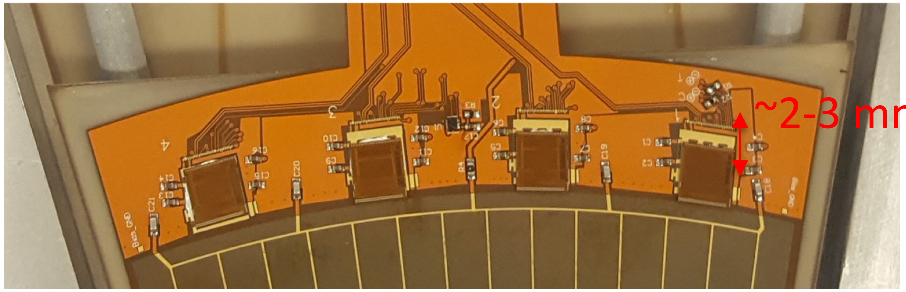
Prototypes: FST-001, FST-002

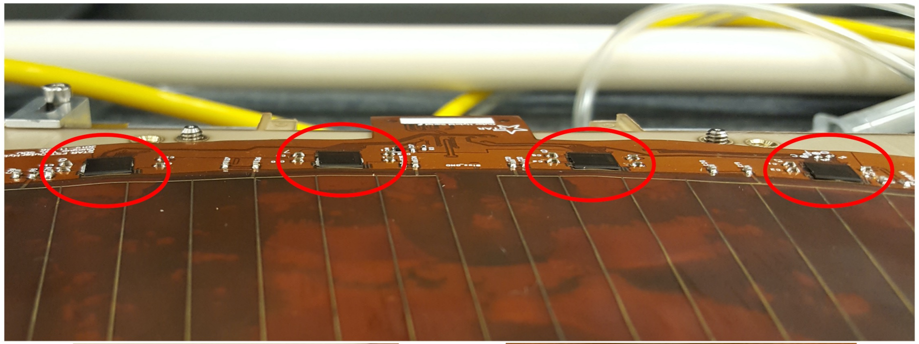
- ❑ Goal: quickly produced prototypes for sensor testing
- ❑ Many issues found: flatness, bubbles, shifting…

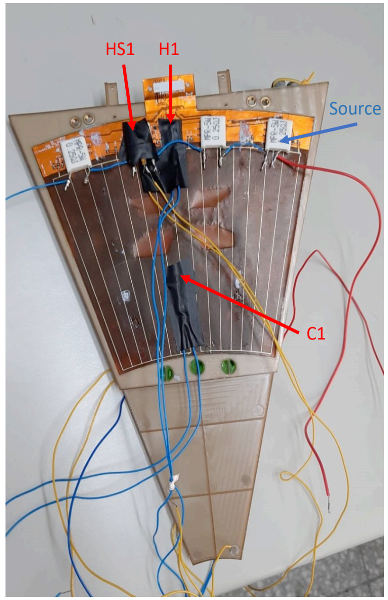


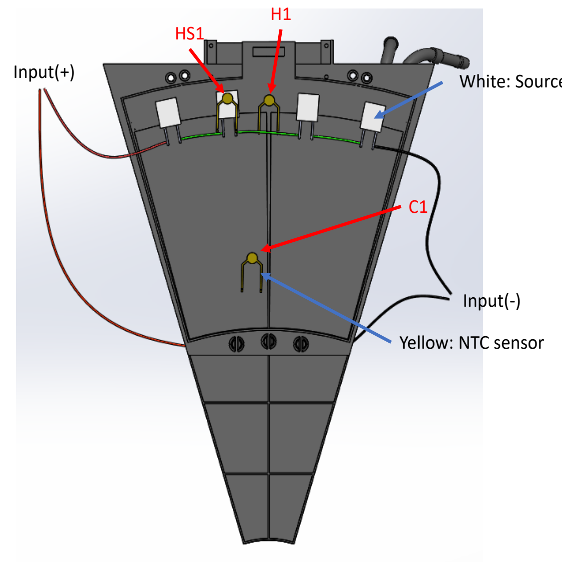


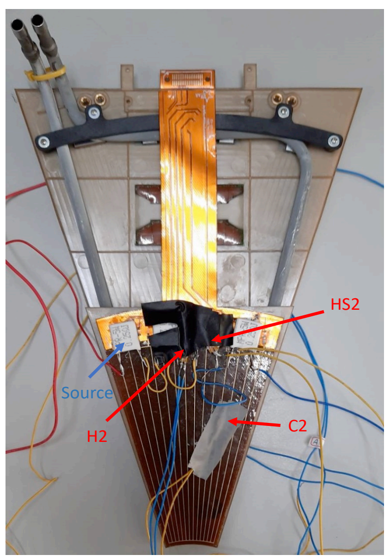
Flatness (RMS)	Thicker hybrid	Thinner hybrid
Inner	0.2942 (mm)	0.2663 (mm)
Outer	0.4654 (mm)	0.2585 (mm)

