

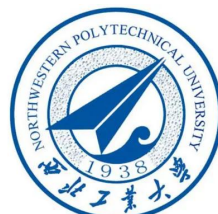


UP module and stave prototyping

Zhijie Wang (Lanzhou University) on behalf of the LHCb UP team

2026/10/30

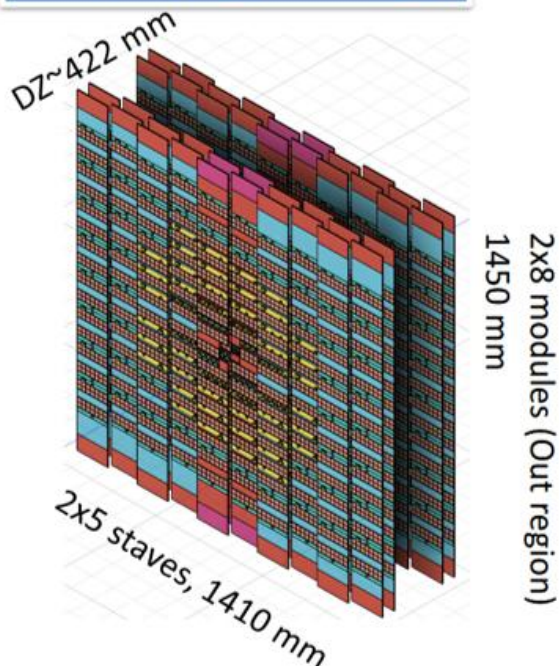
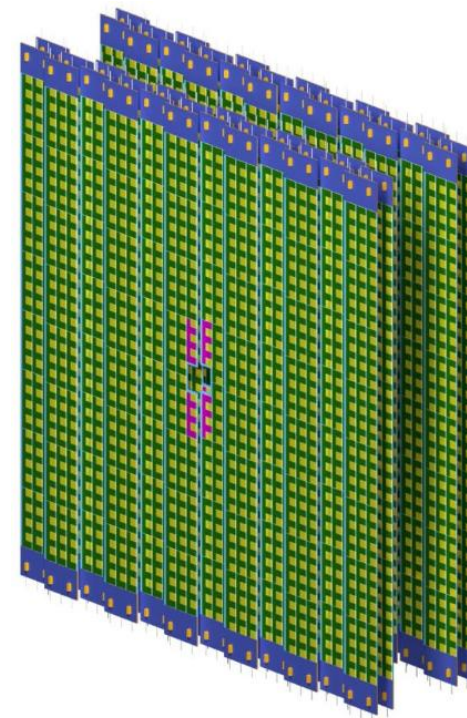
The 12th China LHC Physics Conference (CLHCP2026)



- Introduction
- Assembly of Module Prototype
- Assembly of stave Prototype
