UP bare stave design and thermal study

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on behalf of UP wp3 group

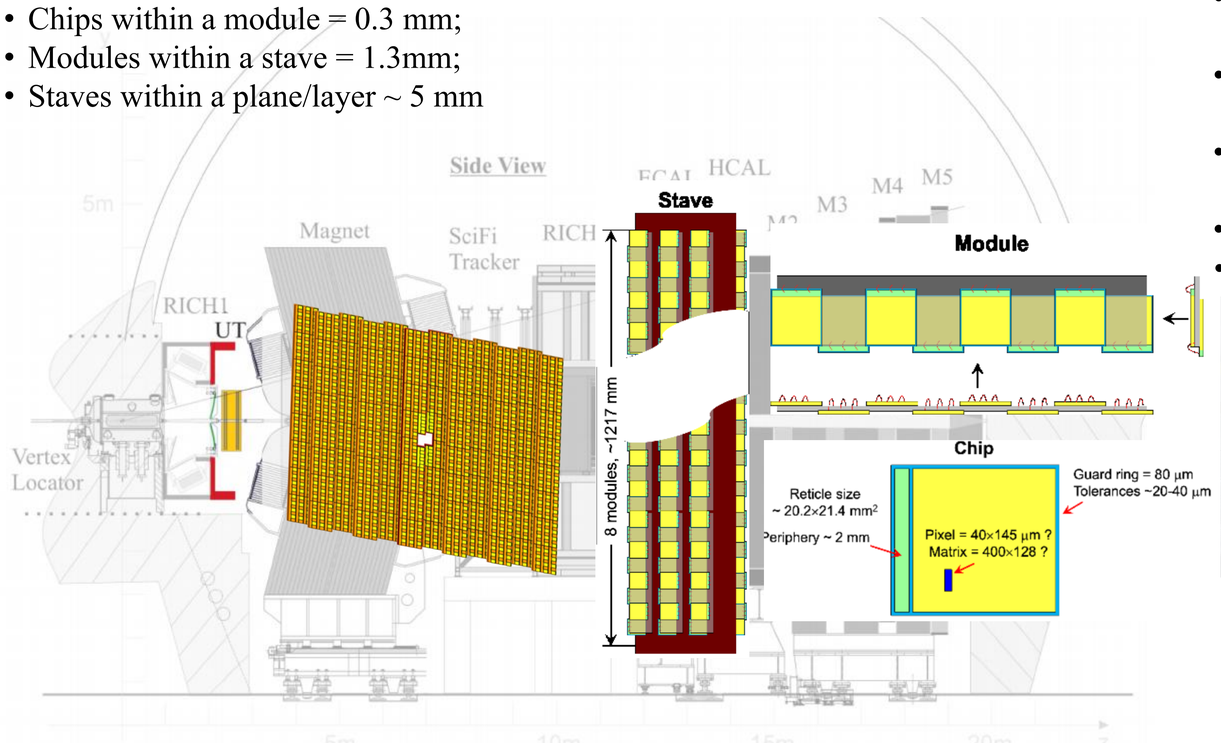
Upstream Pixel of LHCb

Layout:

- 1536 silicon sensors, organised in 4 planes, 48 vertical staves and 48 modules.

Detection overlap:

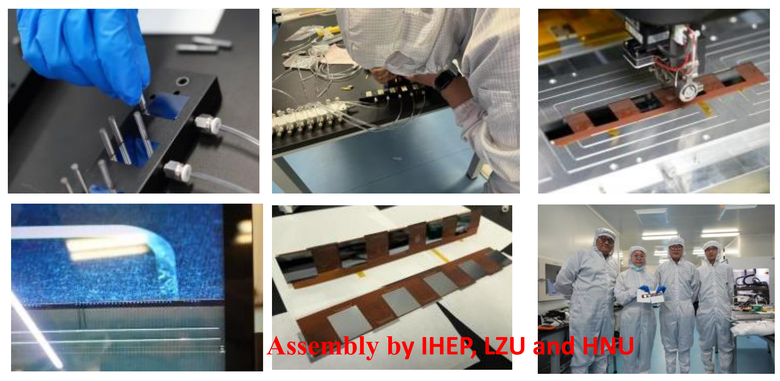
- Chips within a module = 0.3 mm;
- Modules within a stave = 1.3mm;
- Staves within a plane/layer ~ 5 mm