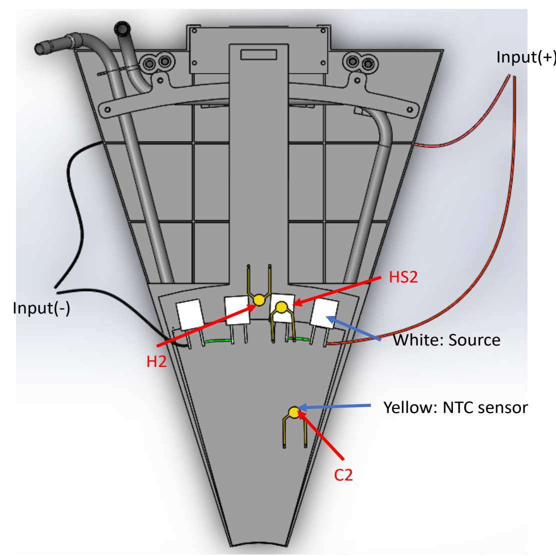





HS1
H1
Source
C1

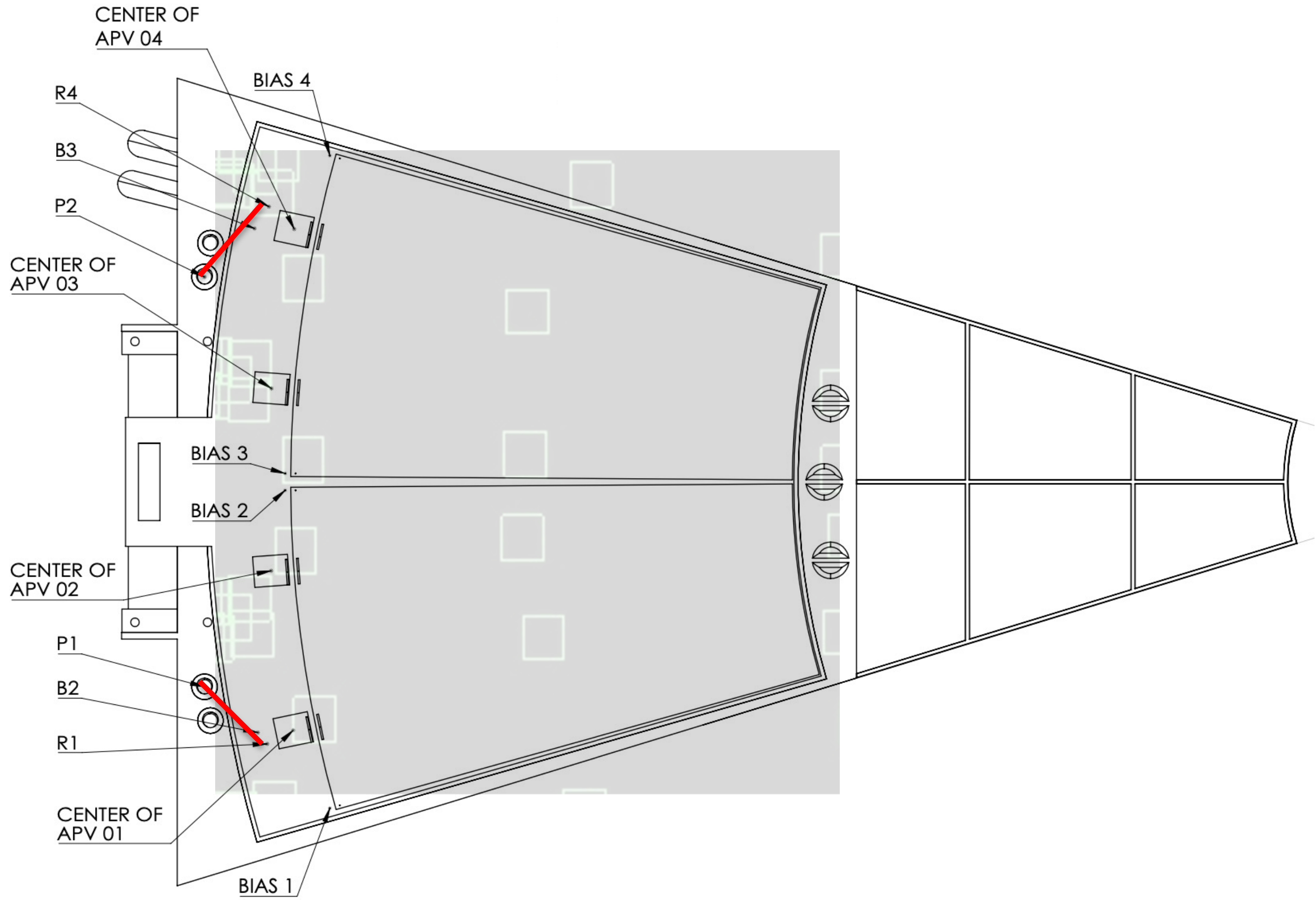

H1
HS1
Input(+)
White: Source
C1
Input(-)
Yellow: NTC sensor


HS2
Source
H2
C2

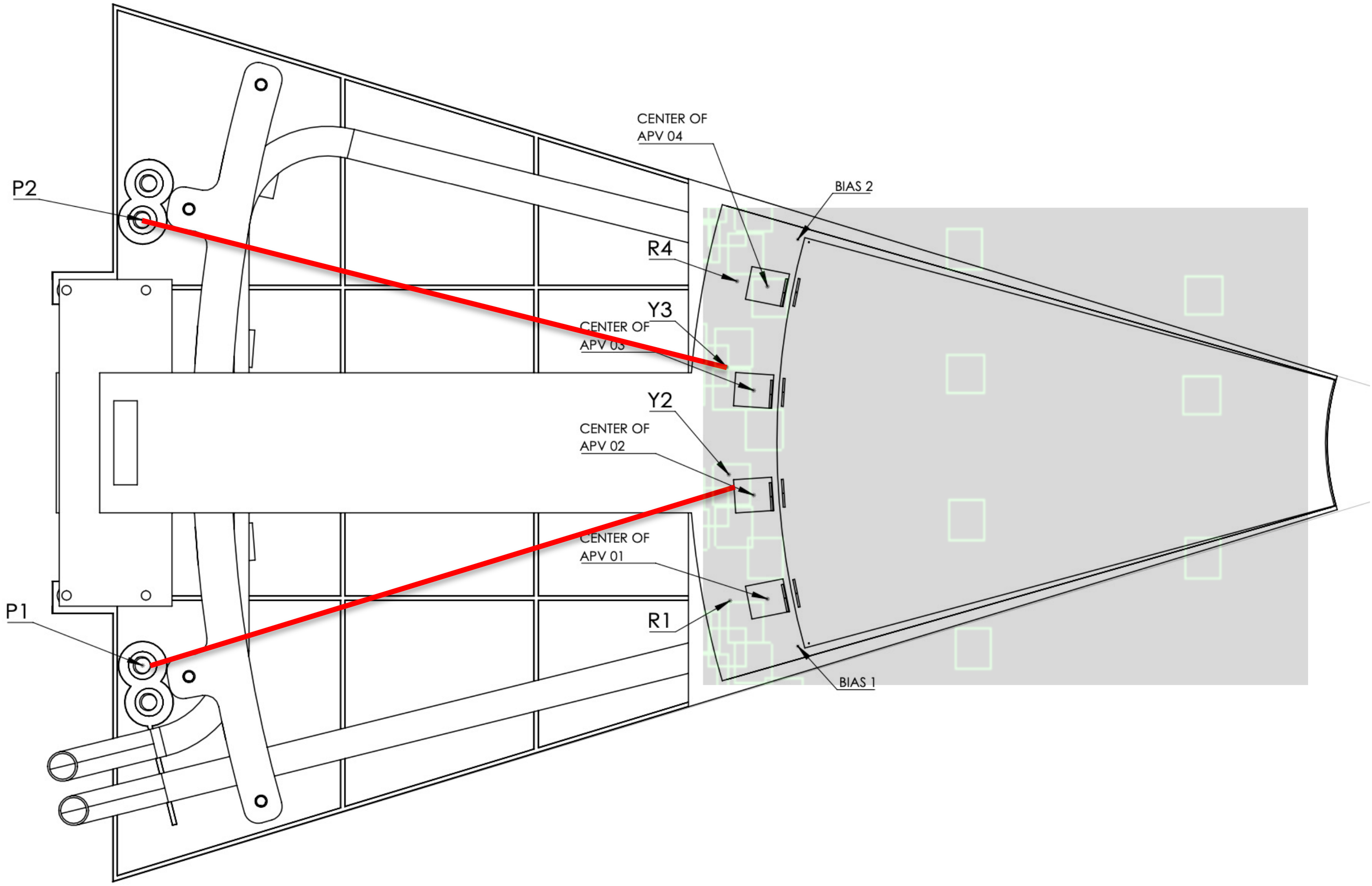

Input(+)
HS2
Input(-)
H2
White: Source
Yellow: NTC sensor
C2

Quality Assurance: Outer

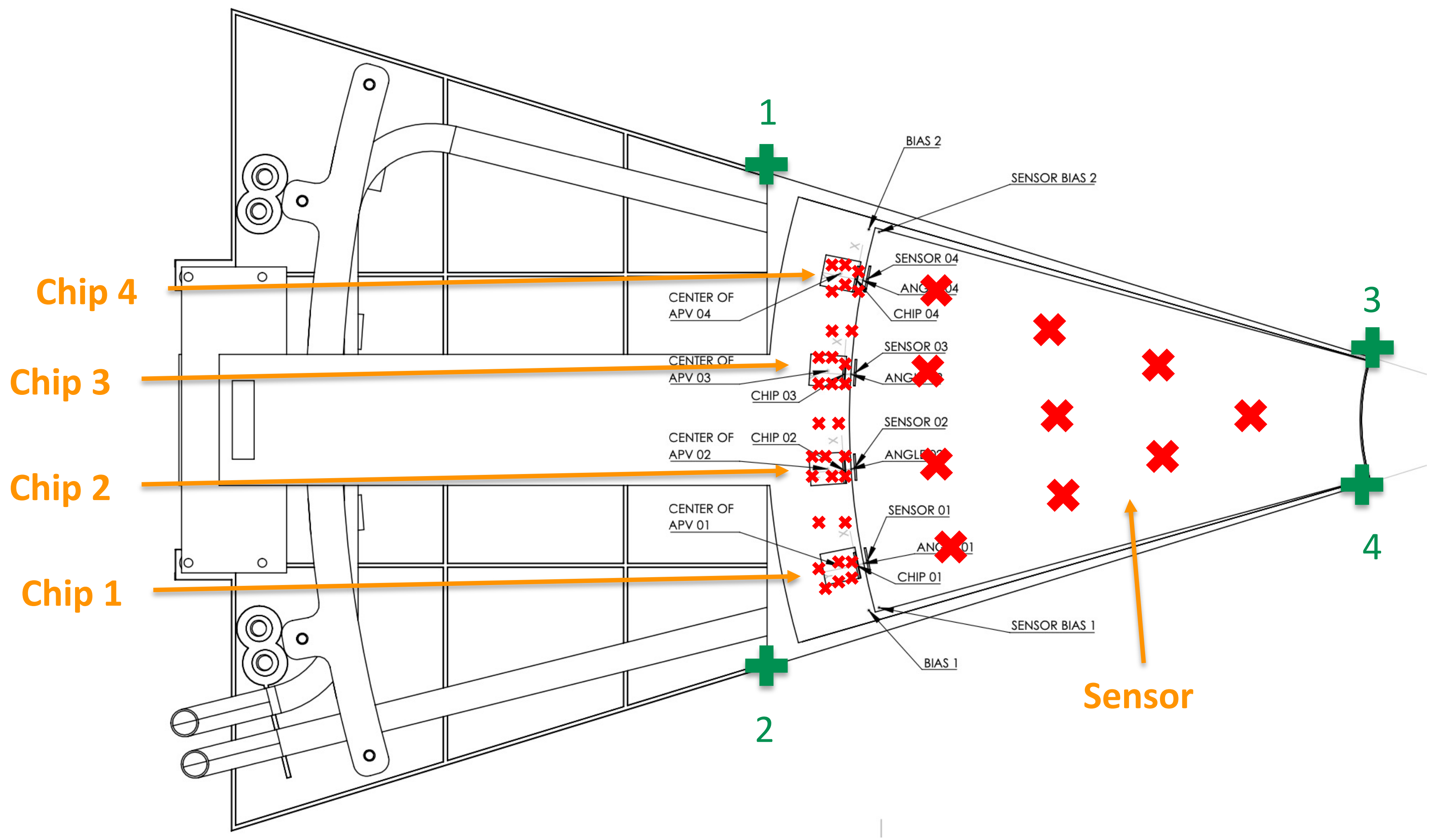
- Use OGP to measure the flatness
  - 5 points at chip areas and 9 points at sensor area
  - Distances from guide pins to reference points (in x and y)



- Use OGP to measure the flatness
  - 5 points at chip areas and 9 points at sensor area
  - Distances from guide pins to reference points (in x and y)



Measurements: Inner



Inner: Dimension

- Unit: mm

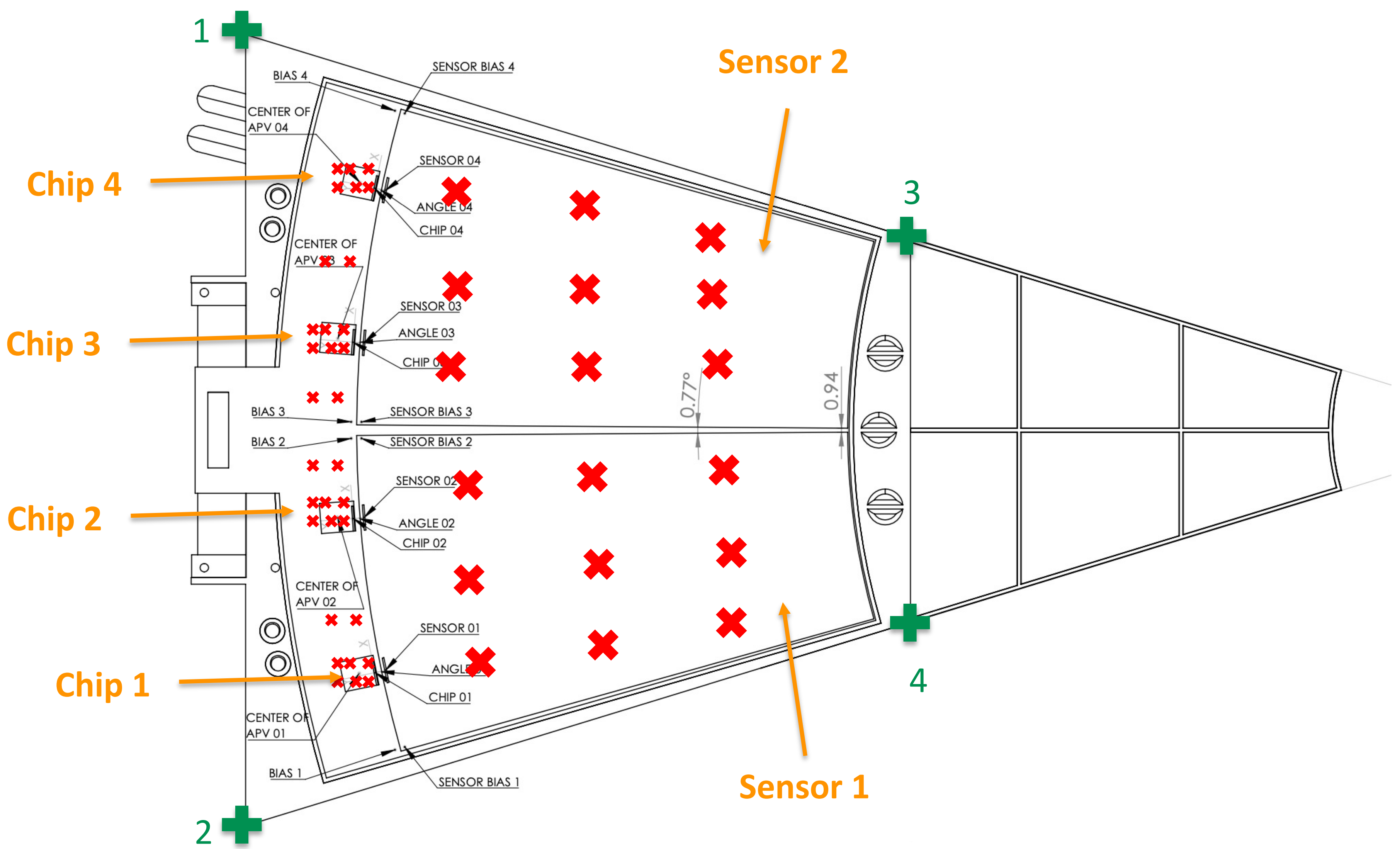
	Part	D12	δD12	D13	δD13	D24	δD24	D34	δD34
Solidworks		113.13		144.46		144.46		28.66	
Inner	1	112.785	0.345	144.03	0.43	144.049	0.411	28.497	0.163
	2	112.796	0.334	144.018	0.442	144.05	0.41	28.472	0.188
	3	112.783	0.347	144.014	0.446	144.046	0.414	28.451	0.209
	4	112.698	0.432	143.996	0.464	143.942	0.518	28.493	0.167
	5	112.775	0.355	143.953	0.507	144.077	0.383	28.503	0.157
	6	112.787	0.343	143.956	0.504	144.076	0.384	28.51	0.15
	7	112.771	0.359	144.001	0.459	144.045	0.415	28.479	0.181
	8	112.738	0.392	143.942	0.518	143.996	0.464	28.44	0.22
	9	112.704	0.426	143.998	0.462	144.043	0.417	28.458	0.202
	10	112.789	0.341	144.025	0.435	144.08	0.38	28.484	0.176

