Automatic Module assembly development for ATLAS High-Granularity Time Detector

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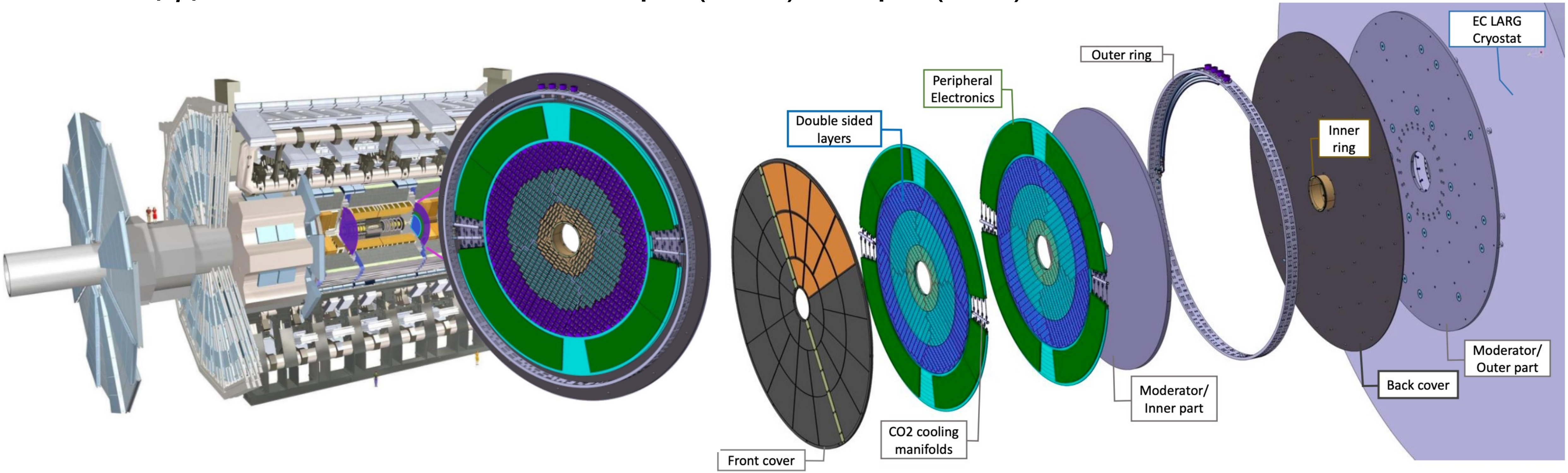
Outline

- Overview of the HGTD module
- The gantry system in IHEP
- Automatic assembly workflow
- Module status, WB & production estimation
- Summary

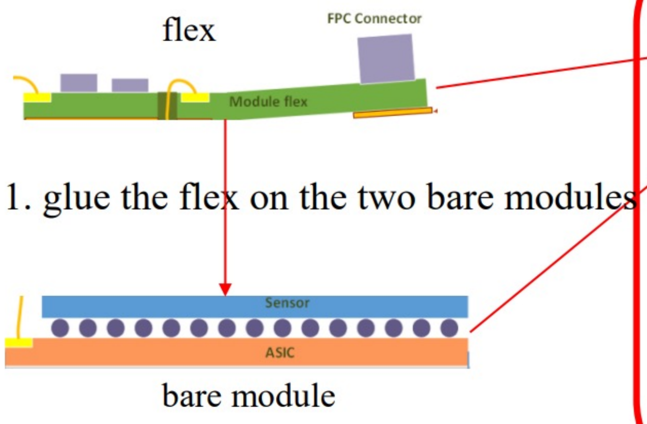
High-Granularity Time Detector

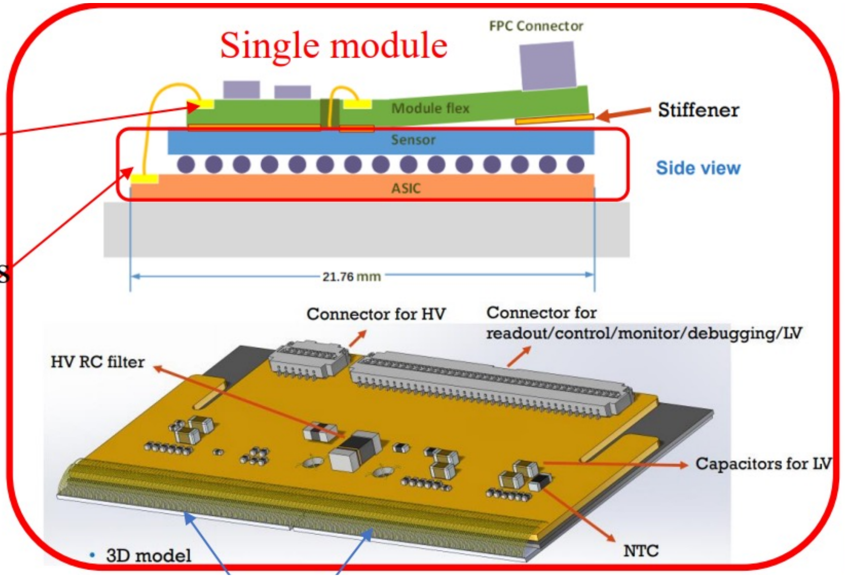
- The High-Granularity Time Detector (HGTD) is to deal with the high pile-up environment for the future HL-LHC, can provide time resolution of ~30-50 ps/track.
- HGTD end-cap has two instrumented double-sided layers mounted on cooling disk.
- Position: $\pm 3.5m$, Active area: $6.4m^2$
- $2.4 < |\eta| < 4$, time resolution: 35 ps (start), 70 ps (end)

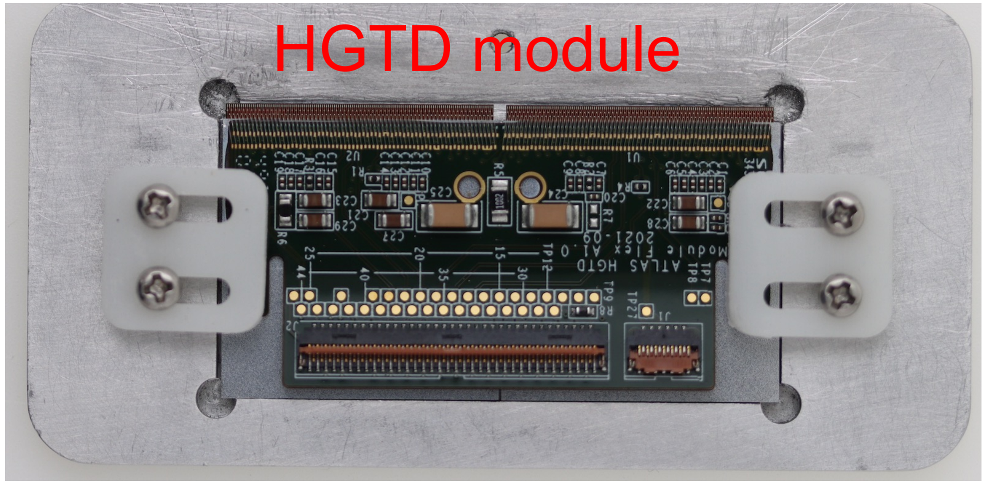


High-Granularity Time Detector

- The HGTD module has one flexible PCB (flex) and two hybrid.
  - The hybrid has one LGAD sensor bump-bonded to an ASIC.
  - Glue the flex and hybrids together.
  - Wire-bonding between flex and ASIC pads.
- 8032 HGTD modules will be assembled and loaded on the support at different sites: IHEP, USTC, LPNHE, IFAE…
- Over 1/3 of the modules (>3000) will be assembled at IHEP.

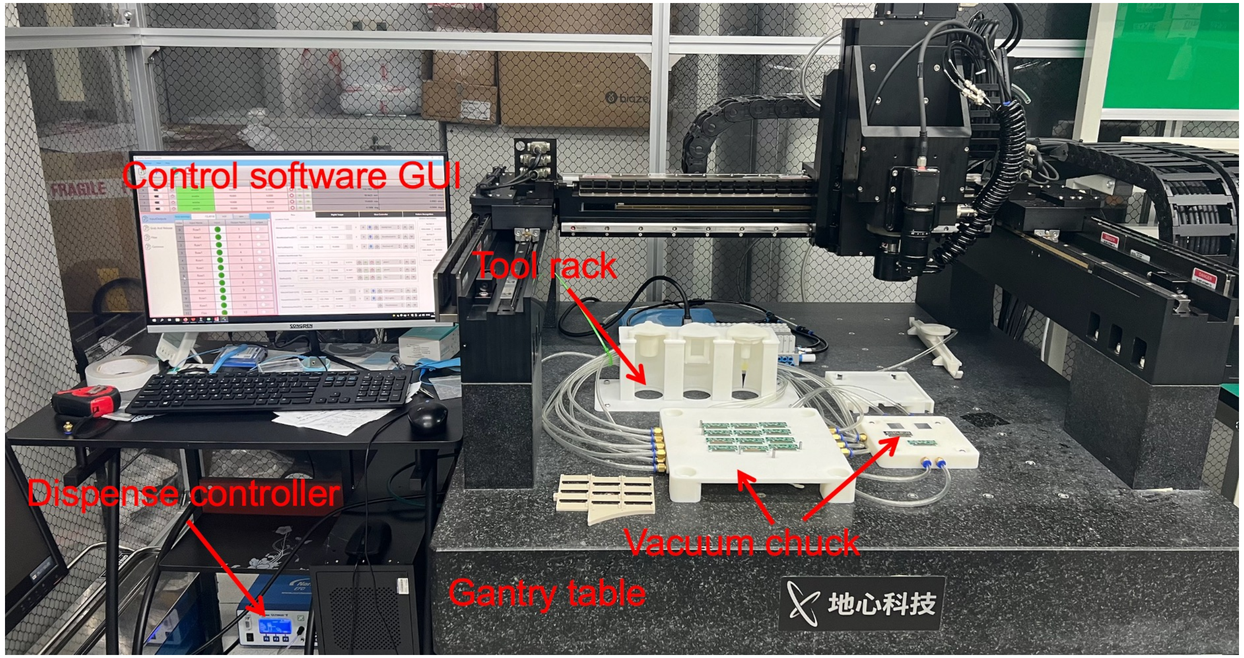




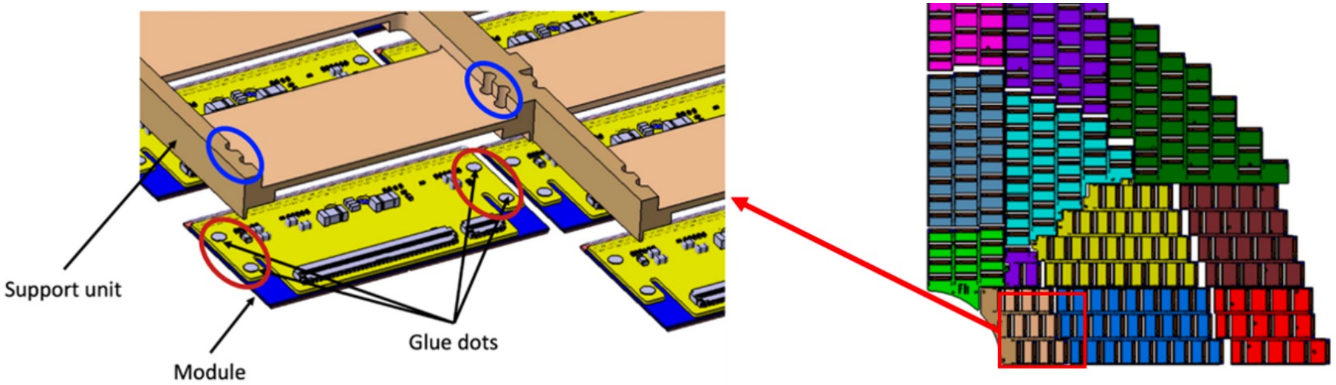


HGTD module assembly at IHEP

- ~ 3000 modules will be assembled and loaded at IHEP
- To assemble such a large number of HGTD modules with high precision. A robotic gantry system is set at IHEP
  - High-precision pick-and-place;
    - Repositioning resolution: ~1 μm;
  - Dispensing control system;
  - Vision system with camera;
  - Customized tooling;
  - Control software:
    Open source C++ & qml with GUI



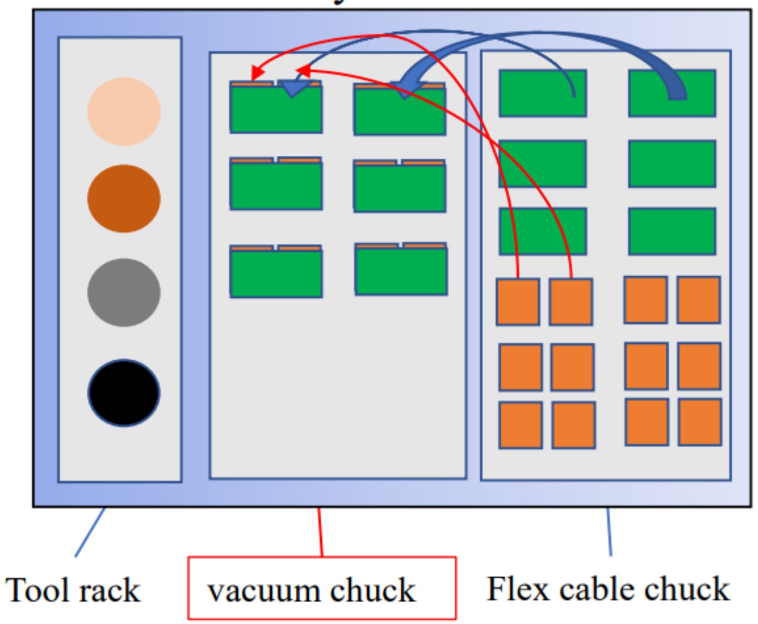
- It will also load the module on the support units.