- Summary

Layout of UP

FTDR/Scoping doc. design



As in FTDR/scoping doc., UP has 4 layers

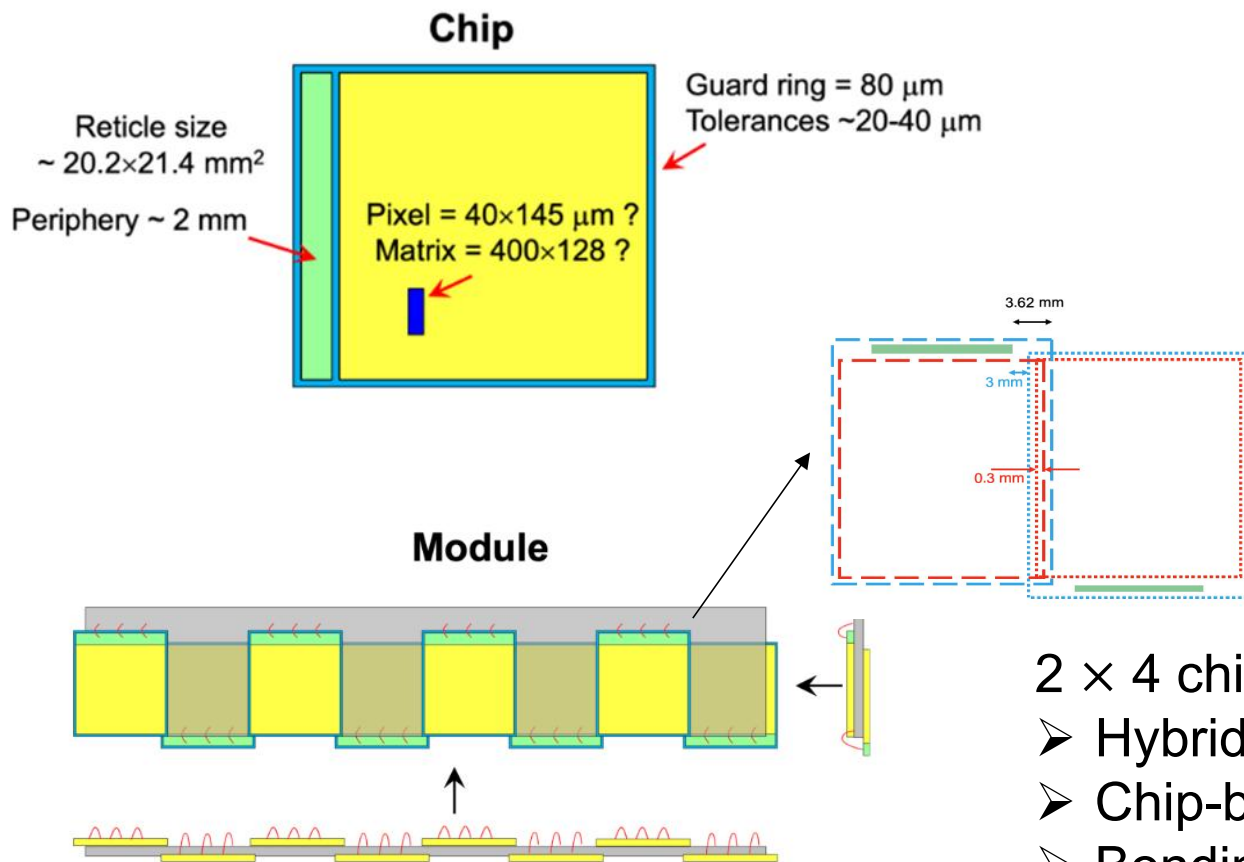
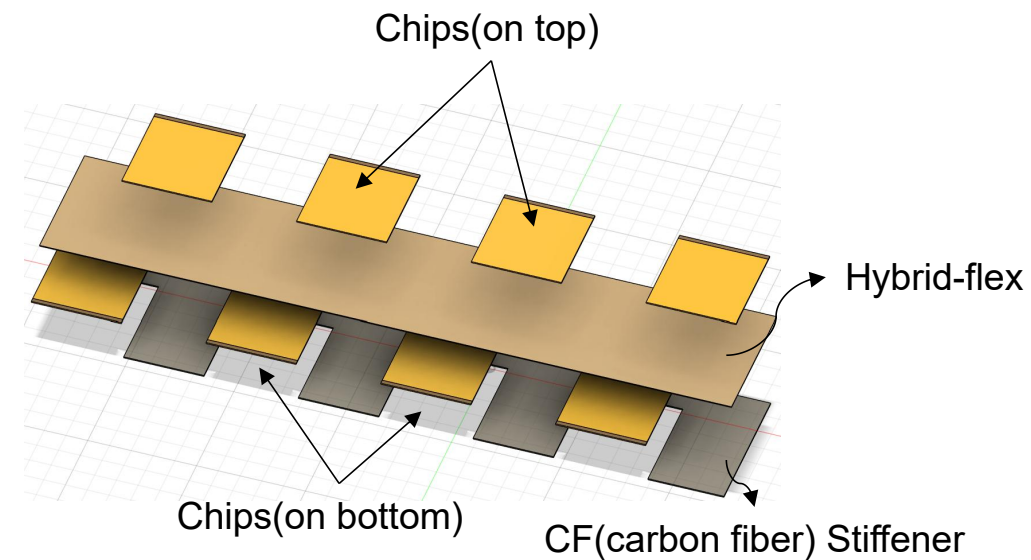
- Each layer has 2×5 staves
- The modules are staggered vertically, mounted on both the front and back sides of the UP stave
- Center hole for beam pipe is 8×8 cm
- 70×64 HVCMOS chips/layer