Inner: Flatness

- Unit: **μm**
- Flatness: maximum difference between measured points

	Part	Chip 1	Chip 2	Chip 3	Chip 4	Sensor
Inner	1	73.2	25.8	40.7	84.2	484.4
	2	129.7	55.3	69.6	144	397.2
	3	136.3	38.6	27.7	101.5	182.7
	4	30.5	52.5	39.4	59.3	815.8
	5	172.8	76.4	47.7	48.4	574.4
	6	167.2	74.7	46.1	54.6	545.2
	7	137.9	66.1	71.1	159.2	313.3
	8	112.8	58.2	57.5	33.6	483
	9	157.7	92.9	93.1	174.7	158.6
	10	23.6	50	85.6	176	887.7

Plan for the Measurements: Outer



Outer: Dimension

- Unit: mm

	Part	D12	δD12	D13	δD13	D24	δD24	D34	δD34
Solidworks		188.09		165.39		165.39		91.38	
Inner	1	187.585	0.505	164.882	0.508	164.93	0.46	91.183	0.197
	2	187.603	0.487	164.895	0.495	164.927	0.463	91.199	0.181
	3	187.62	0.47	164.87	0.52	164.878	0.512	91.228	0.152
	4	187.582	0.508	164.879	0.511	164.867	0.523	91.176	0.204
	5	187.598	0.492	164.899	0.491	164.916	0.474	91.2	0.18
	6	187.584	0.506	164.864	0.526	164.943	0.447	91.155	0.225
	7	187.577	0.513	164.896	0.494	164.922	0.468	91.19	0.19
	8	187.551	0.539	164.81	0.58	164.865	0.525	91.093	0.287
	9	187.518	0.572	164.837	0.553	164.899	0.491	91.141	0.239
	10								

Outer: Flatness

- Unit: μm
- Flatness: maximum difference between measured points

	Part	Chip 1	Chip 2	Chip 3	Chip 4	Sensor 1	Sensor 2
Inner	1	92.4	62.8	87.4	117.2	346.6	415.5
	2	114.1	72.3	43.1	69.7	291.3	434
	3	90.2	33.5	56.1	41.5	319.5	365.6
	4	78.1	40.8	39.4	45.8	144.4	129.2
	5	37.2	20.7	36.1	59.5	254.3	241.4
	6	80.6	43.4	80.7	112.4	444.5	418.4
	7	63.1	45.8	28.3	60	199	135.8
	8	85.3	36.3	53.3	112.8	293	391.8
	9	74.1	29.8	76.7	158.8	340.5	240
	10						

Final QA

- Outsource (Taiwan CK Techno Co.,Ltd.) the measurements of flatness and parallelism (800 USD per module)

量測報告 CK20094

報告編號： CK20094
品 名： FST_single_module_outer_1102
客 戶： 國立成功大學 物理學系
樣品數： 1 pcs
量測日期： 2020/7/16~25
量 測 員： David
確 認 者： Henry

溫度℃	溼度%
20.9	49.3
20.9	54.2
儀器編號	
-	-
QT0180	-

註記：(1) -
(2) -

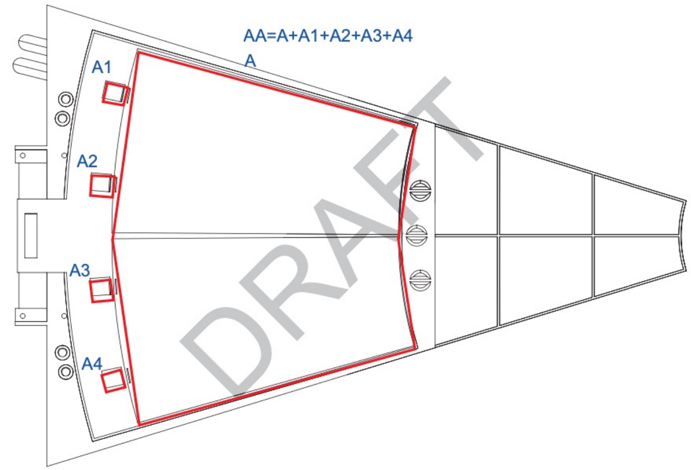
UNIT: mm/∠° CK20094

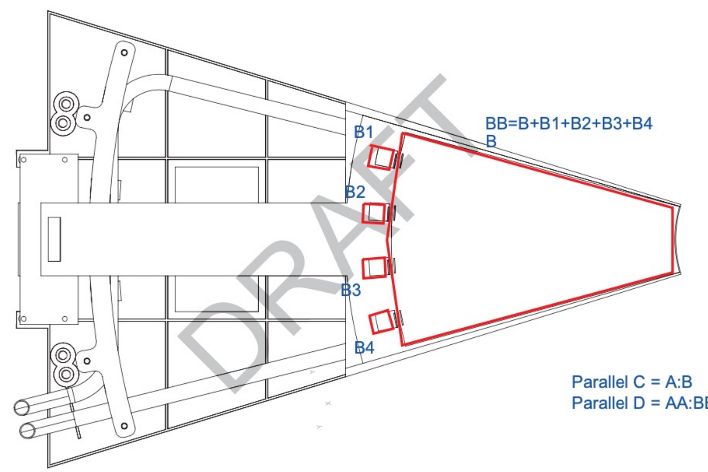
位 置	項目	檢查工具	-1				
A	平面度	CMM	0.535				
A1	平面度	CMM	0.072				
A2	平面度	CMM	0.018				
A3	平面度	CMM	0.108				
A4	平面度	CMM	0.008				
AA	平面度	CMM	0.633				
B	平面度	CMM	0.122				
B1	平面度	CMM	0.070				
B2	平面度	CMM	0.054				
B3	平面度	CMM	0.012				
B4	平面度	CMM	0.012				
BB	平面度	CMM	0.297				
C	平行度	CMM	1.457				
D	平行度	CMM	1.501				
Blank							

測試方法： 依據 T-511(R4)、512(R2) 社內指導文件執行。
說 明： 1. 認證範圍外的項目以 "** " 註記
2. 不確定度評估方法參考 ISO Guide 98-3「量測不確定度表示法指引」執行。
3. 量測能力係以95%信賴水準，k=2擴充不確定度表示。
4. Uncertainty = 7.3 μm
5. 量測追溯：

儀器編號	儀器名稱 / 型號	序號	校正報告	校正日期
QT0180	CMM / BND-CC9108	0096601	L-IR-108-05-510	2019/05/28

【CMM】三次元座標量測儀





Plan for the Measurements

- Plan to outsource (Taiwan CK Techno Co.,Ltd.) the measurements of flatness and parallelism
- Extremely expensive:
  - **Flatness** for single inner or outer MS (before assembly):
    - Price: **~200 USD/pc**
    - Method: optical
  - **Flatness** and **parallelism** for assembled module:
    - Price: **~400 USD/pc**
    - Method: mechanical (their know-how)

  → Total of 60 sets: **48,000 USD** **Working on getting a better deal**

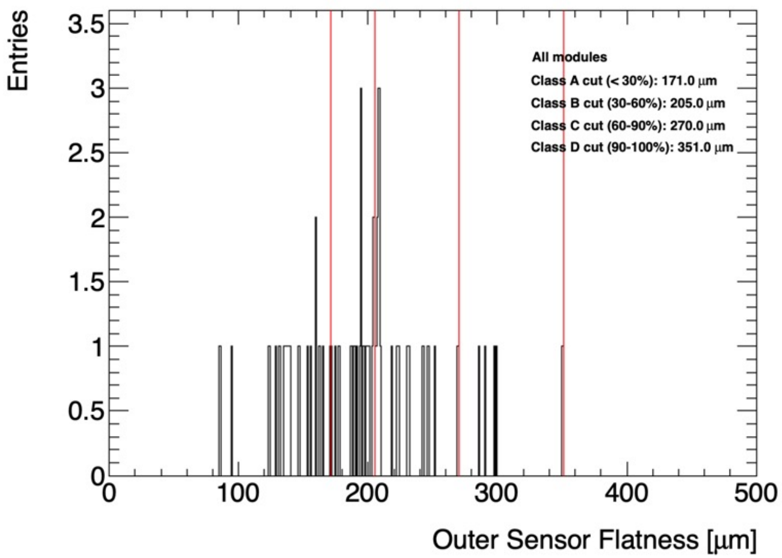
- Plan for the prototypes:
  - **Flatness** for single inner or outer MS (before assembly) at TiDC
  - **Flatness** and **parallelism** for assembled module (first 10) by CK Techno