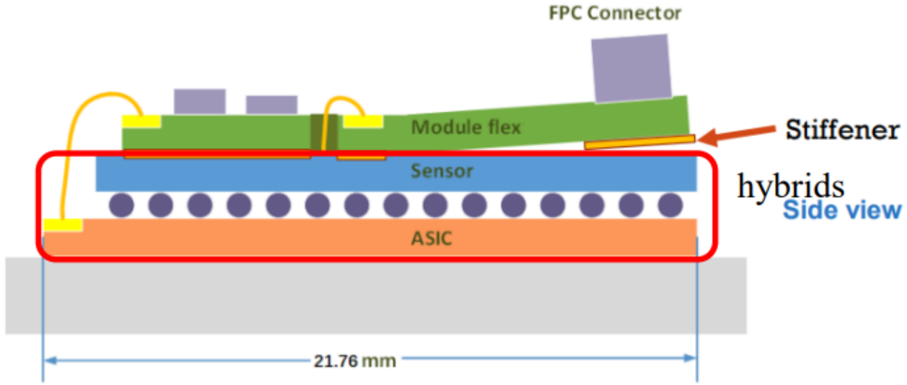


Assembly procedure steps

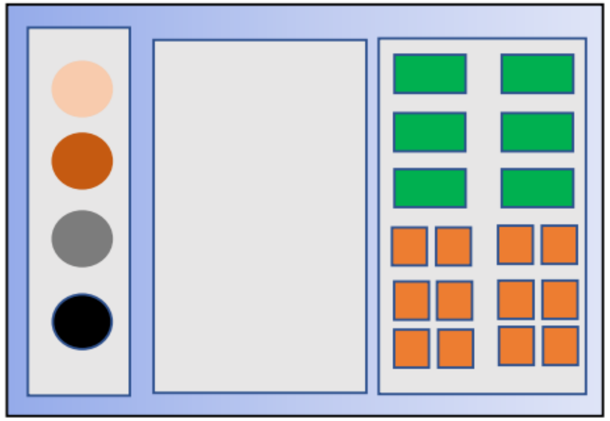
- To glue the flex on the hybrids with the gantry:

Gantry table

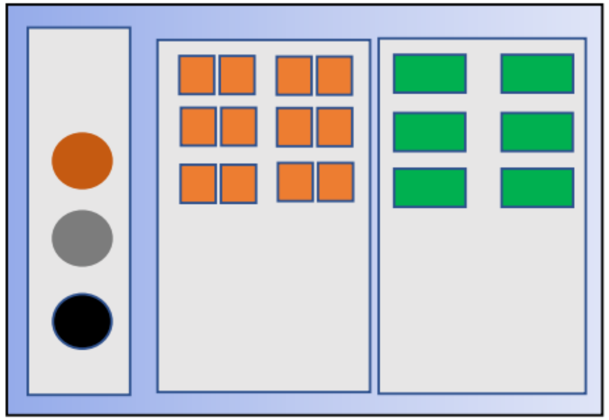




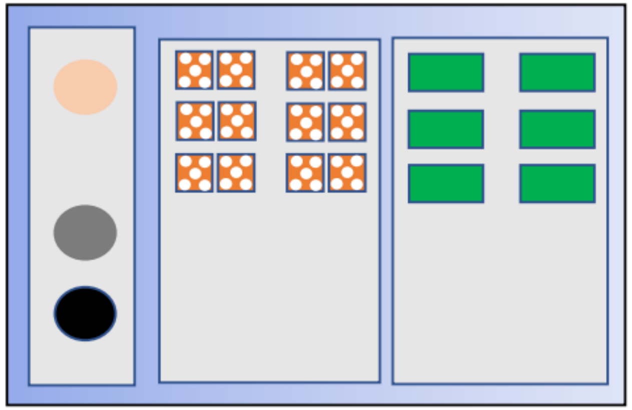
Prepare the tools, flex and hybrids



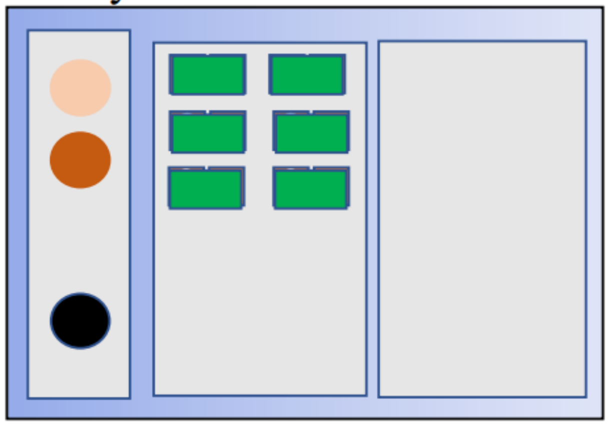
Pick-and-place the hybrids to the vacuum chuck



Dispense glue on the hybrids



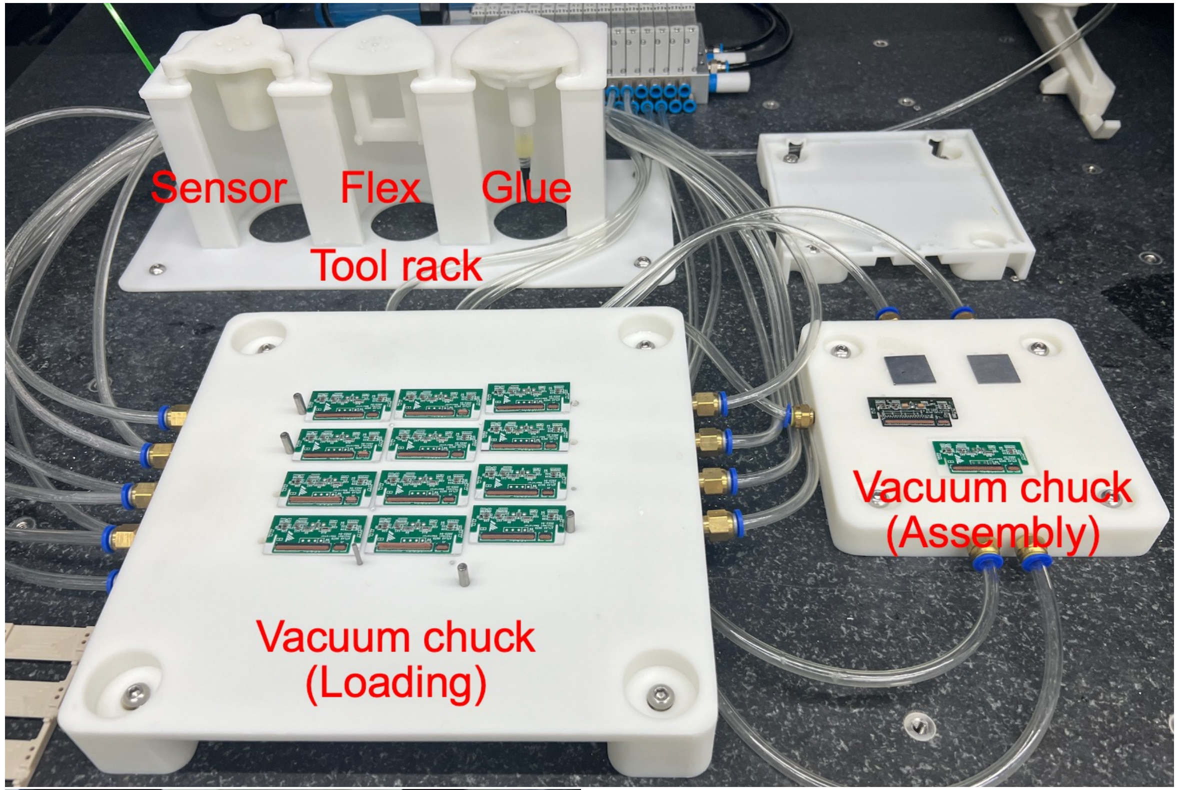
Pick the flex and place it on the hybrids

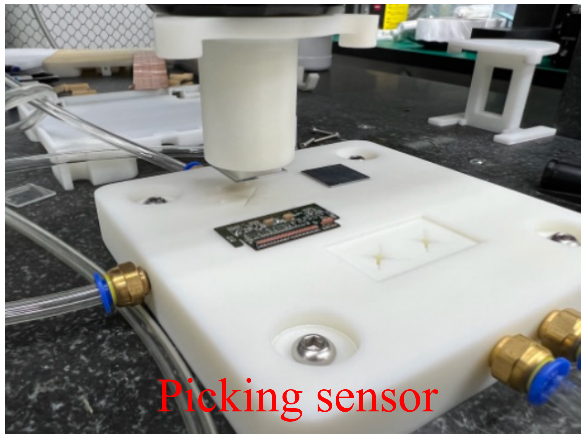


Customized tooling

- All tooling is made by 3D-printing.
  - Tool rack
  - Sensor tool to pick up the hybrid/ASIC/…
  - Flex tool to pick up the flex;
  - Gluing tool to dispense glue;
  - Vacuum chuck to hold modules/hybrids/flex/…

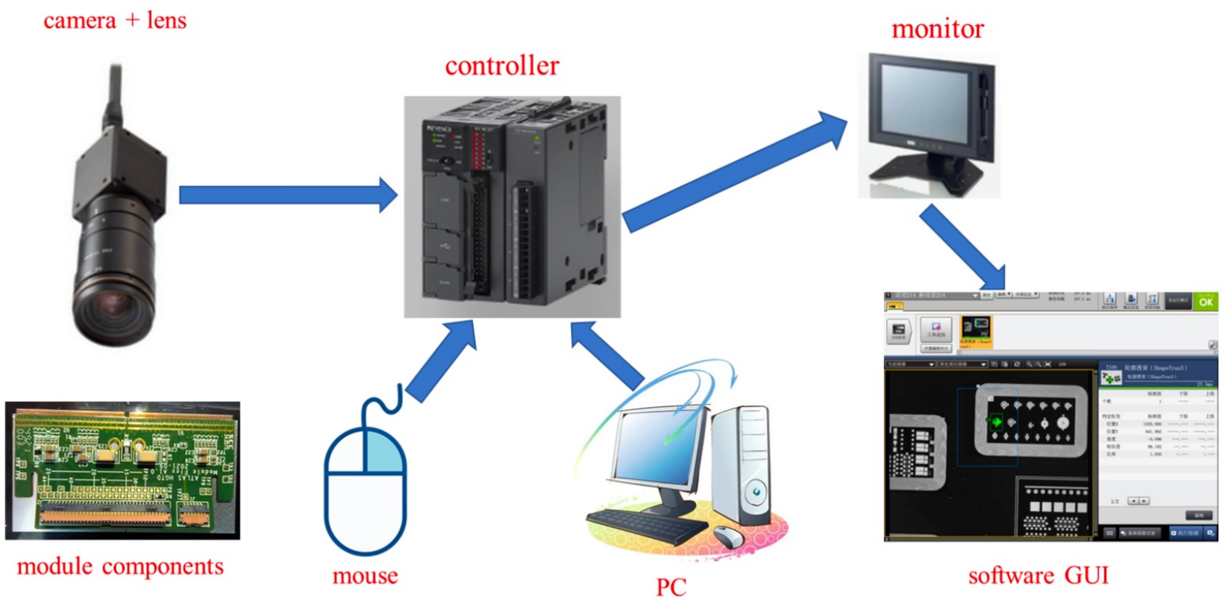
- Use the vacuum from the gantry to pick up the sensor/flex/gluing tool and their target.

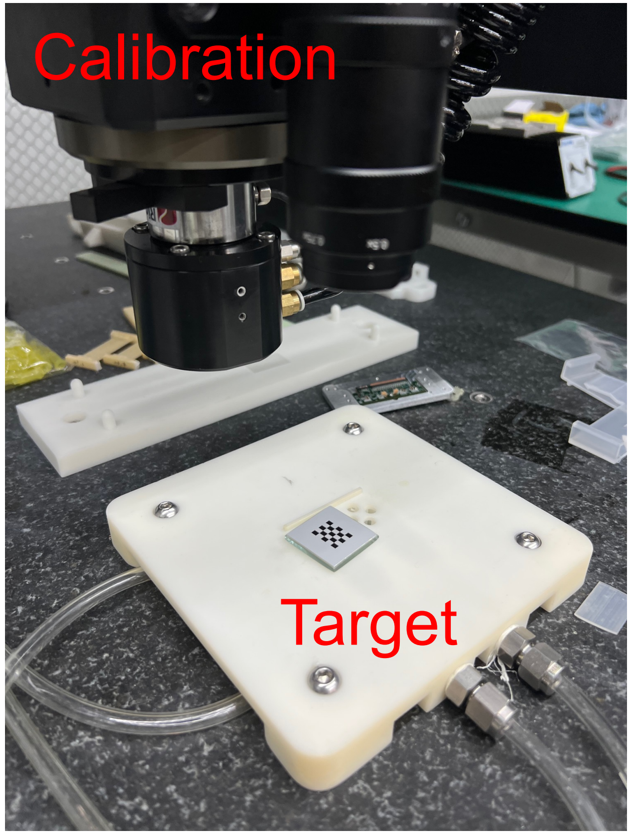




Vision system

- Use a camera to locate all the components for a module.
- The control software is integrated with Keyence vision system.
- Position in the picture from the camera → Position in the gantry system
  - A calibration target is set to calibrate the camera.
  - Take several pictures for calibration.
  - 1 pixel in picture ≈ 6.7 μm at current magnification.