A new design still has 4 layers

- 2×6 staves per layer, $3 \times 2 \times 8 = 48$ modules per stave
- 72×64 HVCMOS chips / layer
- Still 8×8 cm beam pipe hole

Readout electronics placed externally → reducing material budget
Reduce detector dead areas → improving track detection efficiency

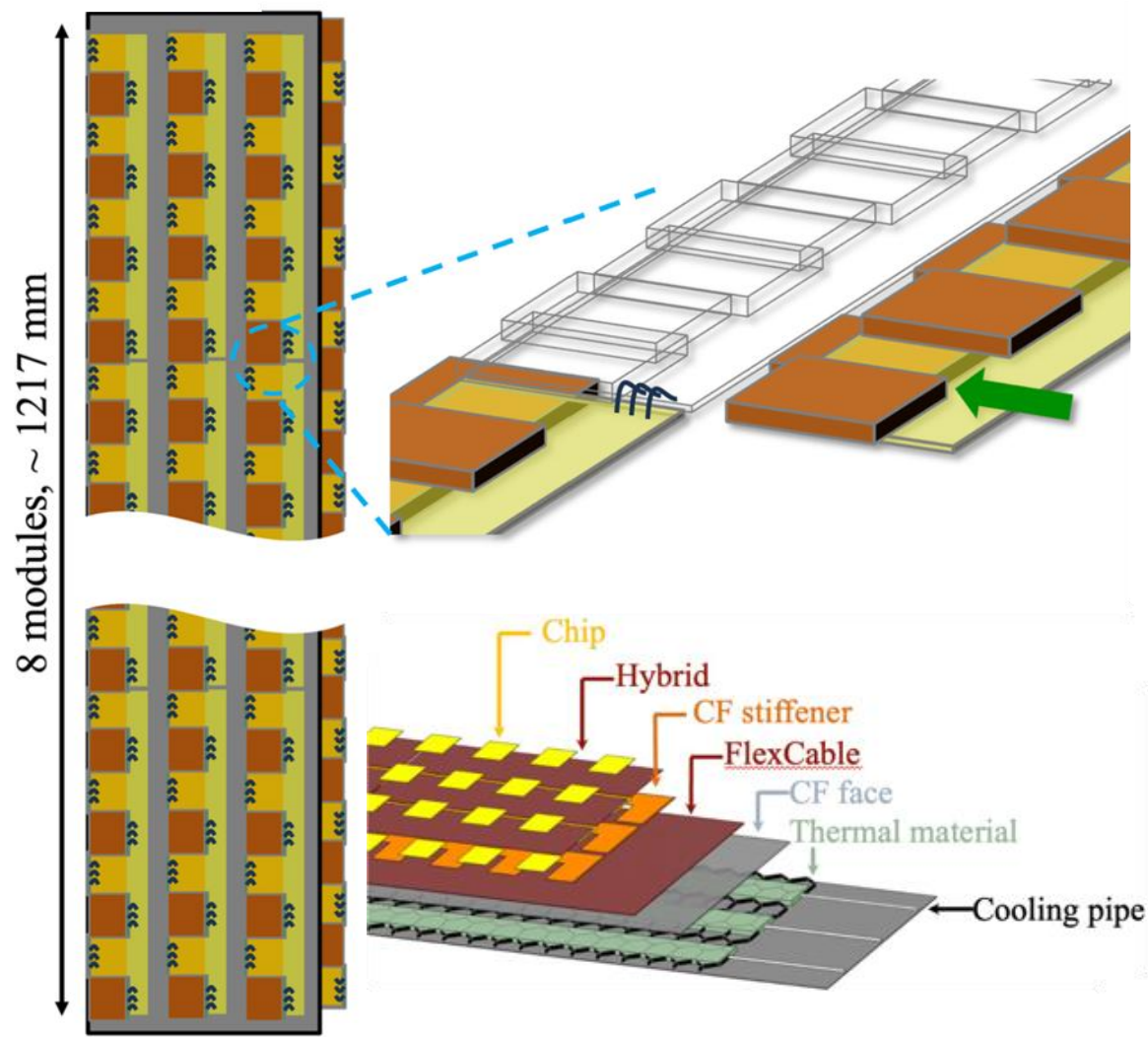
Module design



2 × 4 chips mounted on both face of Hybrid

- Hybrid thickness 0.2 mm
- Chip-by-chip overlap ~ 0.6 mm, 0.3 mm for sensitive region
- Bonding pad on hybrid-flex to pad on chip: 3.6 mm

Stave layout design



2 (face) $\times$ 3 (column) $\times$ 8 modules per stave

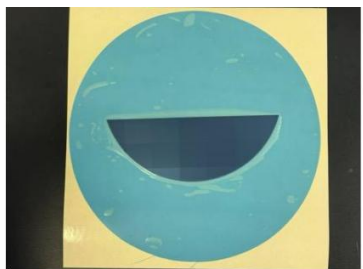
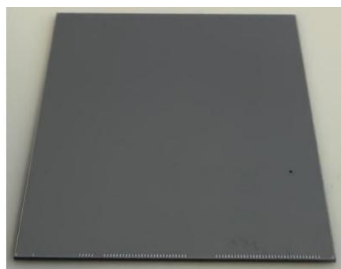
- Bare stave thickness 4 mm, ~5.3 mm w/ chip/module
- Module-by-module in a column overlapped by shorter-hybrid design (~0.3 mm for active area)
- Column-by-column overlapped by assembling on two faces per stave (~1.5 mm for active area)
- Stave-by-stave overlapped by staggered structure in a single Up layer (~5 mm for active area)

Avoid inefficiency from guard ring , dicing margin & safety gap

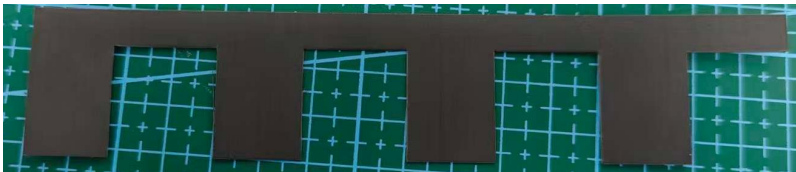
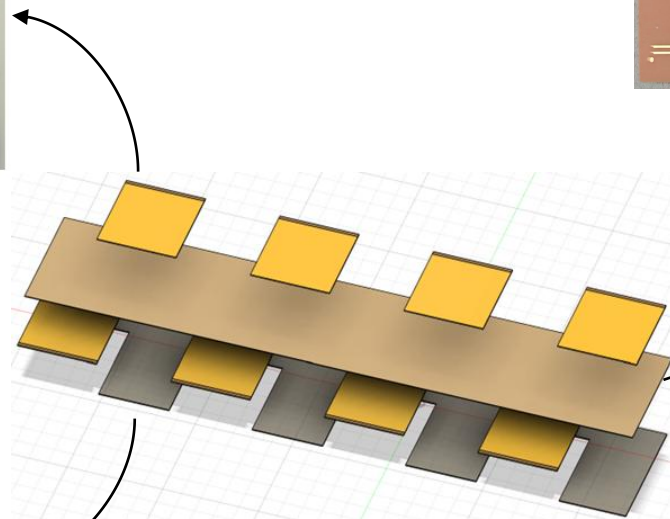
Components for Module Assembling

Materials for module prototype prepared

Chips for mechanical tests



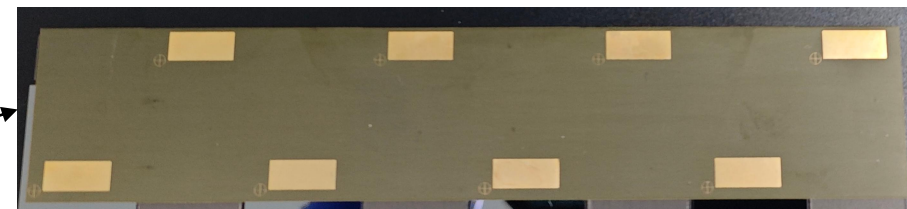
CF Stiffener



Hybrid (v1)



Hybrid (v2)



Hybrid (v3)