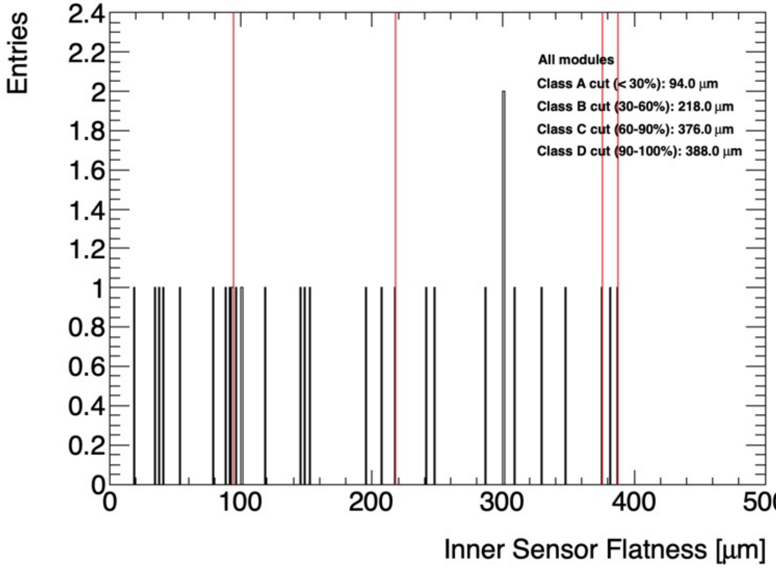
Production time for single module

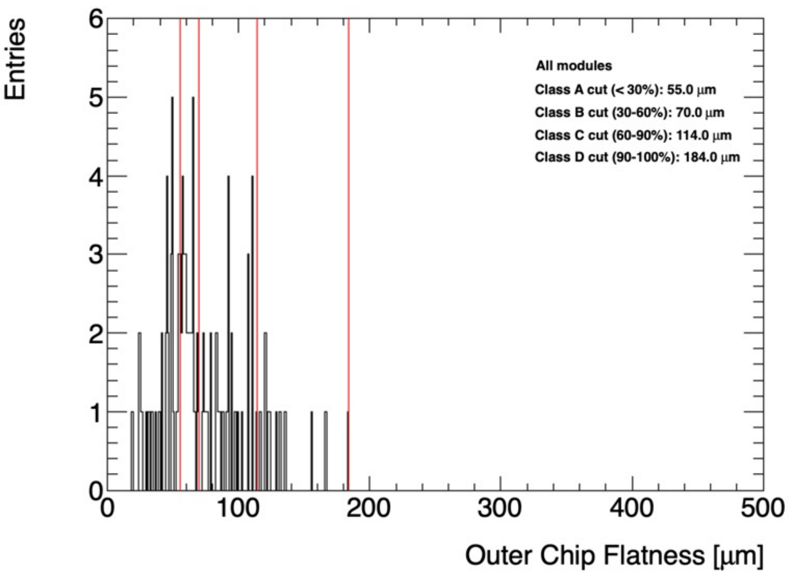
- **Day 1 - Day 10**: preparation (QC for 200 sets)
- **Day 11**: mount Outer Hybrid to MS (FST_prod_001)
- **Day 12**: assembly Outer Wedge and Inner MS (FST_prod_001)
  mount Outer Hybrid to MS (FST_prod_002)
- **Day 13**: mount Inner Hybrid to inner MS (FST_prod_001)
  assembly Outer Wedge and Inner Wedge (FST_prod_002)
  mount Outer Hybrid to MS (FST_prod_003)
- **Day 14**: **Done (FST_prod_001)**
  mount Inner Hybrid to inner MS (FST_prod_002)
  assembly Outer Wedge and Inner Wedge (FST_prod_003)
  mount Outer Hybrid to MS (FST_prod_004)
- **Day 15**: **Done (FST_prod_002)**
  mount Inner Hybrid to inner MS (FST_prod_003)
  assembly Outer Wedge and Inner Wedge (FST_prod_004)
  mount Outer Hybrid to MS (FST_prod_005)
- …
- **Day 72**: mount Inner Hybrid to inner MS (FST-prod_060)
- **Day 73**: **Done (FST_prod_060)**