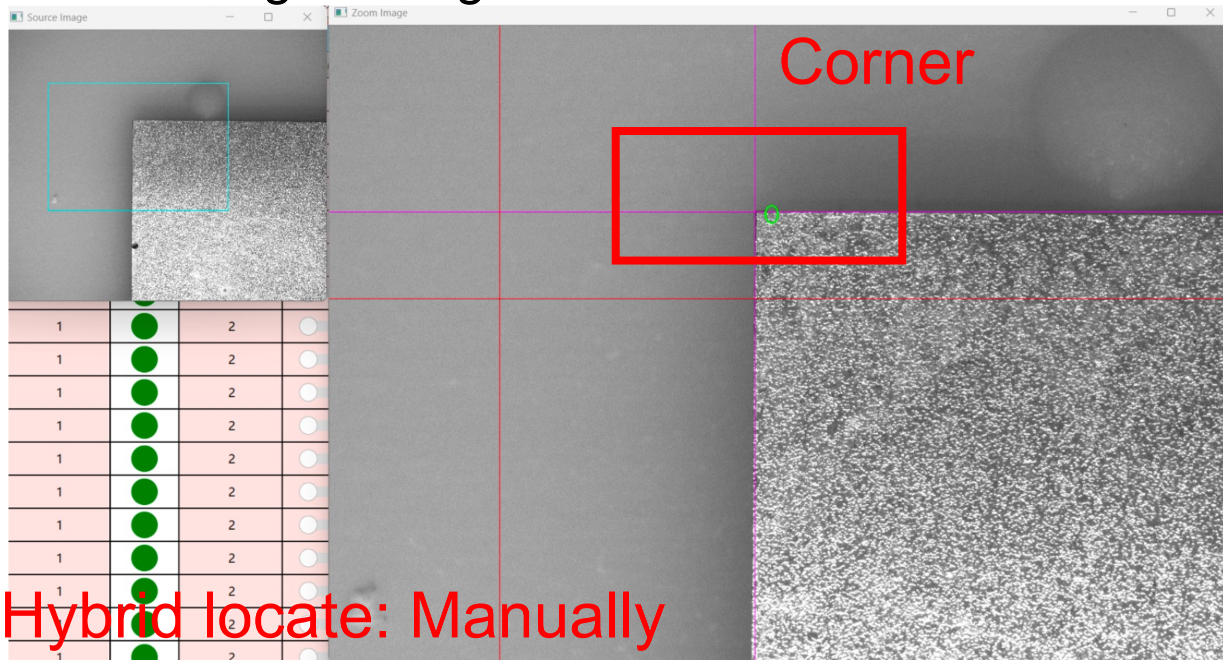


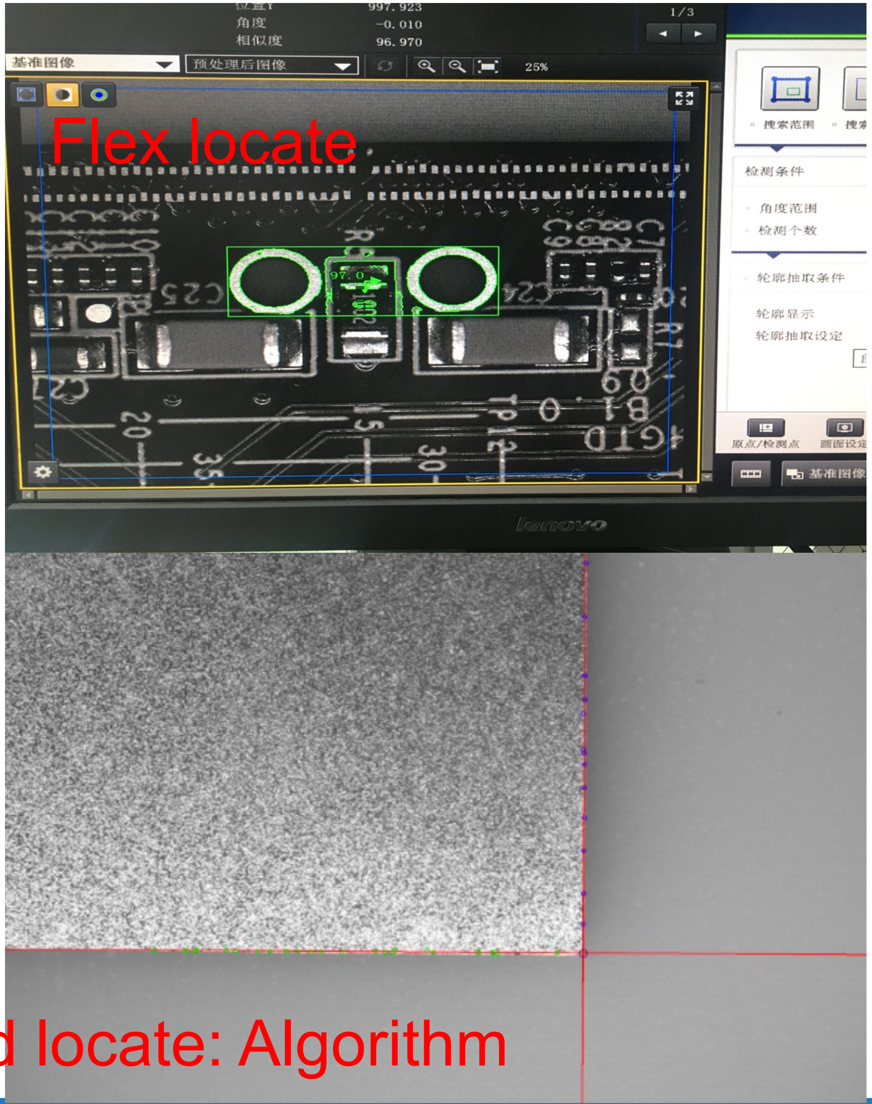


Object localization

- The gantry has to get the position of all components for a module with the camera.
- The control software provides two ways for localization
  1. Manually select the feature with mouse, precision: ~2 px.
  2. Use algorithm to detect the feature, precision: ~4 px.

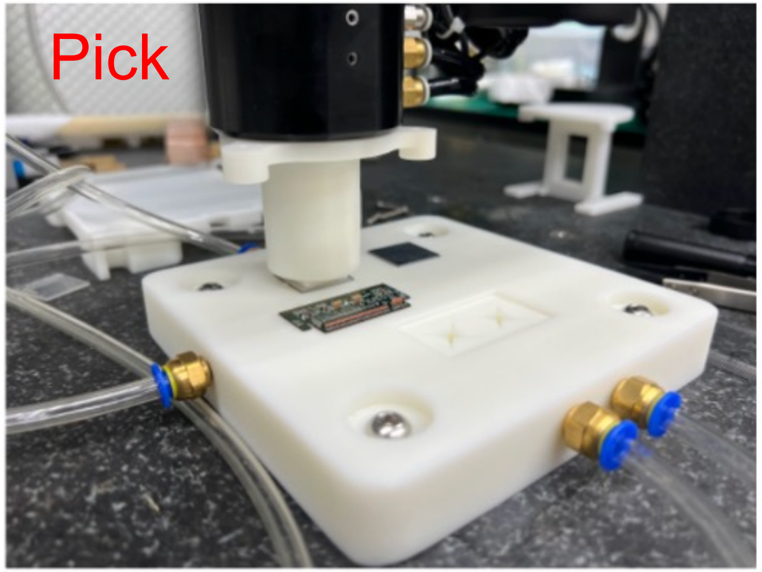
  At module level, 4 px deviation is likely to cause 0.5% rotation.
- Feature to locate the components:
  - Hybrids/ASICs/Glass: Four corners
  - Flex: High Voltage holes

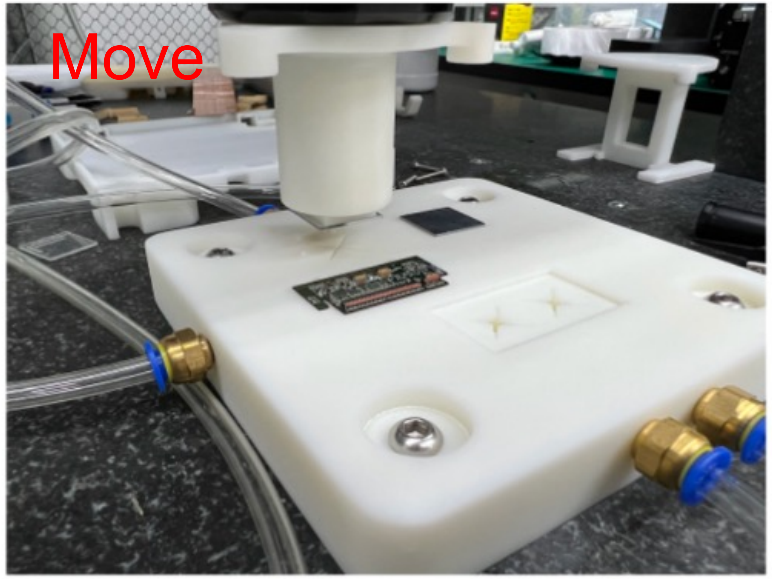




Pick-and-place procedure

- The system can work under different situation.
  - Dummy glass module, digital module with ASICs, full module with hybrids…
- Vision system is to locate the components at two dimension;
- Pressure force sensor is to locate the components at height dimension.
  - Positive pressure force → the tooling touches the target
- Use software to pick, place and release the tooling and target (hybrids, ASICs…)

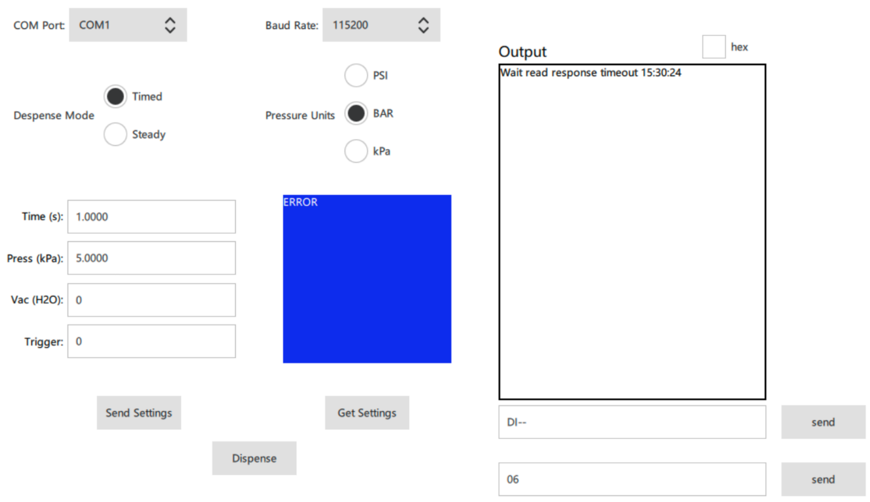




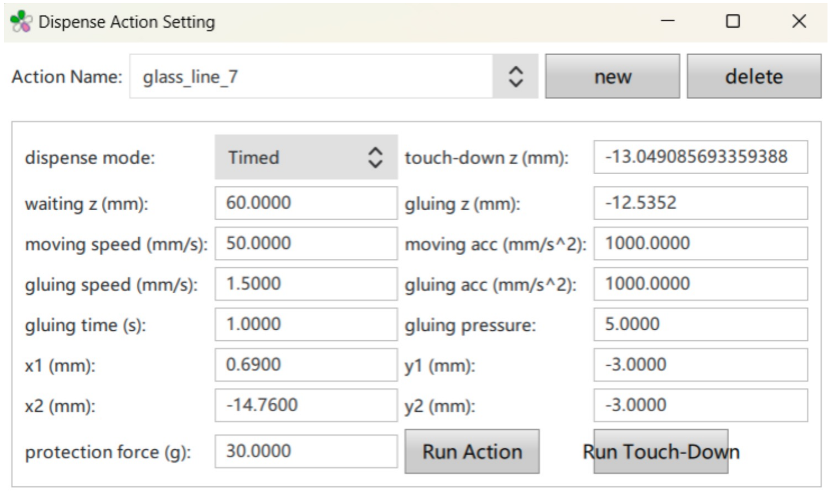
Automatic glue dispensing

- The gantry allows different glue patterns.
- Use software to set the patterns and dispense the pattern with program.

