Automatic module assembly and loading system development for ATLAS HGTD

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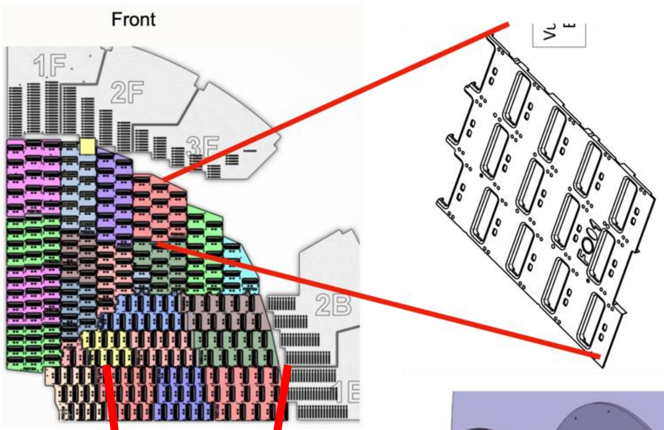
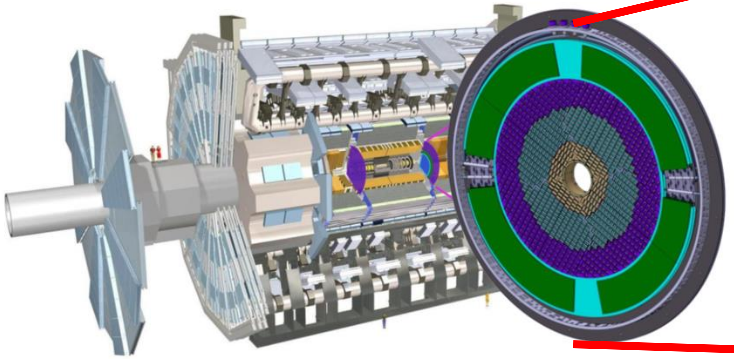
Outline

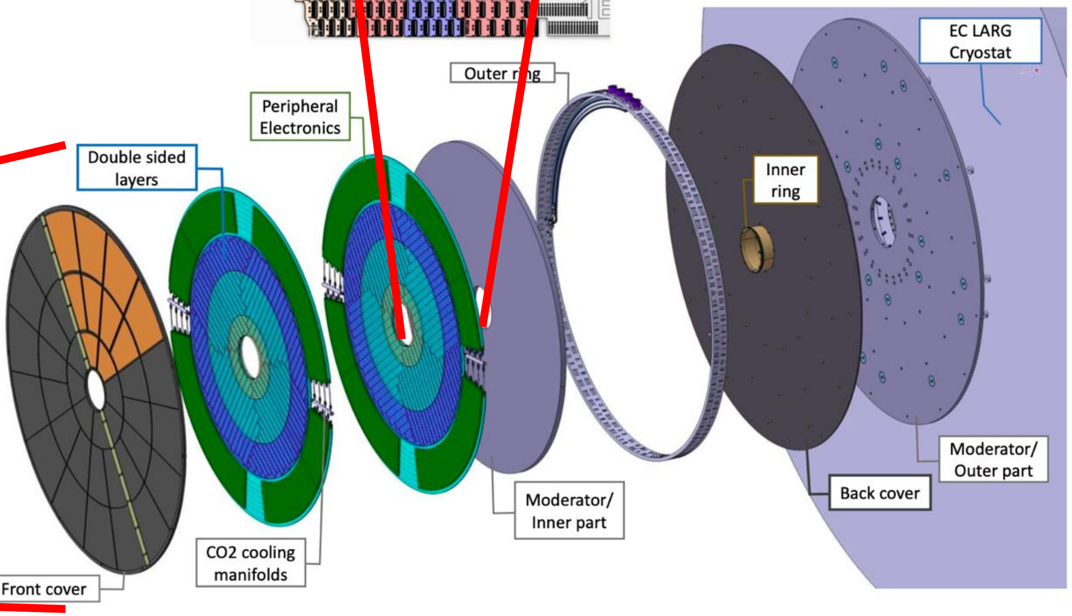
- Overview of the HGTD module
- The gantry system in IHEP
- Module assembly workflow
- Detector unit loading
- Force & thermal simulation
- Summary

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
  - 8032 HGTD modules in total.
  - $2.4 < |\eta| < 4$, time resolution: 35 ps (start), 70 ps (end)
- Contributions from China groups:
  - 100% of LGAD sensor;
  - 34% of module assembly(~4000 modules);
  - 100% of front end electronics;
  - 50% of ASIC test at wafer level;
  - 16% of high-voltage system.

