

Summary of INFN LNF Visit and Forum on tracking detector mechanics 2026 & DRD8 collaboration meeting

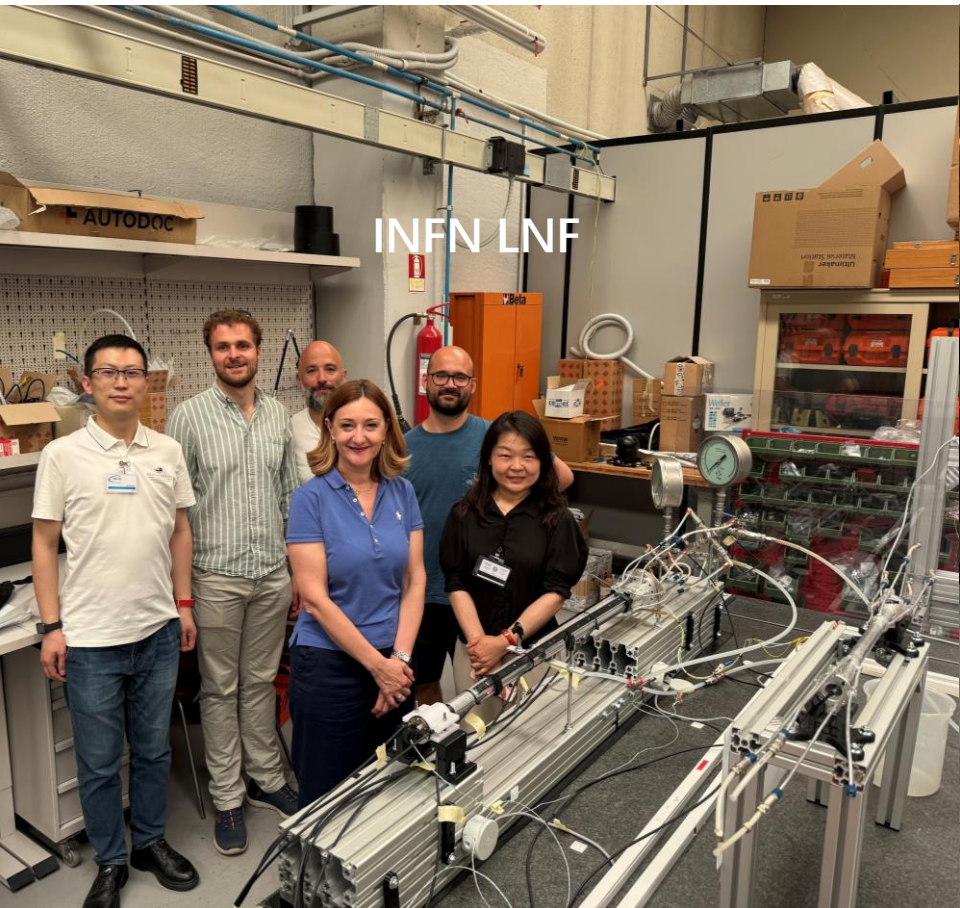
Xiaoyan Ma, Haoyu Shi, Xiaohui Qian

June 15, 2026

For CEPC day, IHEP

Trip Overview

- INFN LNF visit
- 14th Forum on tracking detector mechanics
- 4th DRD8 collaboration meeting