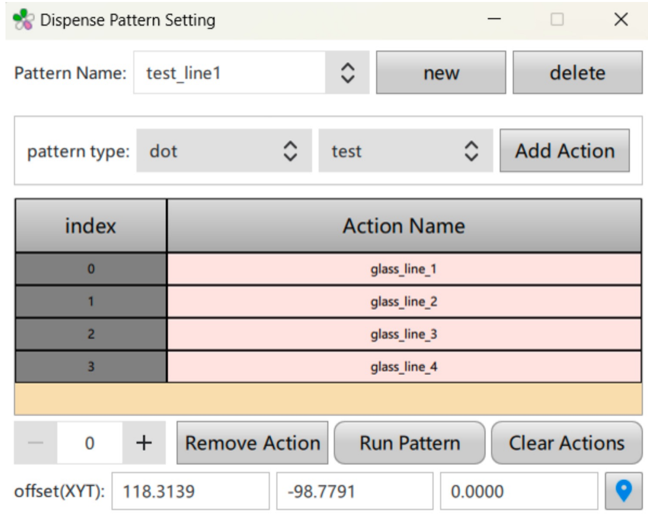
Dispensing controller



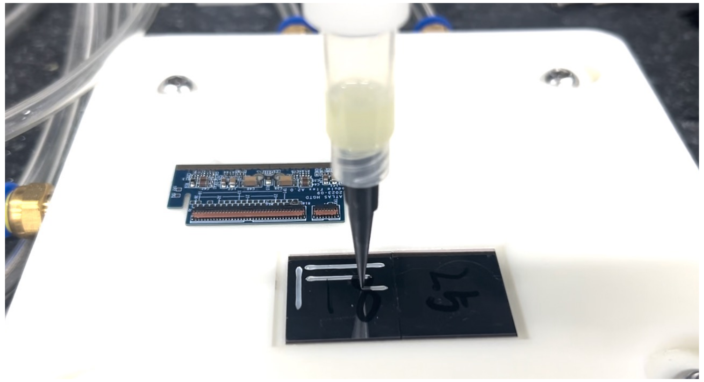
Dispense step



Dispense pattern

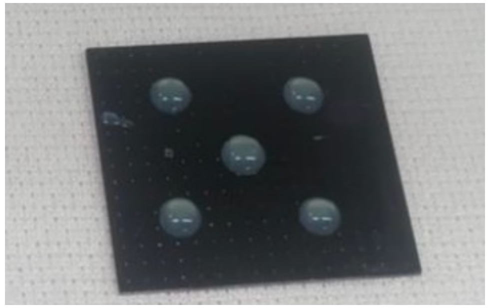


Gluing



Lines

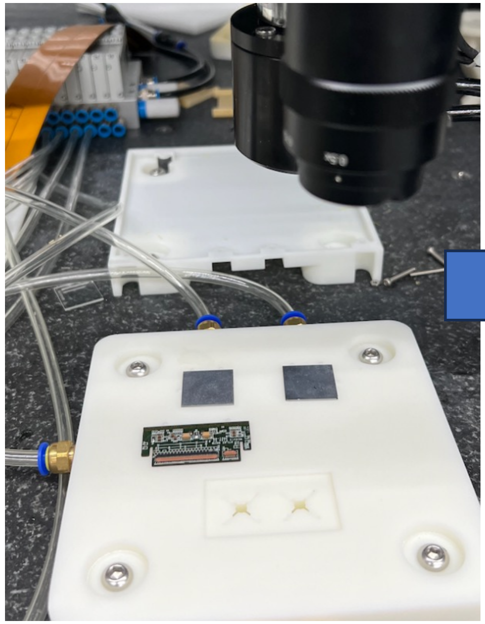
Dots

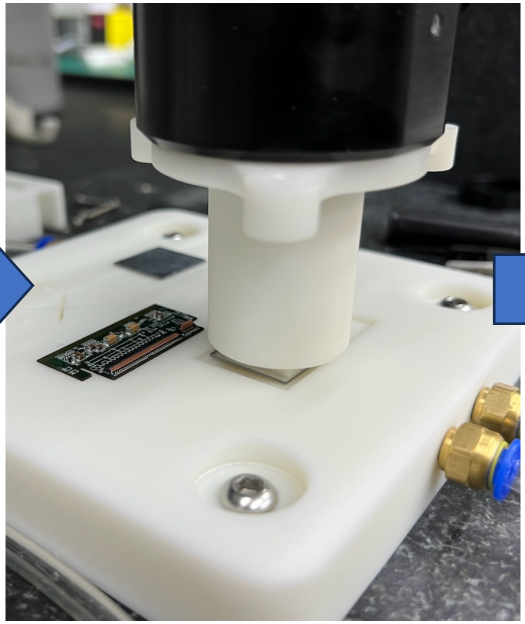


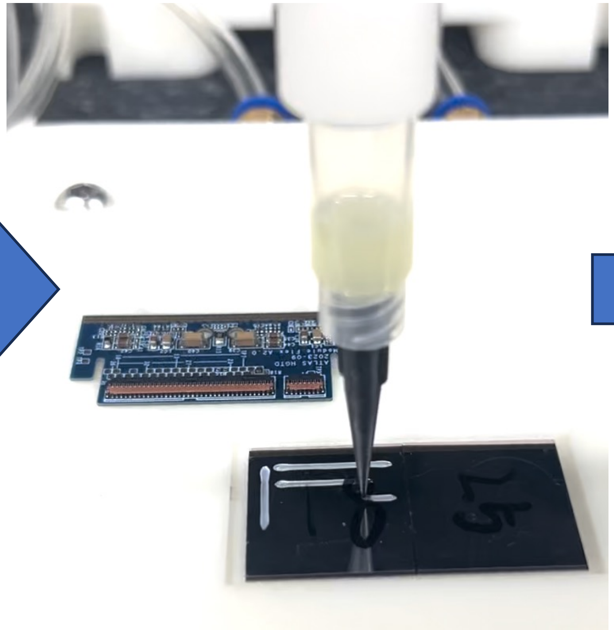
Assembly workflow for single module

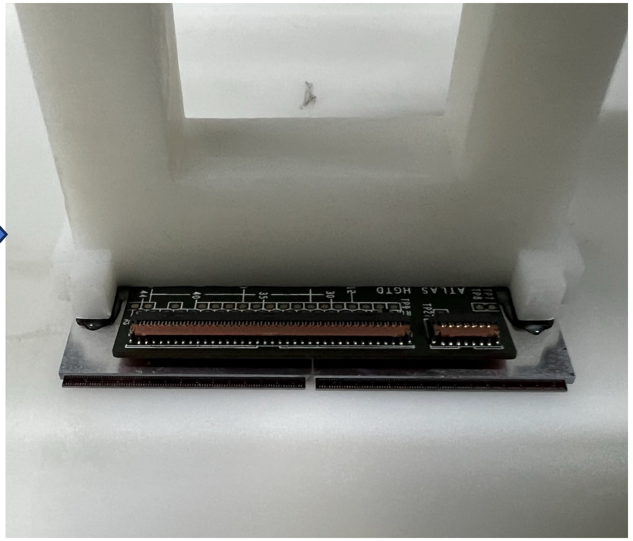
- The total assembly workflow for the gantry system is listed.
  1. Locate the flex, hybrids: ~ 5 mins
  2. Pick the hybrids and place them on the vacuum chuck: ~ 3 mins
  3. Dispensing glue on the hybrids: ~ 6 mins
  4. Place the flex on the hybrids : ~3 mins
  5. Remain the flex tool and wait until the glue gets fixture: > 6 hours

~ 6 hrs & 20 mins/module







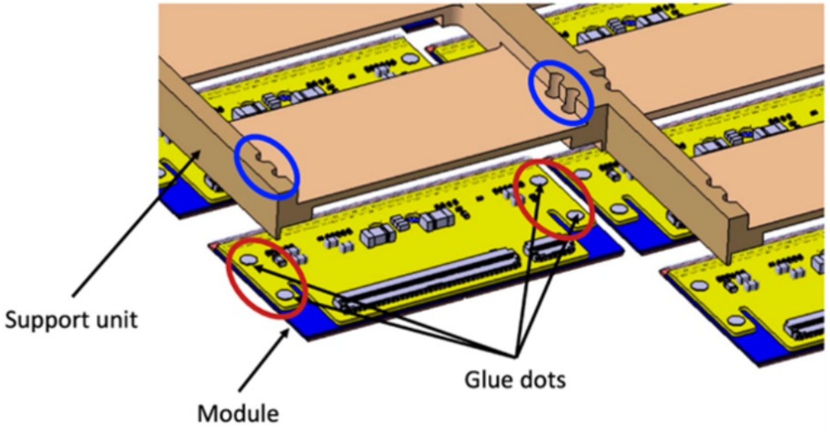


Loading the detector unit

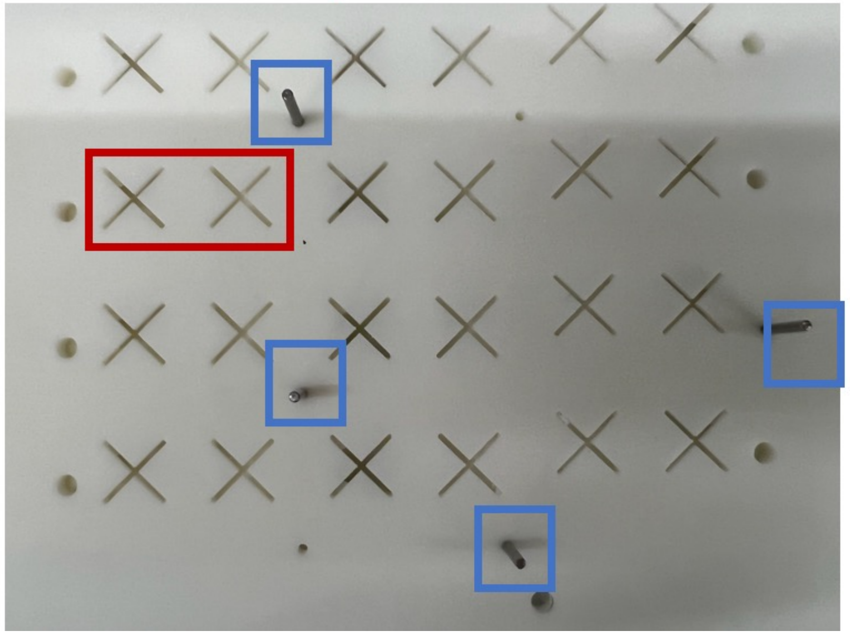
- The gantry will also help to load the modules on the detector units.
  - A new flex tool is designed to pick up the modules with wire-bonding.
  - Put the modules on the vacuum chuck into the array and fix with vacuum.
  - Dispense glue on the wings of the flex.
  - Use pins to locate the support unit, put the support unit on the module array.

☐ Still work on this task, tooling is ready, the software is in development.

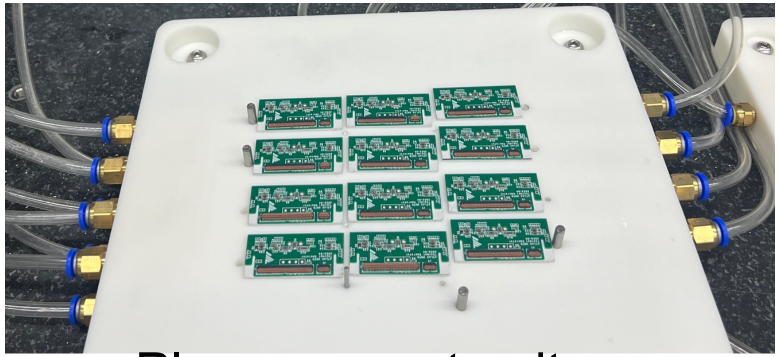
Module Loading



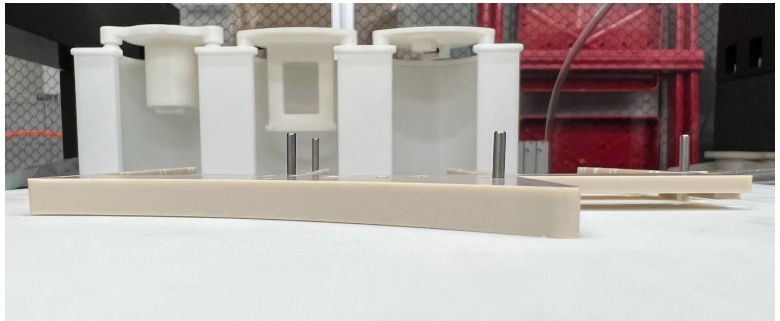
Pins and places for modules



Module array



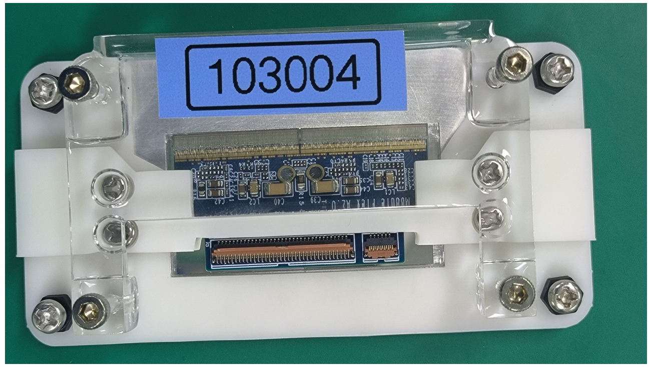
Place support unit

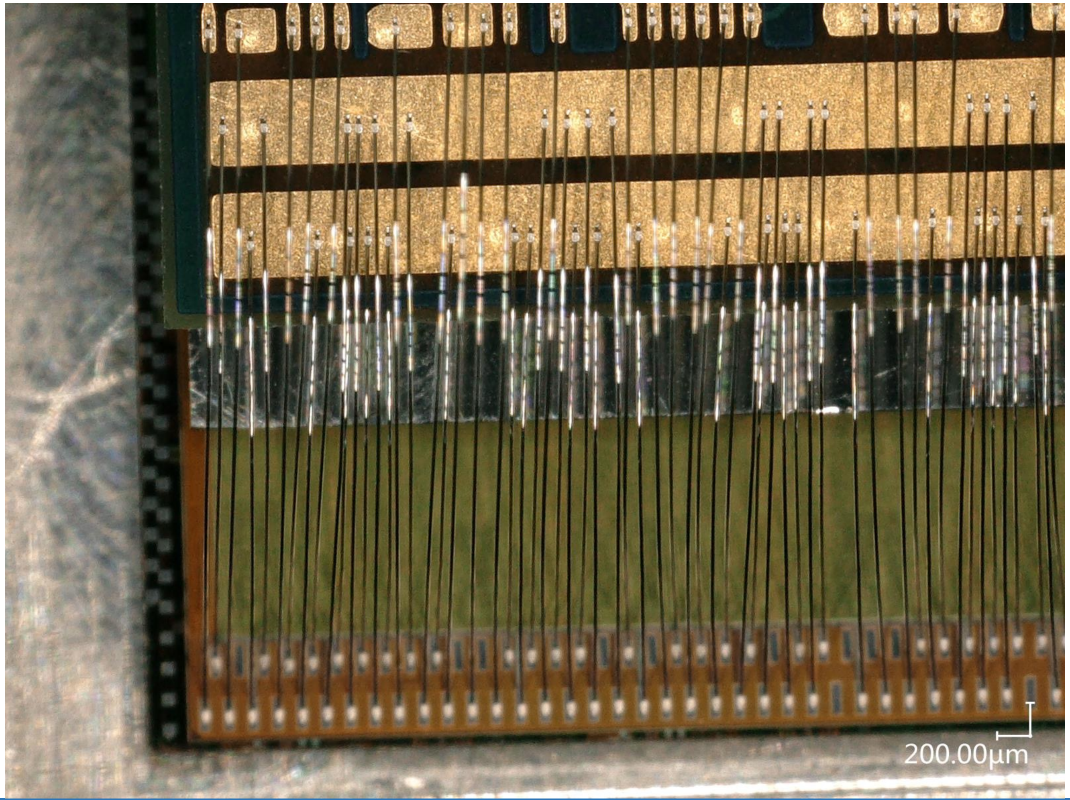


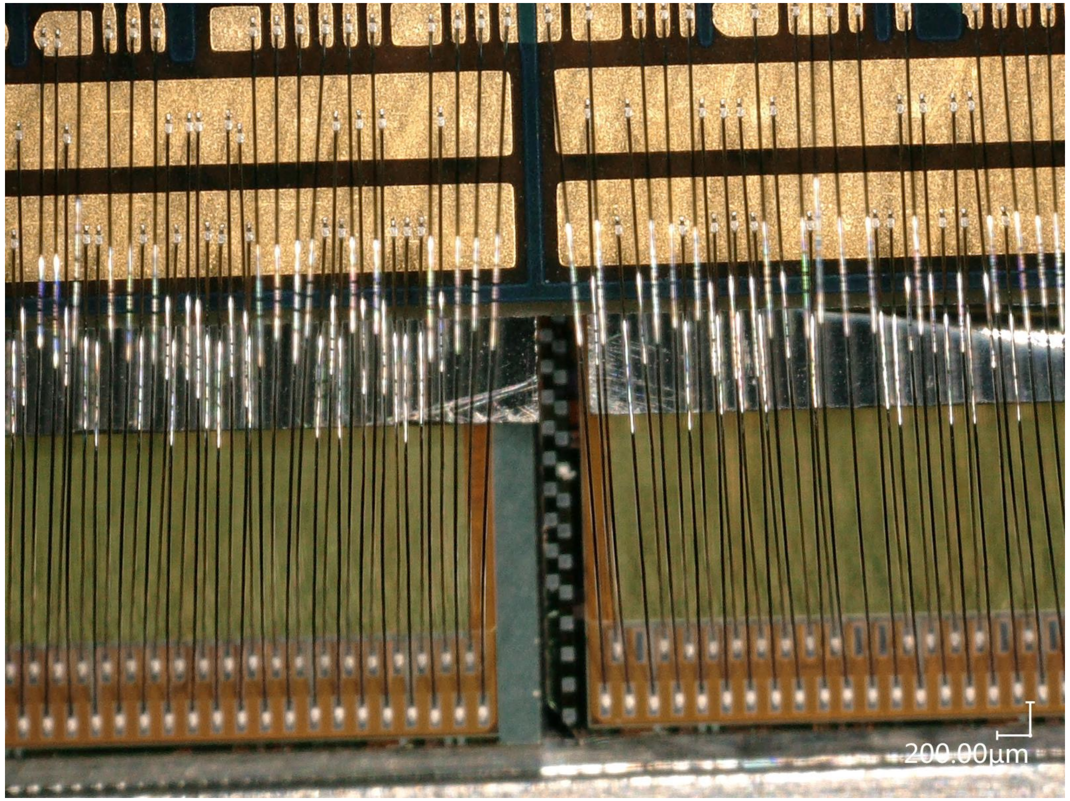
Module status & WB

- 4 full modules & 2 digital modules were assembled currently.
- Latest hybrids: ALTIROC3
- Modules were wire-bonded at IHEP.
  - Pads: 2 rows on ASICs -> 3 rows on flex