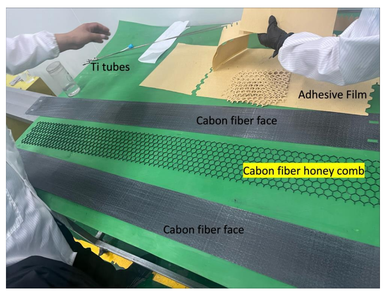


- Within a module, 4 adjacent chips are powered in serial. Maybe also daisy-chained for output e-link. They should have the same e-link/chip configuration.

First module and UP bare stave production

- **Jigs** based now. Using gantry for high precision **later**
  Designed by IHEP & LZU
- Chips positioning according to **D-shape** pins, with **vacuum** fixing
- **Align** the upper and lower jigs using positioning holes.
- Using **five-point method** to glue hybrid and chips.
- Wait for one day until the glue cures.
- Also with **wire bonding tests**: Two layers of the chips are both bonded => looks good

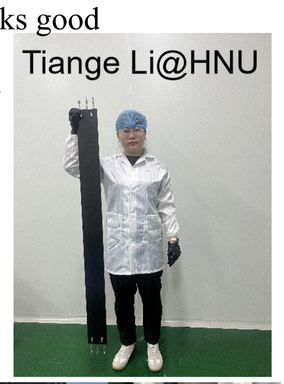


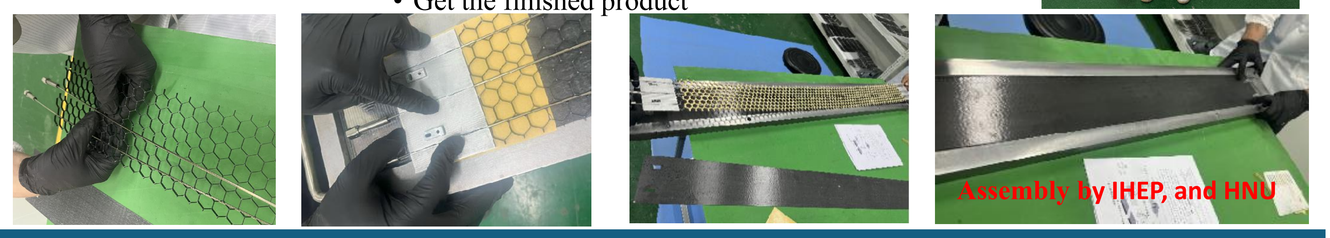


UP bare stave

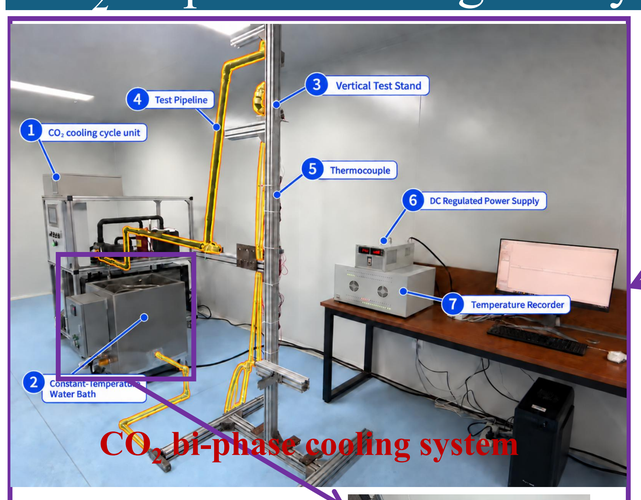
First **full-size bare stave prototype** from manufacturer