INFN LNF visit

■ Colloquium-style seminar in LNF

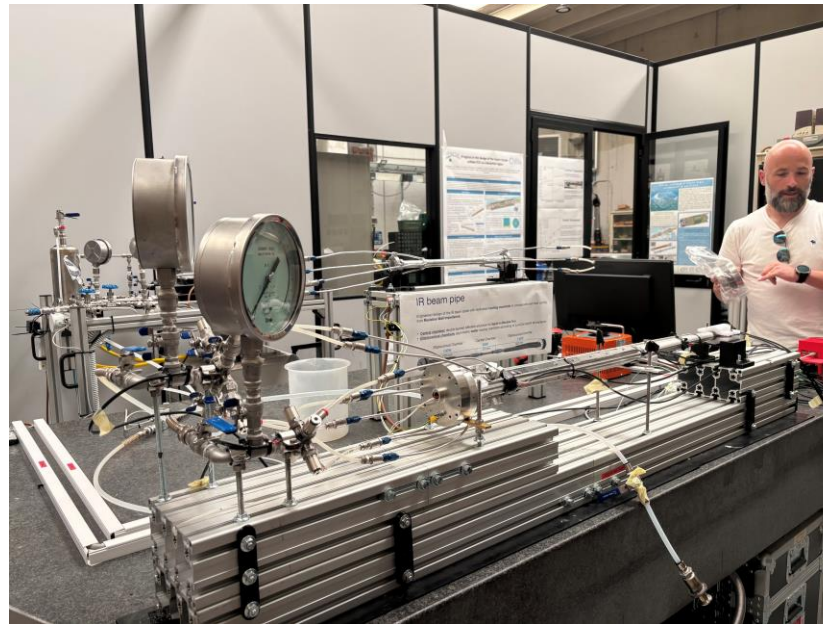
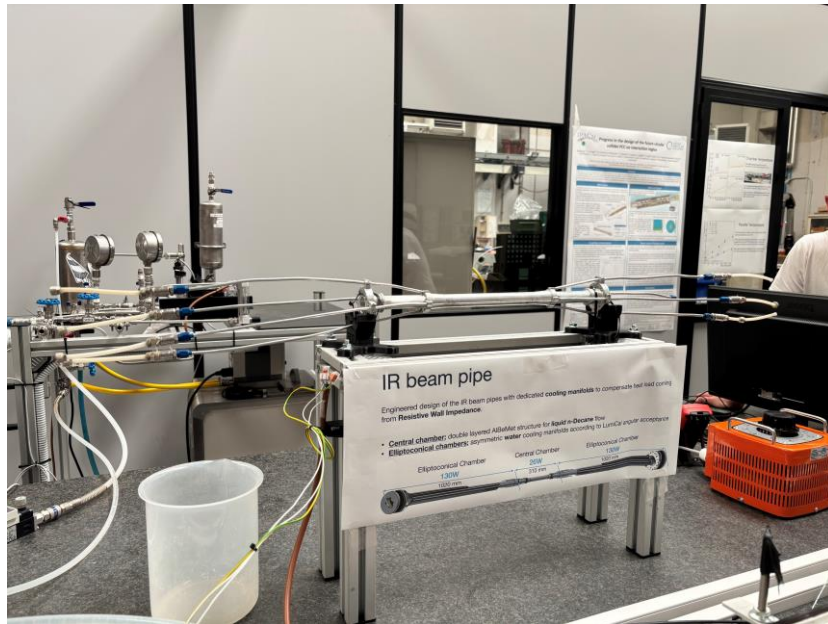


Talk “The baseline design of the CEPC”, by Haoyu Shi

INFN LNF visit

FCC-ee Beam Pipe Mockup

- ❑ AlBeMet162 (design) → Al (mockup)
- ❑ Similar dimension: ID 20mm, thickness 0.35mm → 0.35(O), 0.45mm(I), cooling channel 1mm → 0.9mm
- ❑ Heat load: ~30W (central area), 130W (extend pip, each side)



Tests

- ❑ Welding procedure testing
- ❑ Cooling system validation (Thermal testing in progress)
- ❑ Services assembly procedure

Potential further optimization

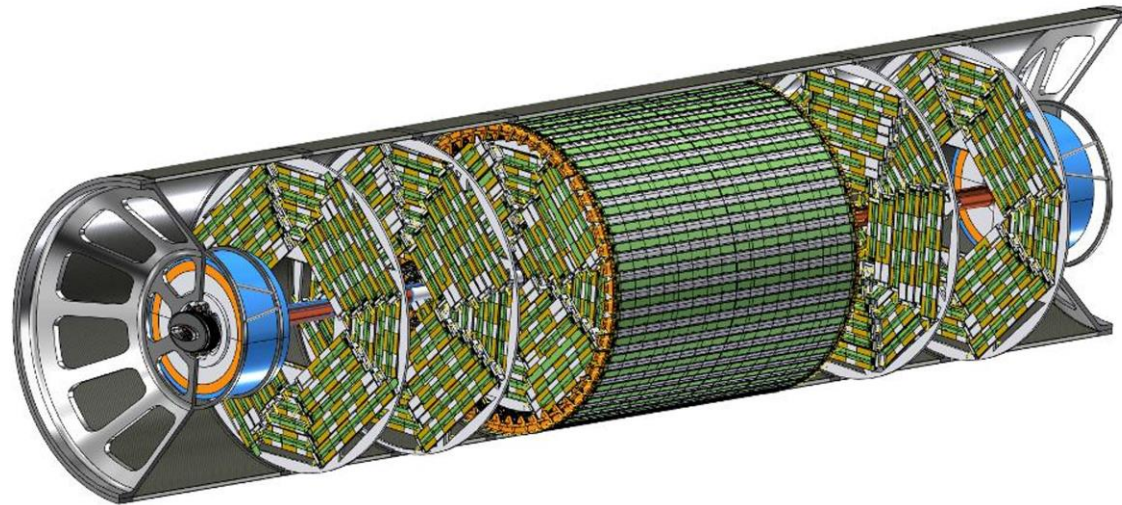
- ❑ Material budget reduction
- ❑ Manufacturing and operation performances improving