✓About 3 pads deviation each side, but succeed in wire-bonding

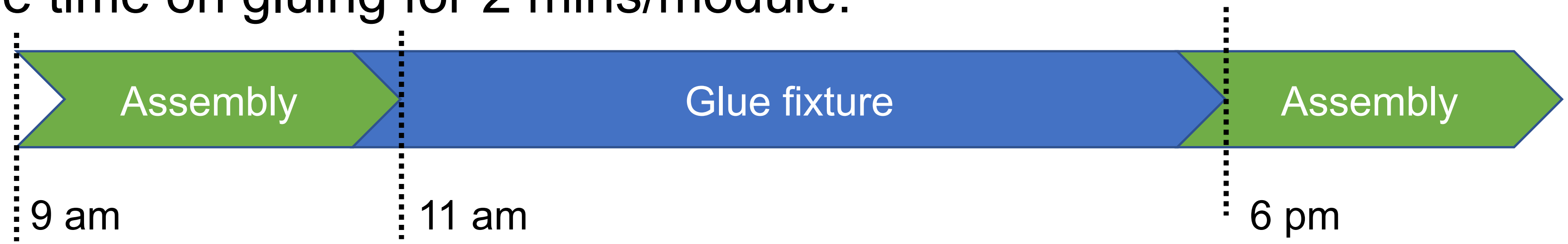






Production rate estimation

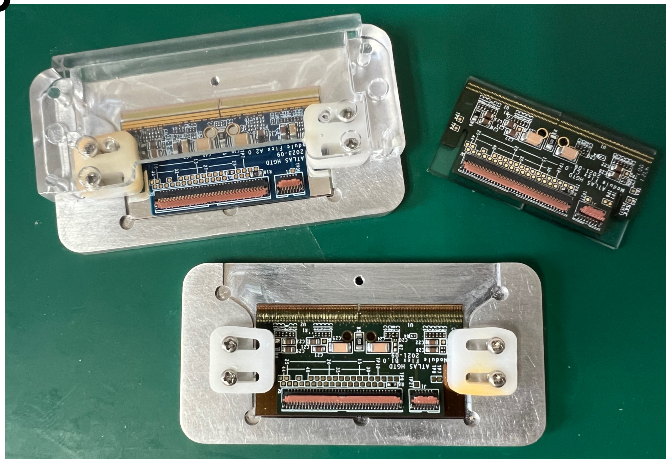
- The final target is to assemble 3000 modules for the HGTD module production.
- Current production rate: ~ 20 mins/module
- Target: 14 modules/day, 3 detector unit (modules on the support) /week
- Current plan:
  - Assembly 7 modules once.
    - Assemble twice a day, no much time wasted on waiting the fixture.
    - Save time on gluing for 2 mins/module.



- Challenges:
  - ☐Design new flex tool & vacuum chuck for module array.
  - ☐Design route for the gantry moving.
  - ☐Stability of the gantry software.

Summary & Outlook

- The automatic module assembly system is developed at IHEP
  - ✓Customized tooling;
  - ✓Object localization with camera;
  - ✓Control software for different situation.
- The gantry succeeded assembling HGTD modules.
  - ✓Assembled the first functional full-size module.
  - Assembled different types of module with different sizes of bare modules.
- A detailed user guide is documented for reference.



- Outlook
  - ☐Develop the module loading procedure.
  - ☐Make plan for the final production.

ATLAS EXPERIMENT

ATLAS Note

ATL-COM-HGTD-2023-XXX

14th November 2023

CERN

Draft version 0.1

ATLAS HGTD module assembly in IHEP: Userguide for the Gantry system

The ATLAS Collaboration

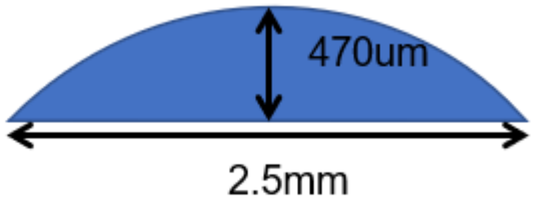
This note is the summary of the improvement and userguide for the HGTD automatic assembly procedure development at IHEP using the gantry system. The gantry system, customized tooling, and the control program is documented in this note. The procedure for the assembly and instructions for the code maintainers are documented as the userguide for the whole system. This system now can reach 30um precision for the module assembly, and the time to assemble one module is about 20 minutes. The process of multiple module assembly is still on progress. The final goal is to assemble 13 good modules per day.

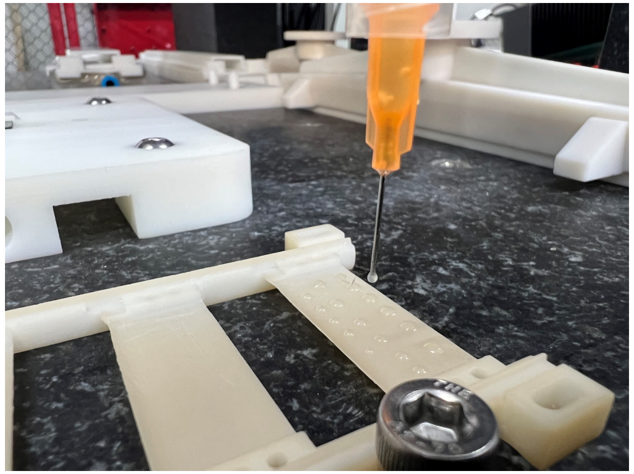
Thanks for your attendance!

Backup

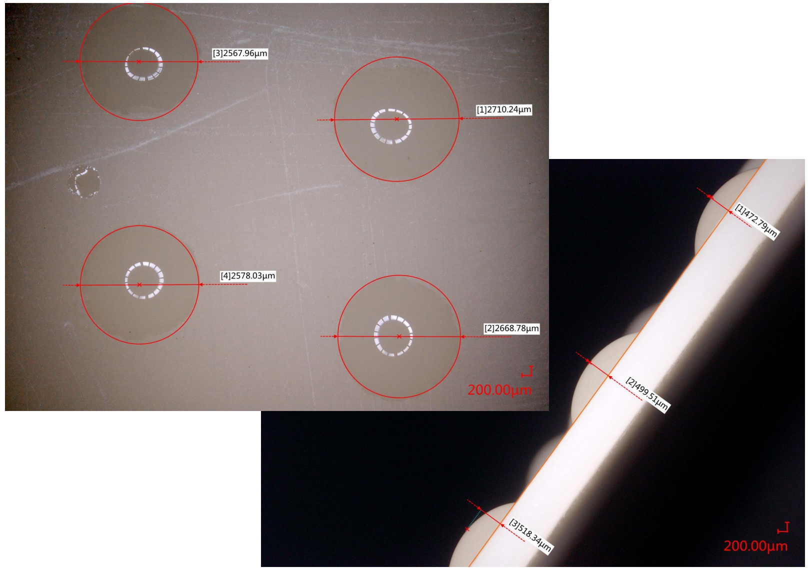
Gluing study

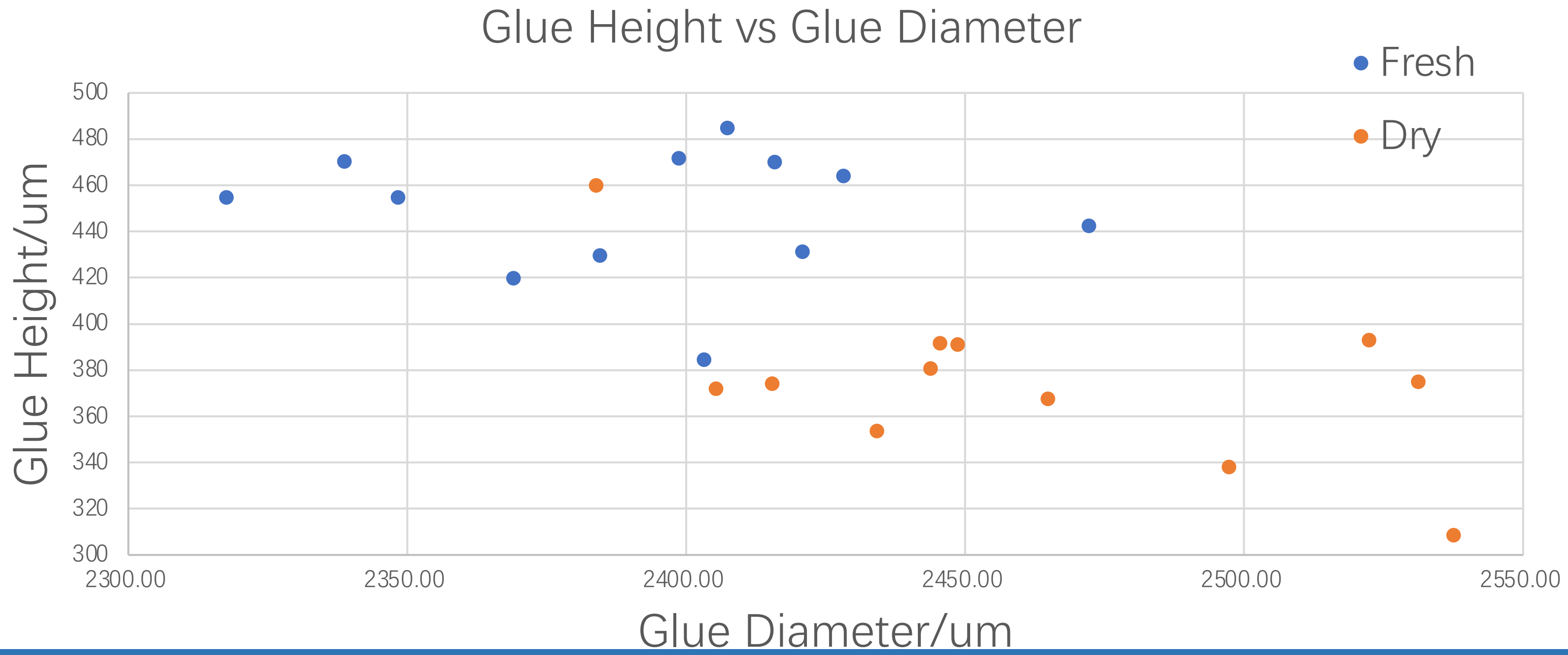
- Study on the glue height and diameter.
  - Mix the glue with specific mixing head;
  - Dispense the glue with the gantry system in IHEP;
  - Dispense the glue on resin instead of Kapton-flex or silicon.