- Two CF facing + CF comb + 3x Ti tubes + 2x Al end of stave
- Ready for QA test + thermal/mechanical studies …
- Place the titanium tube into the carbon fiber comb.
- Fix the aluminum plates at both ends.
- Place the carbon fiber into the Jig
- High-temperature and high-pressure curing
- Get the finished product



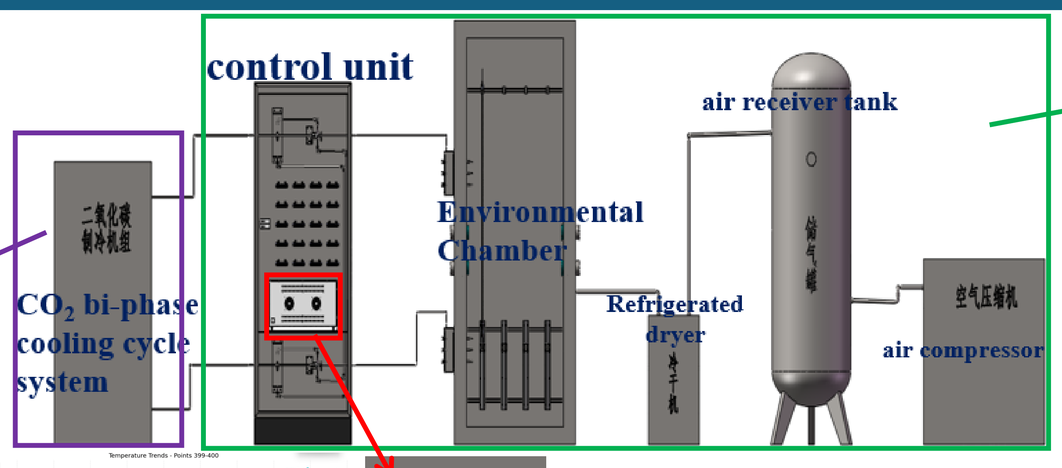


CO_2 bi-phase cooling test system



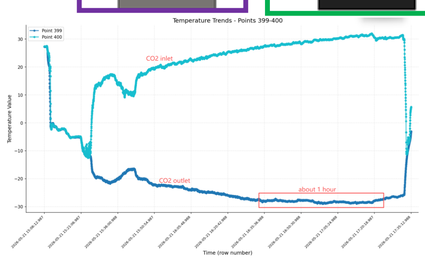
- Constant temperature water bath ensures that the thermal load of the entire loop remains constant.

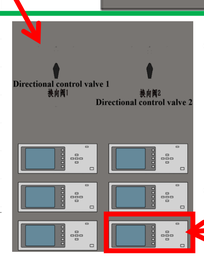




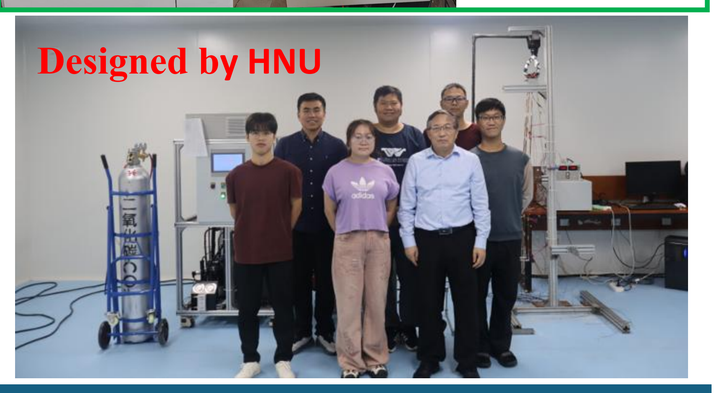


- Internal space: 2.5m* 0.8m* 0.8m (4 staves together)
- Temperatures: -30°C to 40°C
- Humidity: 10% to 80% RH.