INFN LNF visit

FCC-ee IR full-scale mockup plan

- ❑ Validate the beam pipes cooling system
- ❑ Validate the inner VTX air-cooling system
- ❑ Validate support design
- ❑ Check IR assembly procedure
- ❑ Service assembly test: Find best solution for service arrangement
- ❑



- Beam Pipe
- Inner vertex
- Lumical
- Middle vertex
- Outer vertex
- Disks FW and BX
- Support Tube

The goal is to finish this assembly test in this year

Overview of Participated Meetings

14th Forum on tracking detector mechanics

- To discuss issues of engineering and integration for present and future tracking systems
- Topics
 - ❑ Advanced **Cooling** System Technologies
 - ❑ Qualification of **Novel Materials**: Mechanical, Thermal & Radiation Hardness
 - ❑ Engineering for **Complex Mechanical Systems**: Vacuum Compatibility, Lightweight, Precision Alignment & Vibration Mitigation
 - ❑ **Environmental Control Systems**: Robotics, Automation & Intelligent Integrated Architectures
 - ❑ Tracking Systems Lifecycle: **Integration, Operation, Maintenance & Decommissioning**
 - ❑ Service & Lifecycle Management: **Low Mass Budget, High Performance & Smart Integration**
 - ❑ **Numerical Simulations**: FEA with Experimental Correlation, AR & Advanced Tools

*Joint **Forum** on tracking detector mechanics and **DRD8** collaboration meeting (June 1-5)*

Overview of Participated Meetings

4th DRD8 collaboration meeting

■ Work Packages in DRD8

- ❑ **WP1:** Global system design and integration
- ❑ **WP2:** Low-mass mechanics and thermal management
- ❑ **WP3:** Detector cooling
- ❑ **WP4:** Design and qualification tools

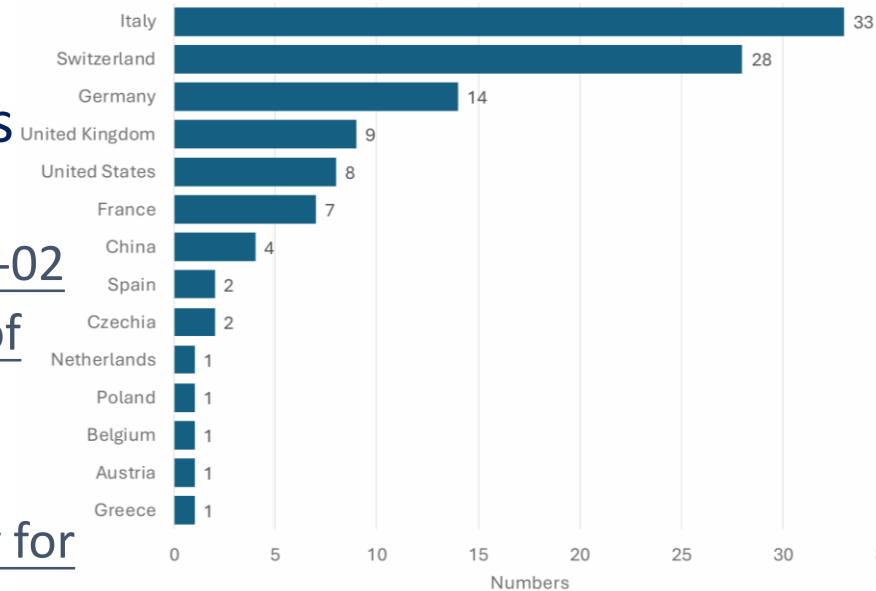
D1.1.1	Ultra-thin beam pipe	Deliver an ultra-thin beam pipe compatible with vacuum operational requirements.	July 2025	July 2027	CH-CERN, CN-IHEP, IT-INFN.LNF
D1.1.2	Alignment system prototype	Develop and evaluate hardware alignment prototype system	July 2025	July 2028	DE-UNI-FR, CH-CERN
D1.1.3	Retractable detectors	Develop a design for a retractable vertex detector with minimum material budget that could withstand the primary and secondary vacuum.	July 2025	July 2028	CH-CERN
D1.1.4	Mock-up & integration	Delivery of a mock-up of the interaction region with integration of vertex detector and services.	July 2025	July 2028	CN-IHEP, IT-INFN.LNF IT-INFN.PI
D1.2.2	Legged robots and robotic airships in cavern	Deliver robots able to perform an autonomous inspection/monitoring of the detector cavern environment.	July 2025	July 2028	CN-IHEP, CH-CERN

