TIDC EIC Workshop

Detector and Physics opportunities for Taiwan EIC team - III

19 August 2022 @ NCKU

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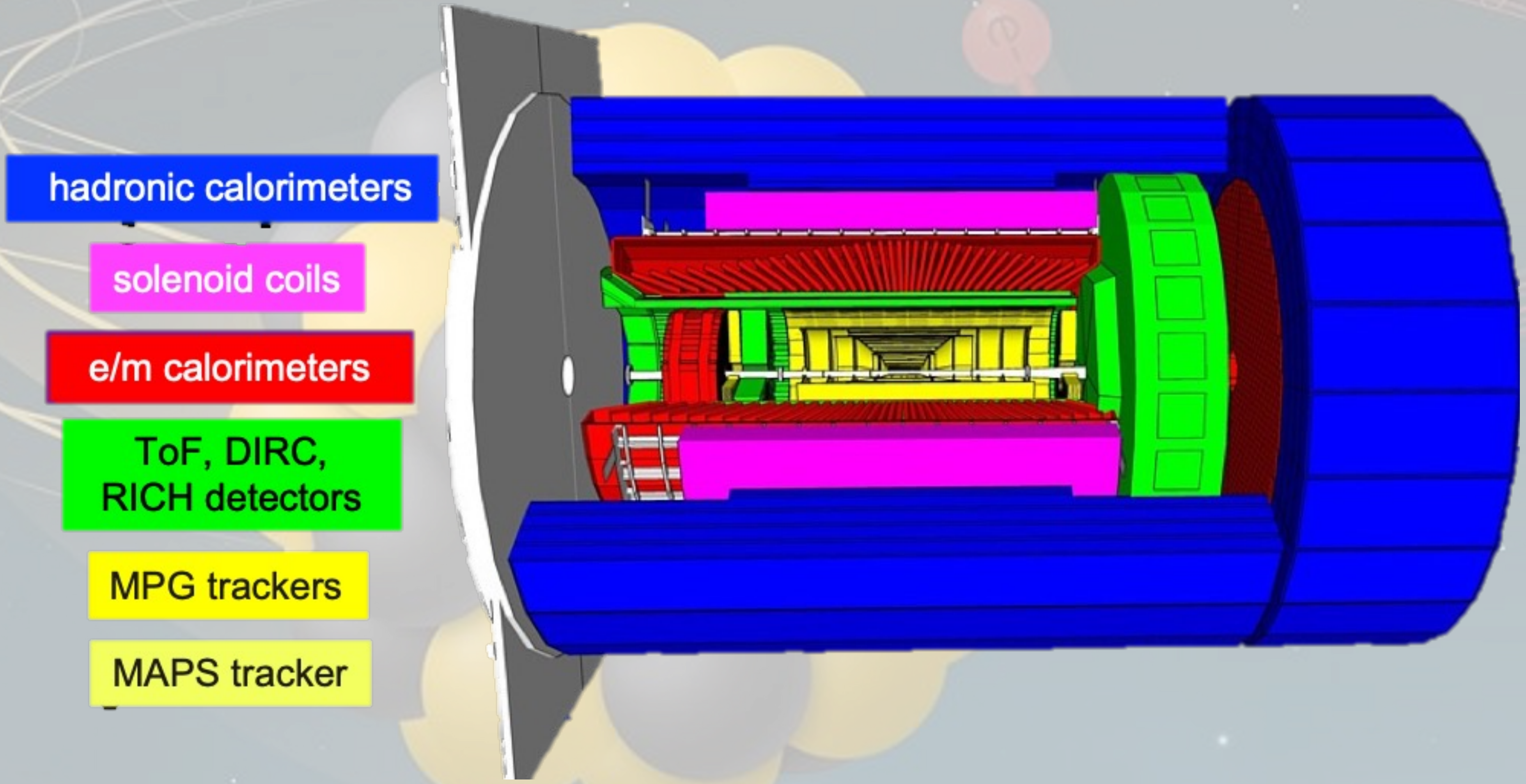
National Cheng Kung University

Detector

EPIC Detector



Detector: Support Structure

The Forward Silicon Tracker

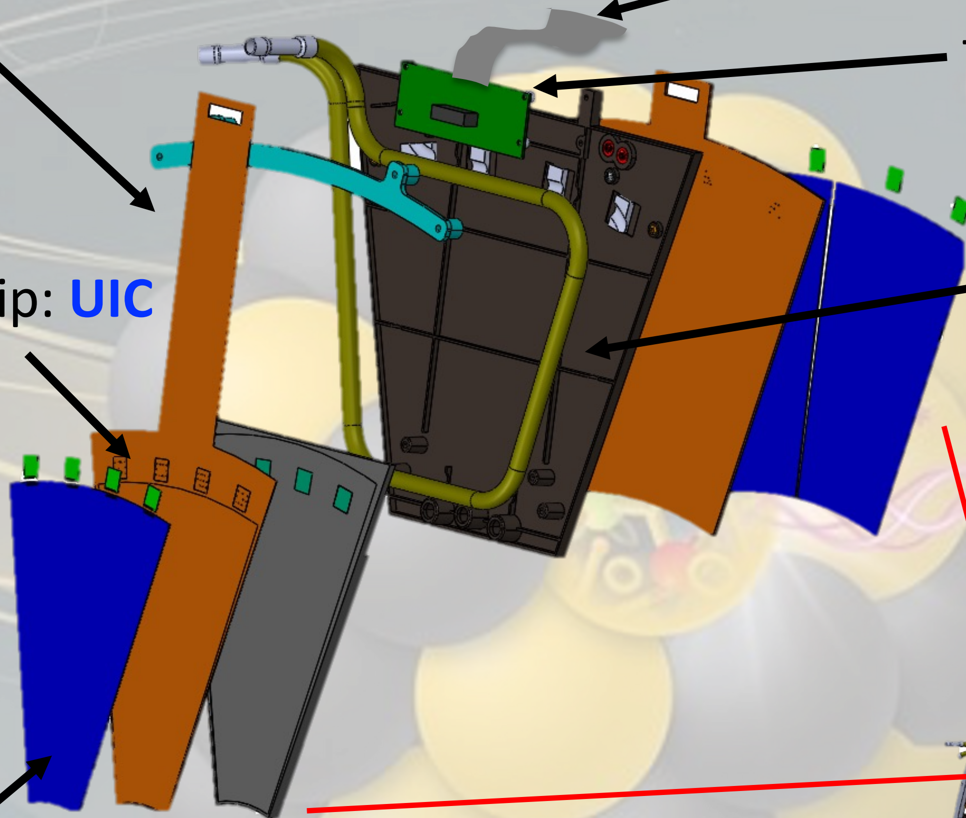
Flexible hybrid PCB: **SDU/IU**

Inner Signal Cable: **BNL/IU**

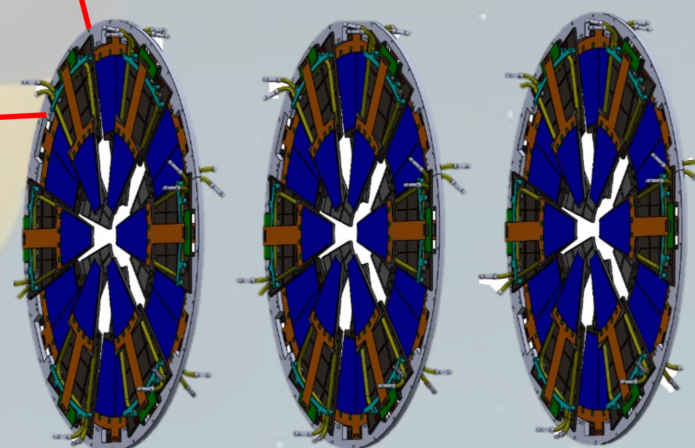
T-Board: **SDU/IU**

APV25 Chip: **UIC**

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



Supporting Structure & Integration: **BNL**



Silicon sensor: **UIC/BNL**

Cooling: **BNL/NCKU**

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

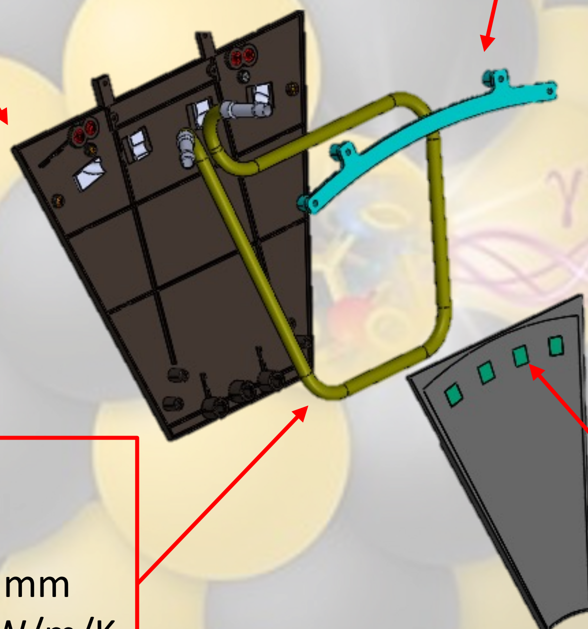
Design of Mechanical Structure

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**

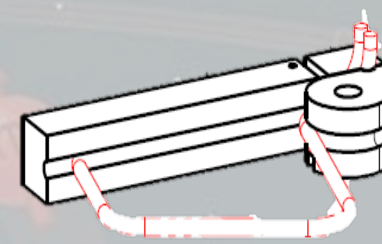
Tube:
- ❑ Material: Stainless 316
- ❑ Size: OD 6.35 mm, ID 5.54 mm
- ❑ Thermal Conductivity: 14 W/m/K
- ❑ ES&H: **Good**
- ❑ Rad.: **Good**

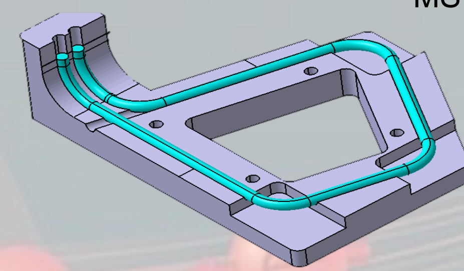
Heat sink:
- ❑ Material: Al 6061
- ❑ Size: ~8.2 x 8.0 x 3 mm^2
- ❑ ES&H: **Good**
- ❑ Rad.: **Good**

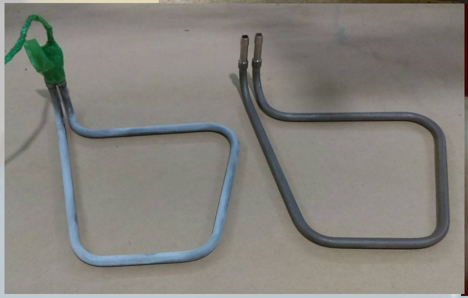
*PEEK has been used in collider experiments: e.g. STAR HFT

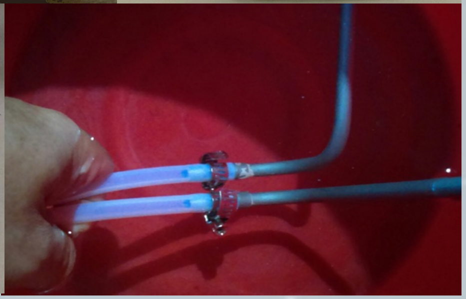
Manufacture of Cooling Tube

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







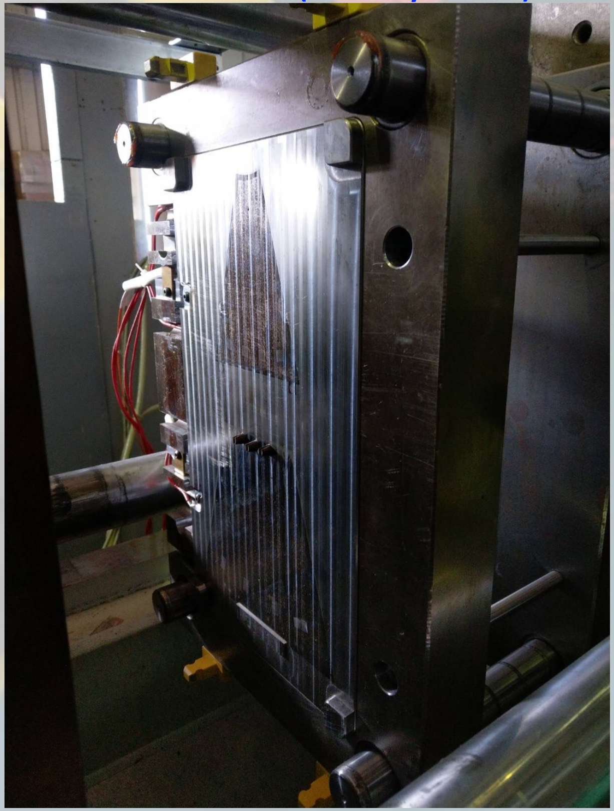


Injection Molding for MS

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

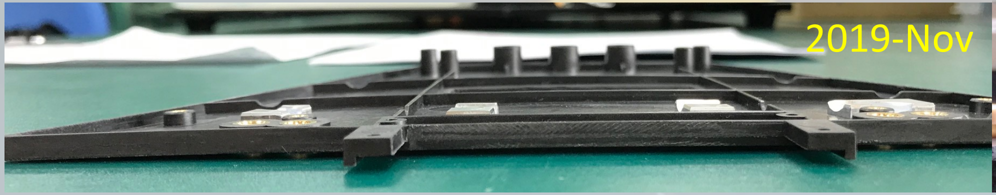
Moving Half (Core Side)

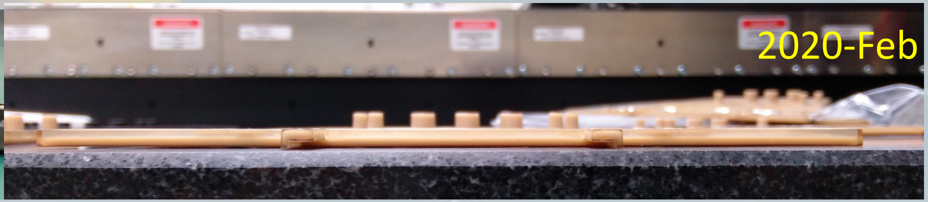
Fixed Half (Cavity Side)



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)

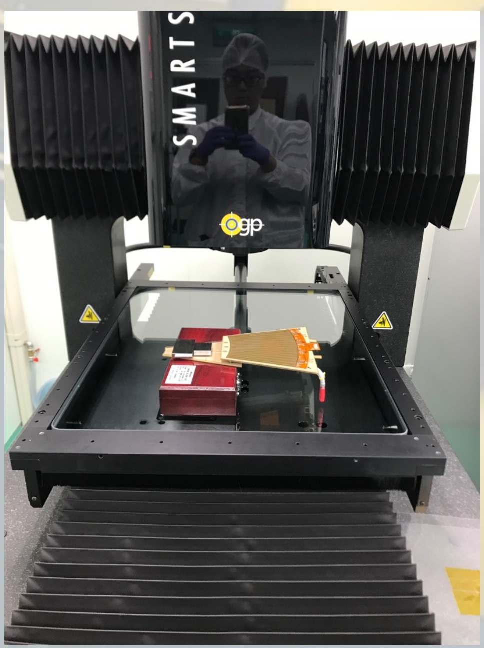




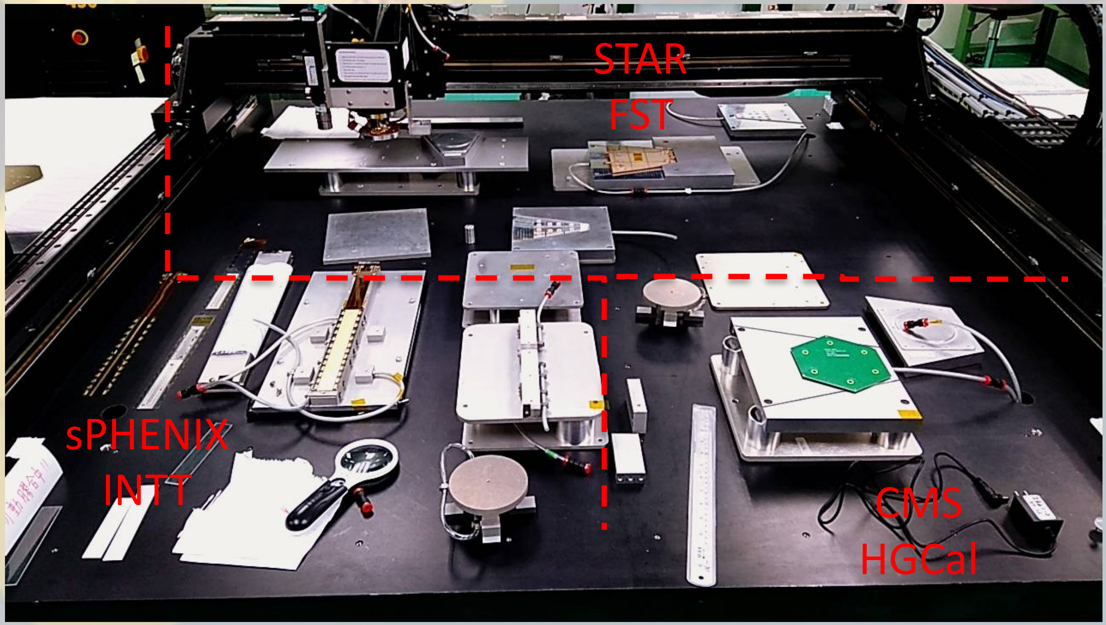
Assembly Procedure: Facilities

- 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

Optical Gauging Products (OGP)