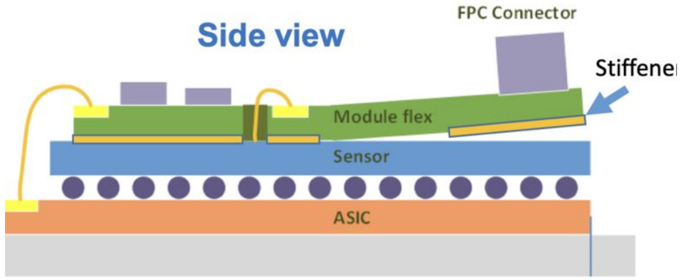


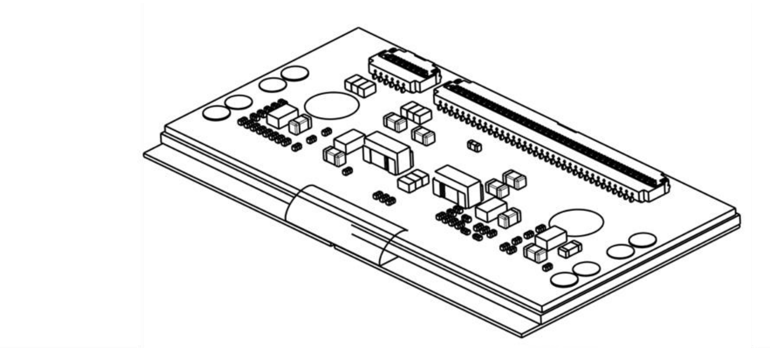


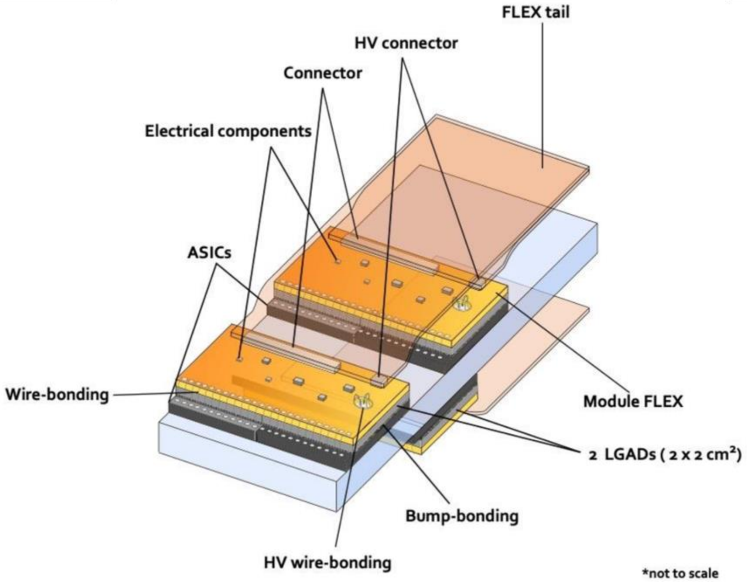


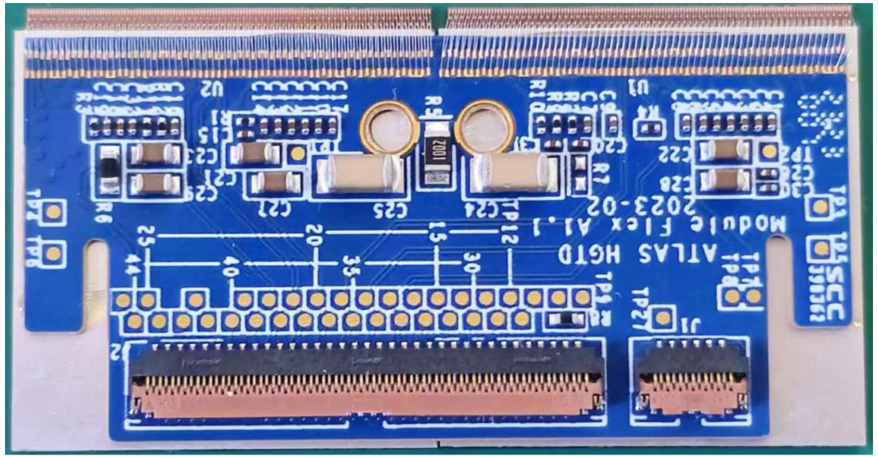
HGTD module

- 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 in different sites: IHEP, USTC, IJCLab, IFAE, Mainz…
- Over 1/3 of the modules (>3000) will be assembled at IHEP.
  - We need to develop an assembly system with high efficiency.
- IHEP will be able to load all types of detector unit.
  - The loading system would be suitable for all types of detector units.



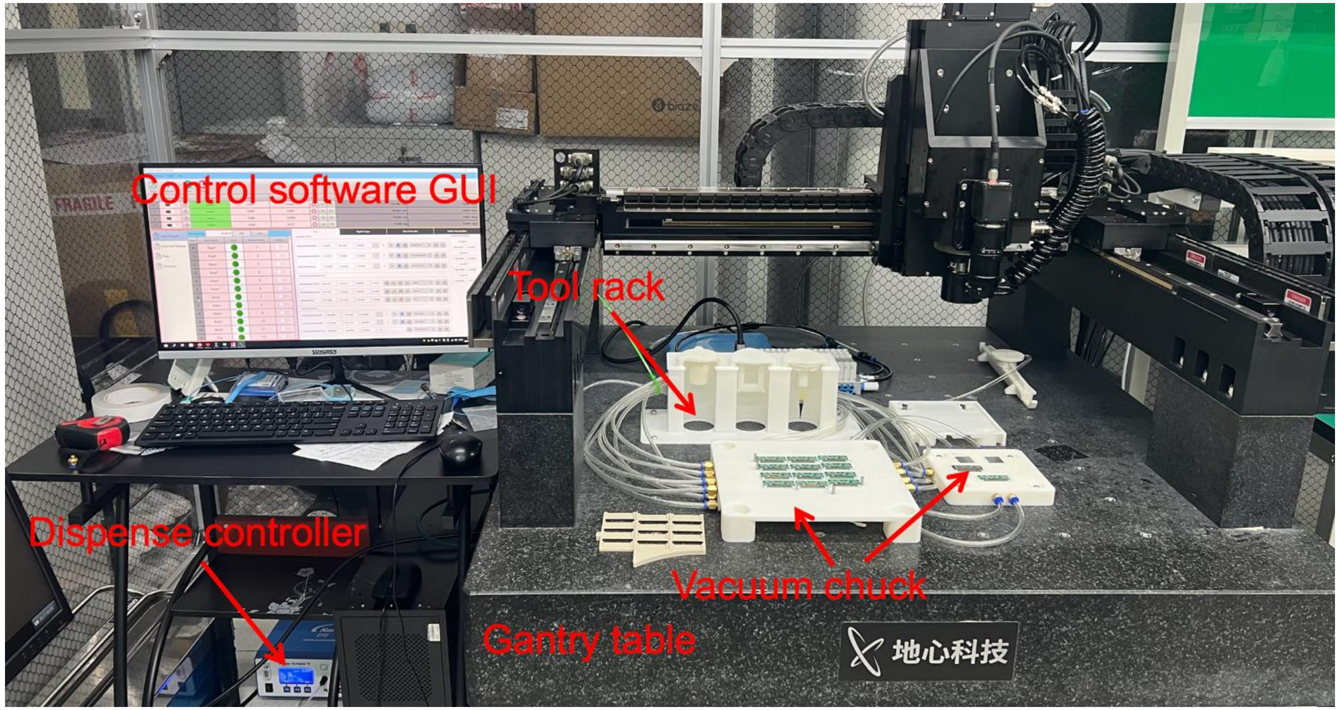




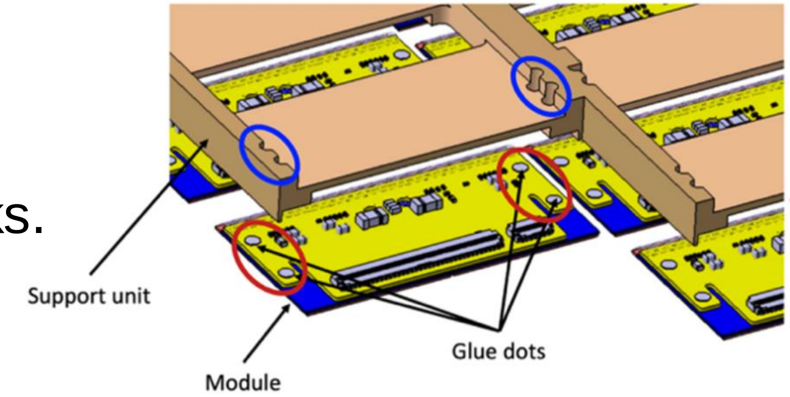


HGTD module assembly at IHEP

- To assemble such a large number of HGTD modules with high precision. A robotic gantry system is developed at IHEP
  - High-precision pick-and-place;
    - Repositioning resolution: ~1 μm;
  - Force sensor to detect stress;
    - With force – tooling touching;
  - Dispensing control system;
  - Vision system with camera;
  - Customized tooling;
  - Control software: Open source C++ & qml with GUI