D3.2.2	Micro-channel prototypes	Prototypes based on thermo-compression/hyperbaric process or hybrid technologies	July 2025	April 2027	CN-IHEP, FR-IN2P3.CPPM, FR-IN2P3.LPNHE, FR-IN2P3.LPSC, FR-LEGI
M3.2.2	Fluidic and thermal results of integrated systems	Report summarising results of demonstrators	July 2025	October 2027	ES-IMB, ES-IFIC, DE-DESY
M3.2.3	Bi-phase CO2 thermo-fluidic models	Thermo-fluidic model development for micro-channels and annular flows. Heat exchanger characterisation and interconnections	July 2025	July 2028	CN-IHEP, FR-IN2P3.CPPM, FR-IN2P3.LPNHE, FR-IN2P3.LPSC, FR-LEGI
M3.1.3	sCO2 properties	Publication on detailed properties of sCO2 flows in small pipes	July 2025	January 2027	CH-CERN, CN-IHEP, DE-FH-OG
D3.1.1	Krypton system development	Development of a working prototype of a krypton cooling system	July 2025	January 2028	CH-CERN, NO-NTNU
M3.1.4	Krypton cooling performance	Performance testing of evaporative Kr in detector cooling tubes	July 2025	July 2028	CH-CERN, NO-NTNU
D3.1.2	sCO2 system development	Development of a working prototype of an sCO2 cooling system	July 2025	July 2028	CH-CERN, CN-IHEP, DE-FH-OG

Joint *Forum* on tracking detector mechanics and *DRD8* collaboration meeting (June 1-5)

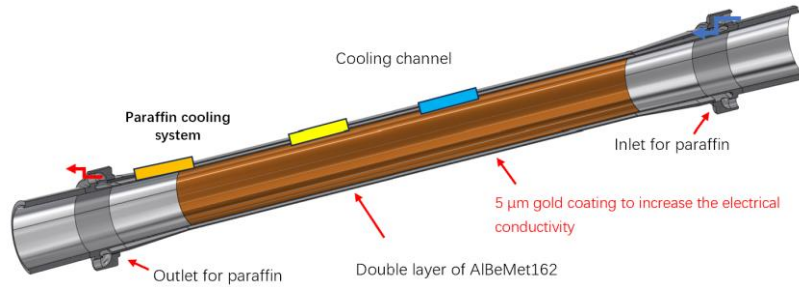
Overview of Participated Meetings

- Record number of participants
 - 112 attendants
 - 3+1 (online) from IHEP
- Record number of contributions: stimulating fruitful discussions
 - 4 talks from IHEP
 - **Xuhao Yuan**: The upgrade of the silicon tracking detector at AMS-02
 - **Xiaoyan Ma**: Structural Design and Thermal Performance Study of CEPC Beam Pipe
 - **Xiaohui Qian (online)**: Triangular carbon fiber beam for CEPC-ITK
 - **Haoyu Shi**: Robotic Radiation Survey and Localization Technology for The Experimental Hall
- Our reflections
 - Rewarding experience: gained significant sights
 - Not highly involved in such events before, should participate more in future
 - Comparing between others' achievements and our status
 - Positive reception: Our talks were well received, capture people' interest and attention to our work



Beam Pipe (FCC-ee research)