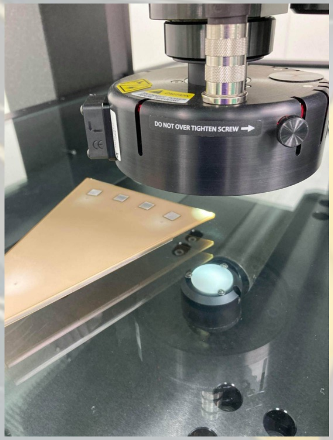


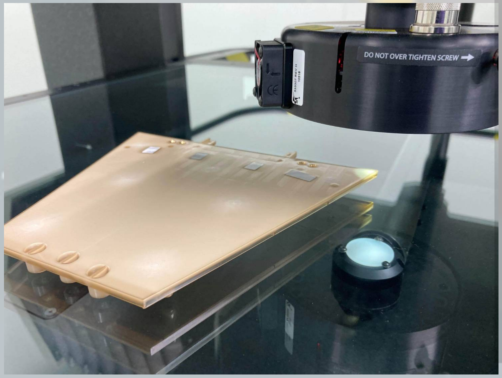
Assembly table and gantry



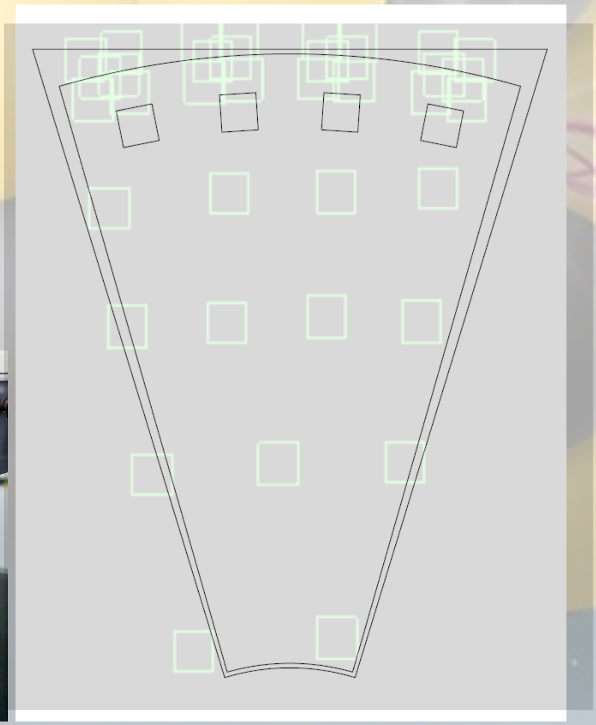
Quality Control

- 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

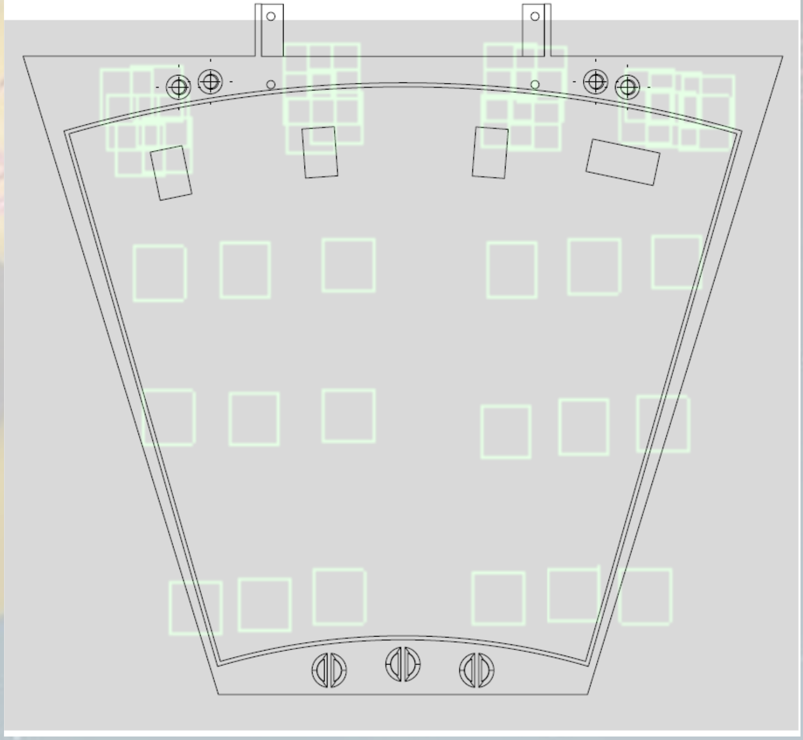




Inner



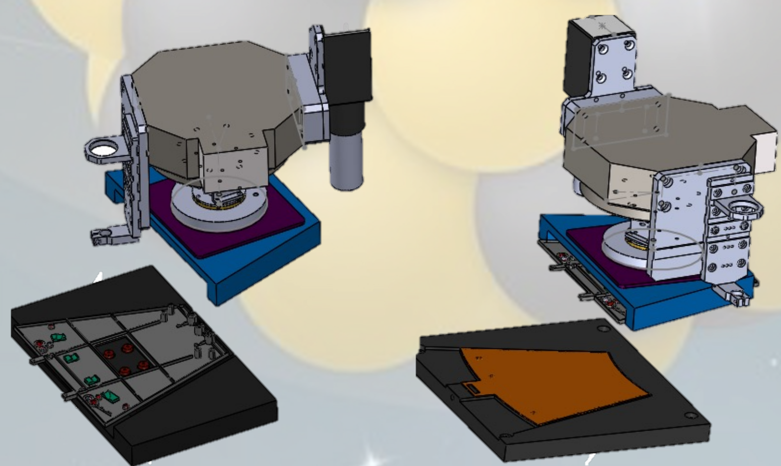
Outer

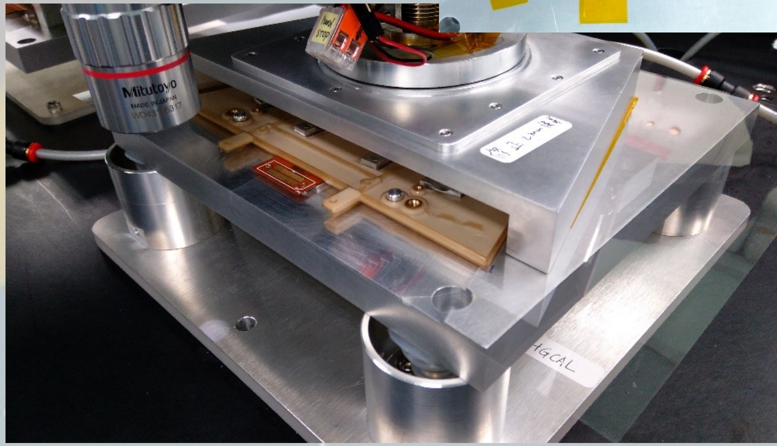


Assembly Procedure: Outer MS

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

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



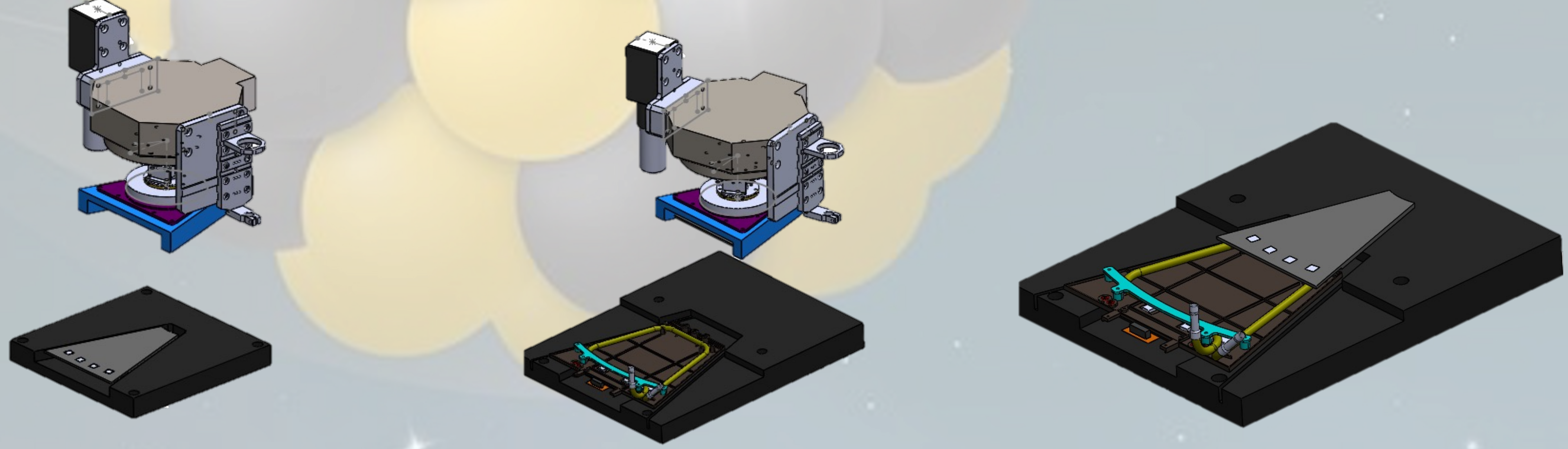


Gluing Procedure for Inner Hybrid

- Glue the inner MS first

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

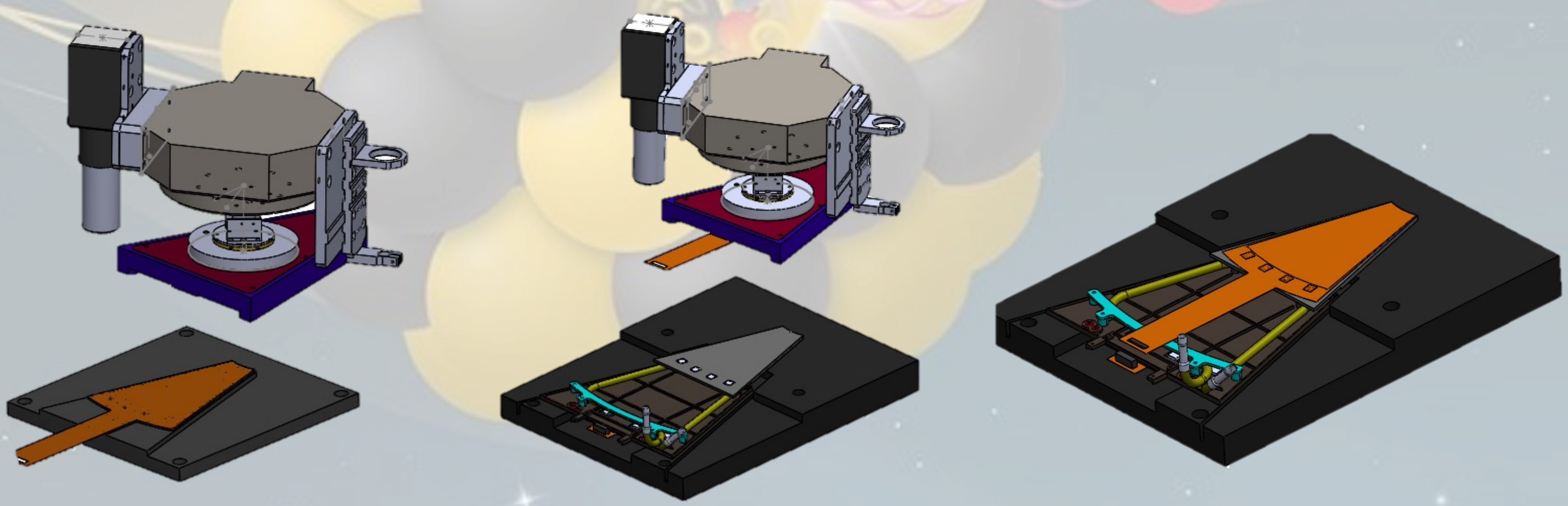
2) Use camera to locate reference points
3) Pick up inner MS and glue it on the outer wedge



Gluing Procedure for Inner Hybrid

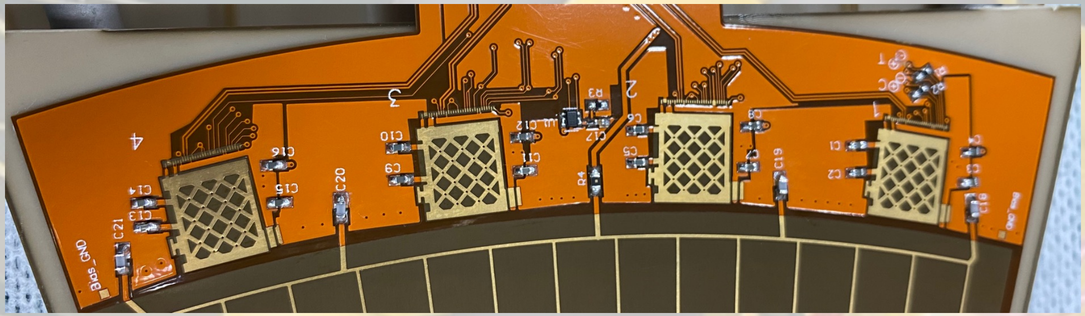
- Follow the “same” procedure as the outer Hybrid

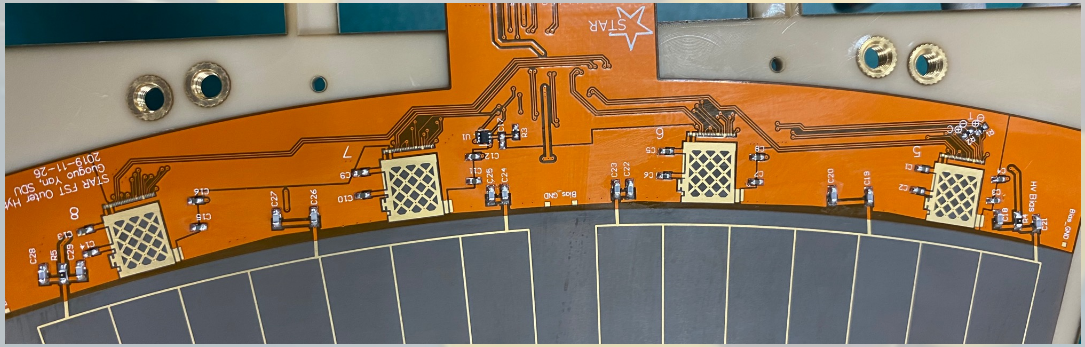
1) Place pickup tool, inner Hybrid + tray, outer wedge + inner MS + tray on table
2) Use camera to locate the reference points
3) Pick up inner Hybrid and glue it on the inner MS