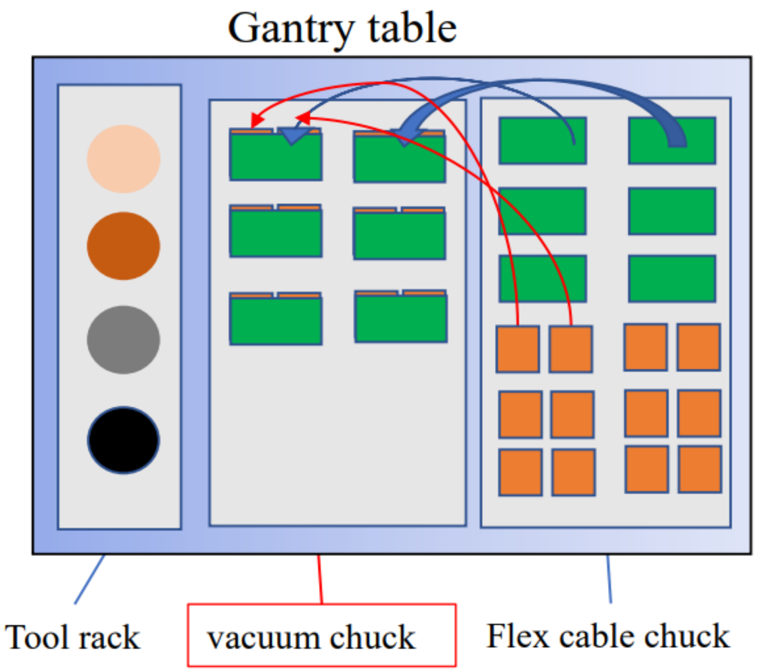


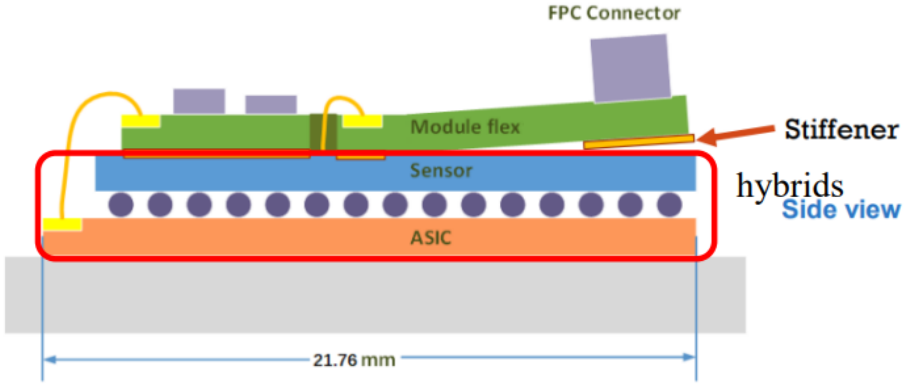
- With customized tooling, the system will handle all the assembly and loading tasks.

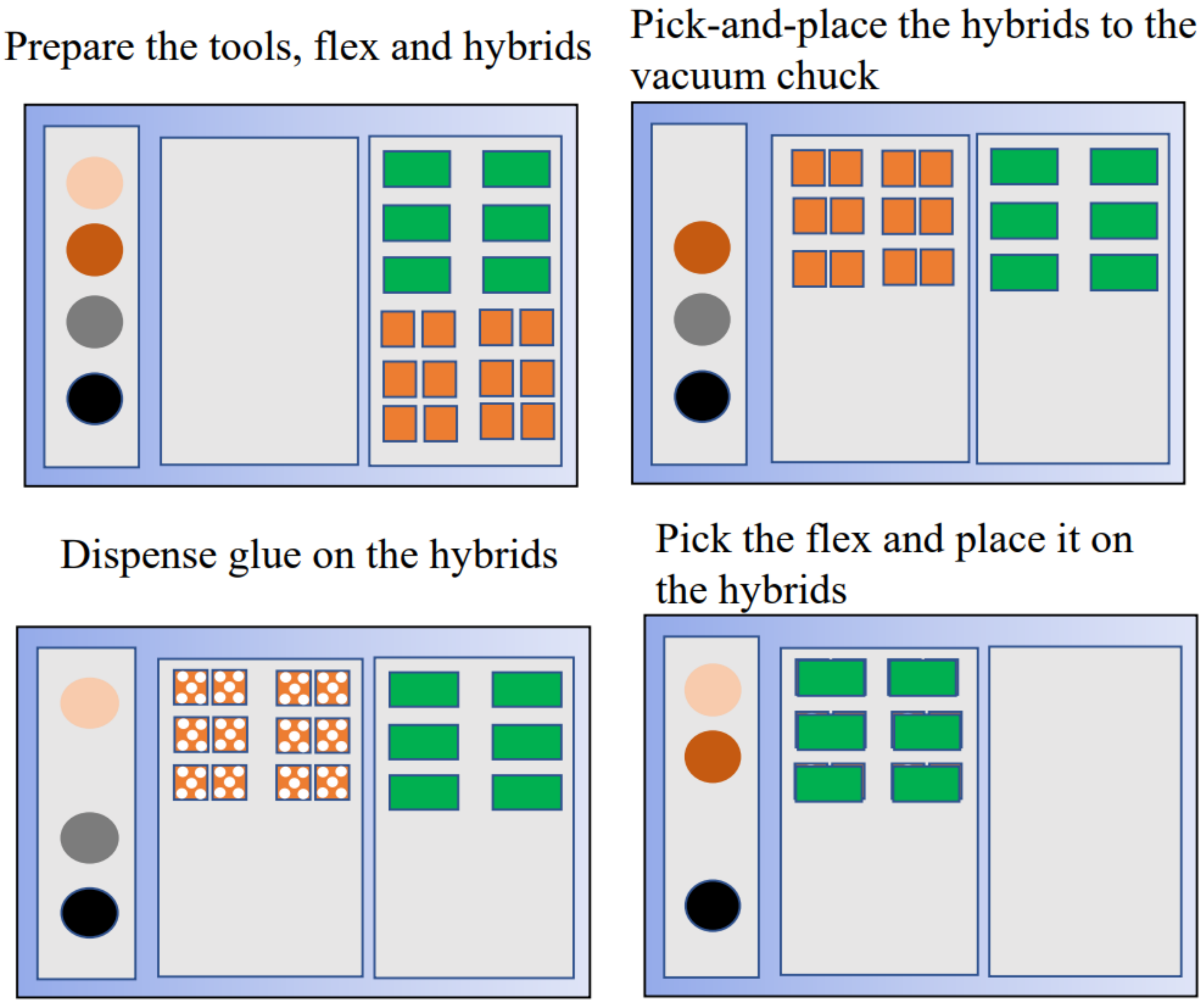


Assembly procedure steps

- The workflow of module assembly:

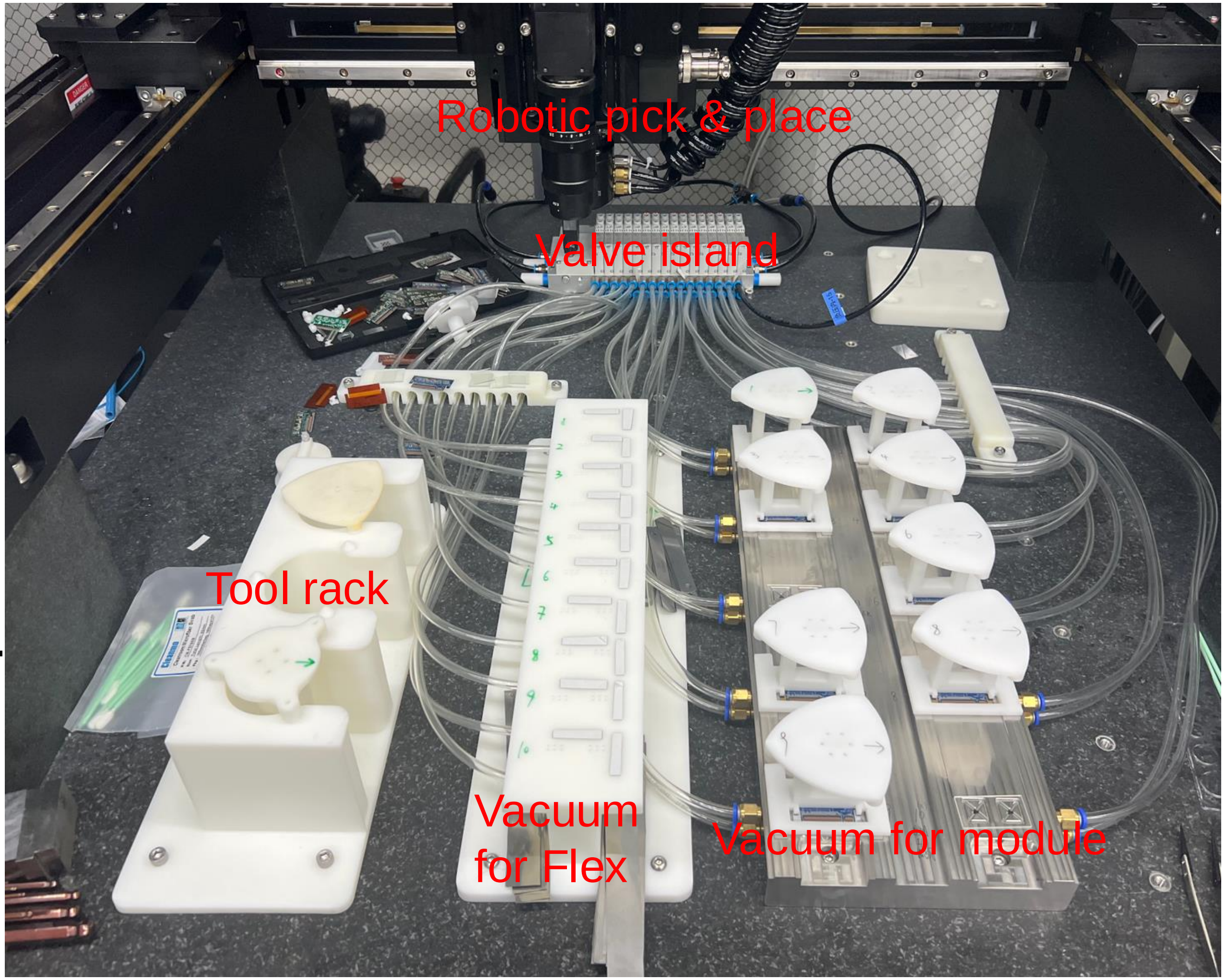






Multi-module assembly system

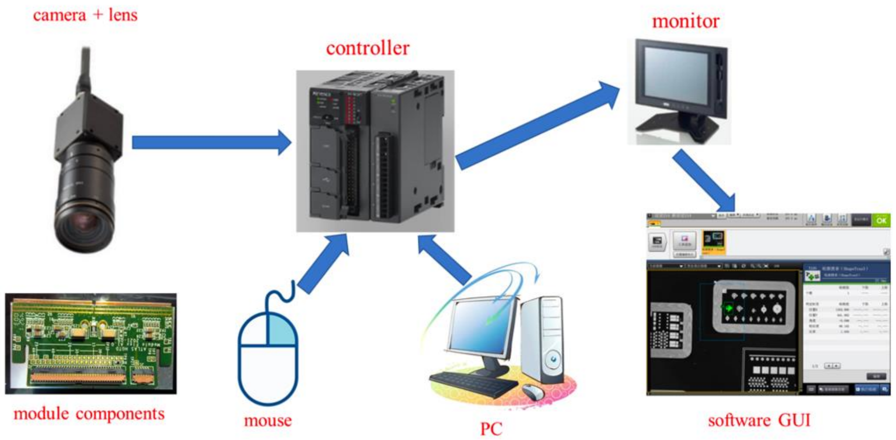
- To assemble multiple modules, we designed and produced vacuum plate for 10 modules.
- This system has:
  - Tool rack and tooling for pick up components:
    - Tool for picking up **hybrids**;
    - Tool for picking up **flex**;
    - Tool for **dispensing glue**;
  - Vacuum plate for flex;
  - Vacuum plate for modules;
    - 10 vacuum chucks on the module plate.
    - Small stairs at the edges of the chuck to control the thickness of the module.
    - Add small thin plate to adjust the thickness.
  - Value island for multi-vacuum.

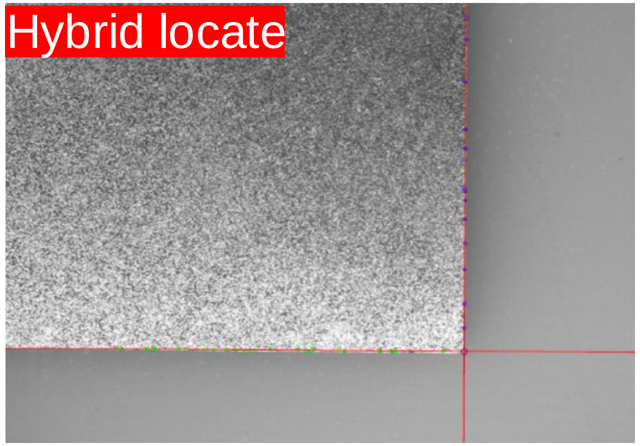


- All the tooling is replaceable.
- Allow us to **assemble 10 modules at one time**.

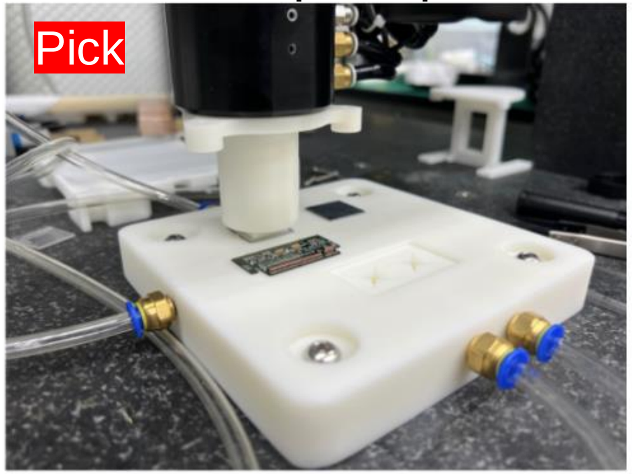
Multi-module assembly system

- The gantry has to get the x & y position of all components for a module with the camera.