■ R&D



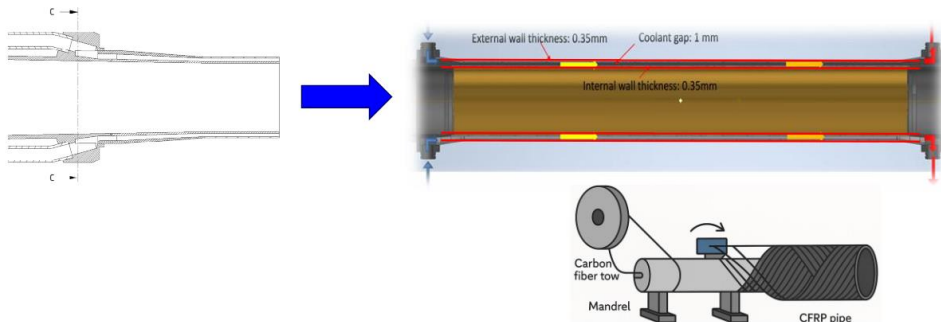
AlBeMet 162 (62% Be, 38% Al) as main material

- Outer layer: 0.35mm of AlBeMet
- 1mm gap for paraffin
- Inner layer: 0.35mm of AlBeMet

The carbon-fiber beam pipe is also under considering and R&D

Beam pipe material budget is > x3 VTX detector layer → Impact parameter resolution is jeopardised

- Exploit Carbon Fibre Reinforced Thermoplastic Composites (CFRTP) technique to reduce liquid paraffin channel and overcome manufacturing problems with metal at inlet/outlet.
 - Study to be performed between INFN and CERN-EP



Beam pipe design parameters (FCC-ee VS. CEPC)

		FCC-ee	CEPC
Outer layer	ID (mm)	22.7	20.8
	Thickness(mm)	0.35	0.15
	Length (mm)		170
Inner layer	ID(mm)	20	20
	Thickness(mm)	0.35	0.2
	Length (mm)		220
Cooling channel (mm)		1	0.2
HOM (W) in Central area		30	220
Material		AlBeMet 162	Be

■ Mockup validation plan

- Beam pipe mockup: thermal test in progress
- IR mockup (assembled VTX, Lumical...): assembly test in this year
- AlBeMet → Al

Beam Pipe (CEPC status)

■ R&D

- Ultra-thin Be pipe samples developed successfully by CNMC Ningxia Orient Group Co.

- Ø20 mm (ID), 0.2mm (thickness), 100mm (Length)

- Ø30 mm (ID), 0.4mm (thickness), 200mm (Length)

- Based on samples Experience from the company

- 0.15mm wall thickness, 100mm length achievable too

- Length extended to ~200mm not yet Guaranteed,
need further trial and breakthroughs in the process

- Encourage them to apply for funding support to continue process research.



Challenges of ultra-thin and long Be pipe:
crack, machining precision, Be-Al welding

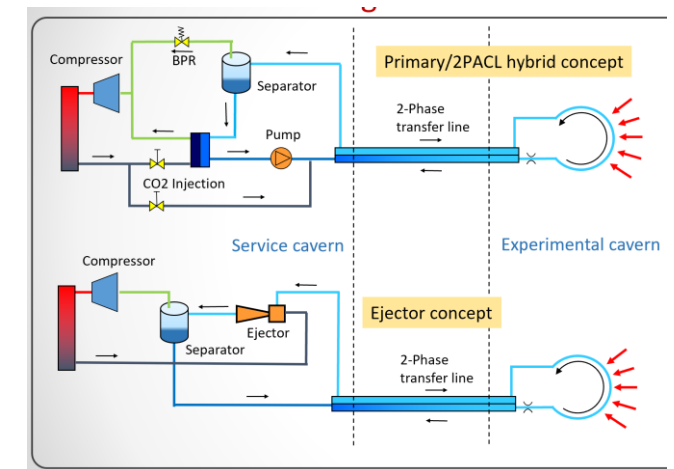
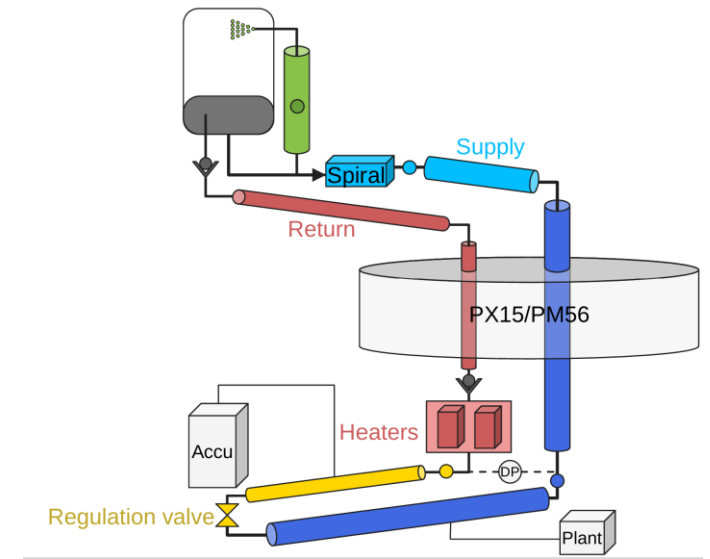
■ Cooling mockup validation plan