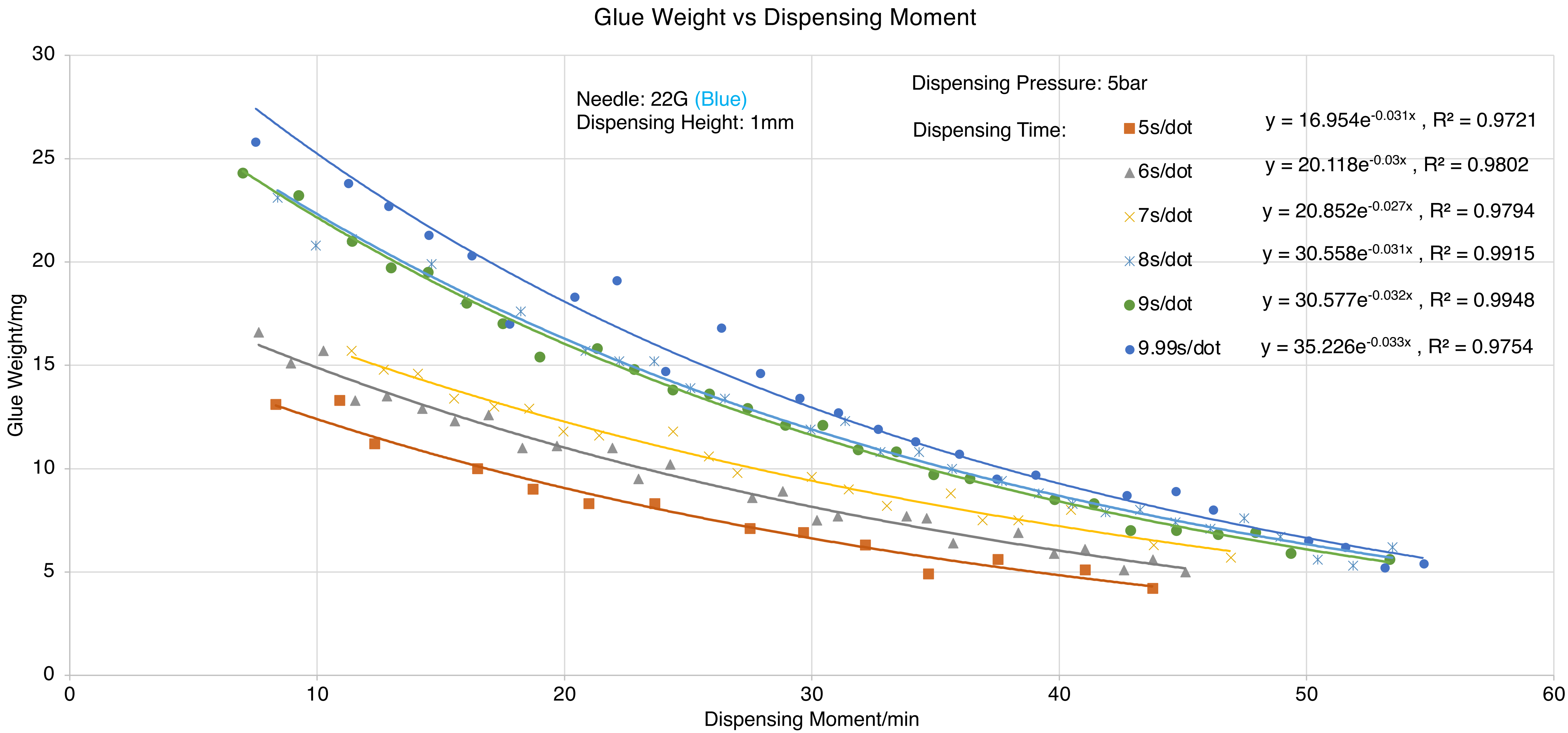


- Glue dots measurement



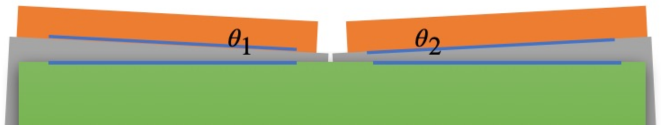


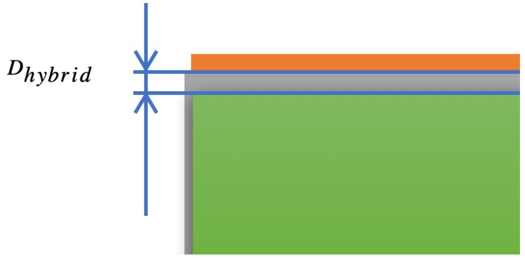
Study on glue weight and curing time



Metrology of the module

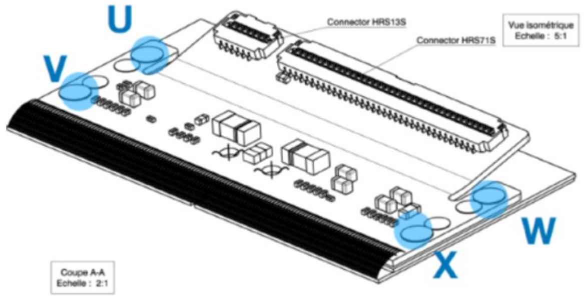
- 18 Full modules were assembled with gantry and the control software.
- The metrology of the module is to verify whether the module can be loaded on the detector unit.
- Requirements:
  - Rotation angle: $\theta_1, \theta_2 < 0.1°$
  - Gap between hybrids: 100-200μm
  - Distance between hybrid and flex: $D_{hybrid} = 194μm$
  - Glue height: 50±30μm, and module thickness: 1.75mm





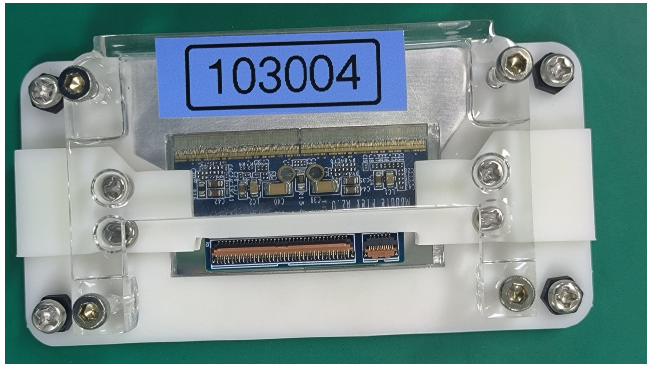
	Glue[mg]	Weight[g]	Gap[μm]	D,left[μm]	D,right[μm]	θ1[deg]	θ2[deg]
Full Module	15 ± 3	3.48 ± 0.06	129 ± 58	309 ± 127	326 ± 134	-0.04 ± 0.19	0.06 ± 0.19

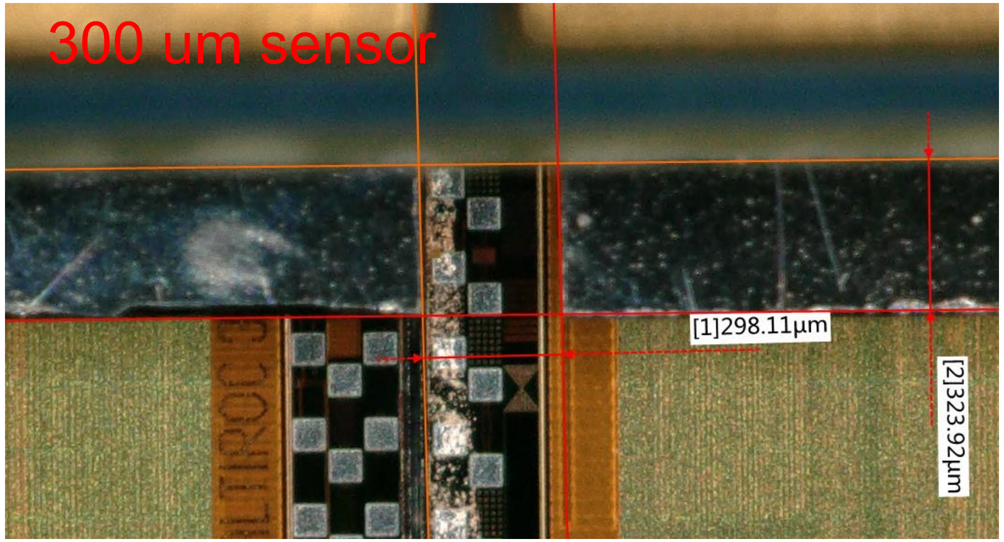
	U[mm]	V[mm]	X[mm]	W[mm]	Mean[mm]	δ[μm]
Full Module	1.73 ± 0.06	1.74 ± 0.06	1.74 ± 0.06	1.77 ± 0.08	1.75 ± 0.06	23 ± 16

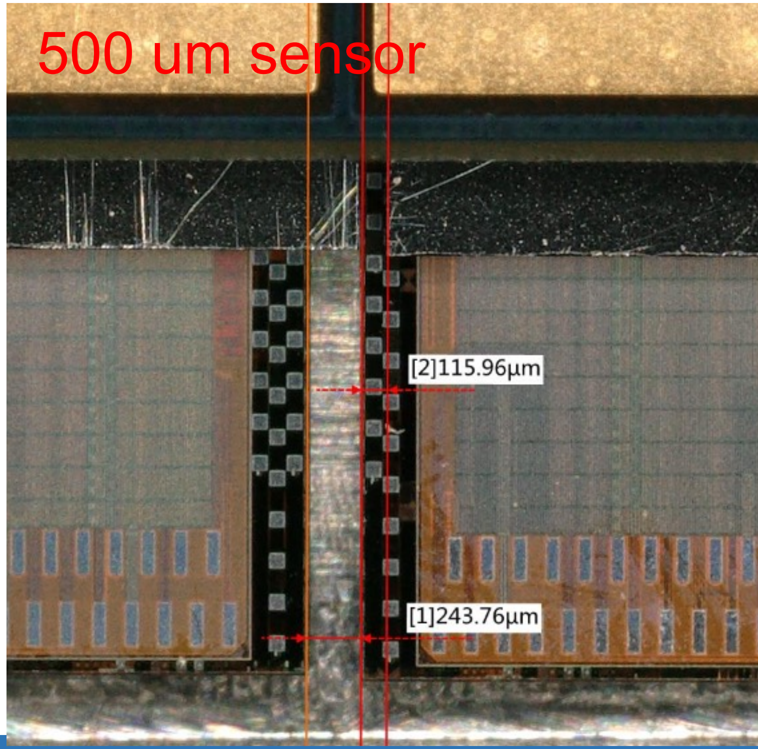


Current assembly status

- 4 full modules & 2 digital modules were assembled currently.
- New ALTIROC3 hybrids, width is dominated by the ASIC.
  - Former ALTIROC2 ASIC has smaller width than sensor.
  - Have to put the two hybrids closer for wire-bonding.
- Two types of ALTIROC3 hybrids:
  - 500 um sensor: risk to touch the sensors (short circuit)
  - 300 um sensor: risk to touch the ASICs (physical damage)
- Adjust the parameters for gap distance in the software for different situation.



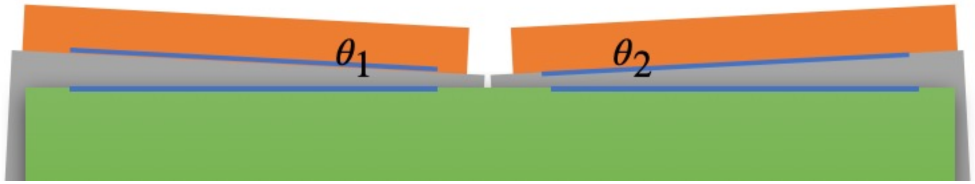




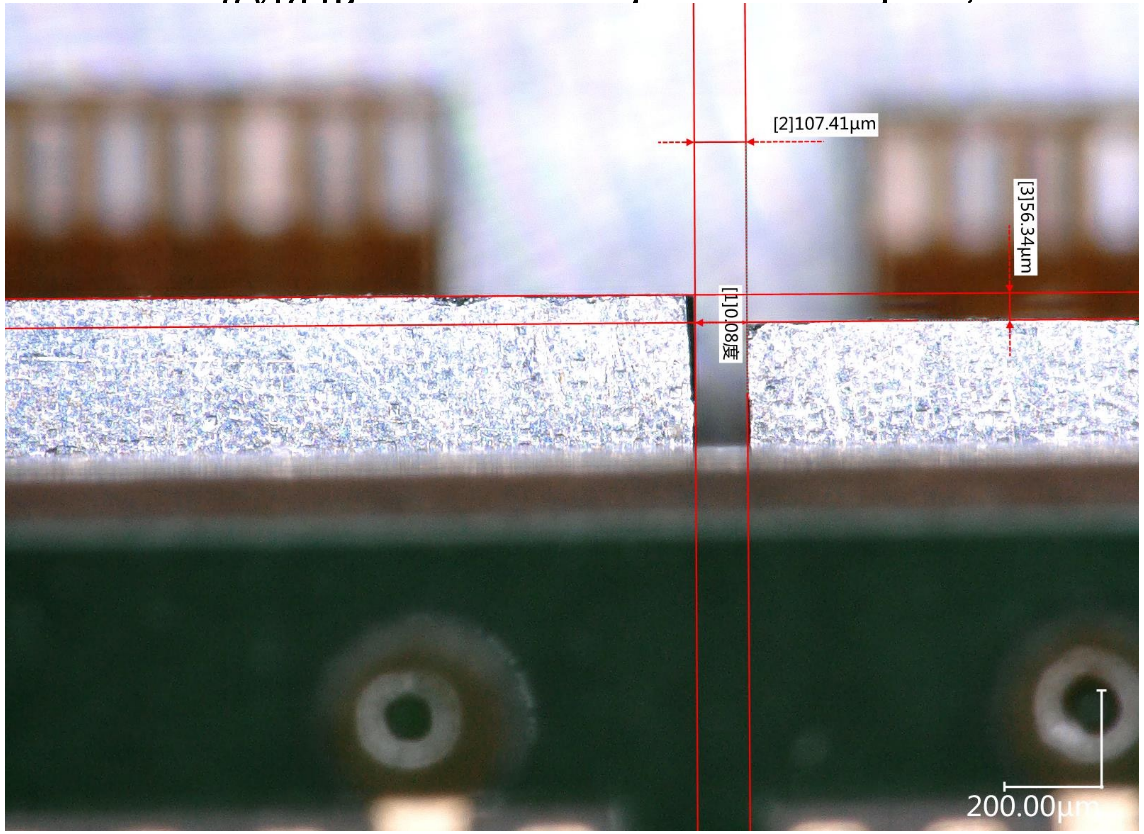
✓ The system works fine!

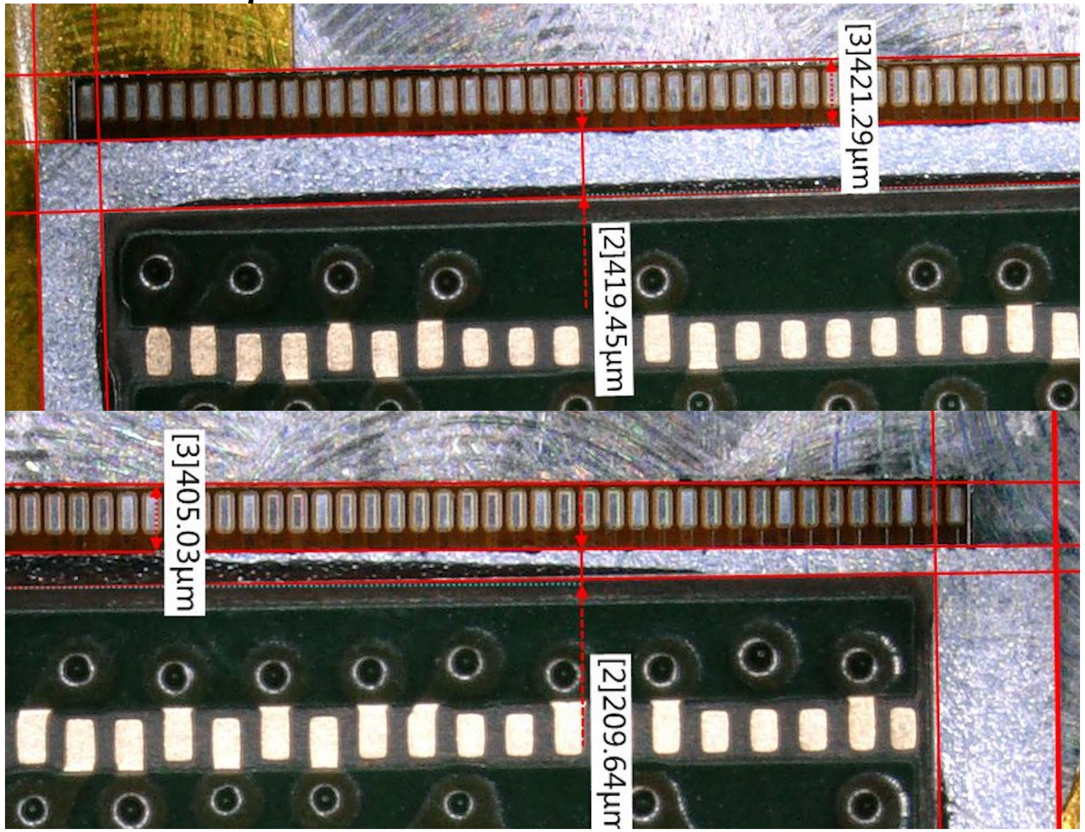
FM005 - Metrology measurement

- Use microscope to measure the metrology



- Rotation: $\theta_1 = -0.29°, \theta_2 = 0.32°$
- Gap between Hybrids is $107.41\mu m$, close to $100\mu m$ and within PDR.
- Now D_{hybrid} is from $200\mu m - 400\mu m$, while the expectation is $125\mu m$