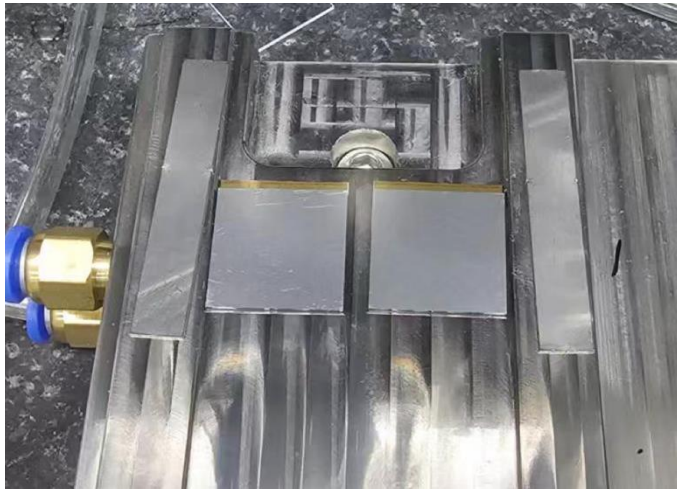


- Force sensor is used to locate the components at Z direction (height).
  - Positive pressure force → the tooling touches the target
- Use software to pick, place and release the tooling and target (hybrids, ASICs…)