- Be→Al
- Simulation finished
- Mockup design and manufacturing investigation in progress
- Cooling test: 2027

During meeting, we presented the development of our Be tube samples, demonstrating our process capability

CO₂ cooling (Others' Research Developments)

- **Core Positioning:** default technology for HEP detectors (represented by 2PACL), operating temperature from +20°C to -40°C
- **Large-scale deployment ongoing:** ATLAS & CMS Phase-2 systems installed, total CMS cooling capacity 550 kW (100 kW per unit at -45°C)
- **Key challenges**
 - 2PACL limited by pump subcooling ($\approx -40^\circ\text{C}$ minimum)
 - Vertical risers cause significant static pressure loss
 - Oil-free compressors lack industrial maturity and funding.
- **Development**
 - **Surface storage & thermosiphon:** Pump-free CO₂ circulation achieved using gravity and buoyancy over ~ 70 m vertical drop
 - **Ejector cycle developed:** replaces mechanical pump, enables operation near CO₂ triple point (-55°C) and surface plant placement

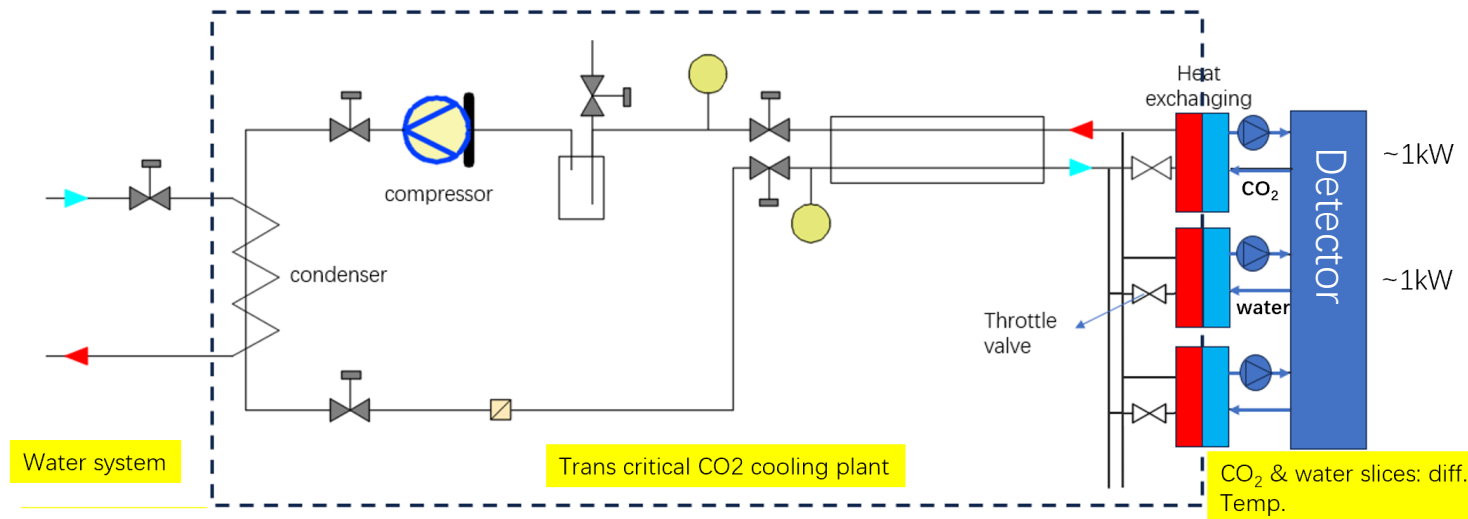


2PACL: Two-Phase Accumulator Controlled Loop

CO₂ cooling (CEPC status)