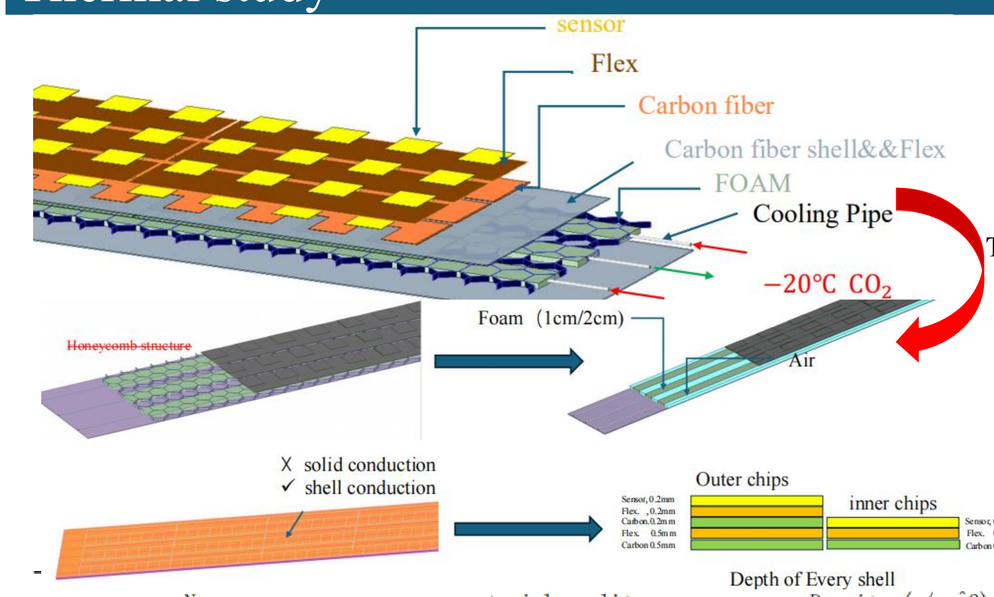


- **Directional control:** The flow direction of the liquid carbon dioxide in one of the three titanium tubes on the carbon fiber board can be changed.
- The outside of the environmental chamber is connected to a **temperature recorder**.

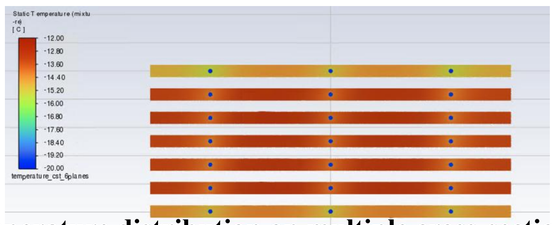


- The unit has passed the preliminary test and achieved stable output at -30°C.