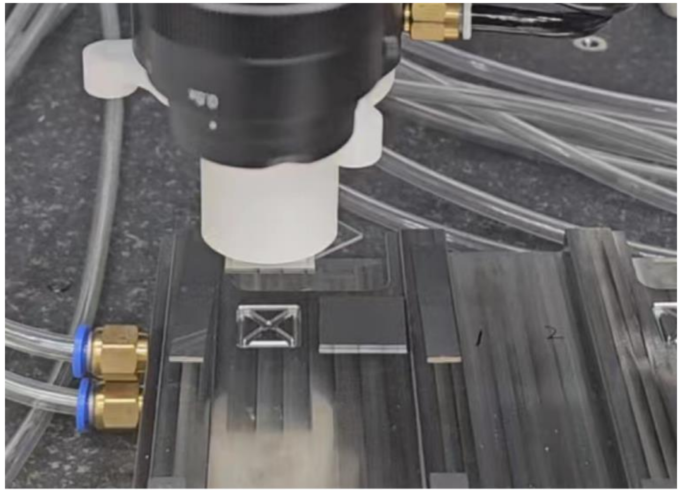


Automatic module assembly workflow

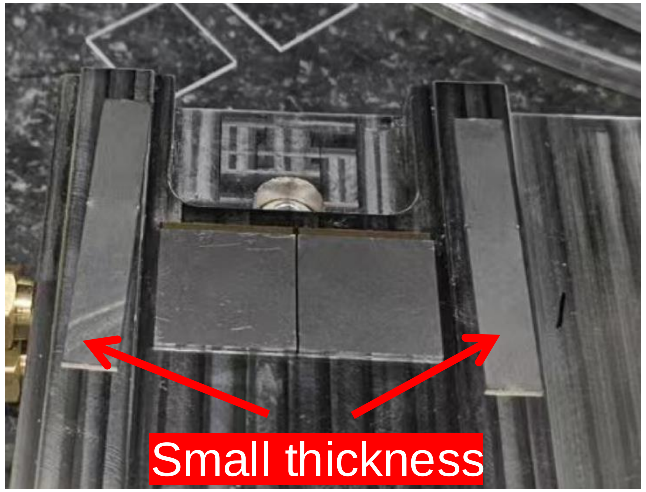
1. Roughly put the hybrids



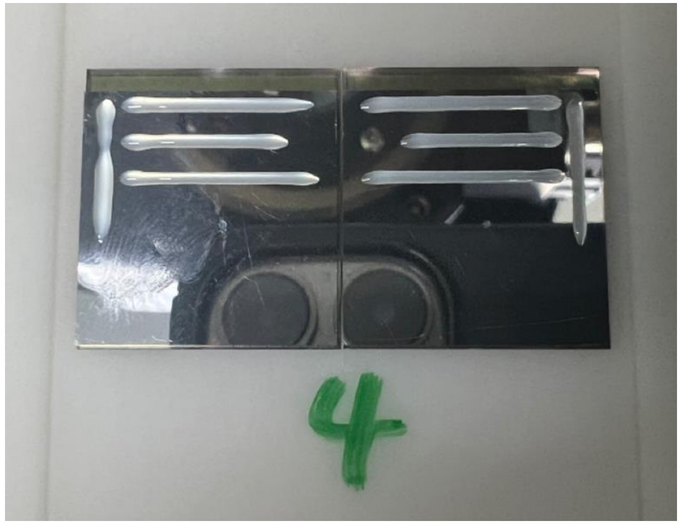
2. Locate and pick up the hybrids



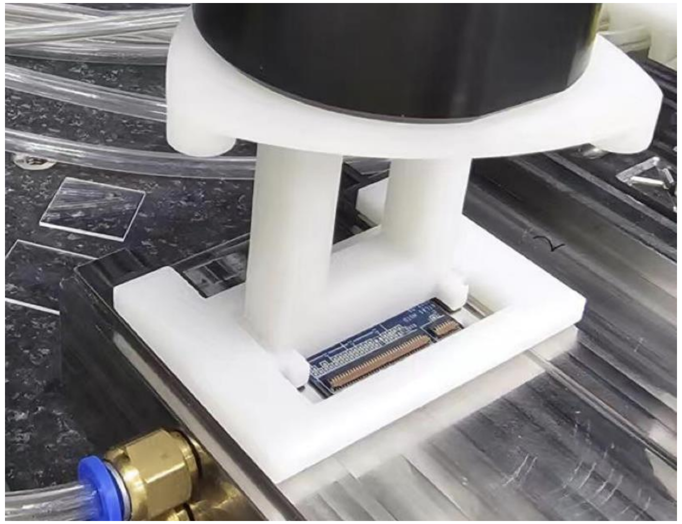
3. Place to the designed position



4. Dispense glue pattern



5. Place the flex on the hybrids

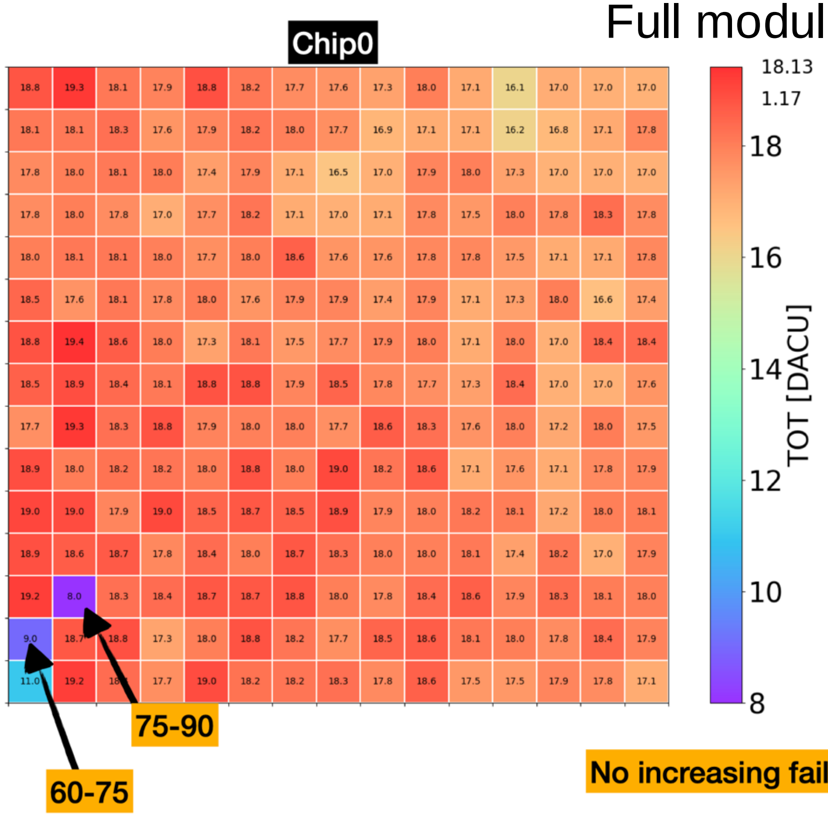


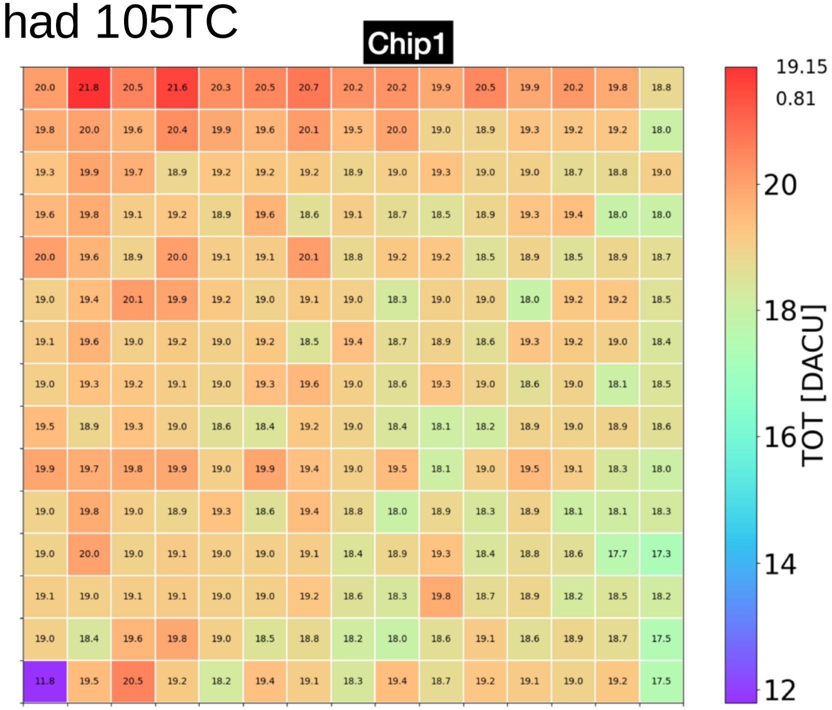
6. Leave for the glue curing

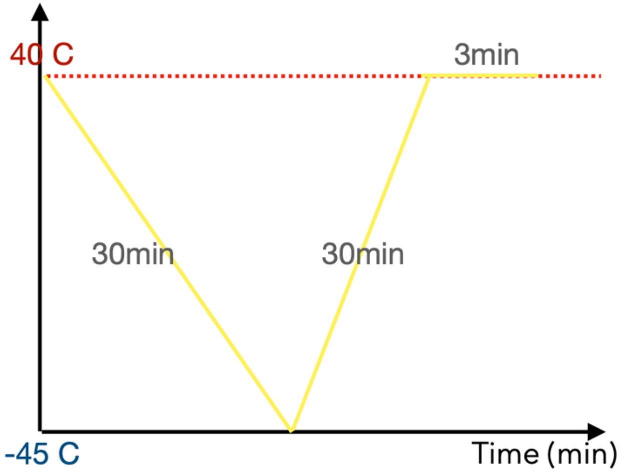
Thermal cycle & module testing

- Modules have tested and thermal cycled from -45 ℃ to 40 ℃.
  - To investigate on the fatigue failure of hybrid solder joints under thermal impact cycles.