Jigs for Module

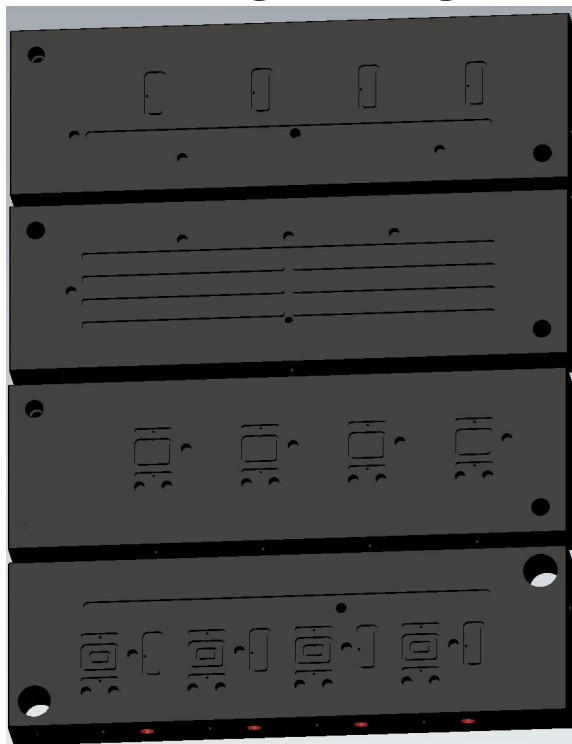
Drawings of Jigs

pick-up tool of
CF Stiffener ↖

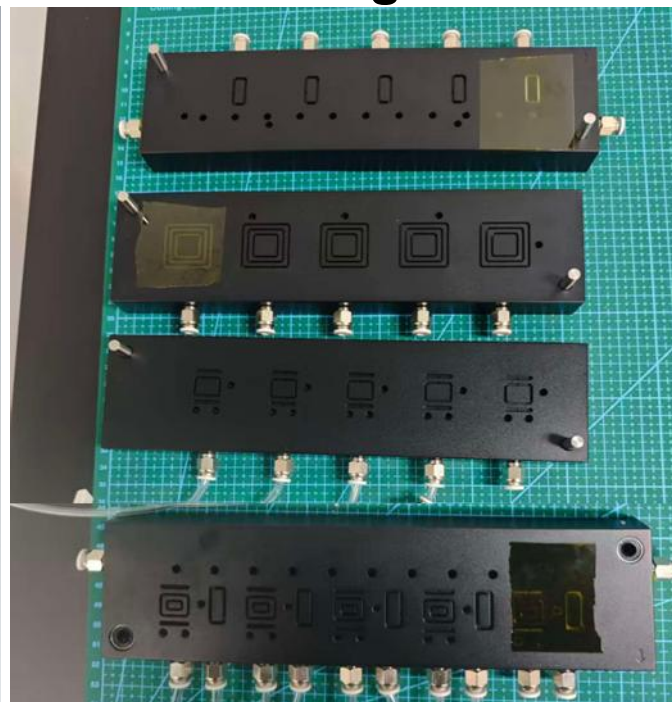
pick-up tool
of Hybrid ↖

Jig of Top Chips ↖

Jig of Bottom Chips ↖



Jigs

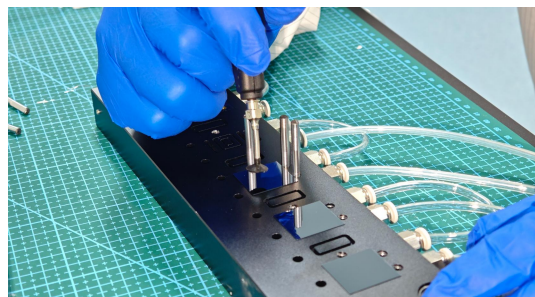
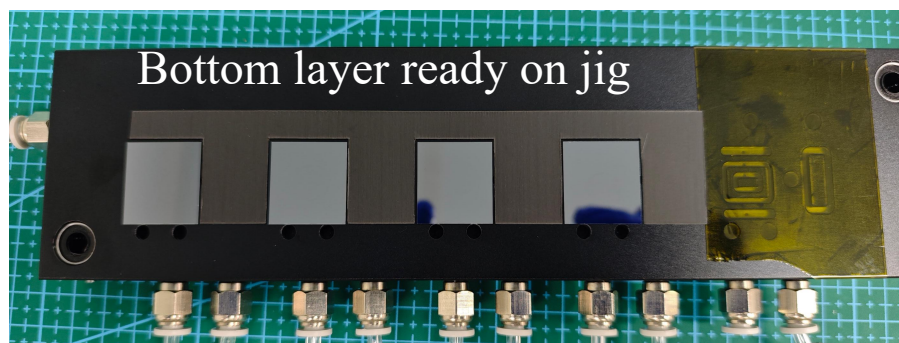
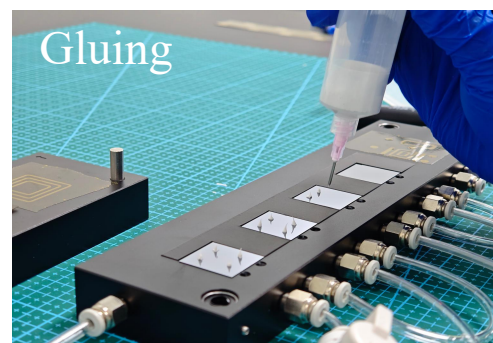
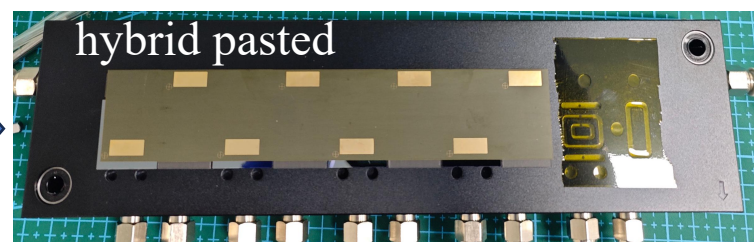
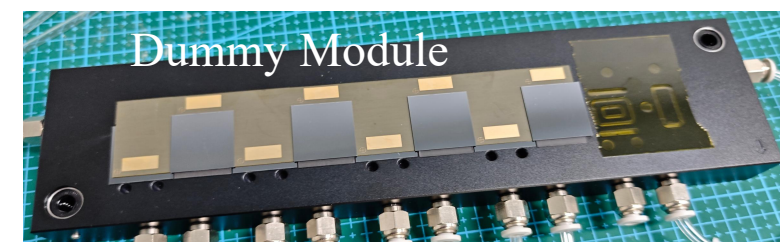