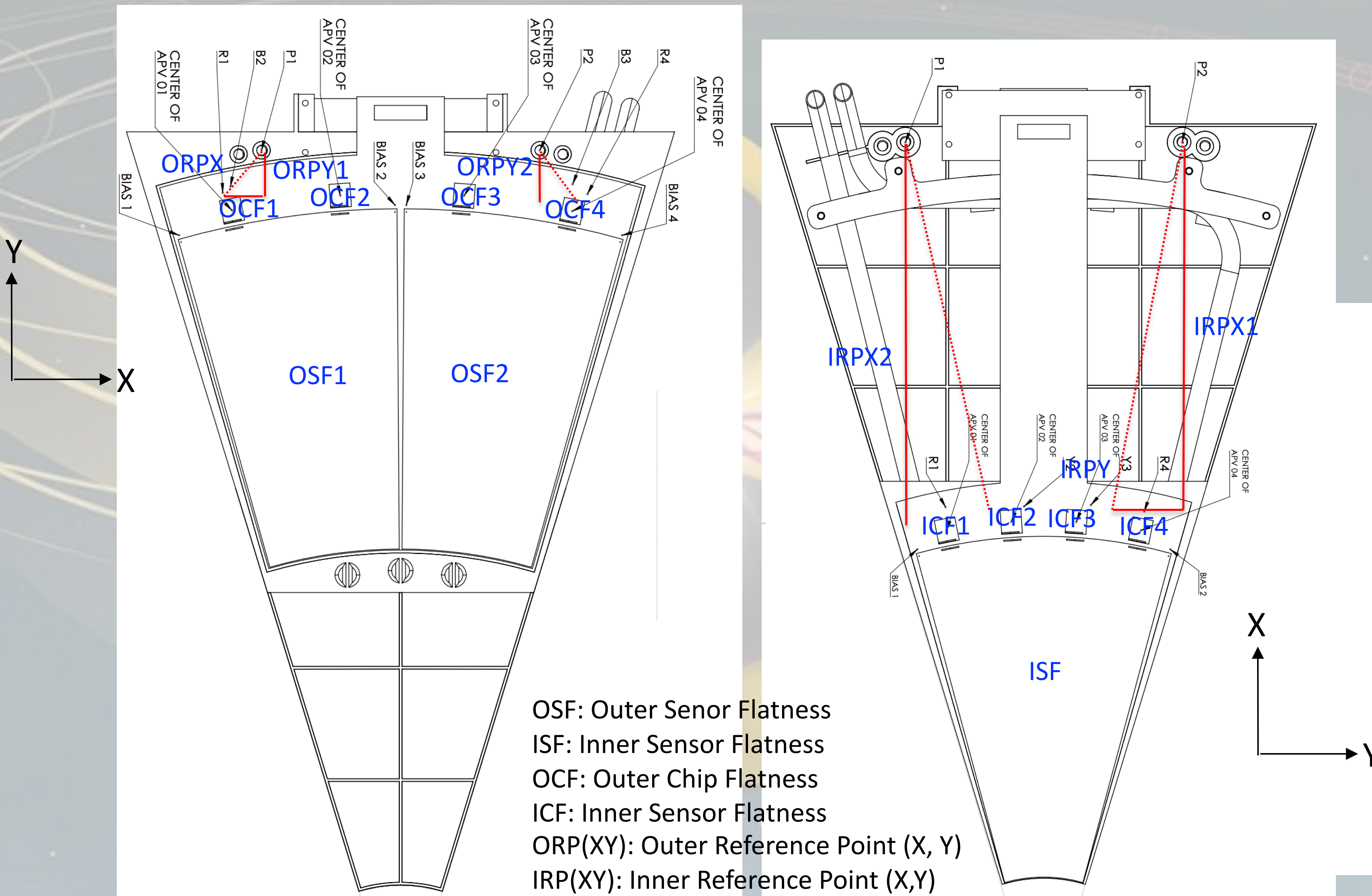
Assembly Procedure: Components on Hybrid

1) Solder components manually
2) Electrical open connection test





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)

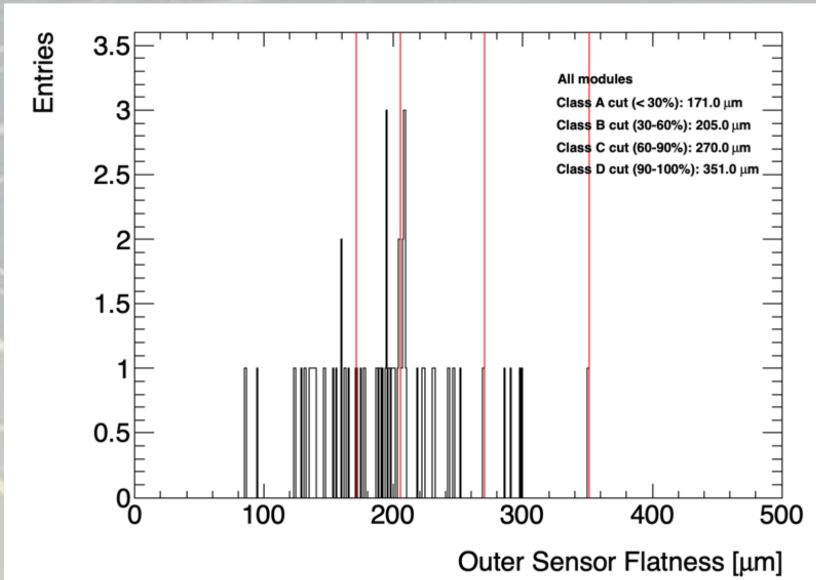
Production Statistics

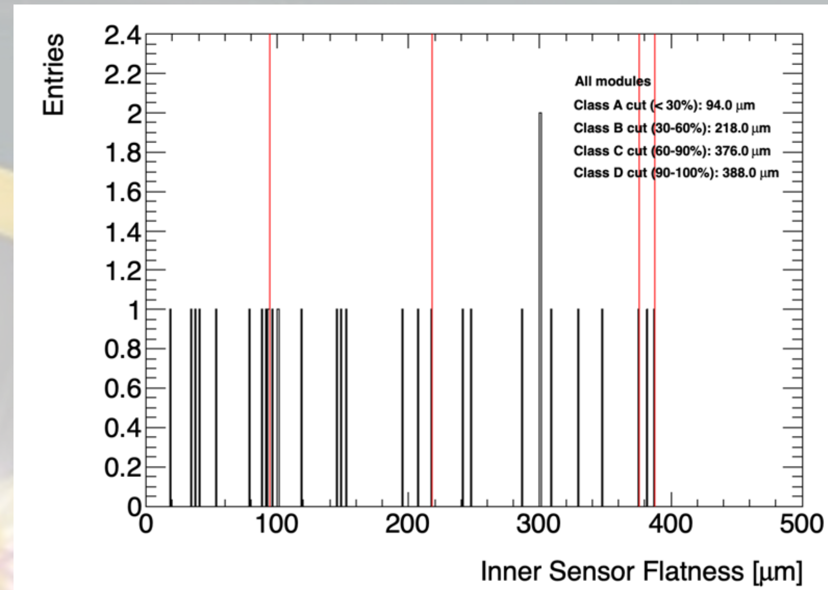
- All the measurements are recorded on Google Sheet:

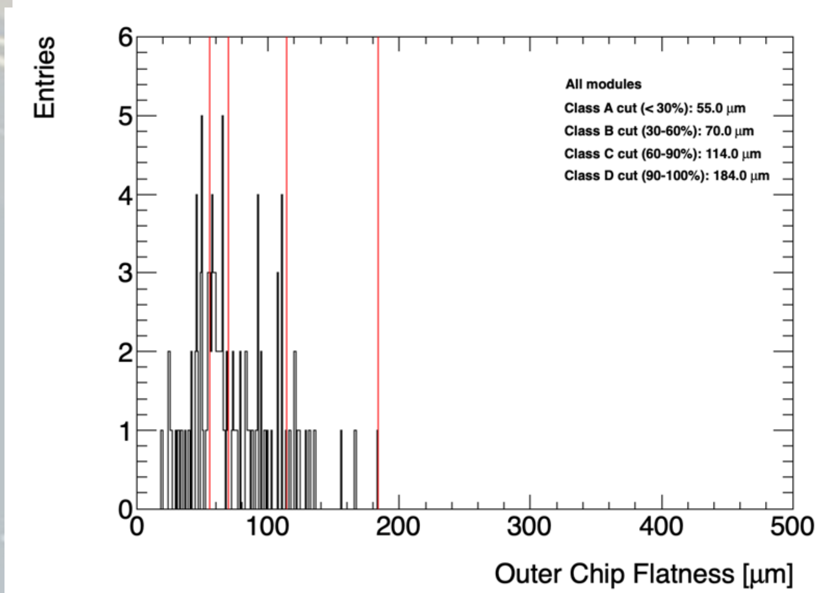
https://docs.google.com/spreadsheets/d/1YLm95aj0zIxxCnsfy0XVoxeI9FWD4RHUv-Pe4qCOfSc/edit?usp=sharing

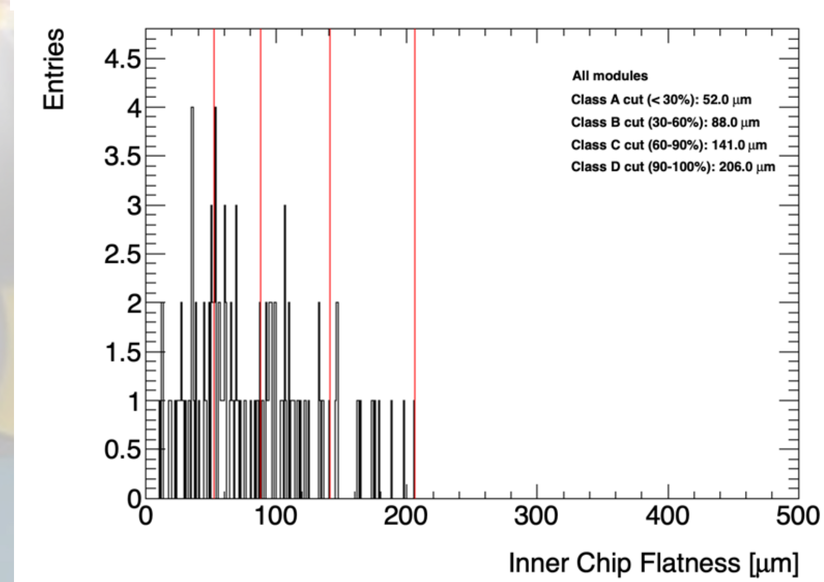
Module ID	OSF1	OSF2	ISF	OCF1	OCF2	OCF3	OCF4	ICF1	ICF2	ICF3	ICF4	ORPX1	ORPY	ORPY2
FST-11	207.36	194.35	286.39	97.19	59.43	31.42	73.15	60.58	98.73	133.33	89.85	41.12	6.08	6.75
FST-12	285.54	230.17	329.6	110.12	56.26	131.73	55.3	17.22	85.92	83.71	32.61	59.59	29.96	30.56
FST-13	246.73	165.61	387.82	58.05	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

Production Statistics

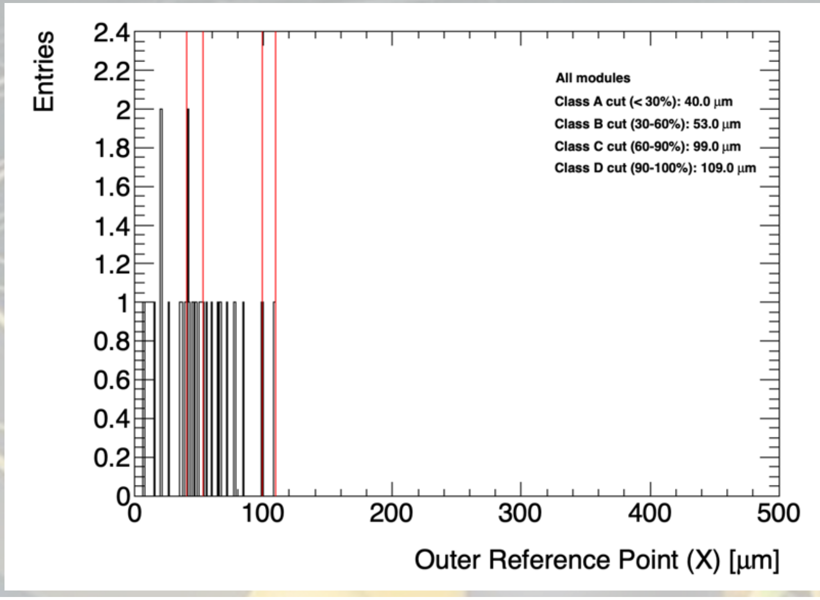


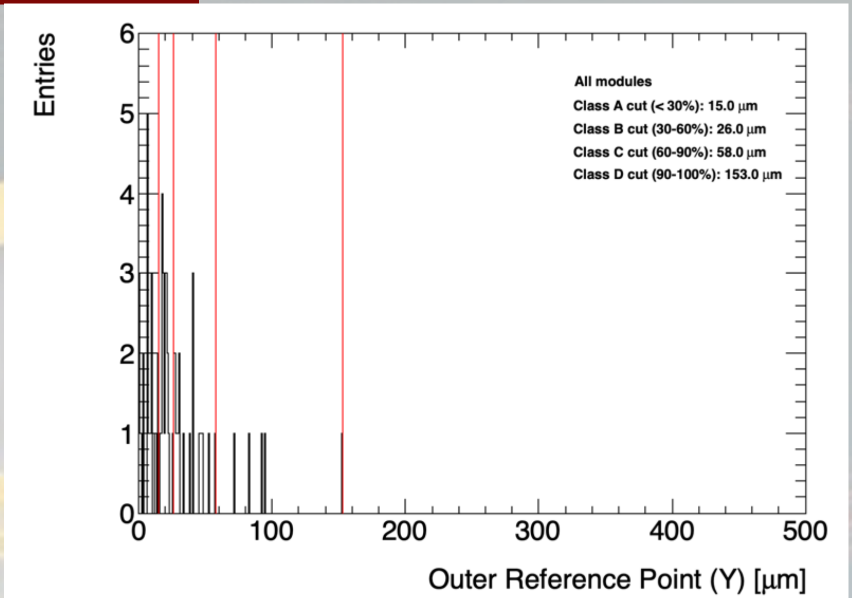


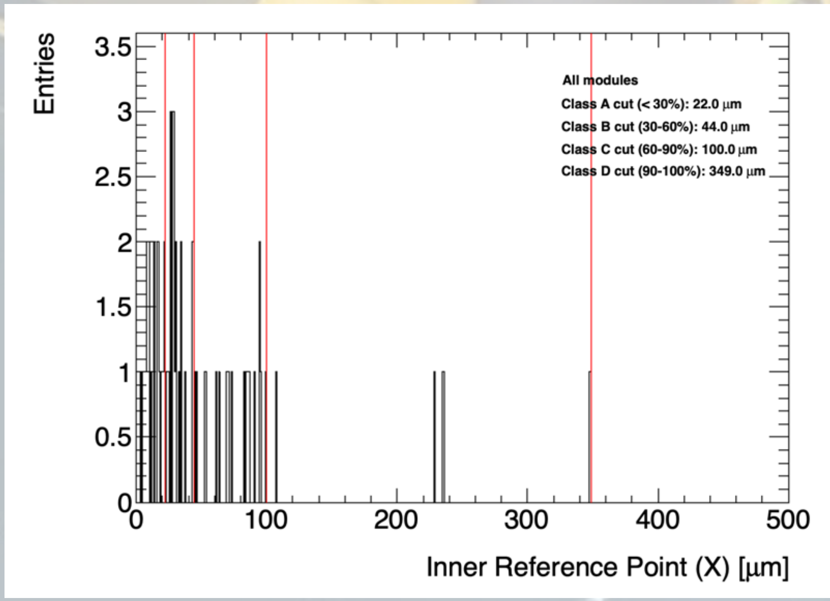


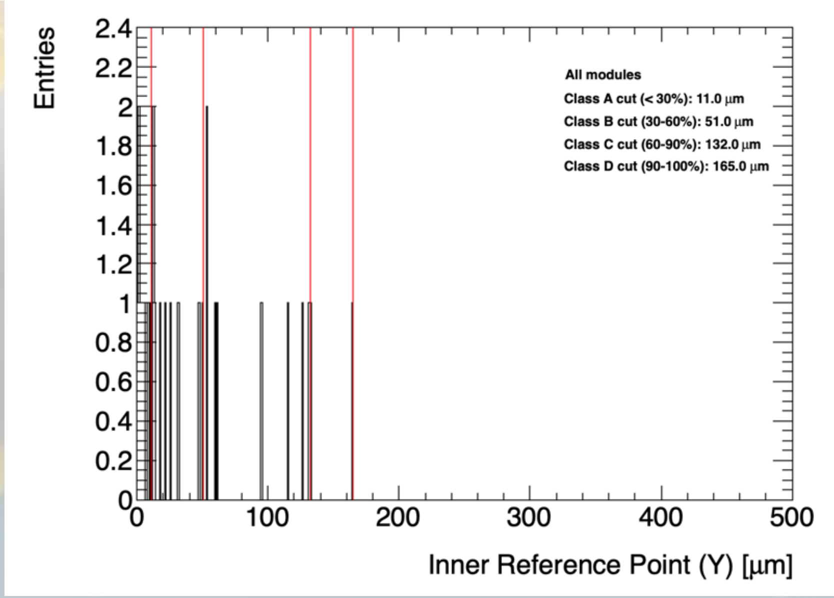


Production Statistics









Grading Matrix

- Assumption: all modules are good unless it encounters some technical issue, e.g. overflow glue…