Full module had 105TC





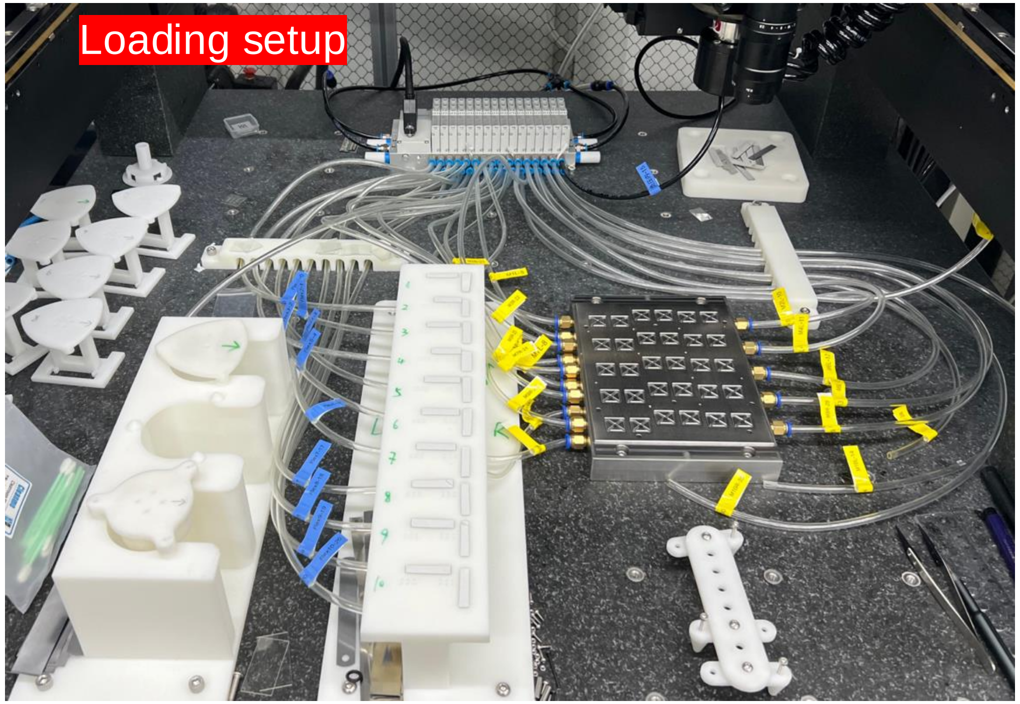


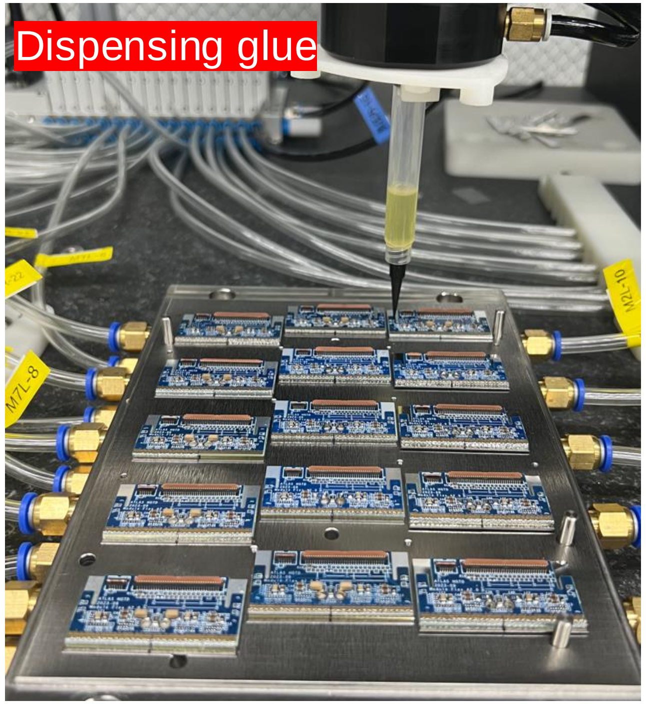
No increasing failures in 90-105.

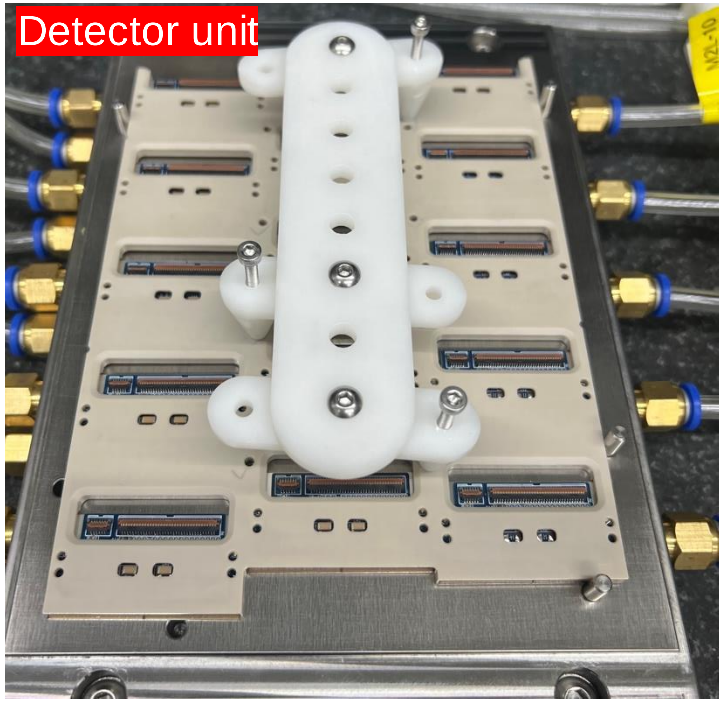
- Disconnections are usually at the corners of the hybrids.
  - Investigate the reason for the disconnection by thermal simulation.

Loading procedure

- Loading with the gantry system.
- Procedure:
  - Change vacuum plate for loading;
  - Locate all modules with camera;
  - Pick & place, dispense glue by the gantry;
  - Place the support unit on the modules with positioning pins.