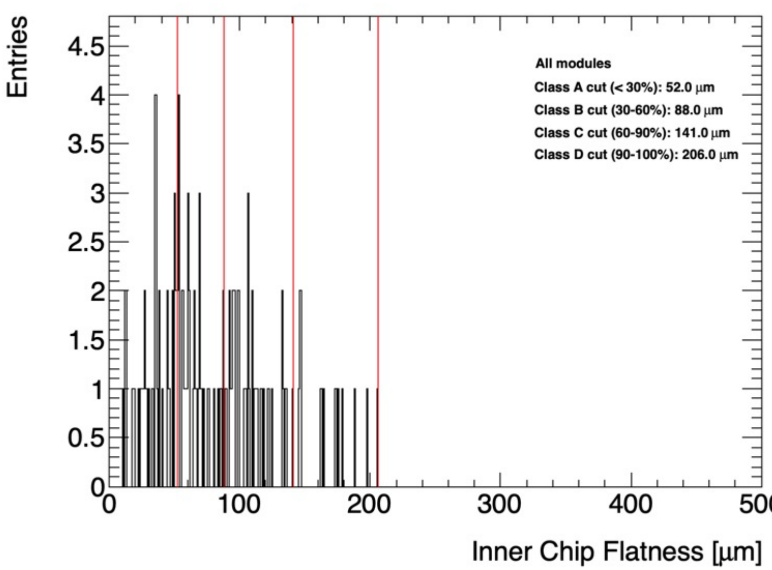
One day per moudle

Production Statistics

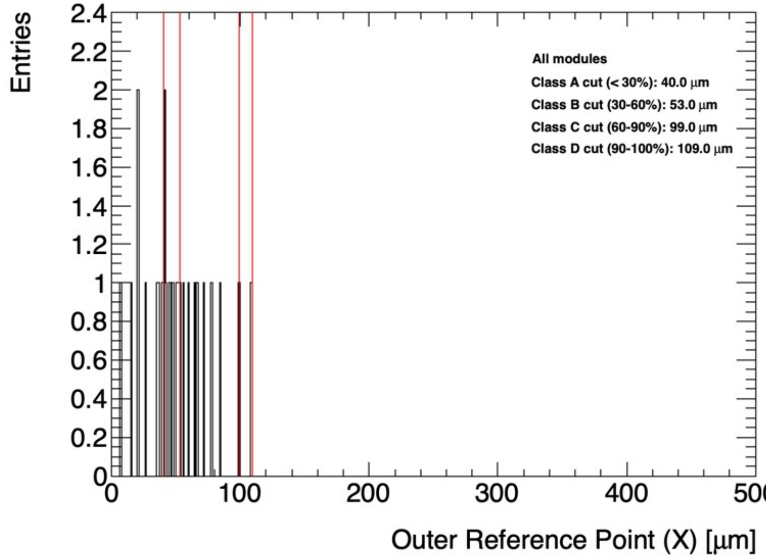


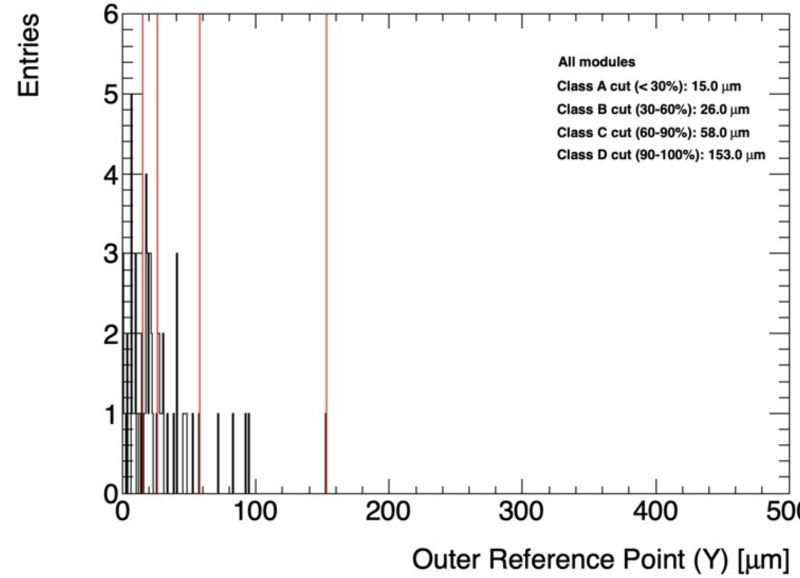


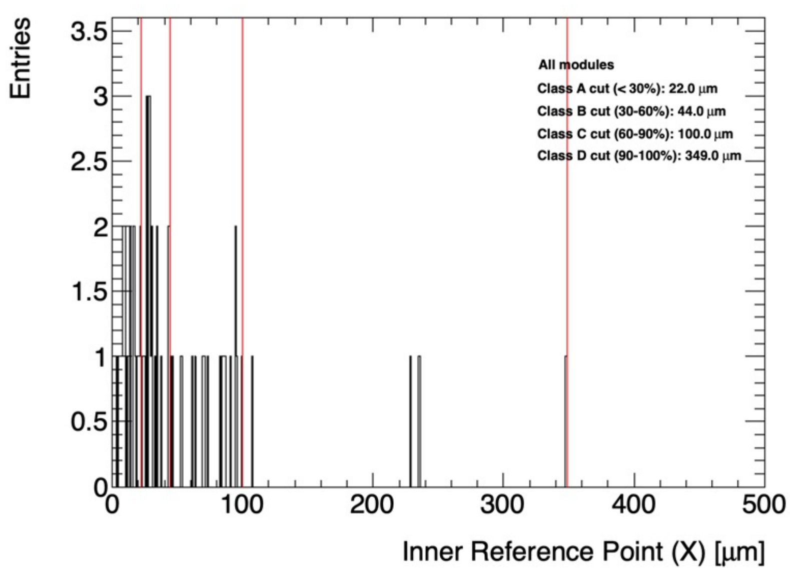


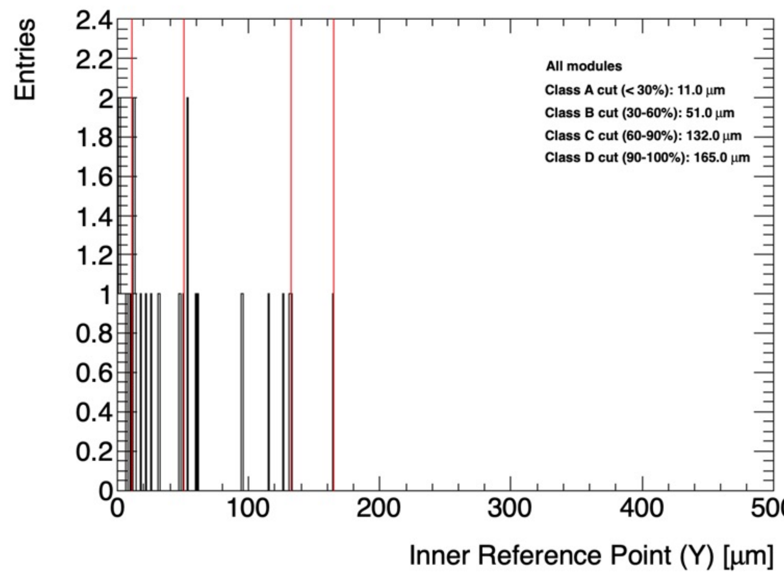


Production Statistics

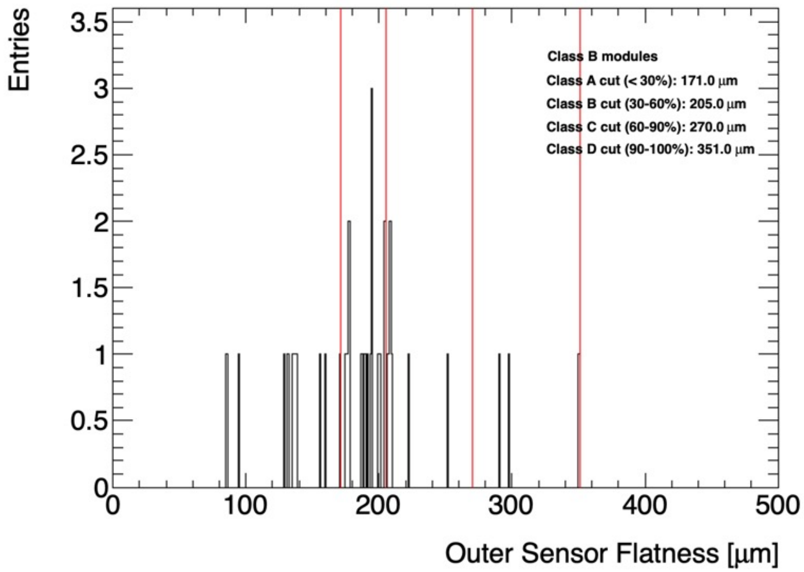


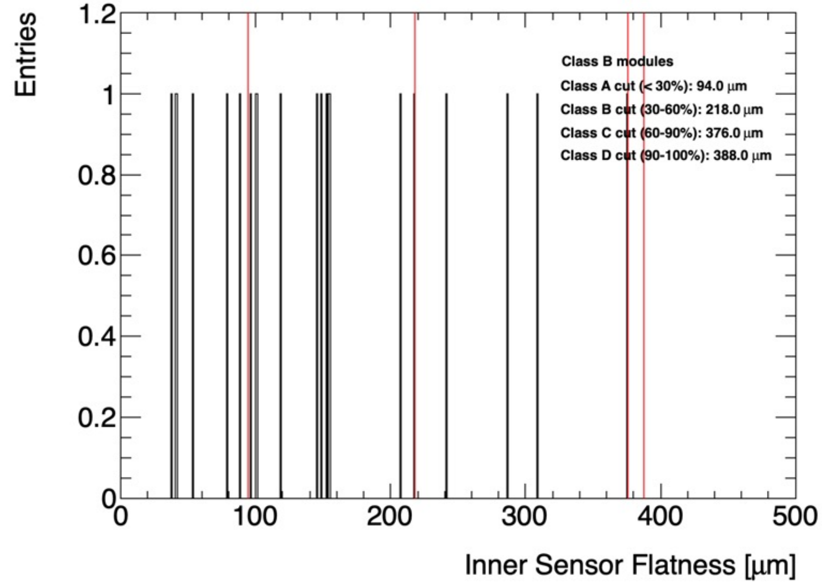


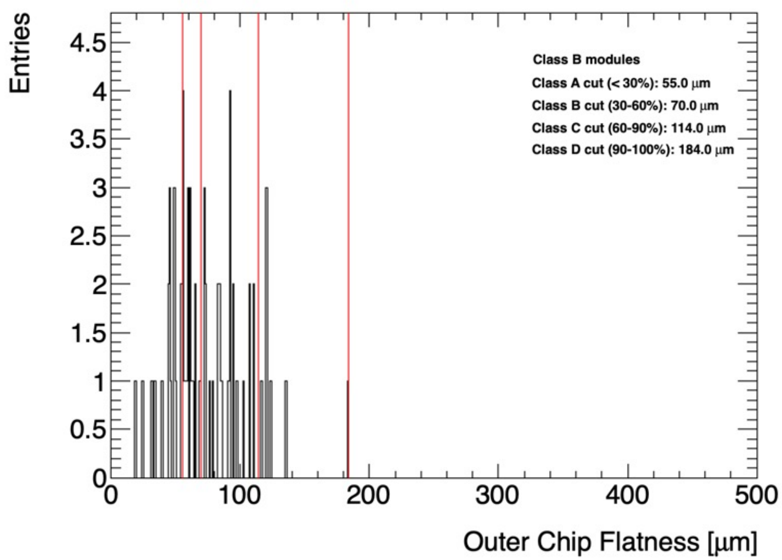


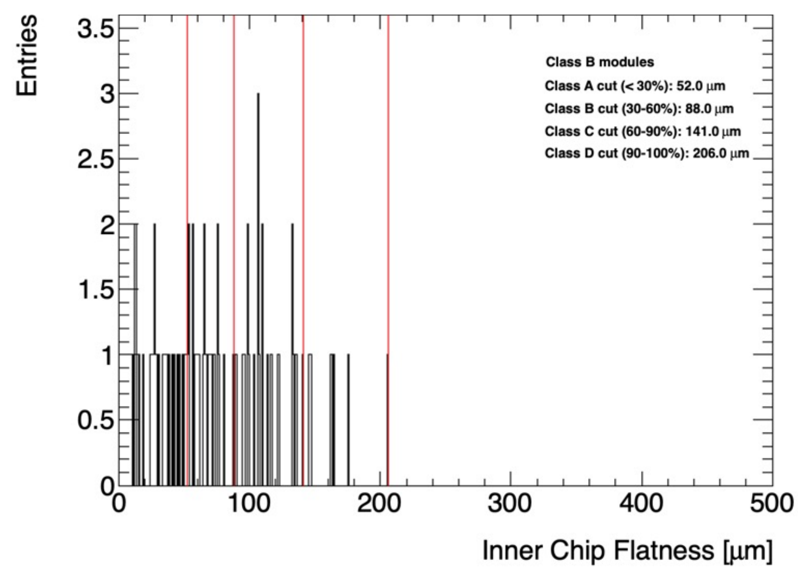


Production Qualities: Class B

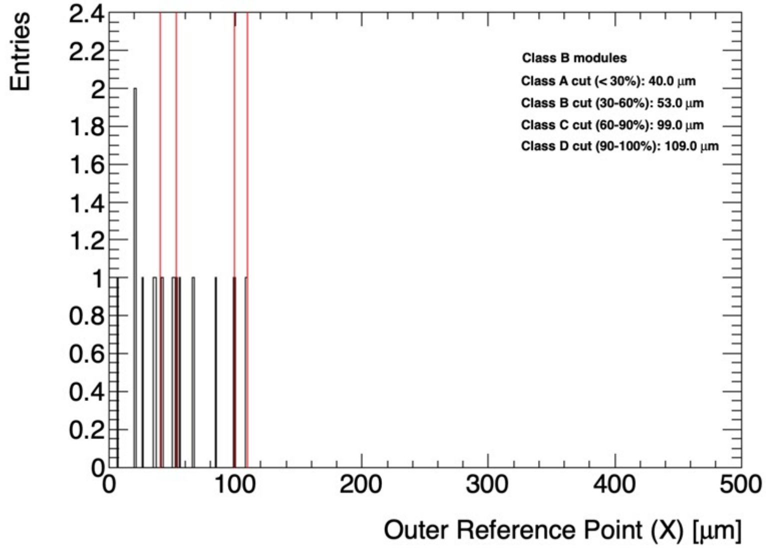


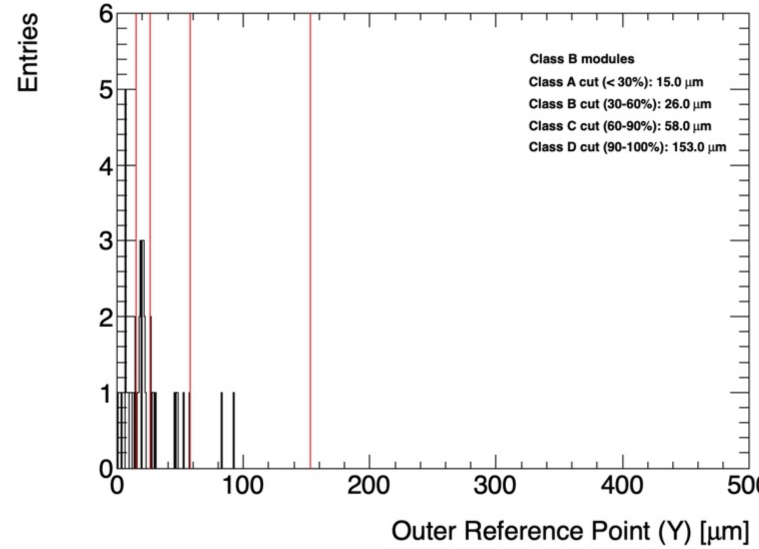