		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

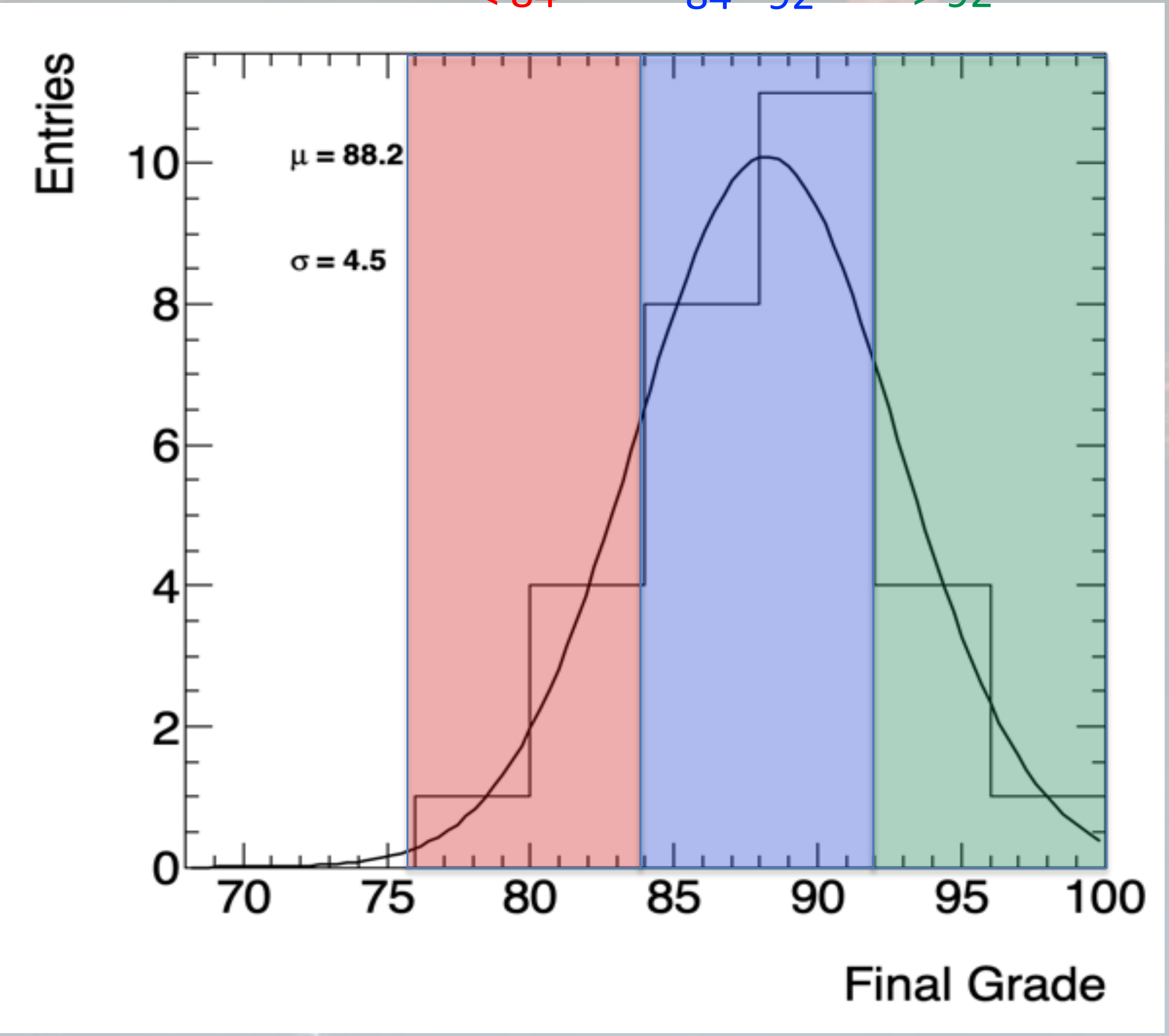
Final Class

Based on FST-07 to FST-35

Class C
< 84

Class B
84 - 92

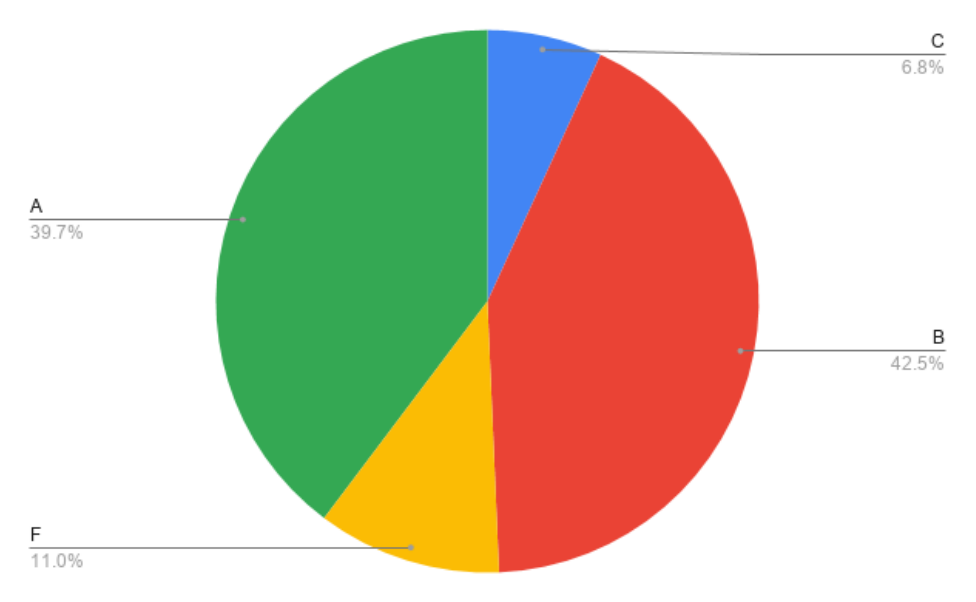
Class A
> 92

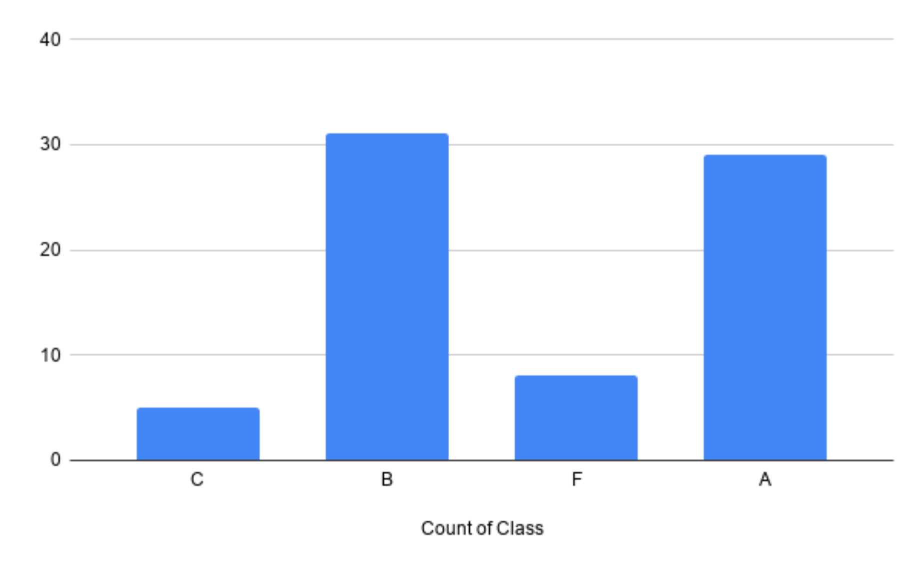


Overall Statistics

- 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

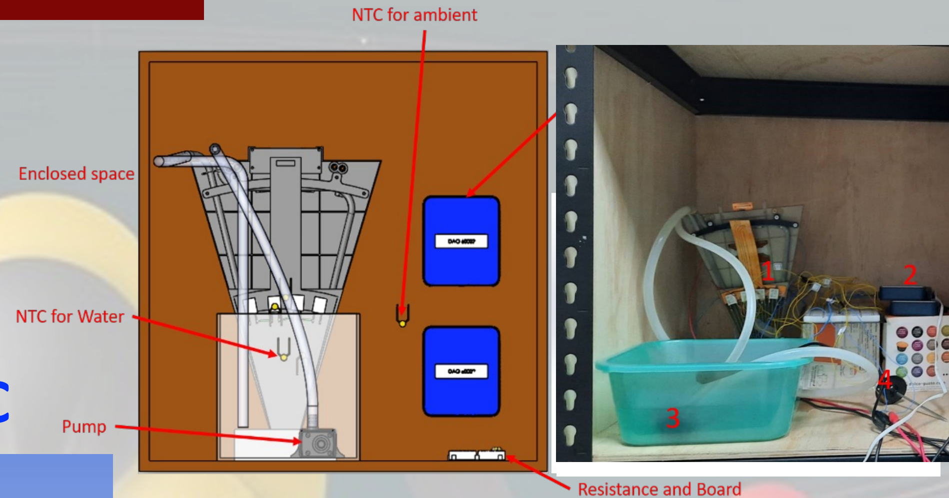
} 49 very good ones

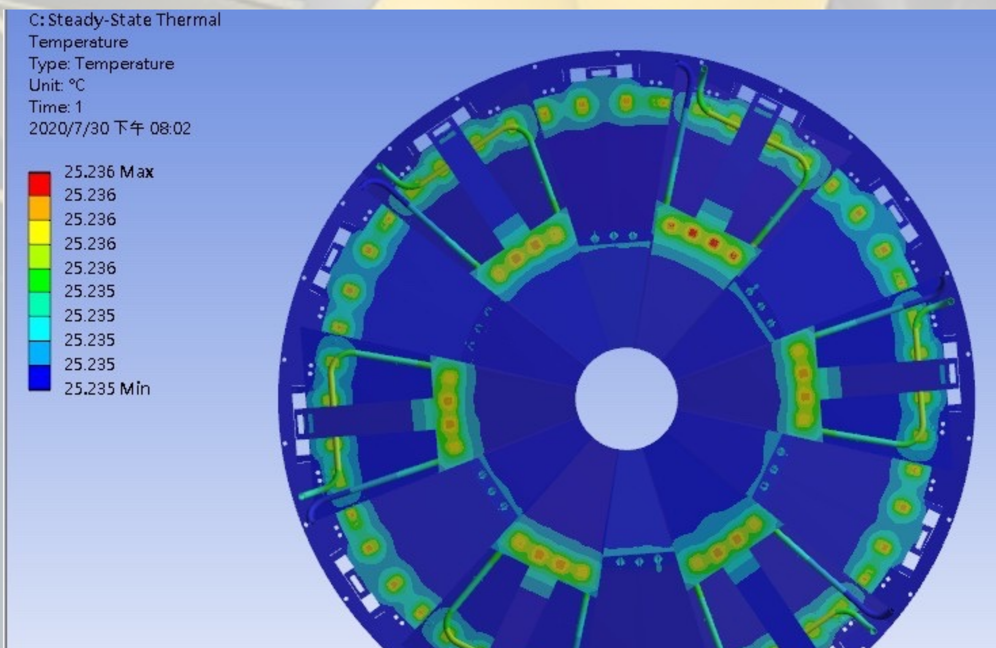




Thermal Analysis

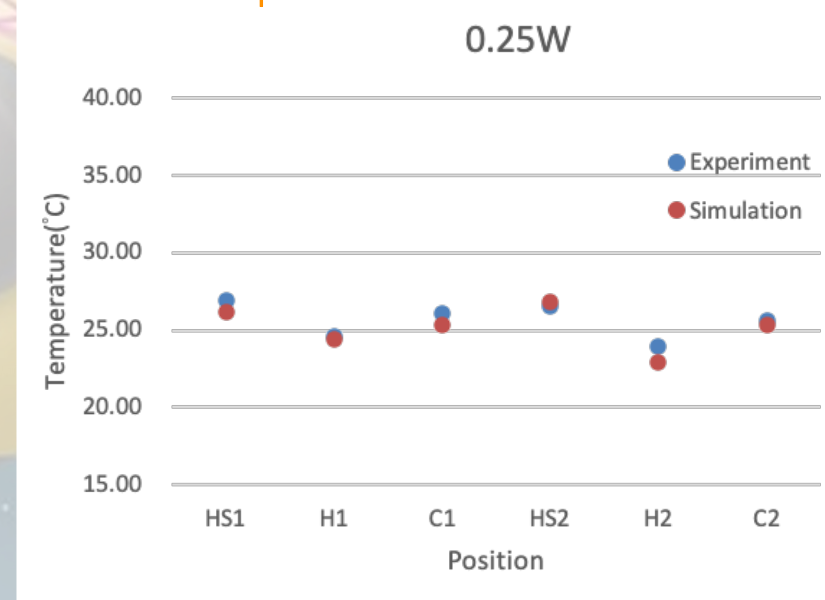
- Careful thermal analysis is performed by using single module with water cooling
- **Temperature at thermal equilibrium is less than 26 °C**





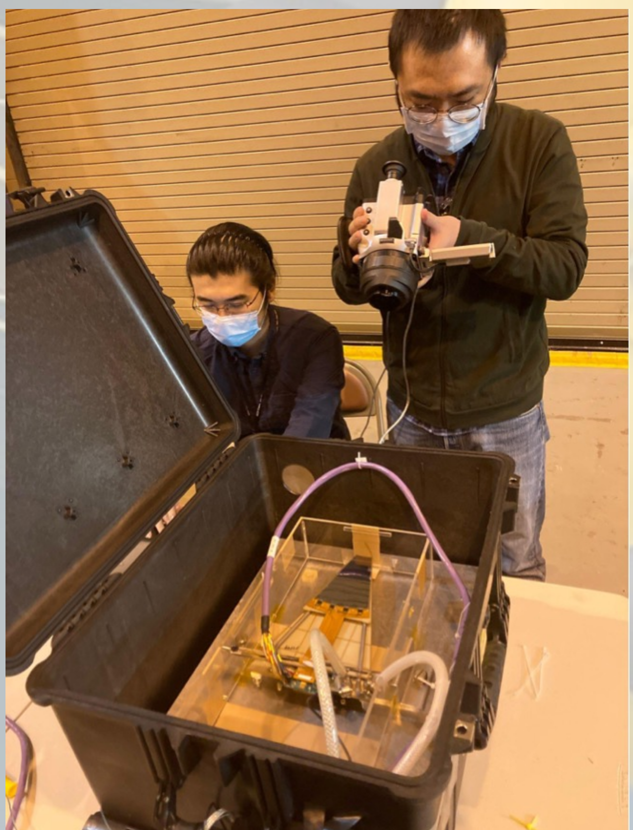
Liquid Temp: 22 °C
Ambient Temp: 25 °C

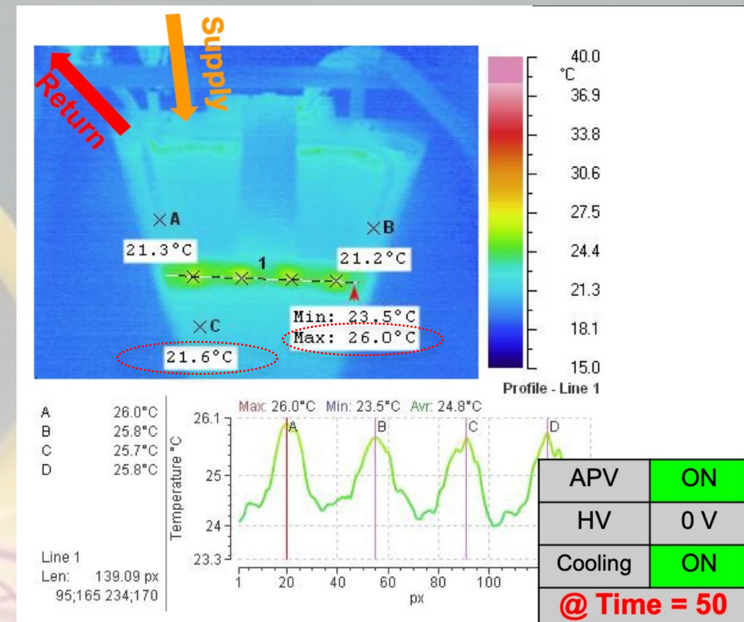
Consistent results between experiments and simulation



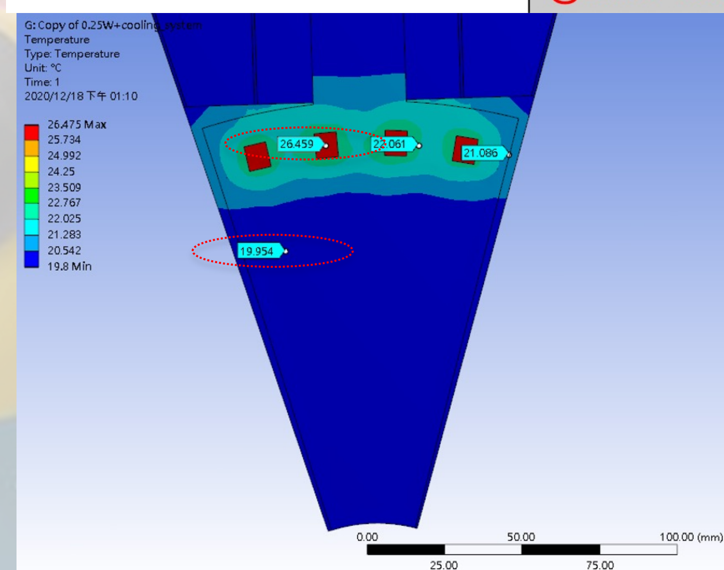
Thermal Analysis – Real Module

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



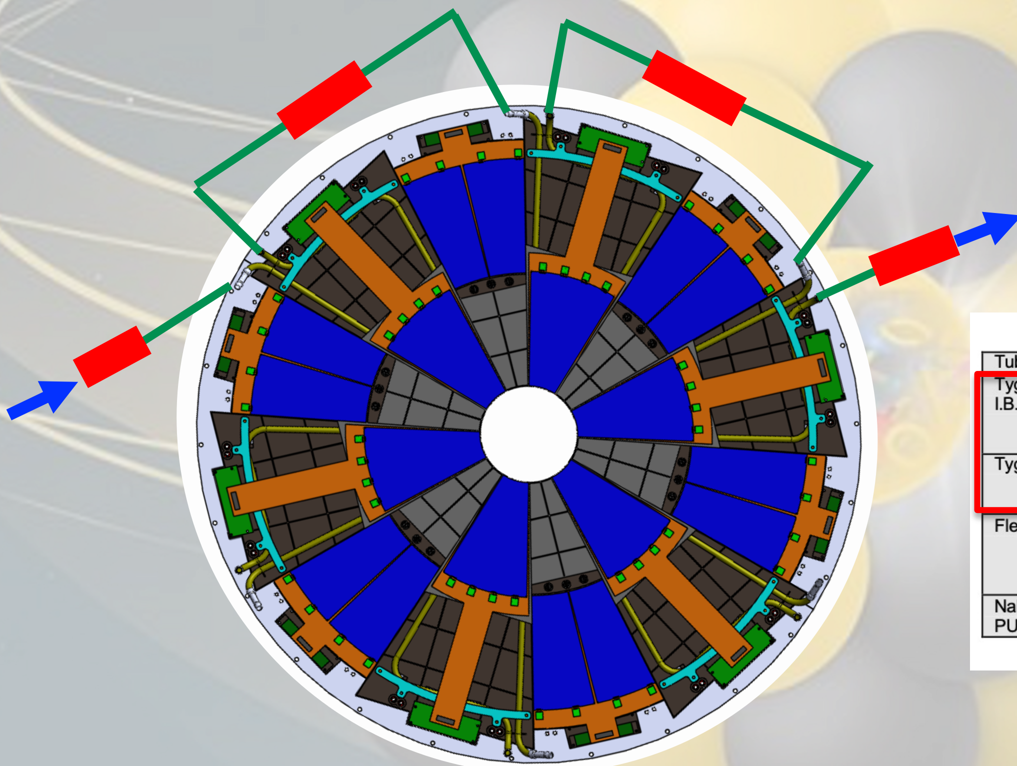


APV	ON
HV	0 V
Cooling	ON
@ Time = 50	



Soft Tube and Connector

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



Soft tubes

Connector

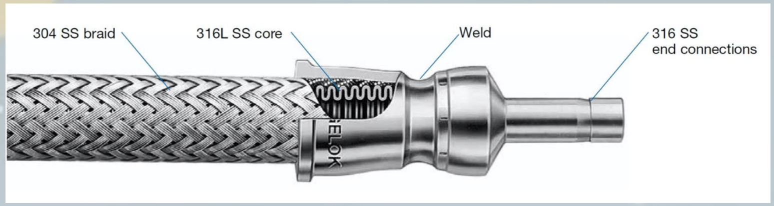
Plan A: plastic soft tube

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.