D-shaped pins

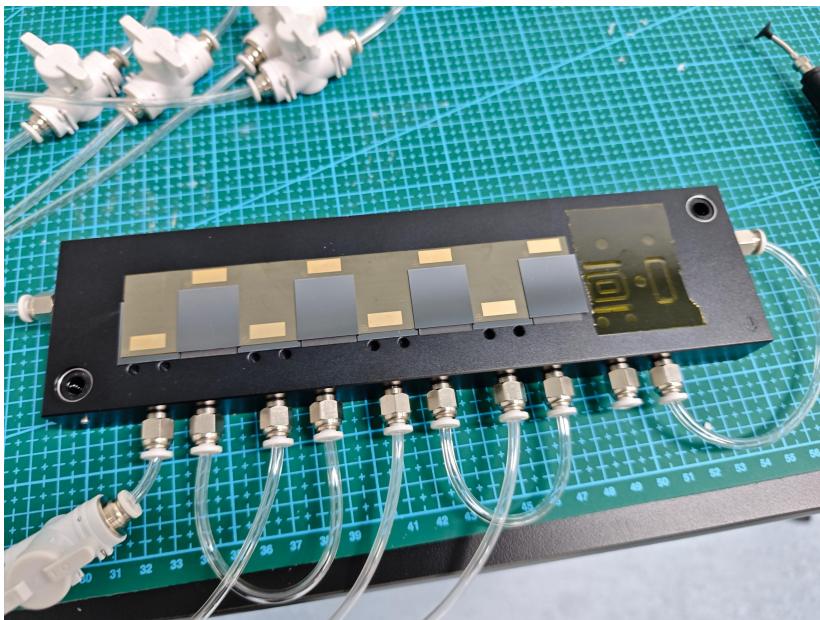


- Corresponding vacuum slots and positioning holes for each component are designed on every jig.
- The machining accuracy of the jigs is 0.01 mm.
- D-shape pins avoid chip contact during removal to ensure precision and protect chips.

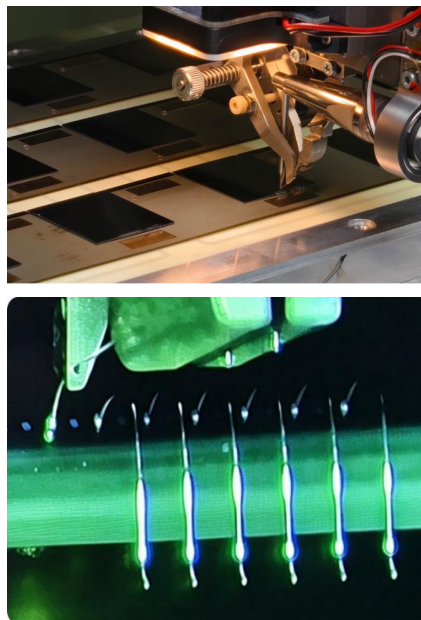
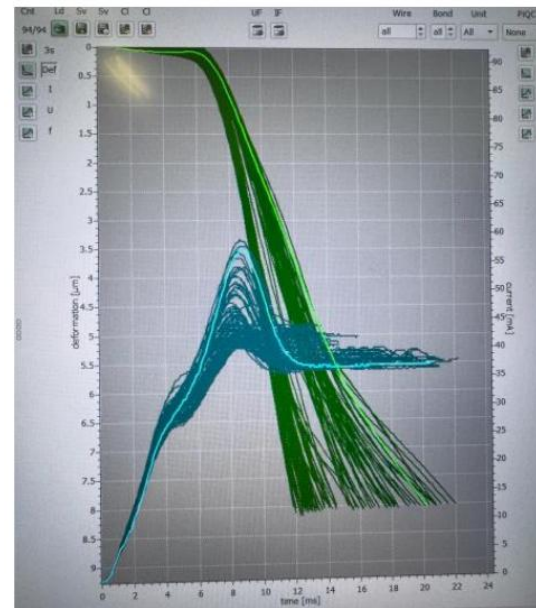
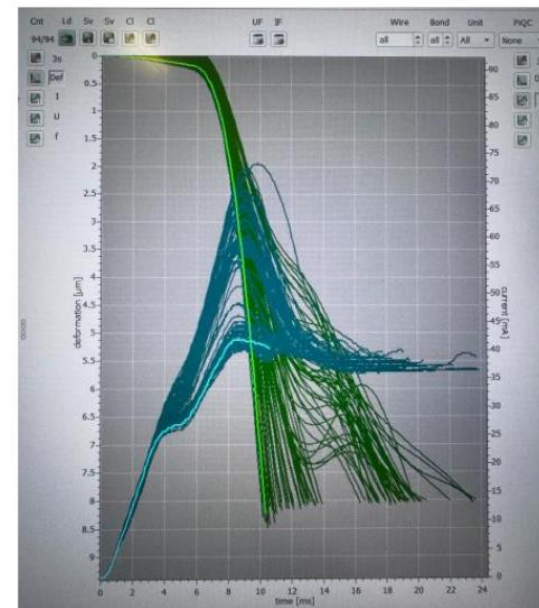
Module Prototype Assembly



Module Prototyping



Module Prototype

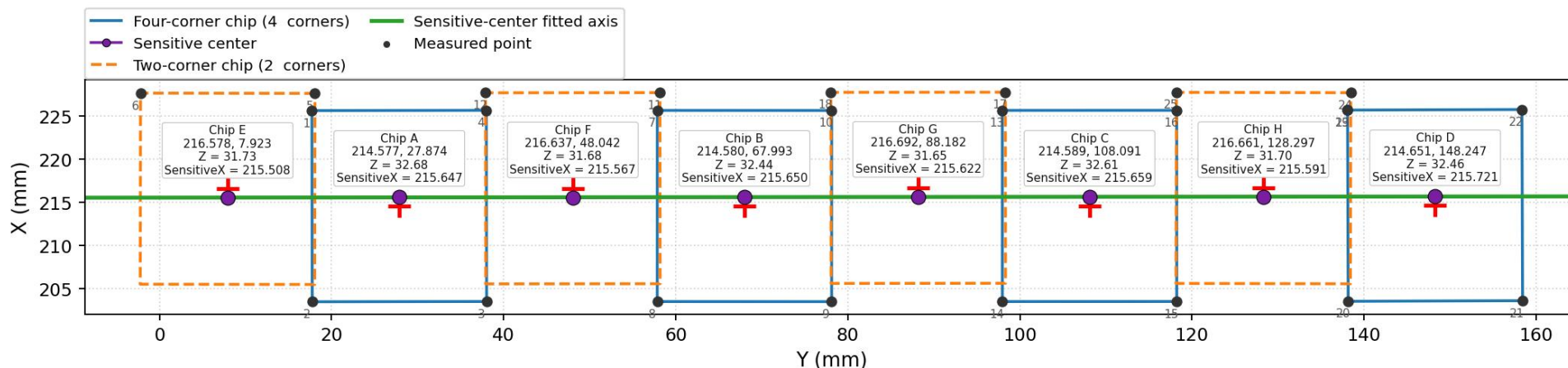


Deformation + US voltage curve for wire bonding on top (left) & bottom (right) chips