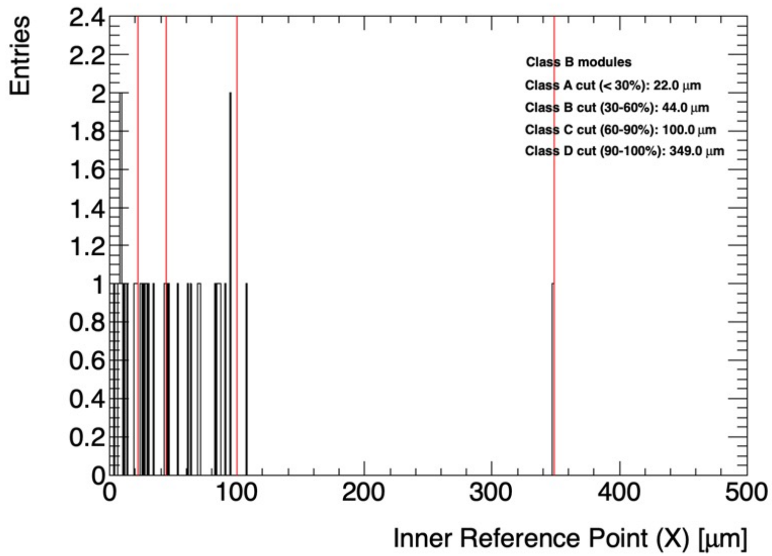


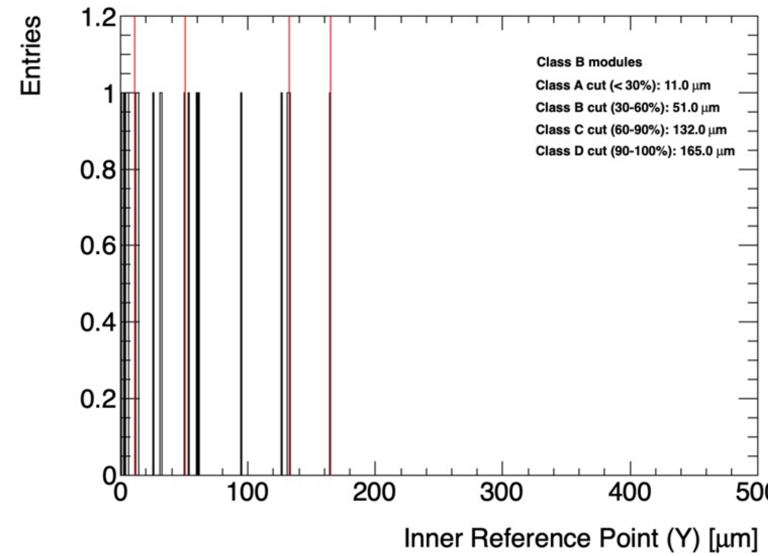


Production Qualities: Class B

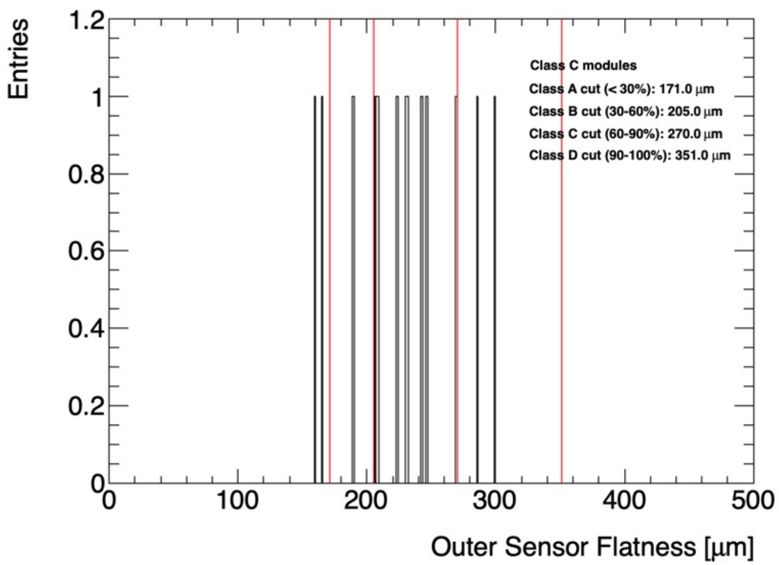


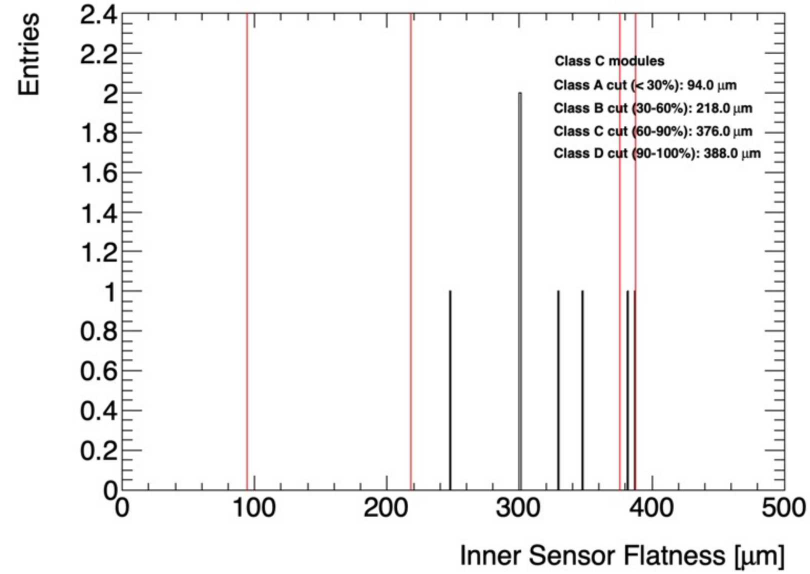


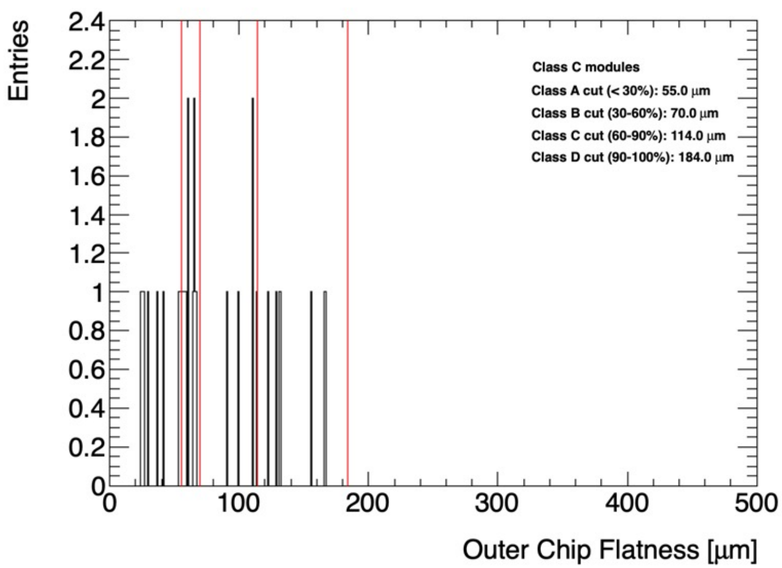


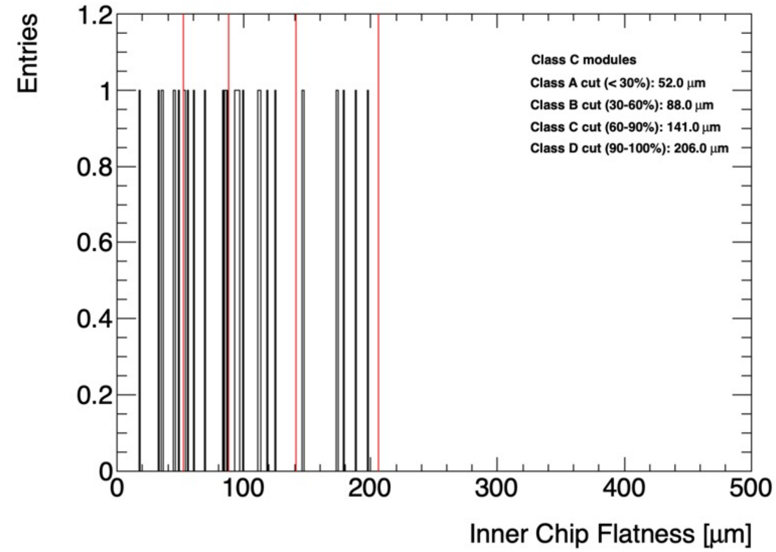


Production Qualities: Class C

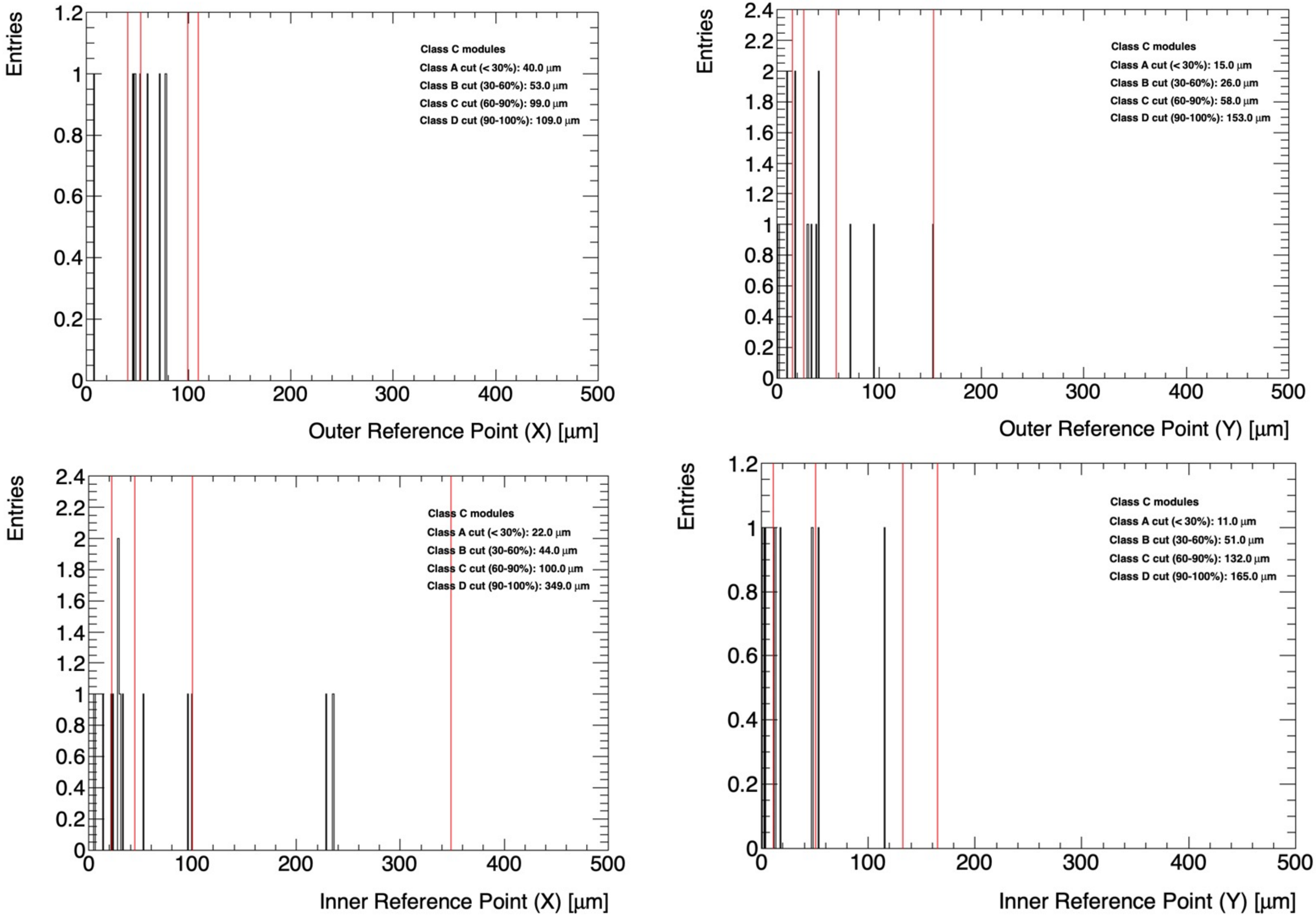






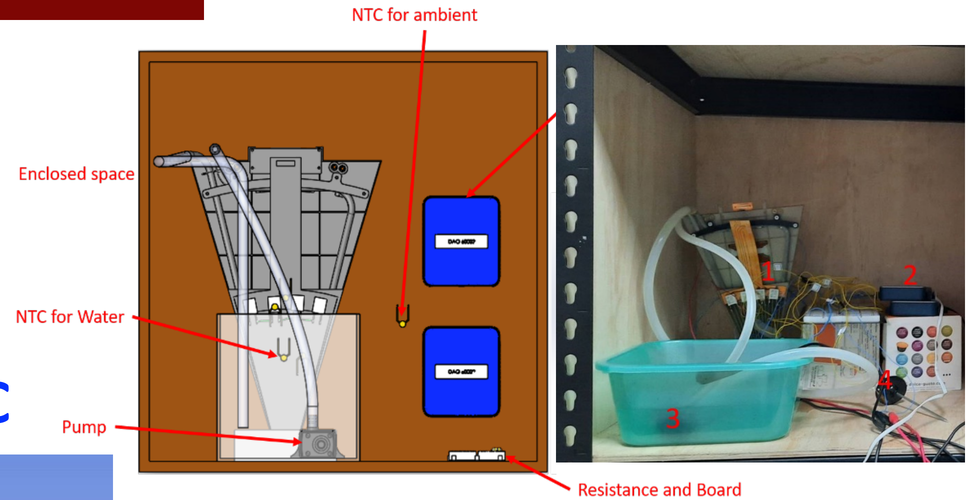


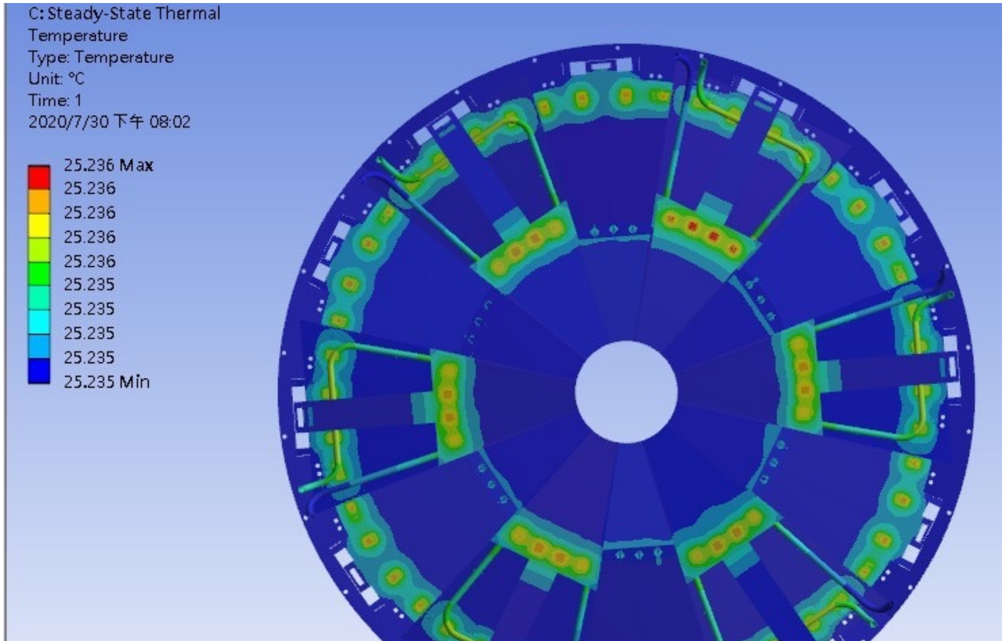
Production Qualities: Class C



Thermal Analysis