DME

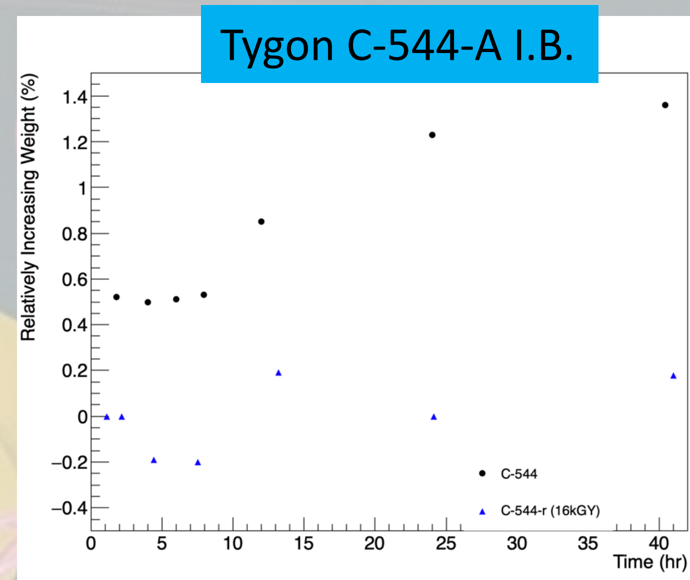
Plan B: metal soft/hard tube

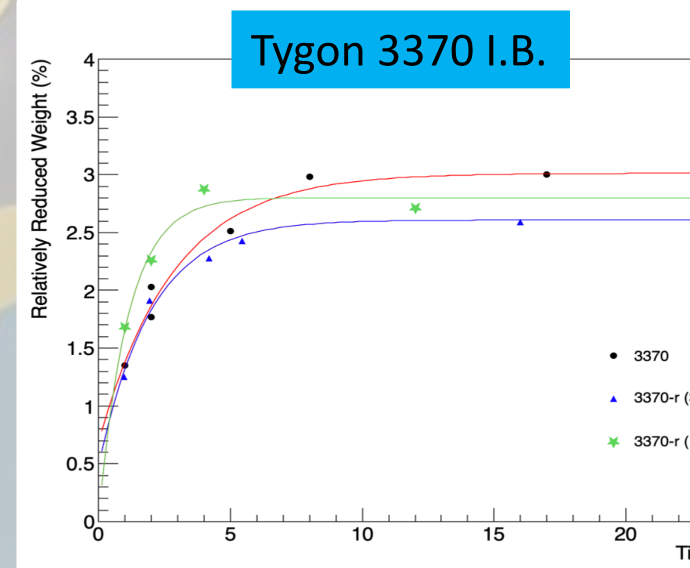


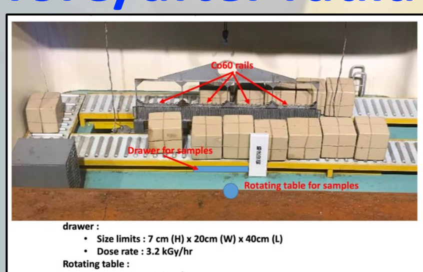
Soft Tube Compatibility & Radiation Tests

- 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)

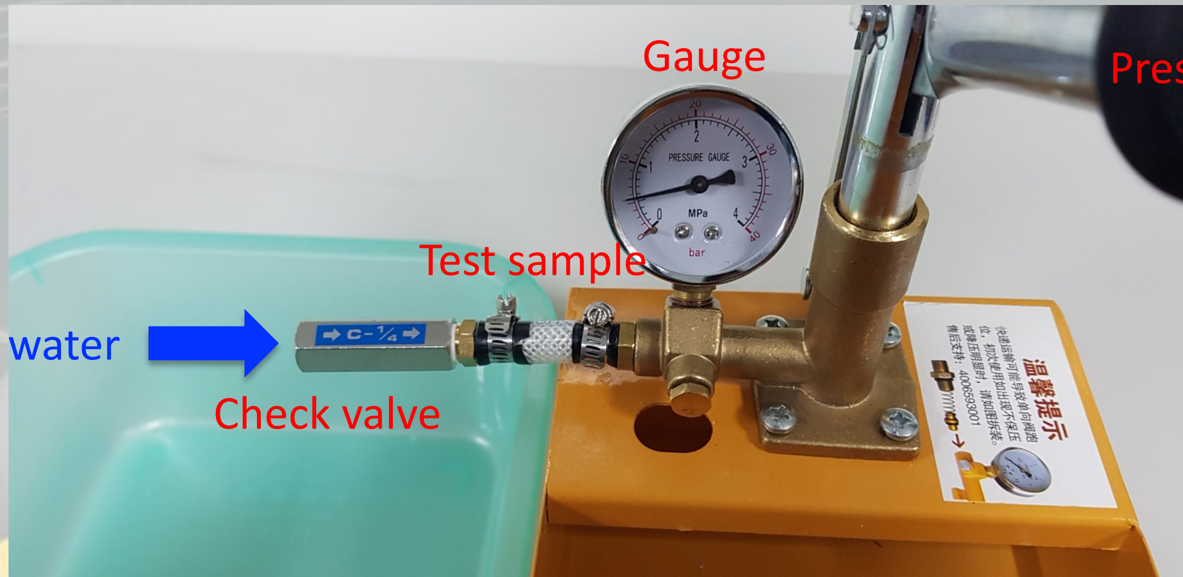
→ **No significant change before/after radiation**





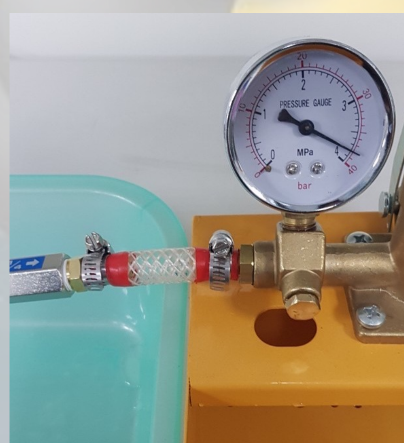


Burst Test on Soft Tubes



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

Detector: Silicon Sensor

Silicon Sensor in the Market

- About 90% of the silicon sensors are made by Hamamatsu

HAMAMATSU
PHOTON IS OUR BUSINESS

- Taiwan is the idea place to provide service of developing and manufacturing the **<u>high-quality</u>** silicon sensors to fundamental science (high energy physics)

TSRI NARLabs 國家實驗研究院
台灣半導體研究中心
Taiwan Semiconductor Research Institute

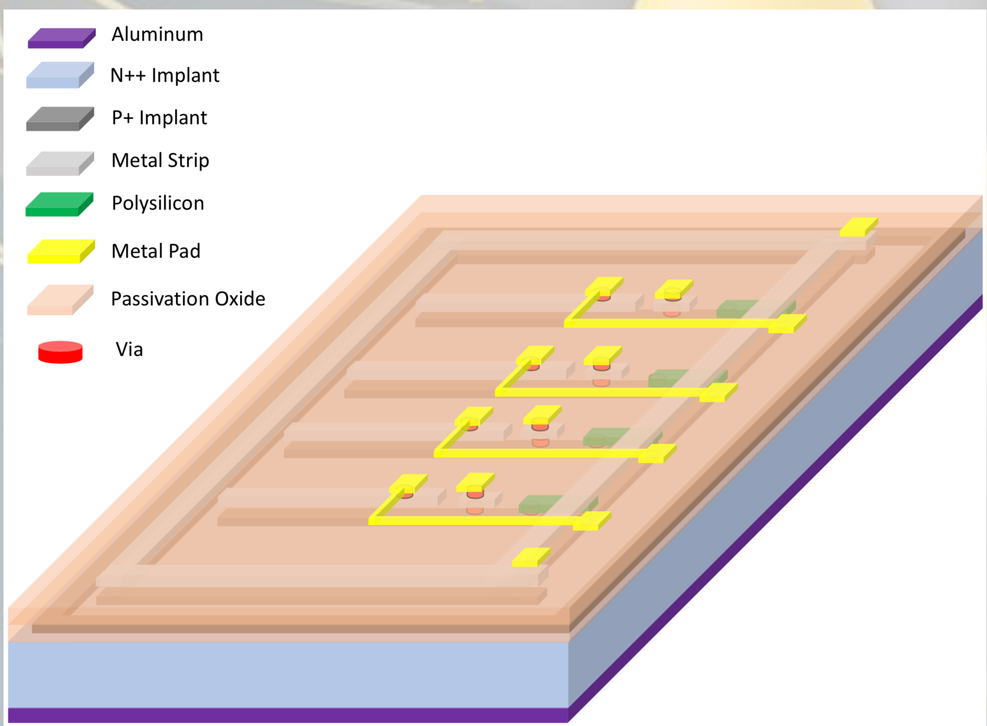
國立成功大學
電機工程學系

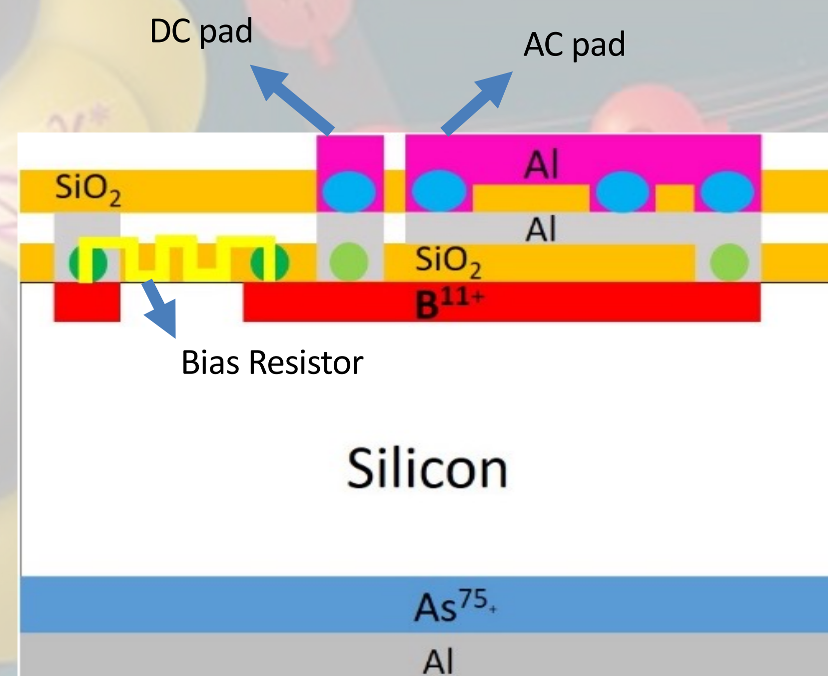
工業技術研究院
Industrial Technology Research Institute

成功大學物理學系
Physics@National Cheng Kung University

Silicon Strip Sensor

- A typical AC-coupled p-in-n silicon strip sensor:
  - Reverse bias of p-n diodes to deplete free charges in the silicon
  - Signal proportional to thickness: typically 300-500 microns

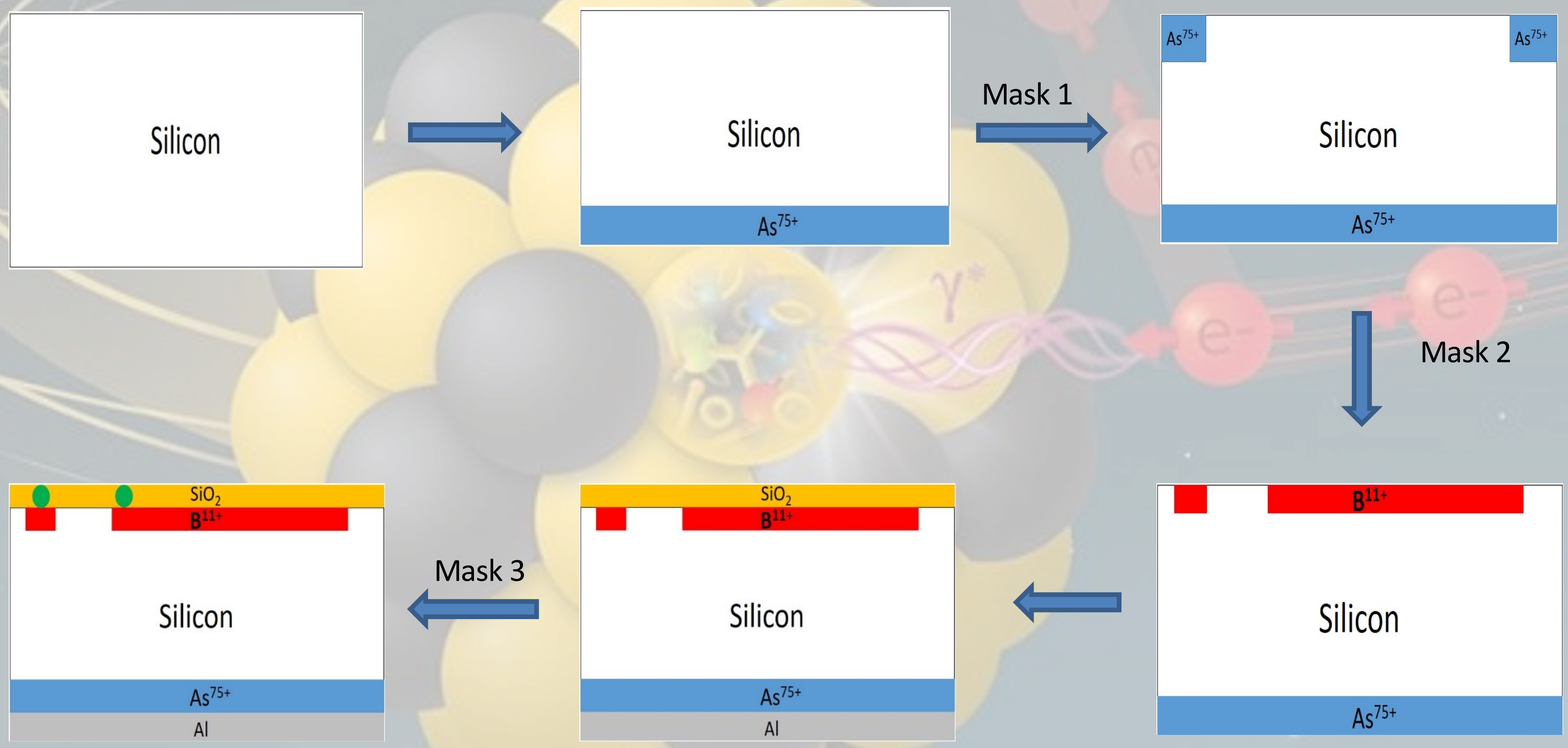




(Preliminary) Fabrication Procedure

1. Implant backside As^{75+} 5E15 200 Kev Annealing 950°C 30 sec

2. Implant front side As^{75+} 5E15 200 Kev (Guard ring) annealing 950°C 30 sec



3. Implant front side B^{11+} 5E15 200 Kev (Implant strips) Annealing 950°C 30 sec

4. Deposition TEOS 5000 A

5. Dry etching TEOS 5000 A for via-poly

(Preliminary) Fabrication Procedure – cont.