■ Research plan

- Cooling plant system design: provide at less 350 kW power for detector
 - Design slice systems : provide different temperatures for detectors
 - Selection of Components\equipment layout onsite
- 2026
- Verification of key components function: accumulator, condensation, high pressure connector... (2027)
 - Small prototype: 2027-2028



Preliminary consideration of flow diagram for small prototype of CO₂ cooling system

Cold plate (Others' research)

- Trends: lower mass, higher heat flux, passive, integrated solutions

Project	Material solution	Key features
FCC-ee / ALICE ITS2	Carbon fiber + polyimide pipes	High thermal conductivity, embedded tubes
Belle II oVTX	CFRP skins + foam core + Kapton	Ω -shape, ultra-low mass
Belle II iVTX	Thermal Pyrolytic Graphite (TPG)	No fluid, in-plane $k = 1500 \text{ W/m}\cdot\text{K}$
HENAPIX	Silicon vapor chamber + nanofibers	Passive, 360° orientation, no pump
FBK / INFN (TPX4)	Si microchannels (DRIE + direct bonding)	CO ₂ boiling, high pressure (~180 bar)

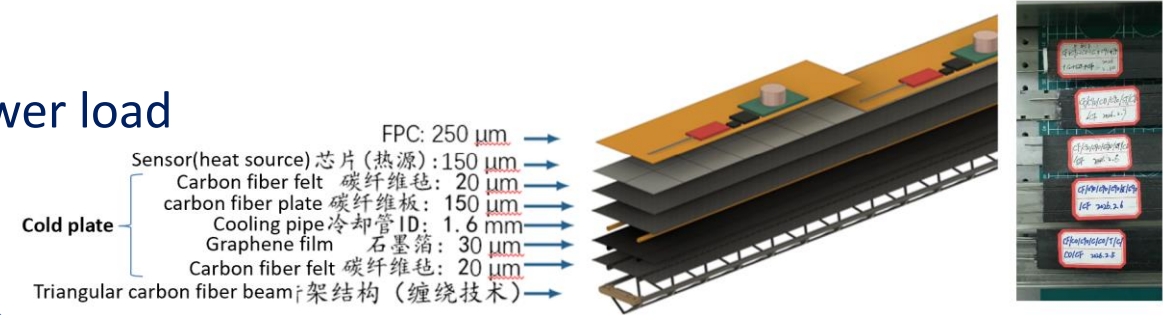
- Four main technology paths: CO₂ boiling microchannels, carbon-fiber embedded tubes, TPG (Thermal pyrolytic graphite) conduction, and nanofiber heat pipes
- Most are in prototype testing & simulation stage

Cold plate (CEPC status)

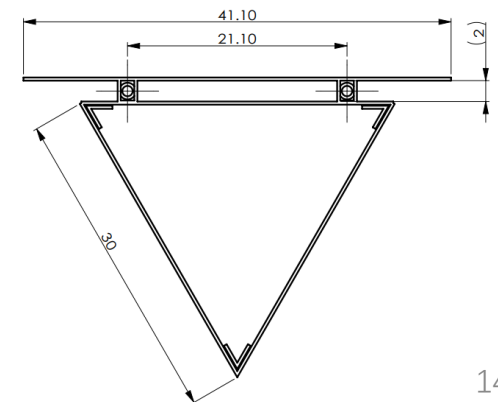
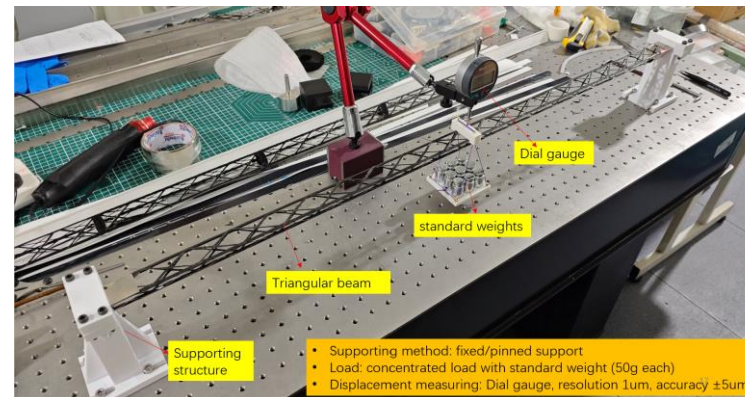
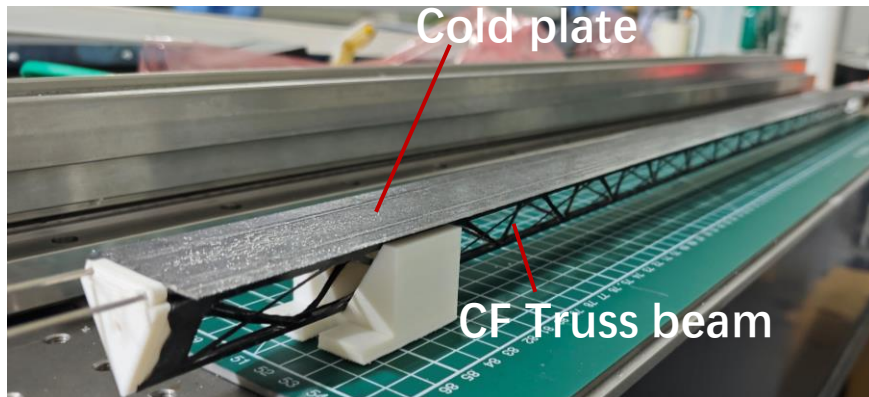
Design, Fabrication, and Testing of CF truss beam for CEPC-ITK was talked by Xiaohui in DRD8 meeting