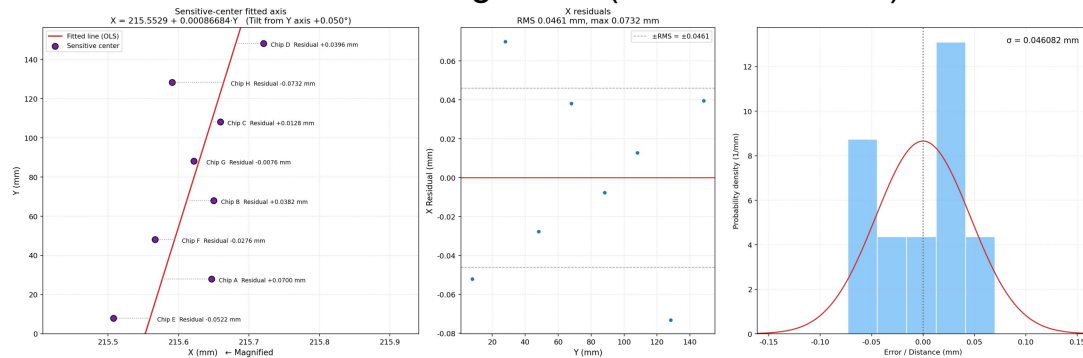
- Assembly is performed using the **jigs**.
- Position the chip using **D-shaped** pins and fix it with **vacuum**.
- **Wire bonding tests**: Two layers of the chips are both bonded.
- **Gantry** and **robot arm** will be used for automated assembly.

Metrology of Module Prototype

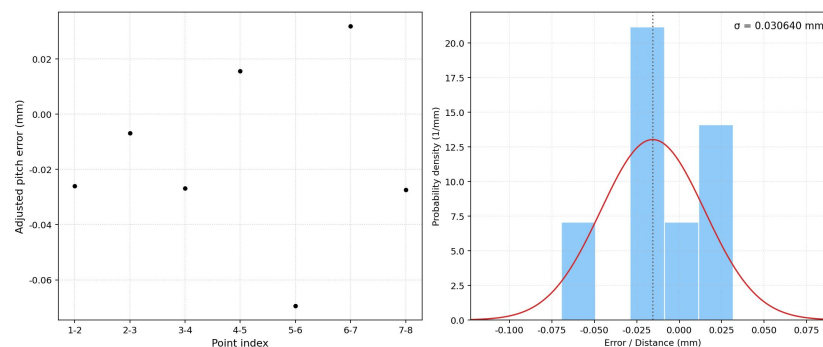
For the assembled module, the positions of 24 exposed fiducial targets on the sensor surfaces are measured to evaluate sensor alignment, gaps between adjacent sensors



Sensor Alignment (X-axis Deviation)



Sensor gap along X-axis



The metrology results confirm that the module assembly accuracy is within 50 μm

CF comb bare stave



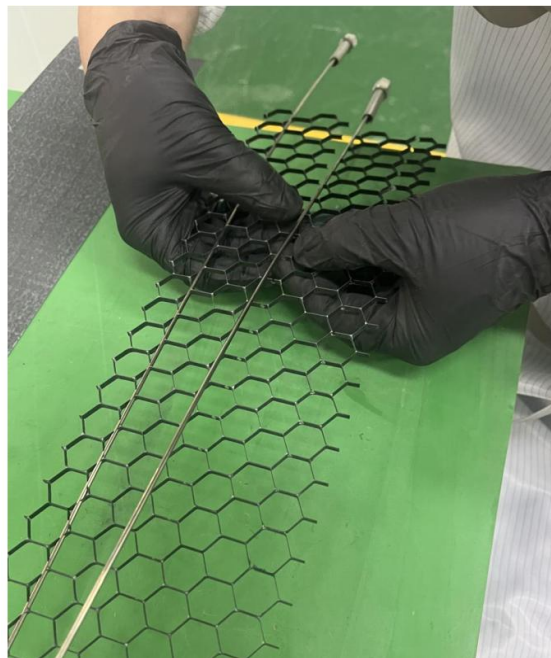
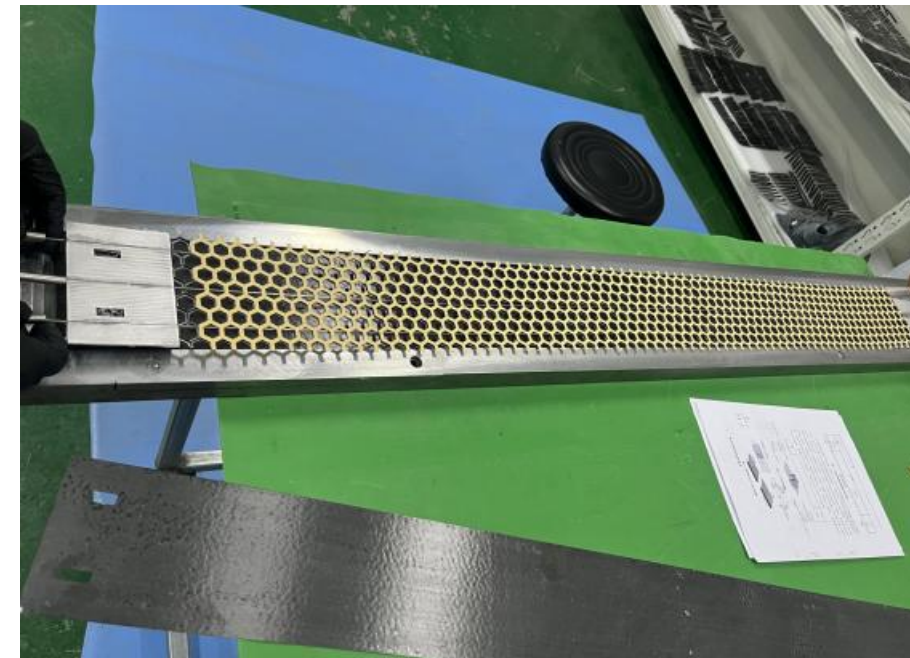
- Carbon fiber honeycomb + two carbon fiber surface