6. Deposition Polysilicon for sheet resistance 50 ohm

7. Dry etching meander shape 3000 A

8.Dry etching TEOS 5000 A for via-1

9. Deposition Al 1 um

10. Deposition SiO_2 5000A

11. Dry etching SiO_2 5000 A for via-2

12. Deposition Al 1um

Current Key Processes

1. **Masks @ Hsinchu/Taiana**
   - Design
   - Manufacture

   } 3-4 months (Need help from NCKU EE/TSRI)

2. **Process flows (1-9) @ Hsinchu**

   Implantation E500HP
   Horizontal Furnace
   E-gun

   - Implant
   - Insulator layer
   - Polysilcon
   - Al (first layer)

   } 4-6 months (Need help from TSRI/ITRI to speed up)

3. **Process flows (10-12) @ Tainan**
   - Protection layers (SiO_2)
   - Al (second layer)

   } 1-2 months (Having lots help from TSRI, Tainan)

Key Parameters in Fabrication

- Implant energy & dosage
- Polysilicon resistor
- Insulator layer width
- Aluminum width

} Know how, valuable…

➔ **Need to tune/optimize them carefully**

Fabrication measurement in TSRI

Wet bench
Clean wafer

PECVD
Deposition of SiO_2

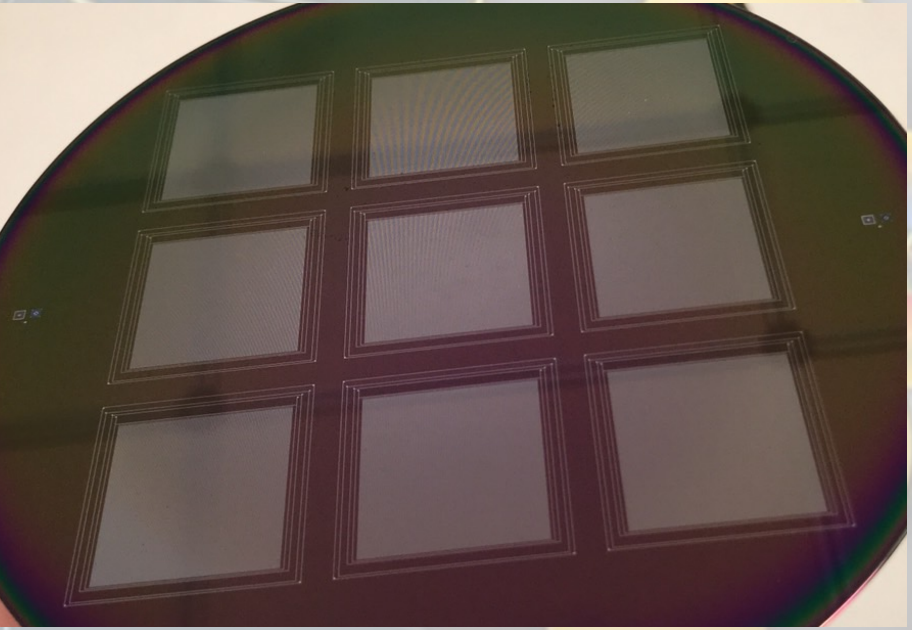
Mask aligner

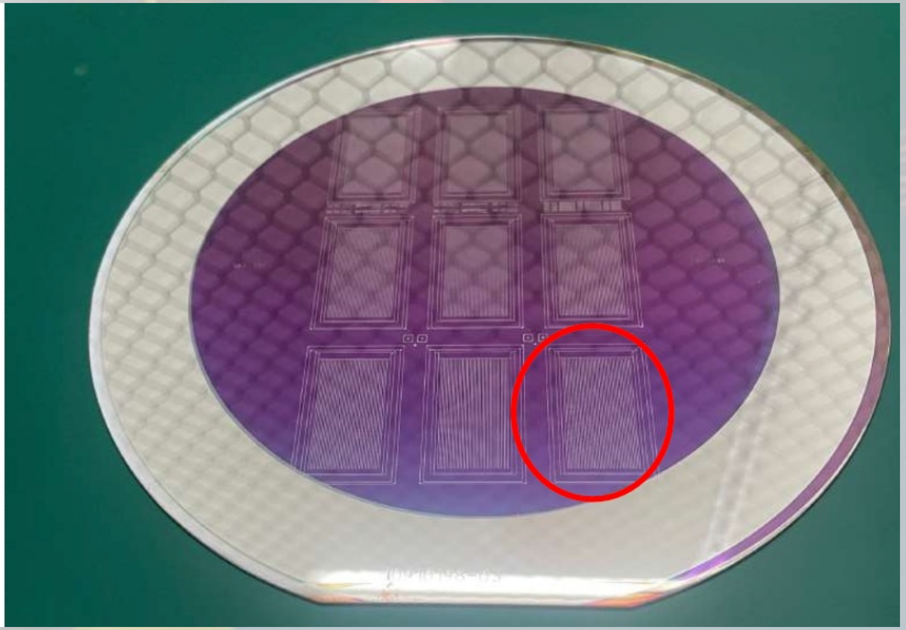
STS
Etching SiO_2

Sputter
Deposition of AL

RTA
Annealing metal

Prototypes





QA test @ NCKU HEP Lab

- C-V test: full depletion voltage determination
- I-V test: leakage current determination

Class 10K cleanroom

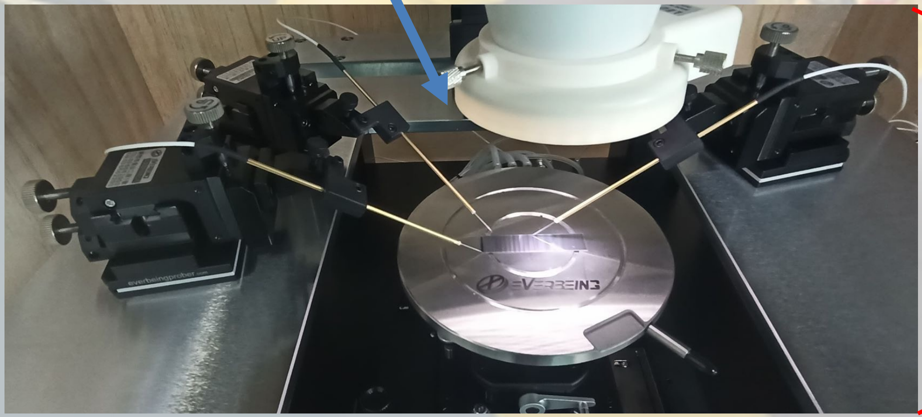
Electrometer (precise Amp-meter)

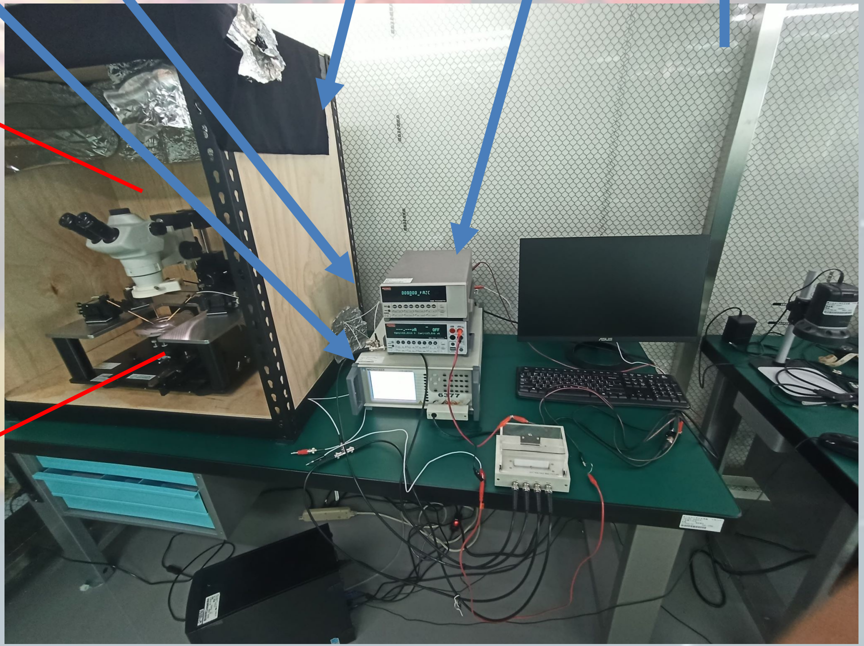
Source Measure Unit (SMU)

Light-tight box

Probe station (4 probes)

LCR Meter



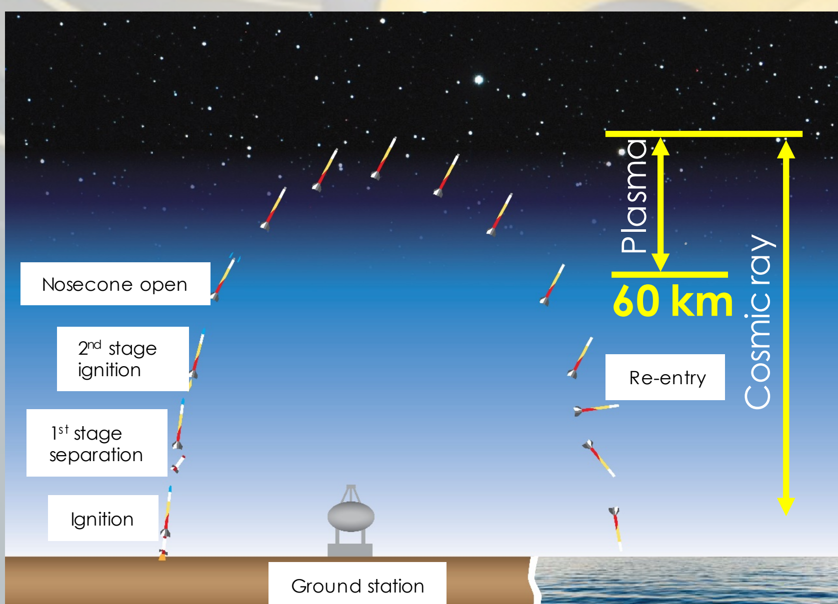


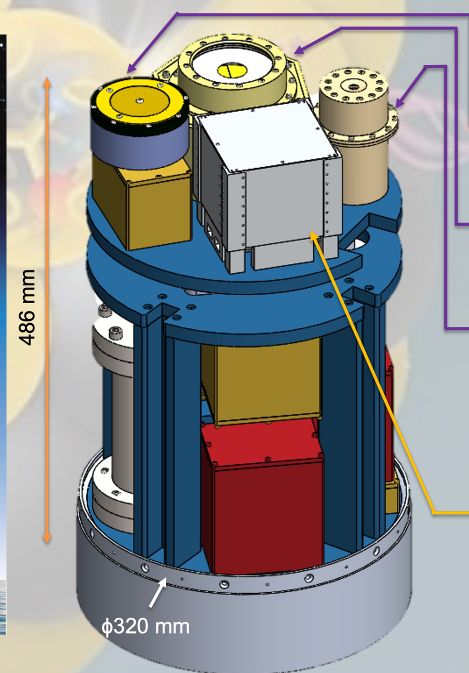
Detector: Scintillator-based

NSPO Sounding Rocket Mission

Hybrid Rocket from NCKU (Prof. Chao)
Mission duration: 15 minutes
Height of Rocket: 80 - 120 Km

Two scientific missions:
- **Plasma**
- **Cosmic rays**





Plasma science
Mesosphere-Ionosphere Plasma Exploration CompleX (**MIPEX**)

i. Planar Langmuir Probe (**PLP**)
  - ➢ Electron density
  - ➢ Electron temperature

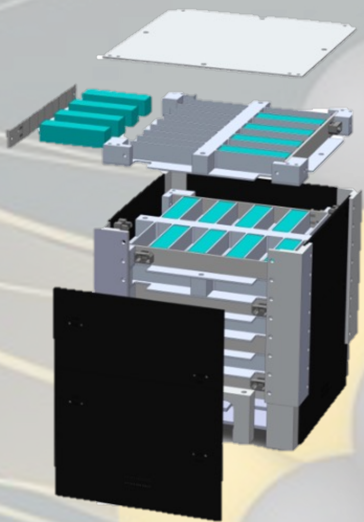
ii. Single Axis Ion Velocity Analyzer (**SAIV**)
  - ➢ Ion density
  - ➢ Ion drift velocity direction

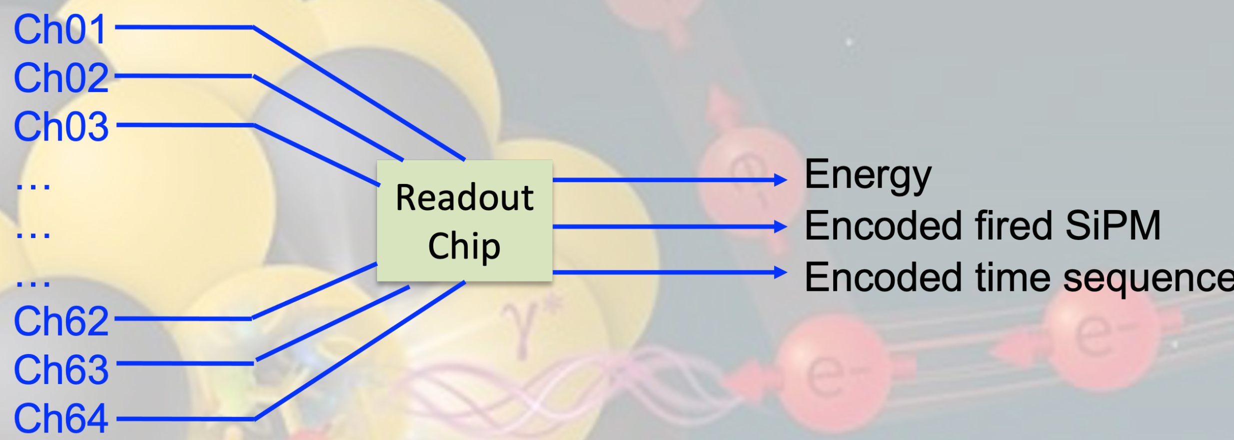
iii. Intensified Retarding Potential Analyzer (**IRPA**)
  - ➢ Ion density
  - ➢ Ion energy distribution function

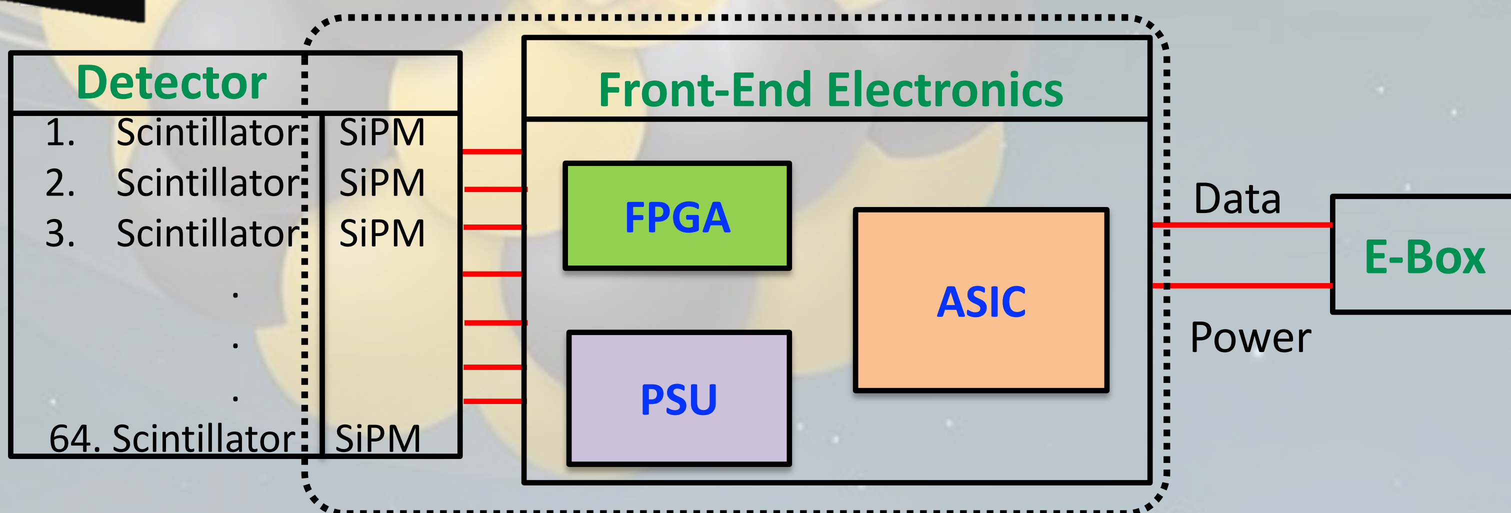
Cosmic ray physics
Compact Scintillator Array Detector (**ComSAD**)
  - ➢ Cosmic ray flux
  - ➢ Cosmic ray energy/angle spectrum