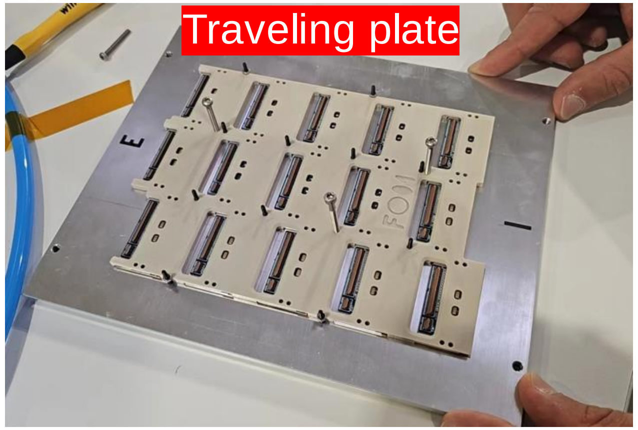


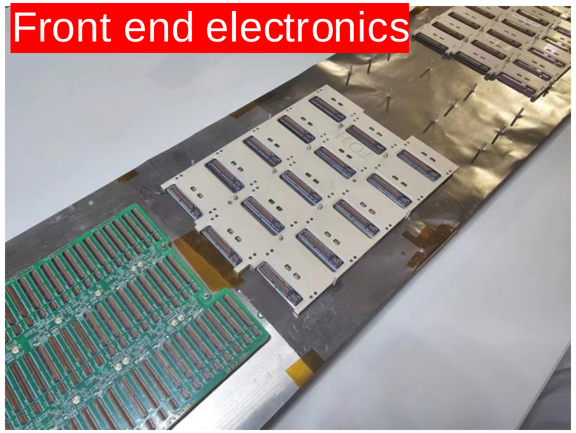




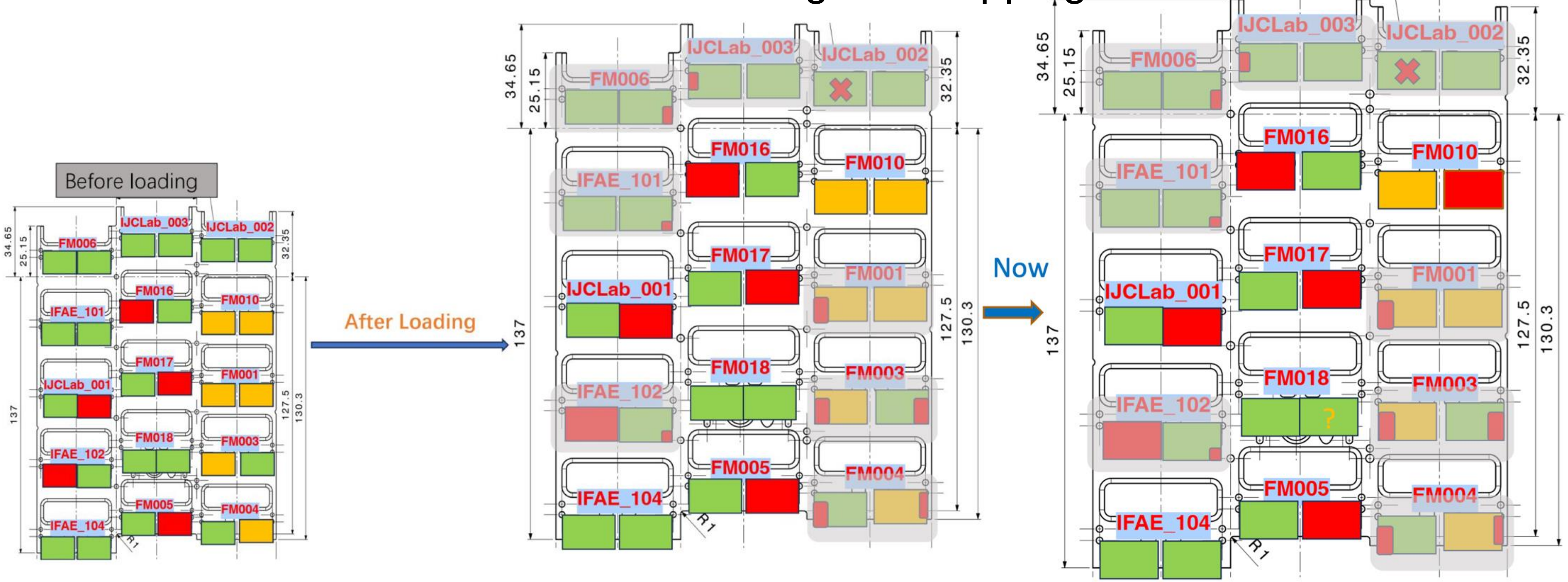
Detector unit testing @ CERN

- The first DU (FO01DU) is sent to CERN in April for further test.



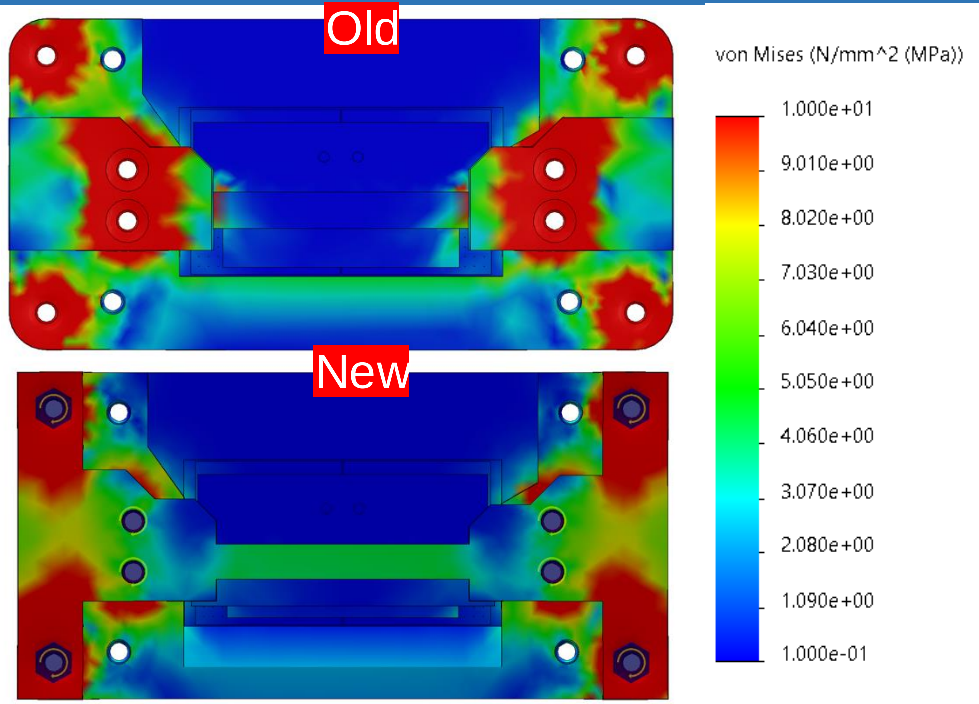


- No large amount of disconnection found after loading and shipping



Module carrier & simulation

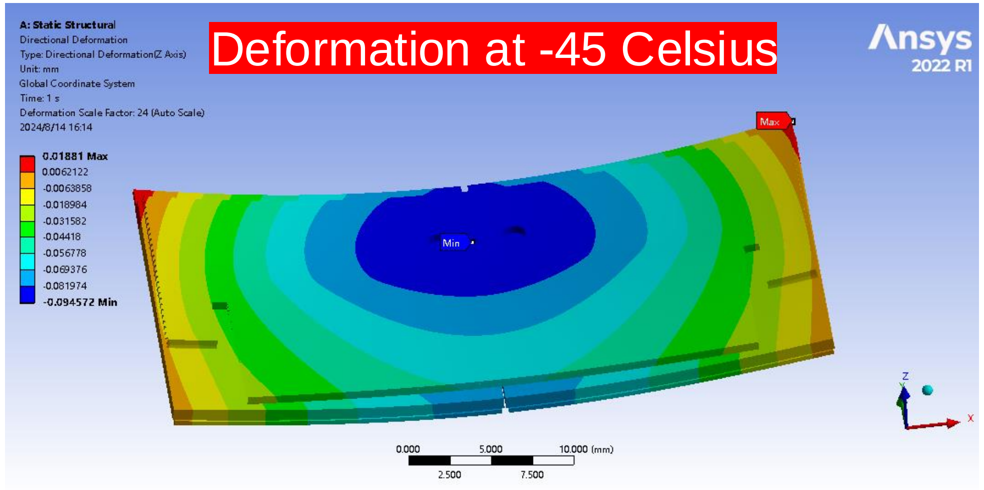
- The modules are stored in the carrier to avoid damage during testing and shipping.
- The modules are fixed by stress and fiction in the carrier.
- We run **force simulation** to update the design of the carrier.
  - The stress on module is better averaged in the new design.



Thermal simulation

- In -45℃, the deformation of the module will cause bending and extra stress on the bumps;
  - Bumps are easily broken at low temperature.
- We are investigating this by thermal simulation

	1st proposal	2nd proposal	Full U shape	Currently using pattern
Pattern				
Largest difference of deformation **on flex**/um	75.0(-29.91%)	88.1(-17.66%)	84.9(-20.65%)	107.0
Maximum stress on pad bumps/MPa	365.20(-32.96%)	463.58(-14.90%)	476.37(-12.55%)	544.75
Average stress on pad bumps/MPa	125.68(-25.69%)	149.96(-11.33%)	151.78(-10.26%)	169.13
Reference glue weight **on each hybrid**/mg	2.39	3.32	3.56	9.41



Summary & Outlook

- Automatic multi-module assembly system is developed in IHEP with the following function:
  - ✓Locating modules by camera;
  - ✓Automatic pick-and-placing system;
  - ✓Automatic dispensing glue system;
  - ✓Module quality control;
  - ✓Multiple modules production(~20modules/day);
  - ✓Detector unit loading.
- > 20 modules were assembled with the current system
- First detector unit FO01DU was loaded, and shipped to CERN as a part of the HGTD demonstrator.

Outlook

- There are questions to be solved:
  - Disconnection from thermal cycle.
  - Disconnection during DU shipping.