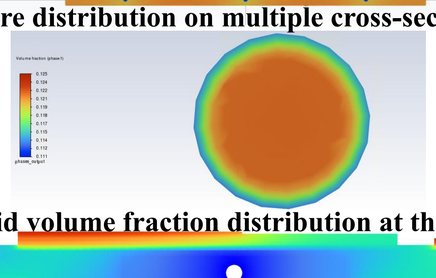
Thermal study



Model simplify

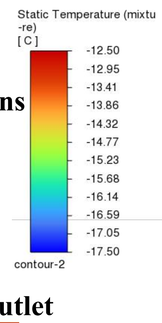


Temperature distribution on multiple cross-sections

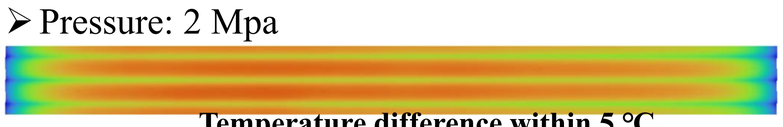


Liquid volume fraction distribution at the outlet

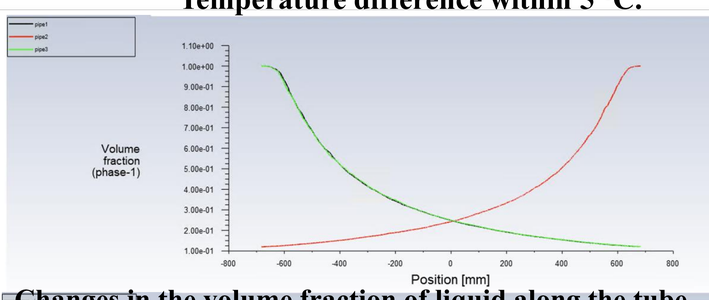
Temperature change across the cross-section



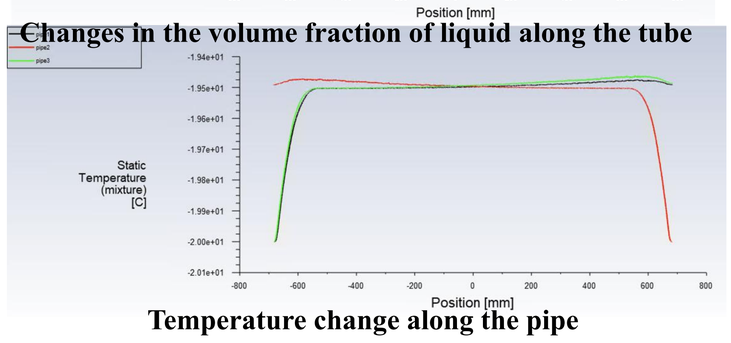
- **Power 2400W, flow rate 1.5g/s, sponge width 2cm**
  - Chips thermal power: 200 mW/cm²
  - flex power: 40 mW/cm²
  - UP box temp: 26.8 ℃
  - CO_2 input temp: -20℃,
  - Pressure: 2 Mpa



Temperature difference within 5 ℃.



Changes in the volume fraction of liquid along the tube



Temperature change along the pipe

Name	material quality	Density (g/cm^3)	specific heat(J/Kg K)	Thermal conductivity(W/mK) W/mK
Carbon fiber	carbon fiber plate	1.43	1130	105(z)
Support	foam	0.56	710	55
Flex	polyimide	1.42	1000	0.4
Sensor	silicon	2.33	703	149
Cooling pipe	titanium	4.43	526	6.7

Depth of Every shell

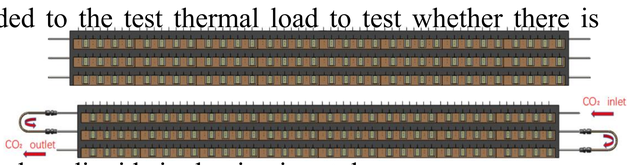
Name	Density(g/cm^3)	specific heat(J/Kg K)	Thermal conductivity(W/mK)	Viscosity(kg/m s)	molecular weight(kg/mol)	Standard state enthalpy (J/kgmol)
Co2 (liquid)	0.9183	2446	0.109	9.657e-05	44	0
Co2 (Gas)	0.103	1828	0.021	1.575e-05	44	1.67e+07

Conclusions

- A relatively mature cooling system has been built (designed by Hunan University).
- Mechanical prototype assembly and bare stave assembly have been completed.
- Thermal simulation test on the structure of carbon fiber honeycomb for bare stave.
- Simulation result: the temperature difference within 5 ℃.

Next

- **Cooling experiment:**
  - Three titanium tubes with heating films attached are added to the test thermal load to test whether there is uneven liquid distribution in the pipeline.
- **Temperature Uniformity Test**
  - Test Uniformity on a Single Module and the Entire Stave.
  - Test uniformity under different flow directions of liquid carbon dioxide in the titanium tube.



The 2026 International Workshop on the High Energy Circular Electron Positron Collider