ComSAD System Overview

- **ComSAD** is a scintillator-based cosmic ray detector equipped with 64 plastic scintillators-SiPM detection units

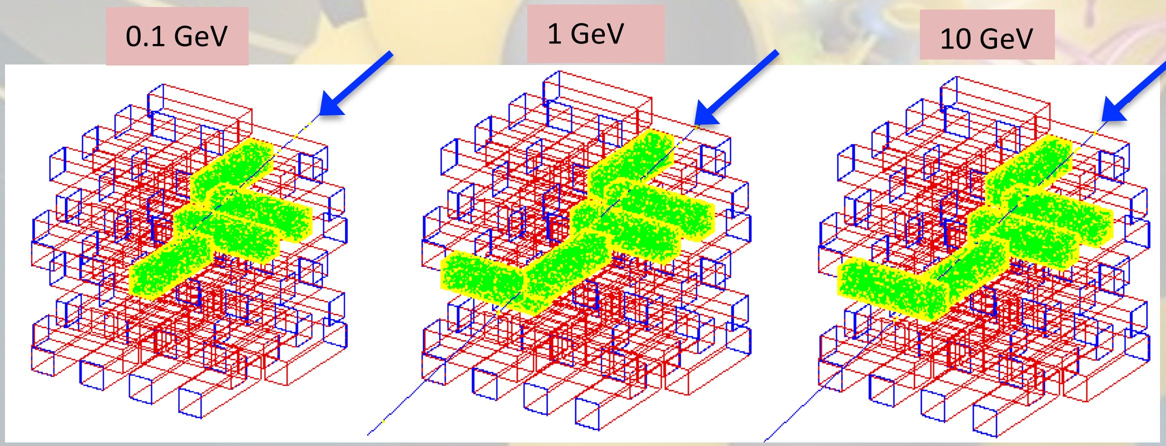




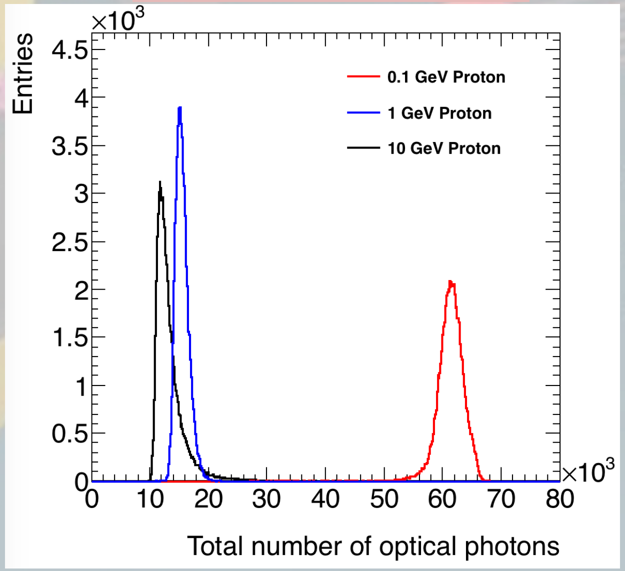


GEANT4 Simulation for ComSAD

- Use GEANT4 package to simulate the detector response for 0.1, 1 and 10 GeV incident protons
  - ➔ Can (roughly) distinguish cosmic rays with different energies

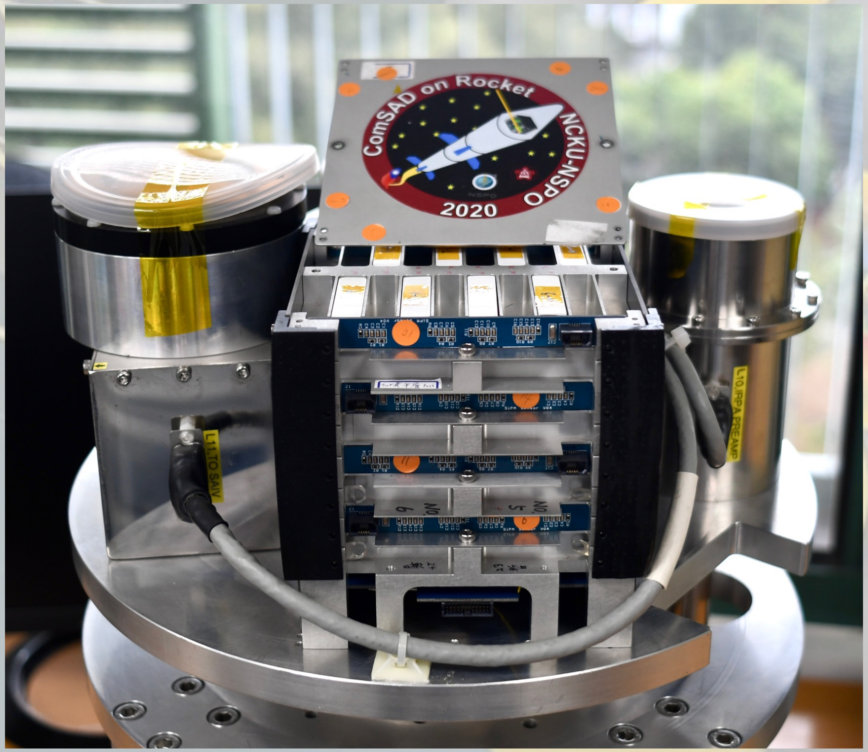


Number of optical photons

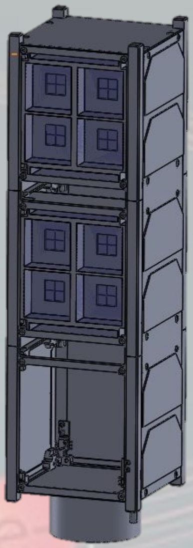


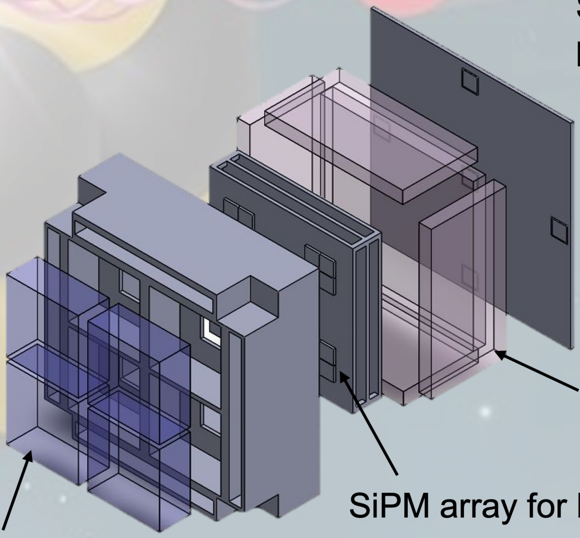
Current Status and Future

- **Journal of Astronomical Instrumentation**
  https://doi.org/10.1142/S2251171722500076, 2022



Similar technology can be applied on Gamma Ray detector for CubeSat





Summary of Detector Opportunities

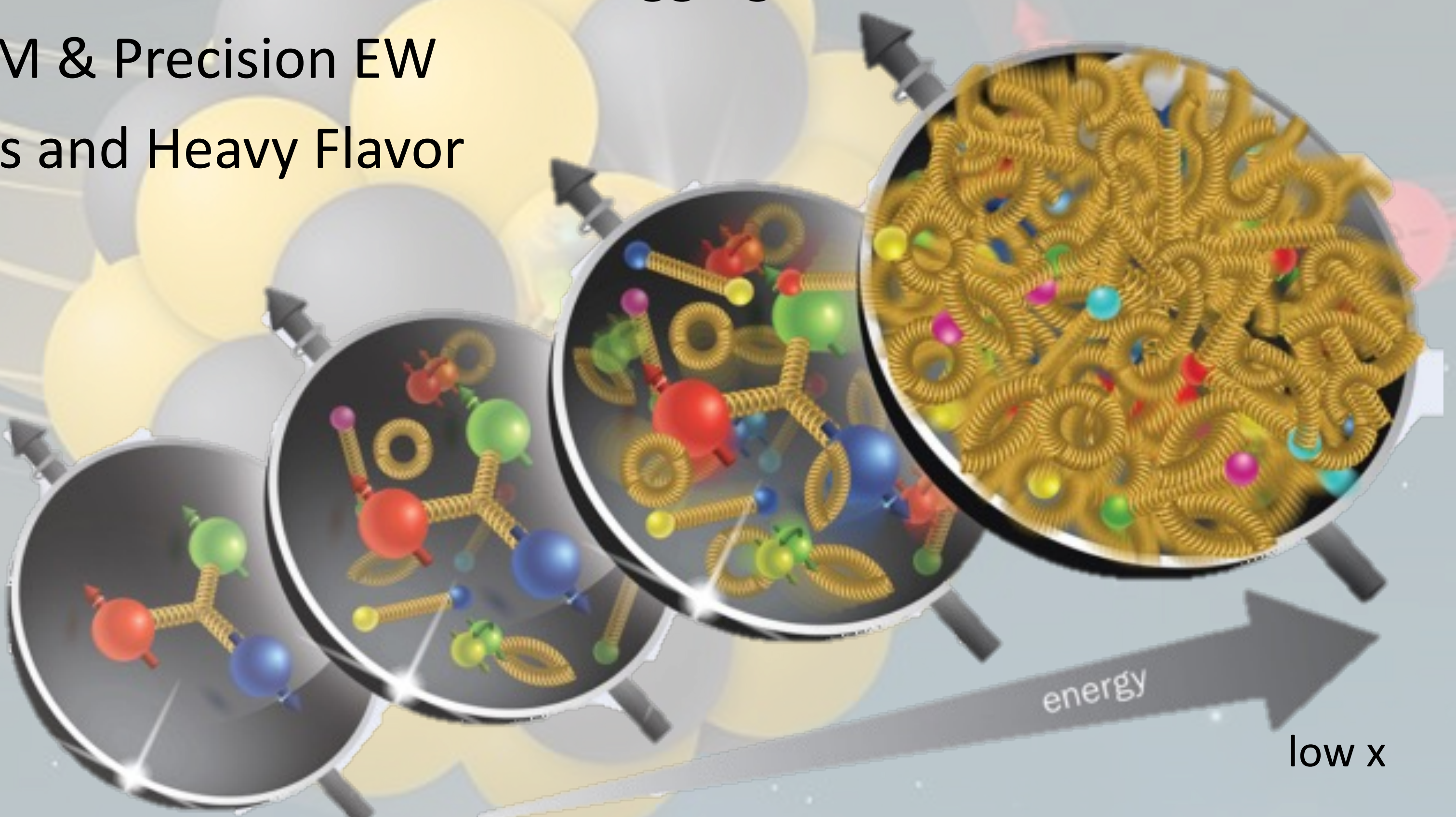
- Detector R&D is very fun, especially from scratch
- Supporting structure and sensor developments are both important

- **Currently working on the EIC Barrel TOF supporting structure**

Physics

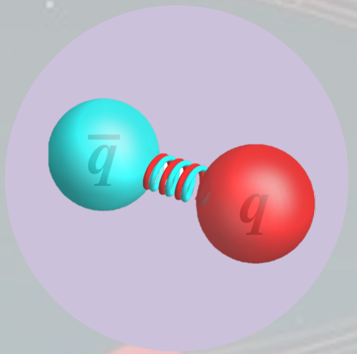
EIC Physics Working Groups

- Inclusive
- SIDIS
- Exclusive, Diffraction, and Tagging
- BSM & Precision EW
- Jets and Heavy Flavor



Heavy Quarkonium

- The bound state of two heavy quarks ($q\bar{q}$)
  - **J/ψ** is a $c\bar{c}$ (1974) and **ϒ** is a $b\bar{b}$ (1977) bound state



- Historically physicists tried to understand the production mechanism and polarization

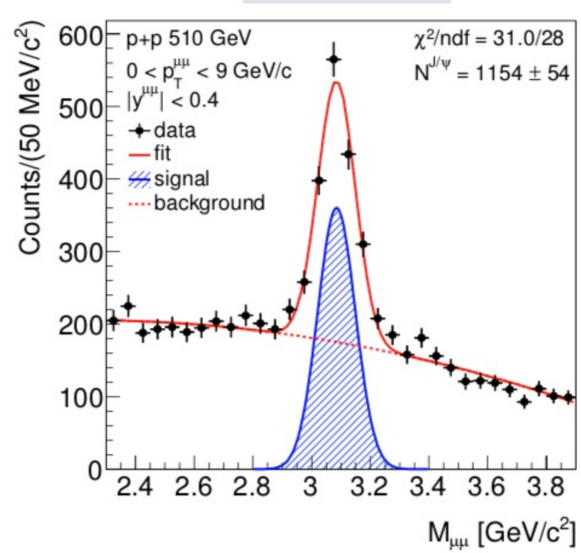
- The production includes two parts:
  - **Hard process (short distance):** the production of $q\bar{q}$ pair and it can be calculated by pQCD
  - **Soft process (long distance):** the formation of quarkonium from qq and it can be parameterized by phenomenological models

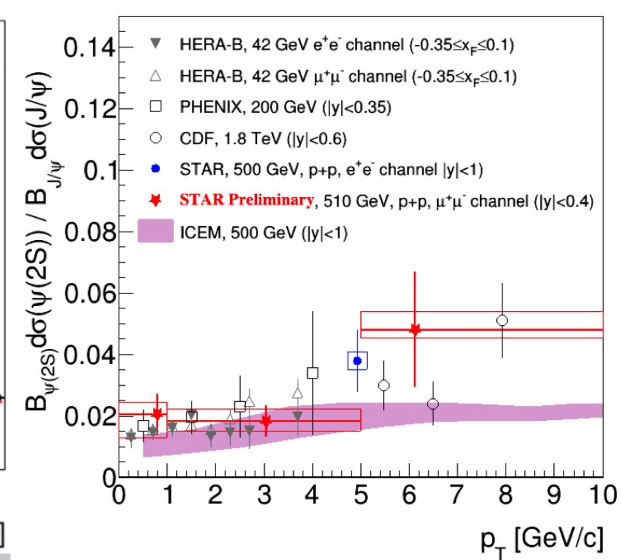
J/ψ Cross-Section in p+p Collisions @ 500 GeV

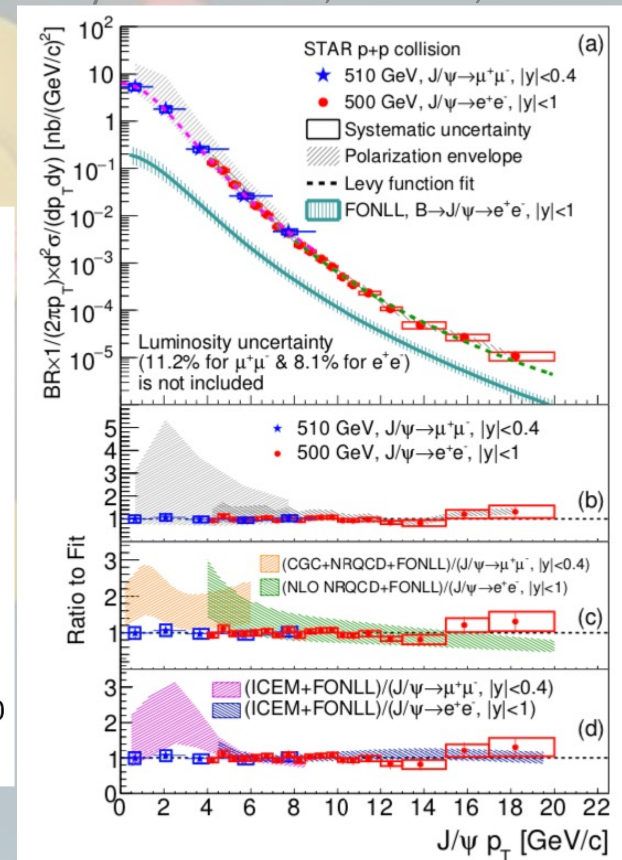
- Consistent with CGC+NRQCD, NLO NRQCD calculations and ICEM (prompt J/ψ)
- ψ(2S) to J/ψ ratio follows the world trend (adding 2017 data)