- Carbon fiber
- Titanium tube

At FTDR level, we expect the same materials as the current UT

- Structure foam: Evonik Rohacell 51 IG (0.051g/cm^3)
- Thermal foam: Allcomp K-9 carbon foam (0.2g/cm^3 , $\sim 35\text{W/m}\cdot\text{K}$)
- Carbon fiber: K13C2U high-modulus carbon fibers in EX1515 epoxy matrix (45 gsm, 0.21mm THICK)
- Ti cooling tube: D 2.75 mm, Thickness 0.1 mm

First bare stave prototype



Two CF facing + CF comb + 3 × Ti tubes + 2 × Al end of stave

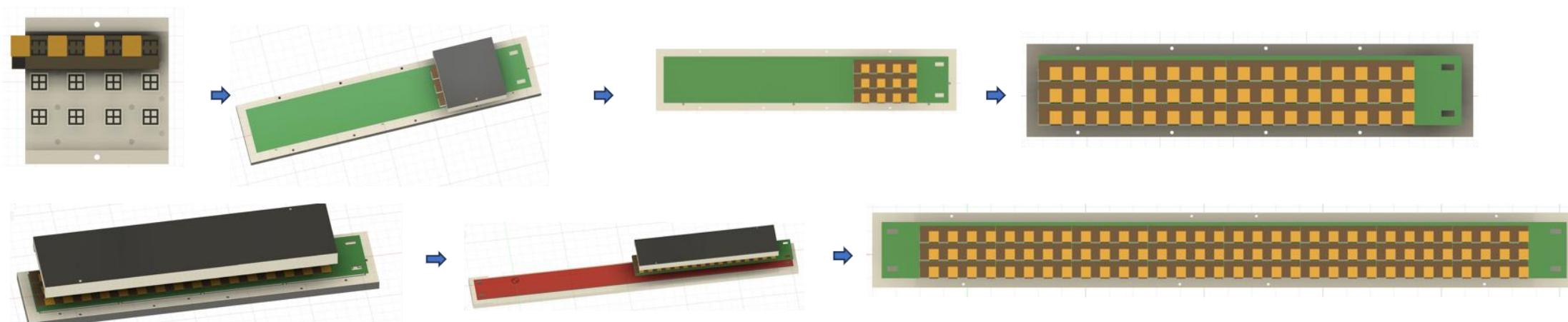
- Titanium tube-embedded Carbon fiber
- Assembling Al plates
- Place the first skin panel into the Jig
- Place the carbon fiber into the Jig

The mass in the active area: $23.2 + 12 \text{ (Ti)} \times 3 + 40 \text{ g} + 120 \times 2 \text{ g}$, with density $\sim 0.5 \text{ g/cm}^3$

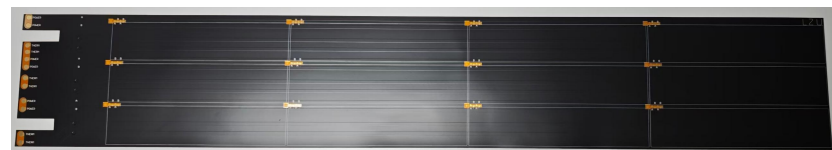
Stave Prototype



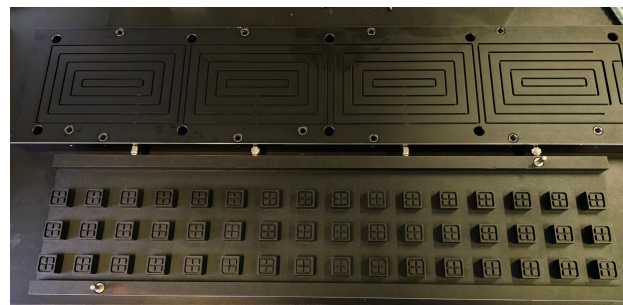
Thermal bare stave consist of Ti tubes and honeycomb panel, with 2 phase CO₂ in Ti tubes.



Stave assembly jigs design and assembly flowchart



Flex Cable



The stave assembly jigs have been manufactured, and assembly is currently in progress.

Objective: Evaluate stave cooling capacity under thermal load

- **Carbon fiber material:**

- Thermal interface material for the UP module -- 5 mm 10mm 15mm
- Thermal conduction