- Careful thermal analysis is performed by using single module with water cooling
- **Temperature at thermal equilibrium is less than 26 °C**

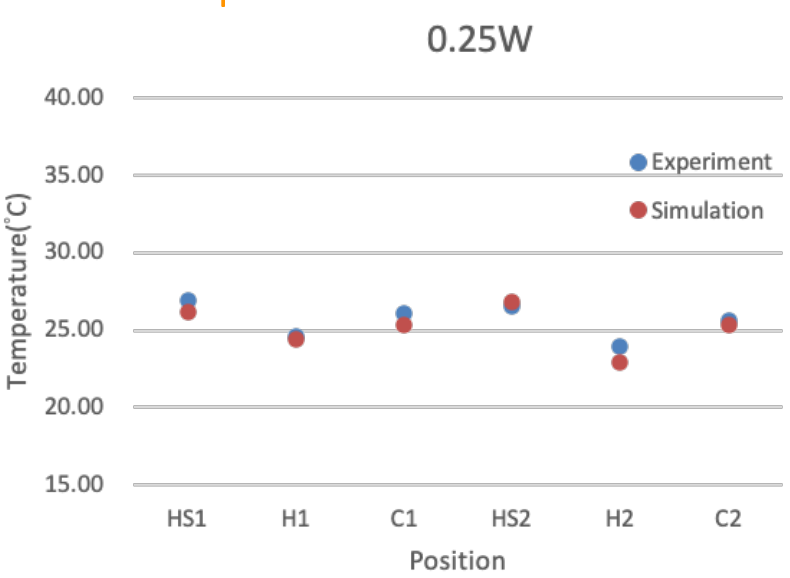




Liquid Temp: 22 °C

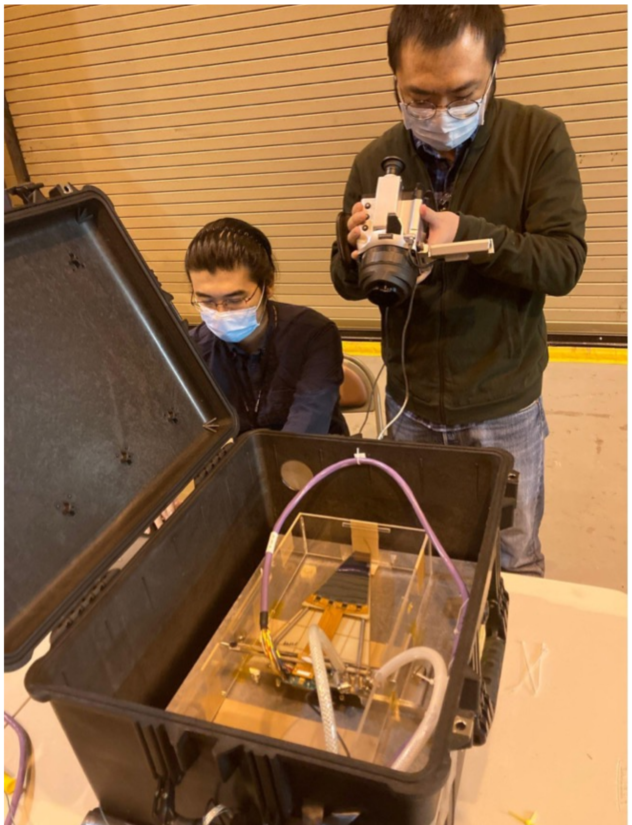
Ambient Temp: 25 °C

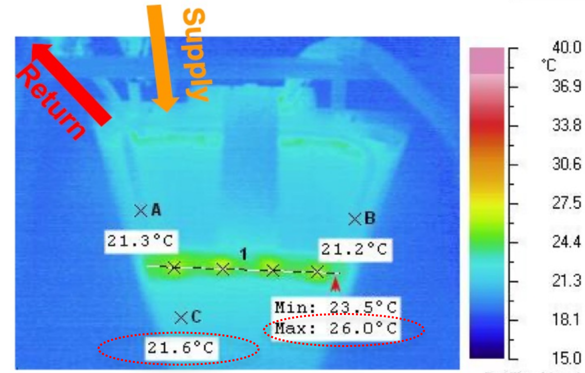
Consistent results between experiments and simulation

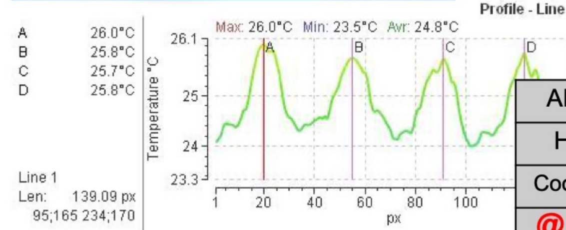


Thermal Analysis – Real Module

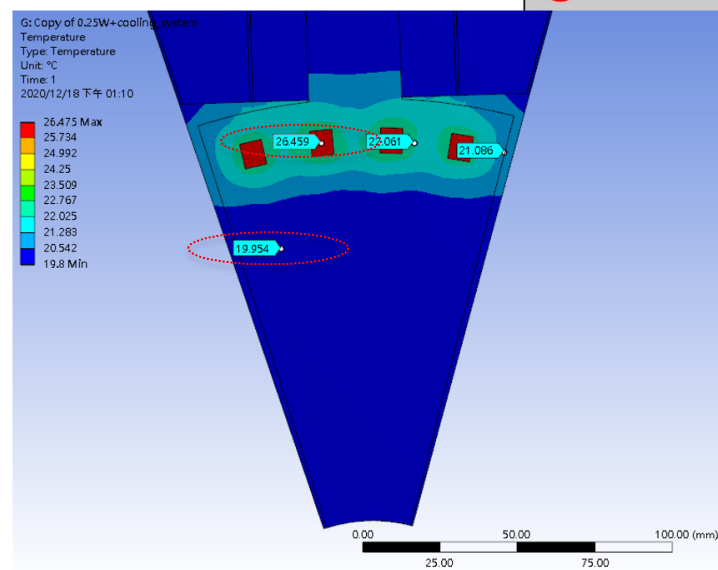
- Cooling test on FST-04 (Dec. 21, 2020@BNL)
  - Ambient T: 19.8 °C
  - Coolant T: 22.2 °C