Phys. Rev. D 100, 052009, 2019

$J/\psi \rightarrow \mu^+\mu^-$

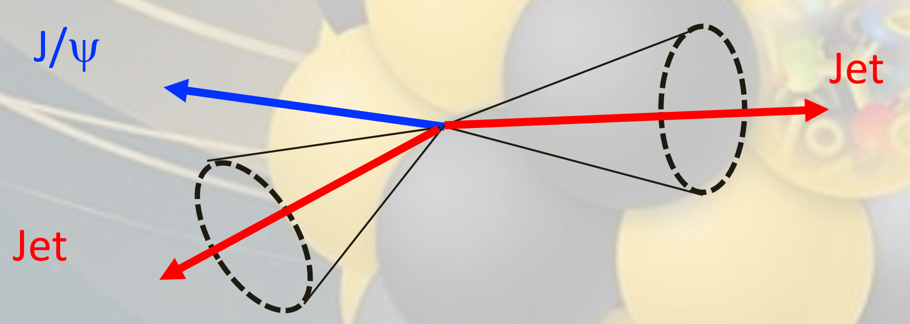


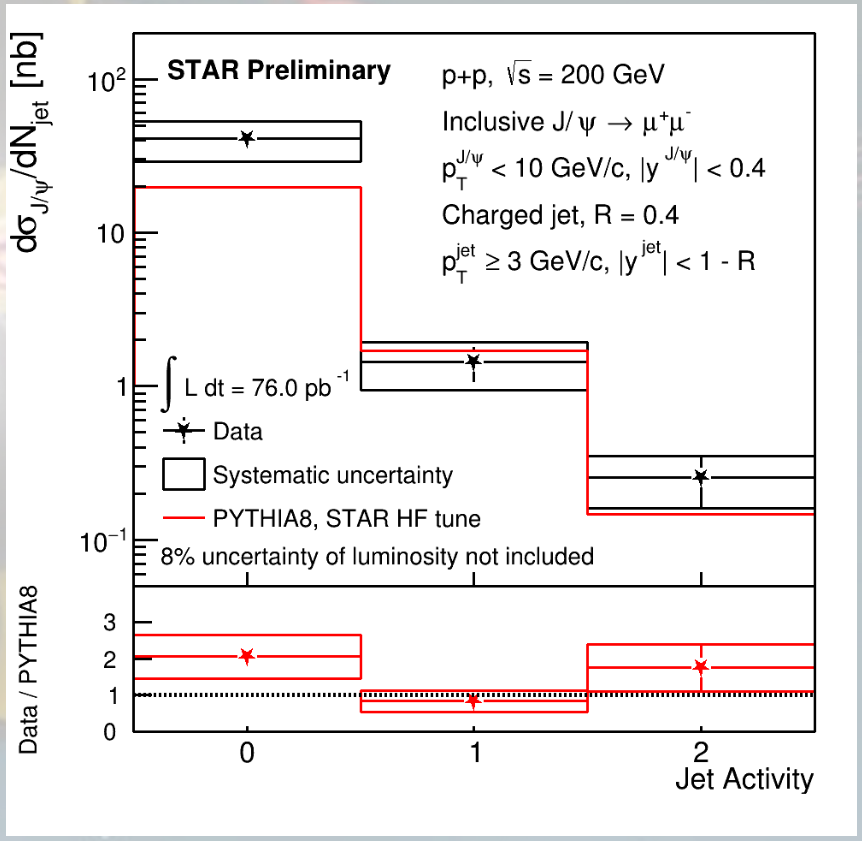




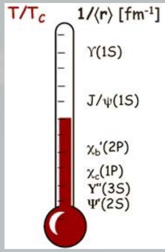
J/ψ Production with jet activity

- Study J/ψ production associated with jet activity could provide theorist a new variable to distinguish different models and have a better understanding of quarkonium production



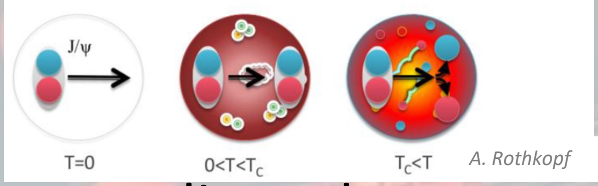


Study QGP via Quarkonium

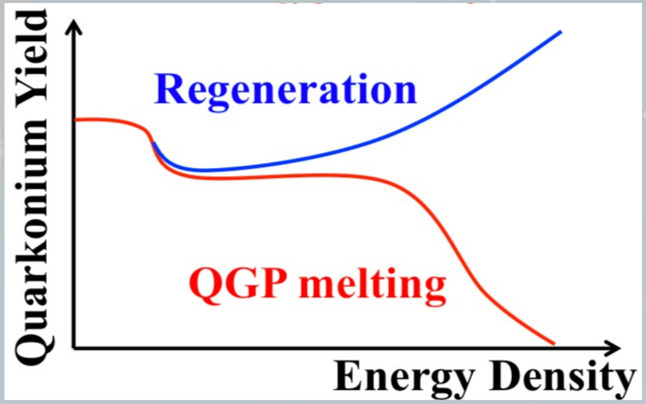


EPJ C61 (2009) 705

- Quarkonium suppression is one of smoking guns of the QGP formation (by T. Matsui and H. Satz PLB 178 (1986) 416)
  - ➔ **Color-screening**: Quarkonium dissociates in the medium
- **Sequential melting**: different states dissociate at different temperatures

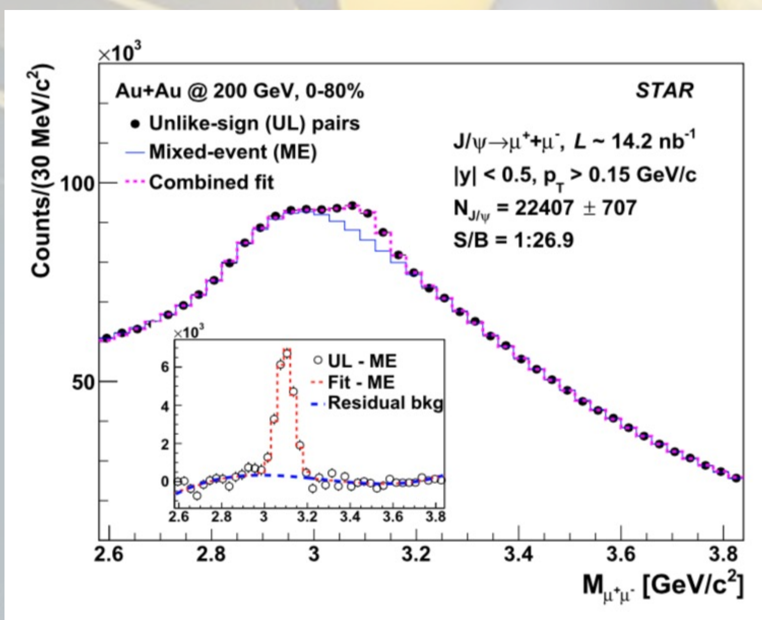


- Interpretation of quarkonium suppression is complicated
  - ***Hot nuclear matter effects***
    - Dissociation
    - Regeneration from deconfined quarks
    - Medium-induced energy loss
    - Formation time effect
  - ***Cold nuclear matter effects***
    - nPDF, nuclear absorption, co-mover et.al
  - ***Feed-down from excited charmonium states and B-hadrons***

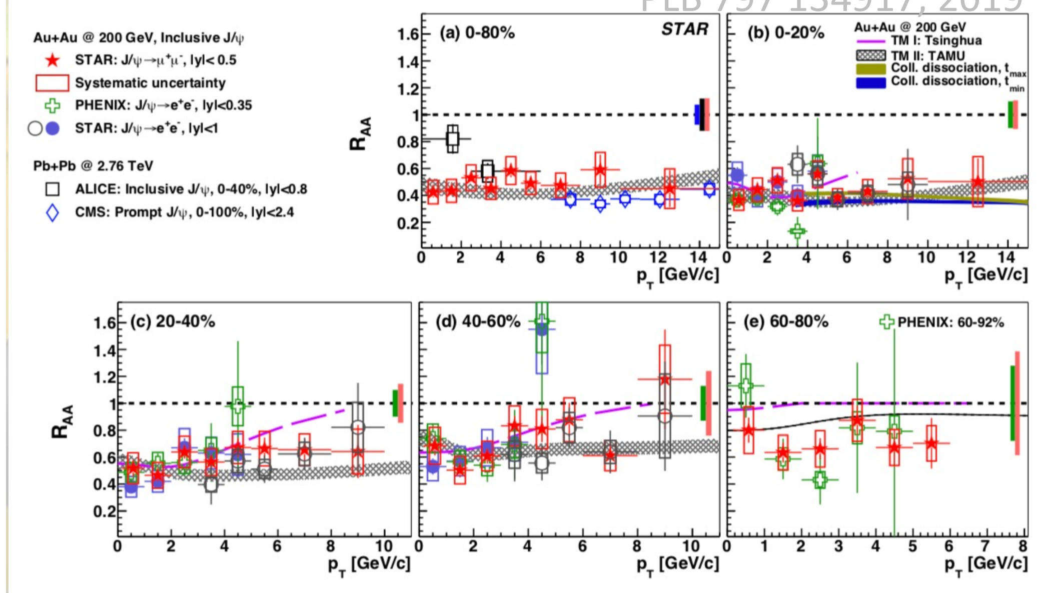


J/ψ R_{AA} vs. p_T

- No obvious p_T dependence in R_{AA} in 0 - 20% centrality bin
- Rising R_{AA} with p_T in 20 - 40% and 40 - 60% centrality bins
  - Rising trend at high p_T could be due to formation time effects, B-hadron feed-down
- Suppression at low p_T: dissociation, Cold Nuclear Matter (CNM) effect, regeneration
- Strong suppression at high p_T in central collisions is a clear sign of dissociation since regeneration contribution and CNM effects are small



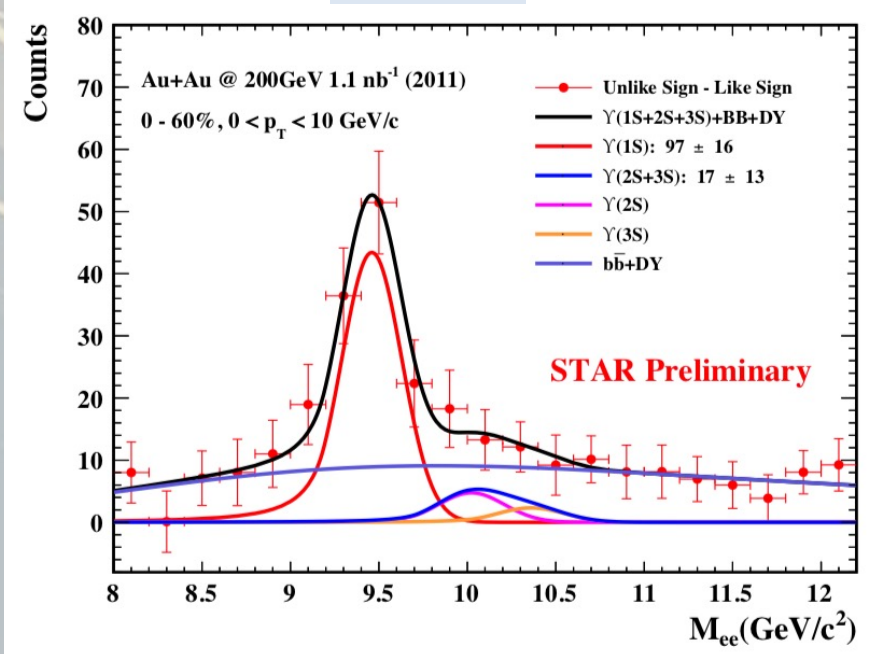
PLB 797 134917, 2019



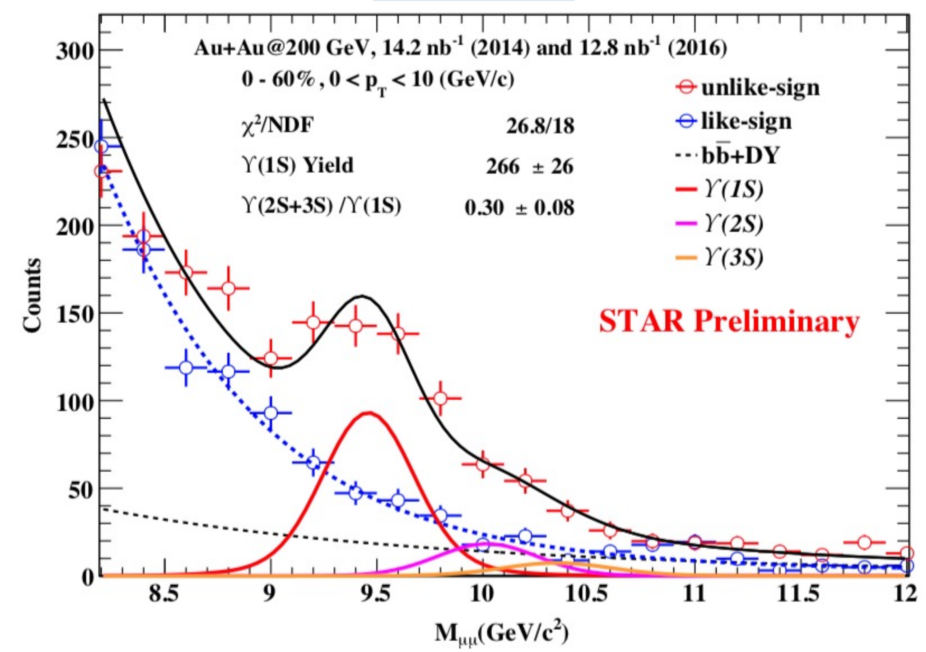
Υ in Au+Au Collisions @ 200 GeV

- Clear Υ(1S, 2S, 3S) signals in Au+Au collisions
  - ➔ First Υ(1S, 2S, 3S) → $\mu^+\mu^-$ measurement at STAR

$\Upsilon \rightarrow e^+e^-$

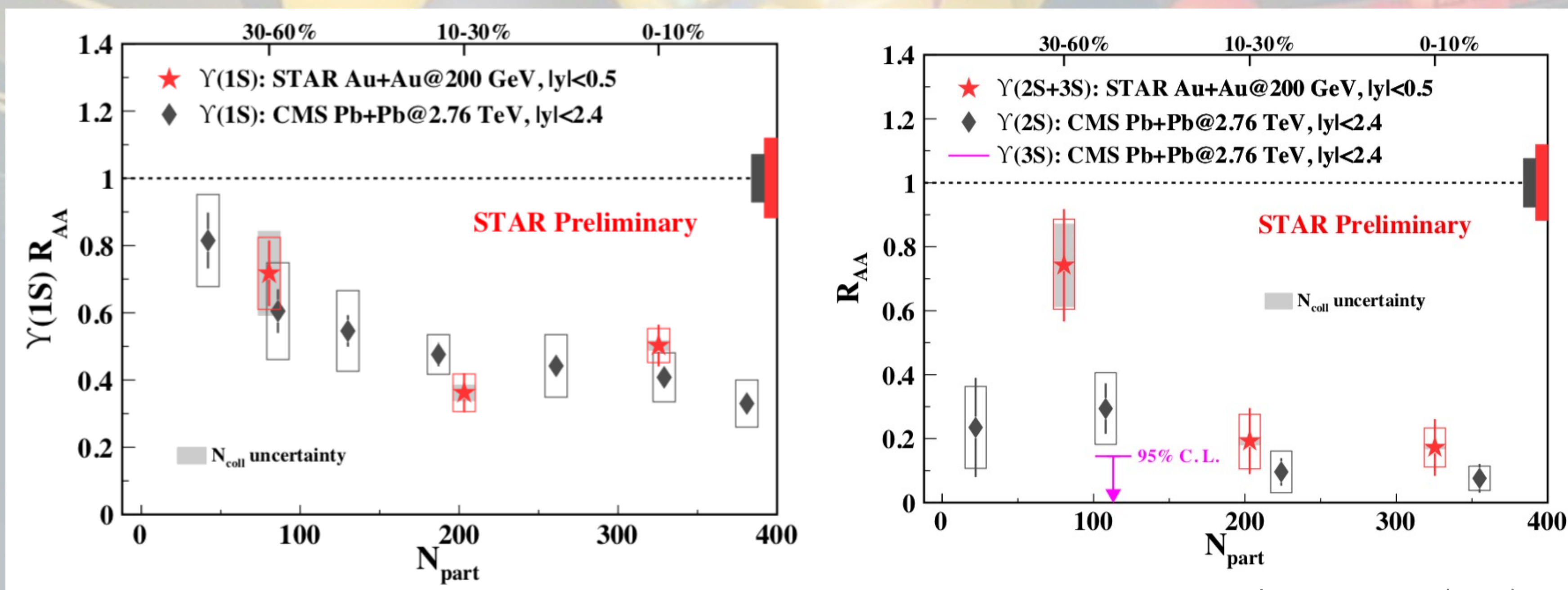


$\Upsilon \rightarrow \mu^+\mu^-$



Υ R_{AA} vs. N_{part}

- Suppression increasing with centrality
- Υ(2S+3S) is more suppressed than Υ(1S), in central collisions
  - ➔ **Sequential melting**
- RHIC vs. LHC:
  - Υ(1S): similar suppression as the CMS measurement
  - Υ(2S+3S): hint of less suppression at RHIC than at LHC



CMS: Phys. Lett. B 770 (2017) 357–379

Summary of Physics Opportunities

- Heavy quarkonium can provide us lots of insights of QCD
- Lots of topics are available related to heavy quarkonium and jet

- **The current STAR Hard Probe (Heavy Flavor + Jet) Convenor**