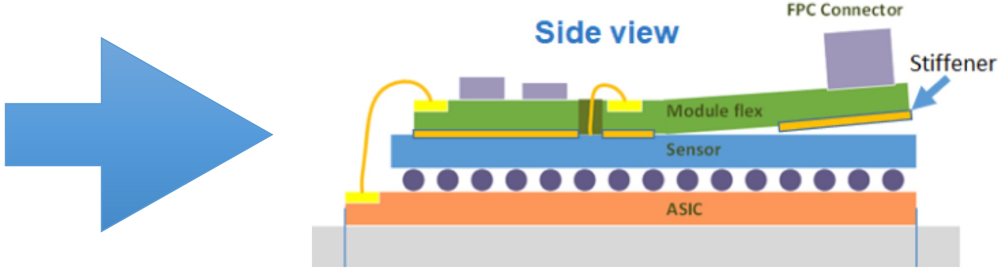




FM005 - Metrology measurement

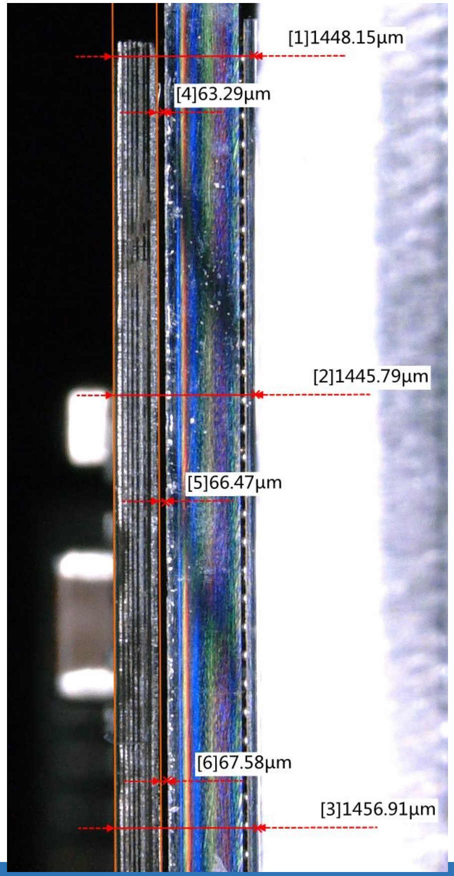
- Module height and glue height
  - Still measure with microscope, but put the scope horizontally.

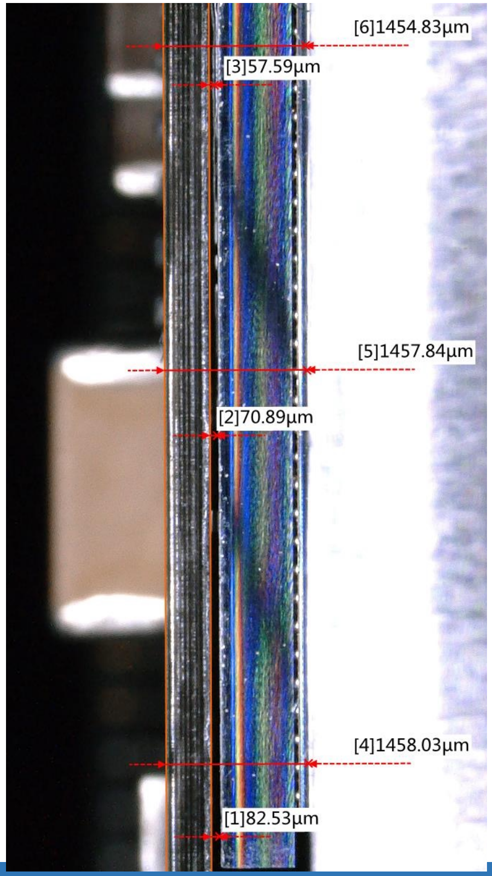
Microscope

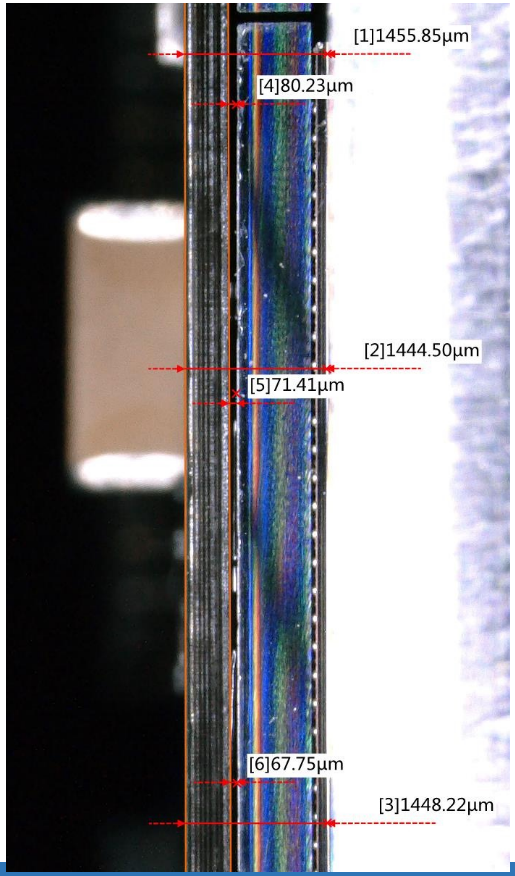


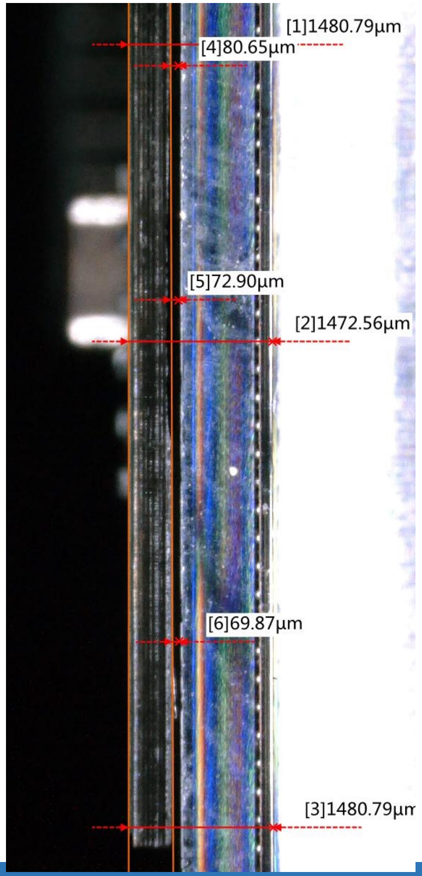
$Left \rightarrow Right$

- Glue Height: $70.93\mu m$ (avg)
- Module Height: $1457.9\mu m$ (avg)





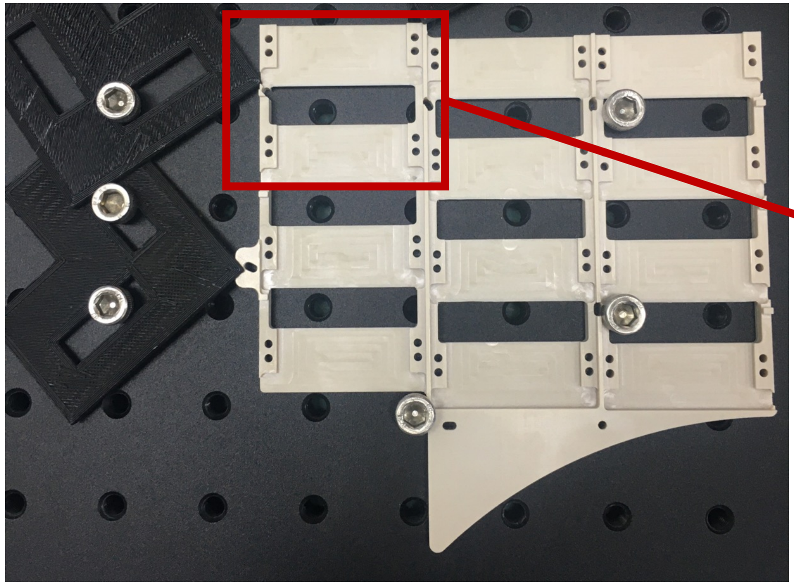


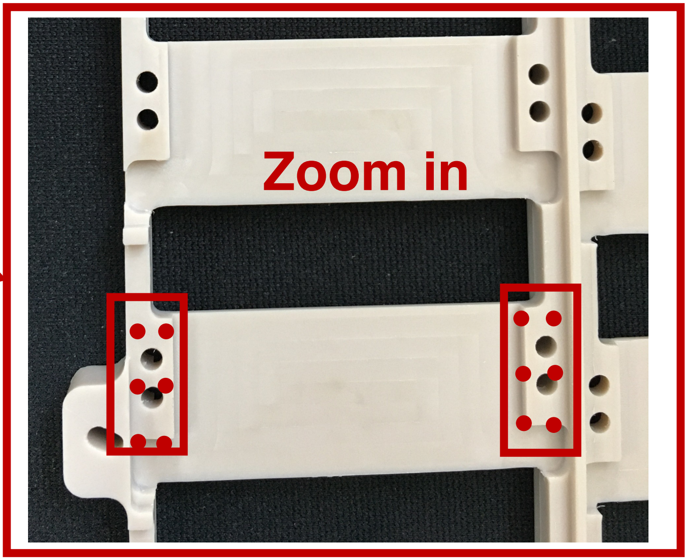


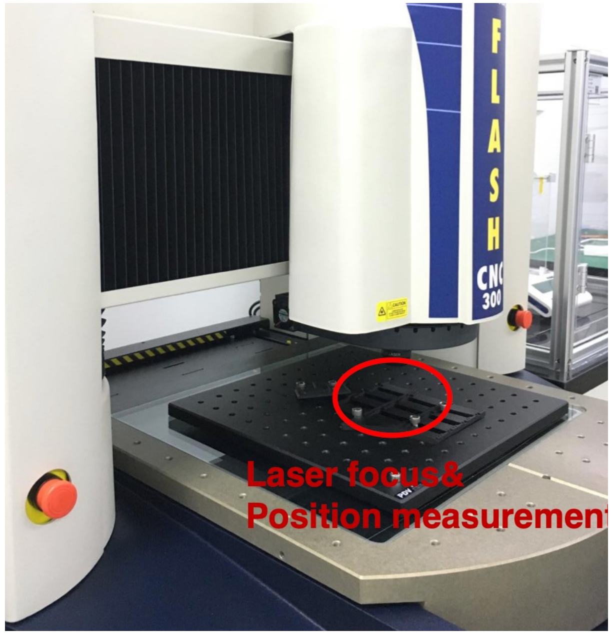
Metrology for support units

- The planarity is measured with smart scope in IHEP

FI1SU



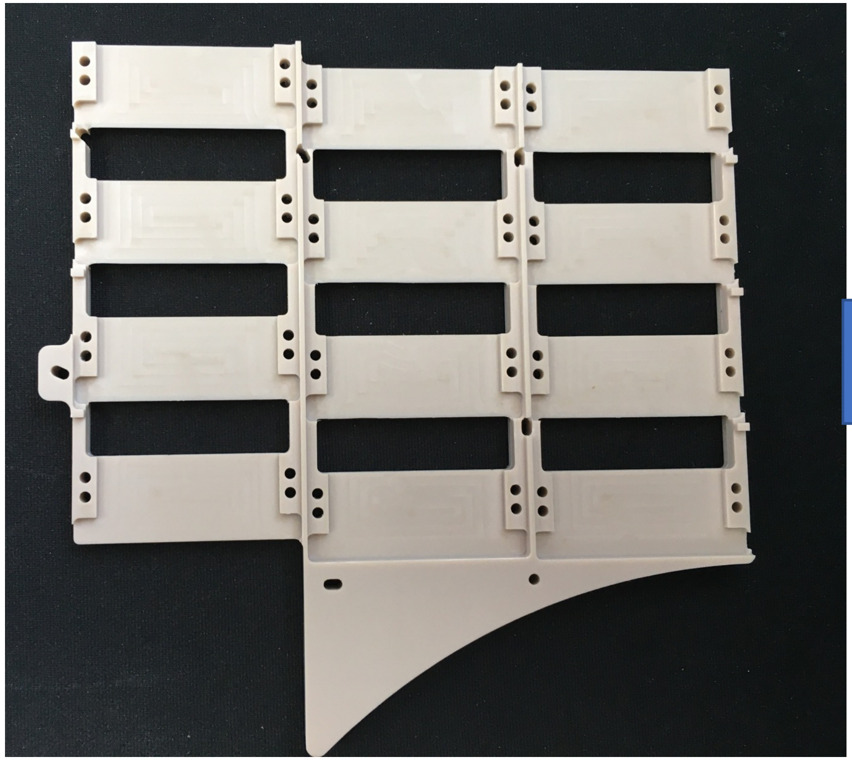




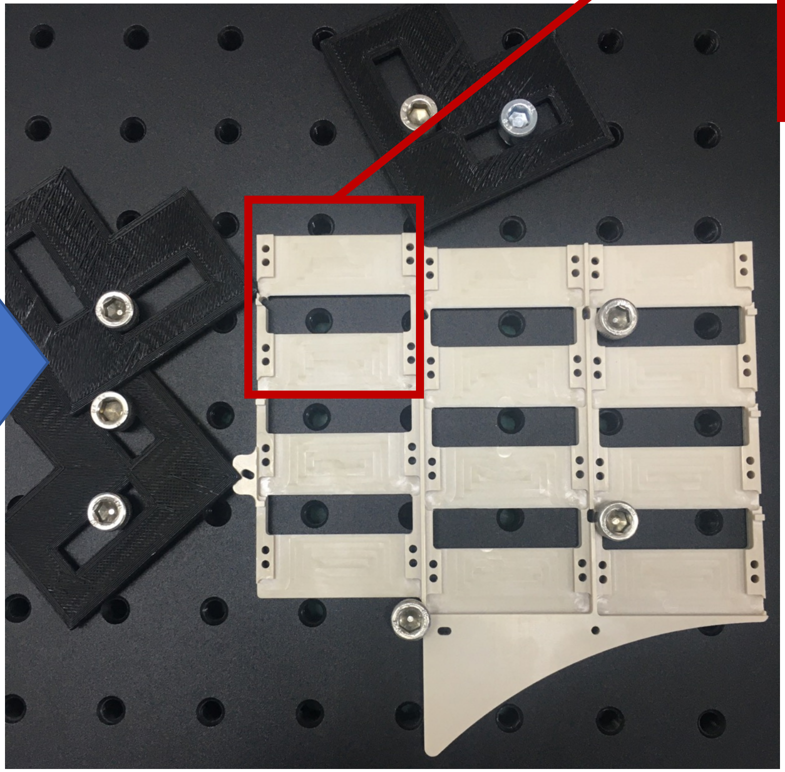
- Planarity of the glue surface:
- Set 6 points for each glue surface and measure their positions with the scope.
- Mean value $\bar{z} = \frac{1}{p}\sum_{i=1}^{p} z_i \;\; (p = 12)$is calculated for the height of the surface.
- RMS value $r.m.s = \sqrt{\frac{1}{p}\sum_{i=1}^{p}(z_i - \bar{z})^2} \;\; (p = 12)$ is calculated for the planarity of the surface.