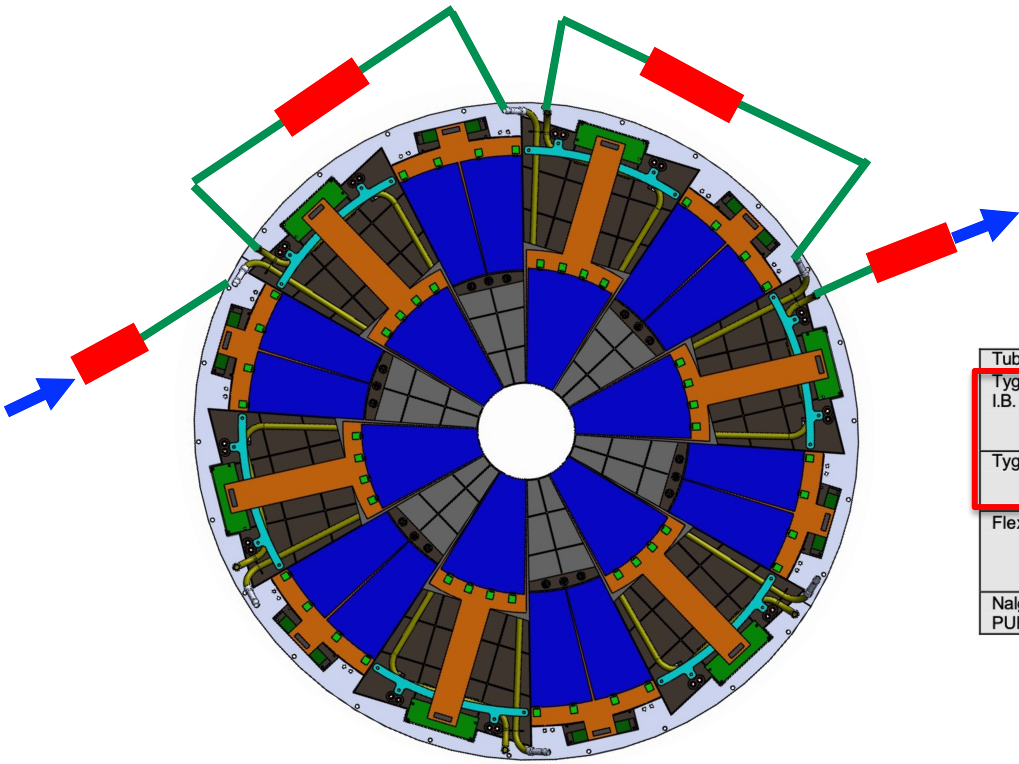


APV	ON
HV	0 V
Cooling	ON
@ Time = 50	



Soft Tube and Connector

- Connect 3 wedges to be 1 set
  - ➔ Total 4 in and 4 out for one disk

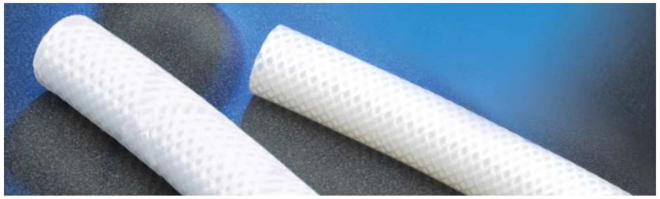


Soft tubes

Connector

DME

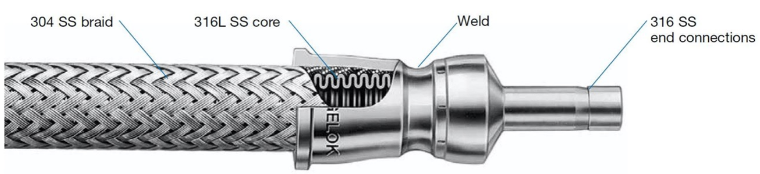
Plan A: plastic soft tube



Recommended Flex Hoses for General Use

Tubing Name	Type	Extraction %	Weight gain %	Comments
Tygon™ C-544-A I.B.	Clear Braided Polyurethane	0.09	0.3	Excellent Compatibility. Good pressure resistance. Temperature Range –73 to 82C. www.tygon.com
Tygon 3370 I.B.	Clear Braided Silicone	1.47	4.8	Good Compatibility. Good Pressure resistance. Temperature Range –73 to 160C.
Flexfab™ 5521-050	Green braided silicone hose	2.08	NA	Good Compatibility. Good Pressure resistance. Temperature range –54 to 150C. http://www.flexfab.com
Nalgene™ 290 PUR	Clear Yellow. No Braid.	0.74	0.3	Excellent Compatibility. Little pressure resistance.

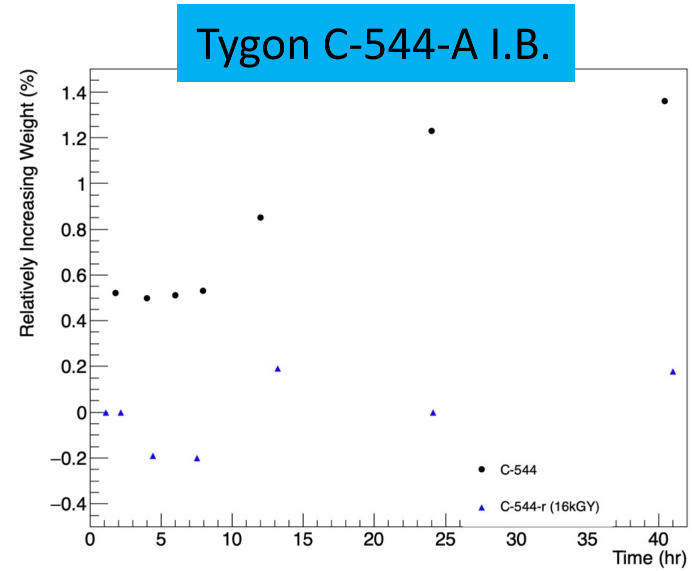
Plan B: metal soft/hard tube

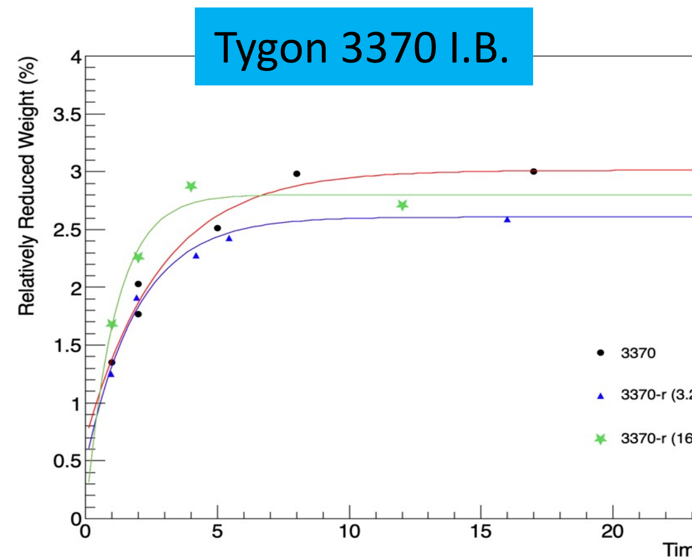


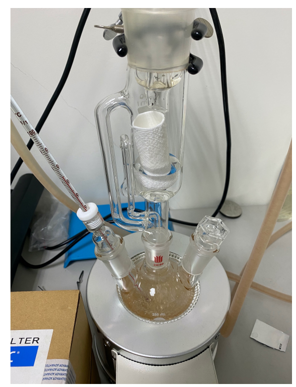
Soft Tube Compatibility & Radiation Tests

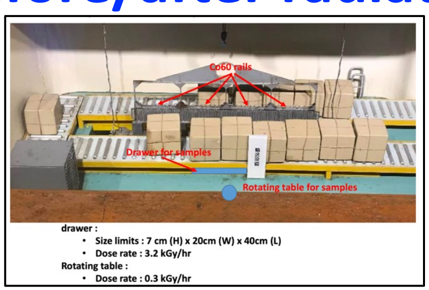
- Use the Soxhlet extraction method (suggested by 3M)
  - **C-544 is stable after 24 hours test**
  - **3370 is stable after 8 hours test**
- Use Co^{60} source at Institute of Nuclear Energy Research (INER)
- Two dosages:
  - 3.2 kGy (from proposal)
  - 16 kGy (5 times higher)

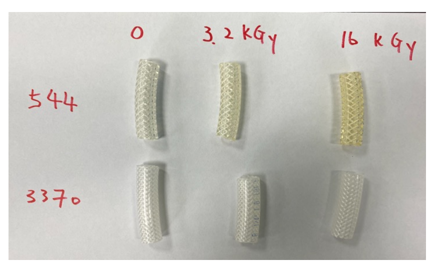
→ **No significant change before/after radiation**



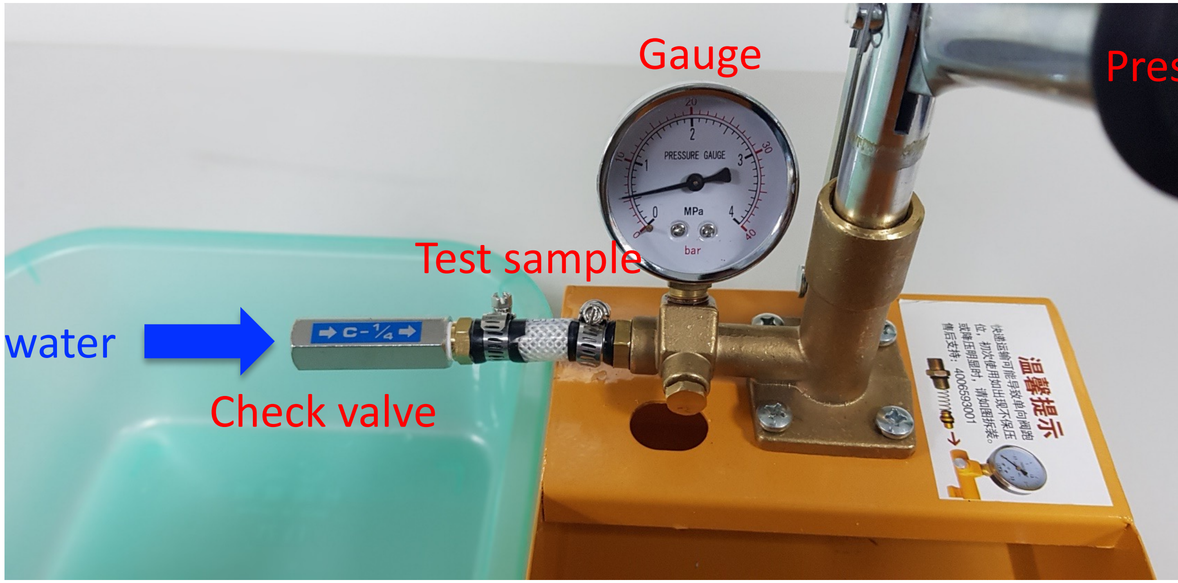








Burst Test on Soft Tubes



3370: 0 kGy
3.2 MPa → 1 MPa

C-544: 3.2 kGy
4 MPa

Deformation Pressure

Radiation dosage	3370	C-544
16 kGy	2.0 MPa	> 4 MPa
3.2 kGy	2.5 MPa	> 4 MPa
0 kGy	3.2 MPa	> 4 MPa