- **The small-scale thermal prototype stave:**

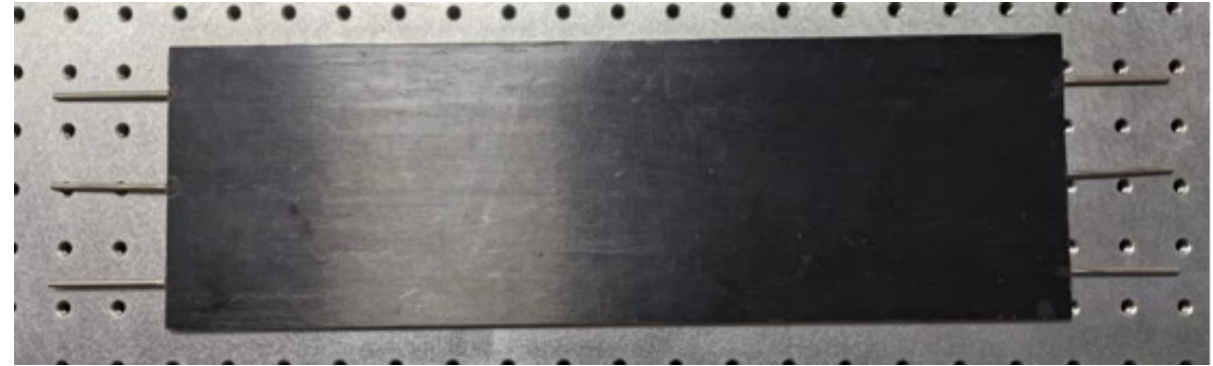
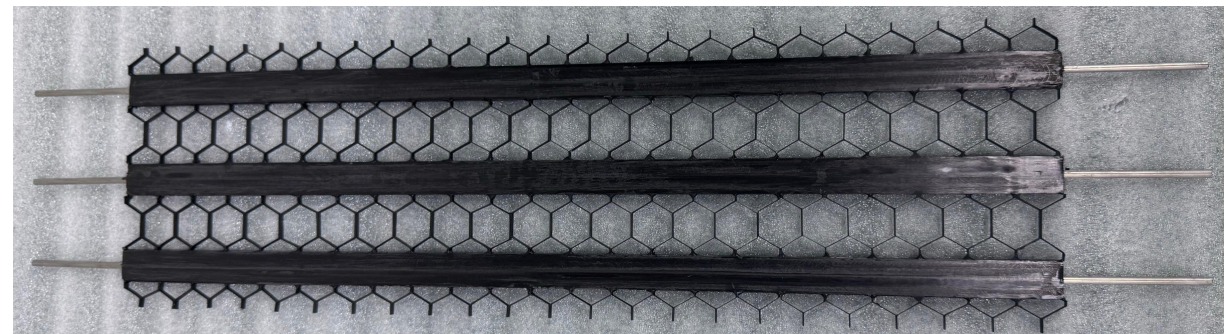
- Carbon fiber (400 mm × 120 mm × 4 mm)
- Titanium tubes (ID ~ 2.3 mm OD ~ 3 mm)
- Cooling by water

- **Thermal test:**

- Equivalent thermal conductivity of the small-scale thermal prototype stave from tube to surface
- Maximum coolable heat power

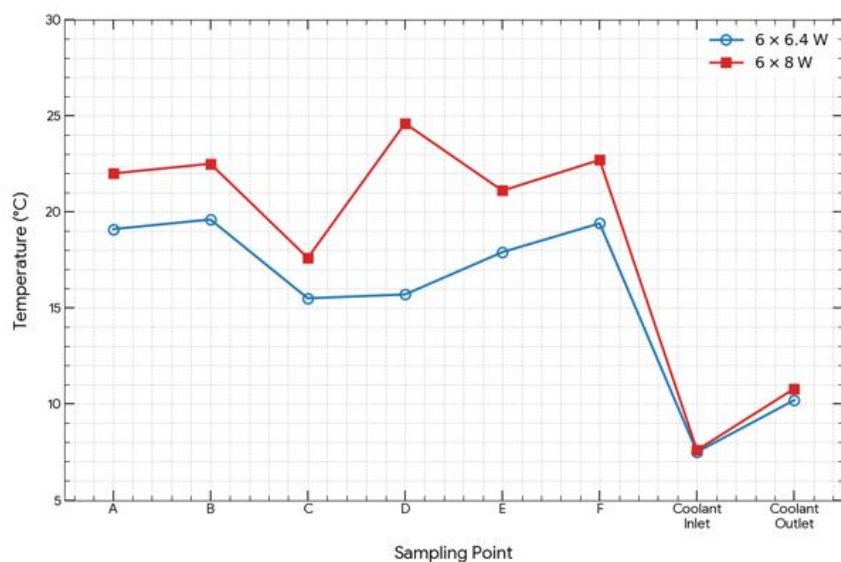
Test Configuration

- 6 tunable heating patches on carbon fiber board
- 12.8 W/m·K thermal grease interface: heating patches / bare stave
- 3 Ti tubes with 5 °C cooling water



Test Results

	A(°C)	B(°C)	C(°C)	D(°C)	E(°C)	F(°C)	Average(°C)	Coolant Inlet(°C)	Coolant Outlet(°C)
$6 \times 6.4 \text{ W}$	19.1	19.6	15.5	15.7	17.9	19.4	17.87	7.5	10.2
$6 \times 8 \text{ W}$	22	22.5	17.6	24.6	21.1	22.7	21.75	7.6	10.8



- Effective cooling achieved at : $6 \times 6.4 \text{ W}$, $6 \times 8 \text{ W}$
- At $6 \times 12 \text{ W}$:
- Temperature rise remains very gradual System maintains measurable cooling capacity

- Designed a 4-layer UP detector geometry with multi-level staggered overlap (chips, modules, and staves), effectively reduces dead area and enhances detector performance. Readout electronics are routed externally to minimize material budget and enhance tracking efficiency.
- Successfully built prototype modules and bare stave , with deformation-voltage tests confirming rigid and reliable support for ultrasonic wire bonding.
- Water-cooled bare stave tests (with embedded Ti tubes at 5°C) demonstrated effective cooling at nominal loads (38.4 W , 48 W), and sustained gentle temperature rise under an extreme heat load of 72 W ($6 \times 12\text{ W}$).

To do

- Full-Scale Prototyping: Fabricate full-scale thermal and electrical stave prototypes with production-grade components.
- System-Level Validation: Characterize high-speed data transmission, signal integrity, and multi-chip readout synchronization.
- Performance Stress Evaluation: Perform long-term thermo-mechanical stress testing and beam tests under realistic operational conditions.

Thank you!