Prototype status

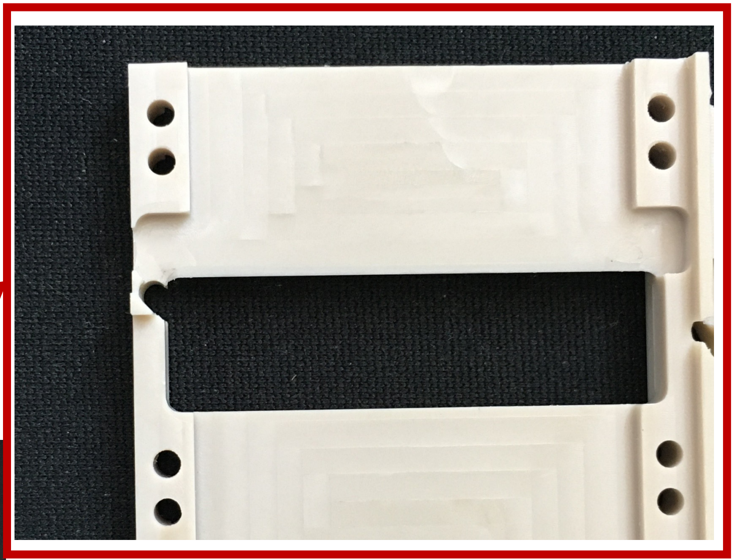
- Machining prototype
  - Manufactured by Shousu(CN)
  - Material: PEEK
  - Well processed at the screw hole area.
- Price: 900RMB (about 130 EUR) for prototype;
- We have asked for quotation(backup).

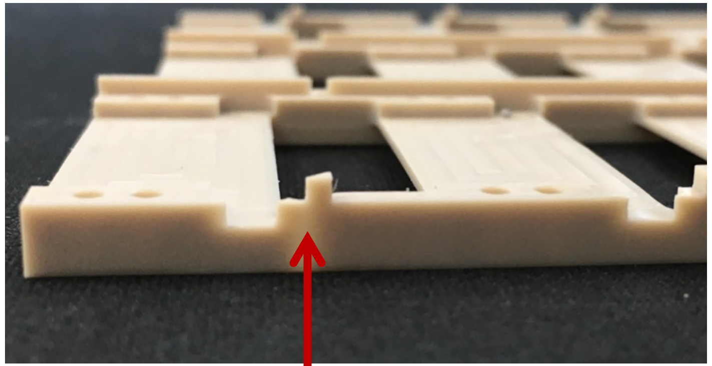


Fixing



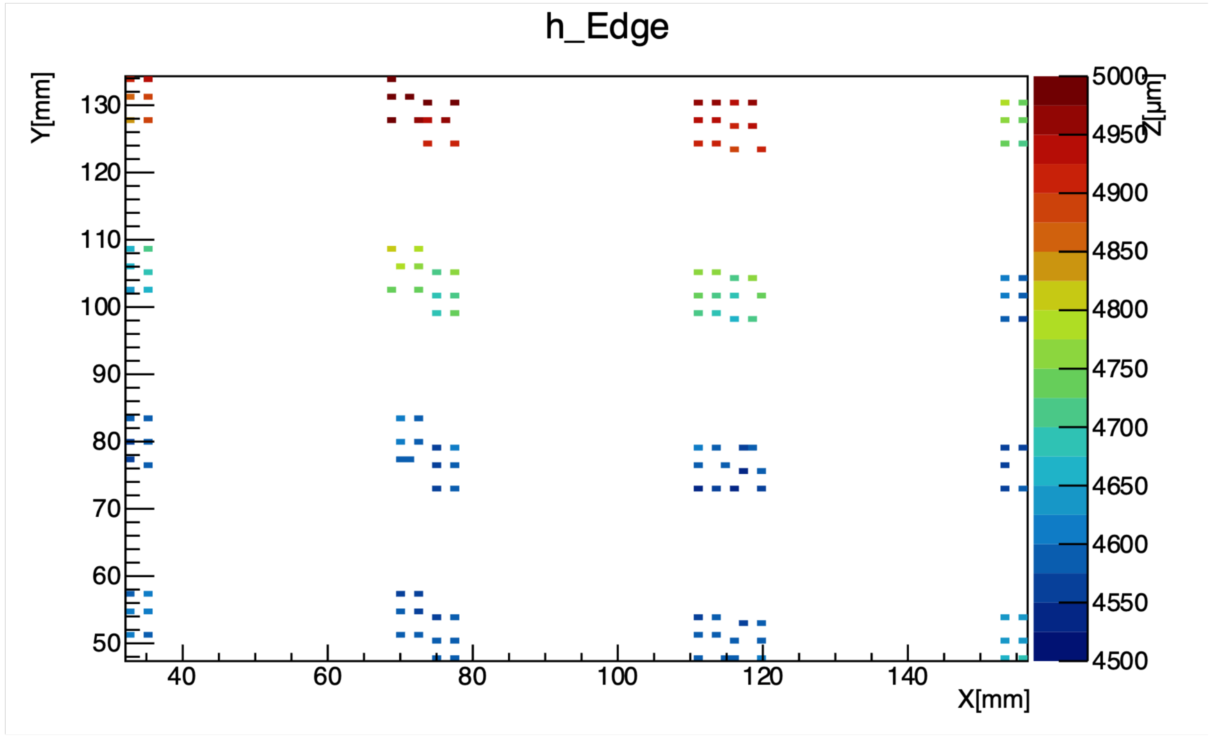
Zoom in

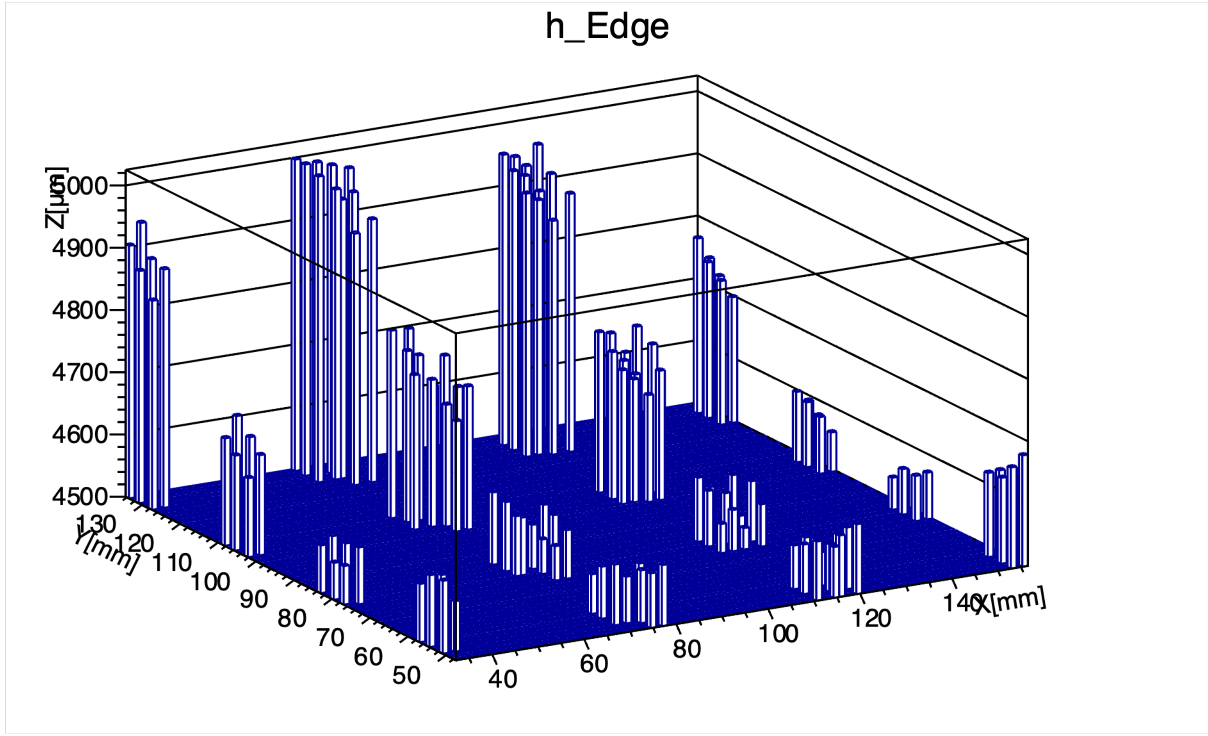


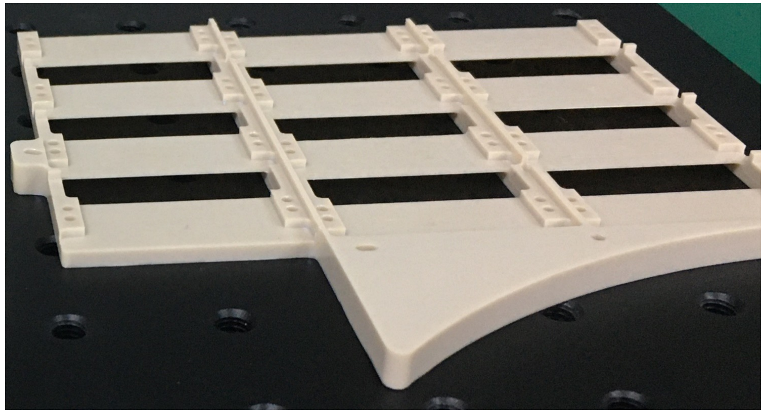


Screw Hole

Overview of FI1SU: machining

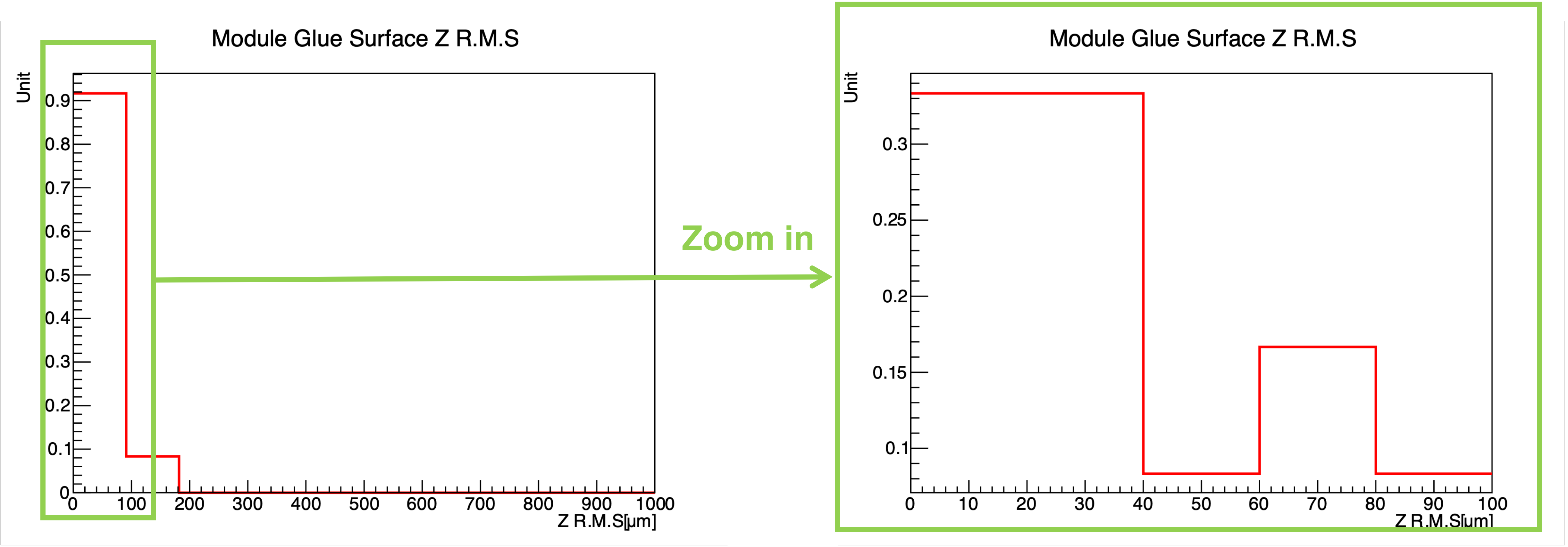






- Compared to the 3D printed prototype, the machining one does not have a very obvious bending.
- The surface is much better.

Planarity of FI1SU



- Prototype PEEK by machining: ~90% modules have RMS < 100 μm.
- The left top corners are higher(about 100 μm) than the other areas.
- There is a bending, but a very small trend.