- Successfully manufactured the triangular CF truss beam and cold plate prototypes
- Process addressed
- Deformation: Test & FEA results matches well under lower load
- Cold plate research on ITK

- Could be use in TPC, ECAL, HCAL...
- **Progress:** mold is under design, candidate powders to increase thermal conductivity: Boron nitride, aluminum nitride
- **Manufacturing and preliminary test:** 2026
- **Process optimization to increase thermal conductivity :**2026-2027



- People were quite interested in the talk
- Consulted Xiaohui on technical details
- Suggestion: pay attention to flatness issue—lessons from CMS



Assembly of triangular truss beam and cold plate

Static mechanical test of triangular beam

VTX cooling (Others' research)

■ Overall trends

- Air cooling as mainstream (low mass, no leak risk)
- Sensor integration: curved sensors+ monolithic microchannels
- Structure design: CF+ foam core+ air channels
- Thermal management target: 50-100mw/cm², $\Delta T < 5-7^{\circ}\text{C}$
- Validation: Full-scale prototype+ wind tunnel + long-term stability tests

■ Key challenges: Natural convection, Curved sensor integration, Long-term stability

■ Research status

Project	Cooling	Key Parameters	Features
ALICE ITS3	Forced air	8 m/s, 20°C inlet	Curved sensors, $\Delta T < 7^{\circ}\text{C}$, sub- μm vibration
FCC-ee Vertex	Air (sealed ducts)	50 mW/cm ² , 3 layers	Compressed air system, multi-layer thermal study
ePIC OB	Internal air	L3/L4 staves	CF I-beam, natural convection significant
Belle II iVTX	TPG conduction	$k = 1500 \text{ W/m}\cdot\text{K}$	Passive, no fluid, $X_0 = 0.202\%$ per 0.38 mm
Belle II oVTX	Single-phase liquid	10°C supply, $\Delta P = 0.36 \text{ bar}$	Kapton tubes, $T_{\text{peak}} < 29^{\circ}\text{C}$
FCC-SEED	Air (R&D)	50 mW/cm ² , $R \geq 17 \text{ mm}$	Curved sensors + mechanical integration

Air cooling validated, RMS displacement < 0.4 μm

challenges: dust, conductivity, CTE

Curved sensors successful, $R = 20 \text{ mm}$, 50–60 μm thick, power similar to flat

VTX cooling (CEPC status)

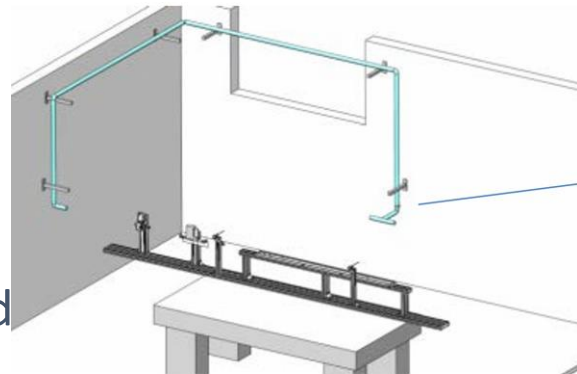
■ Cooling test plan

Phase	Objective	Content	Purpose	
1. Single-layer flat	Preliminary validation	Two lengths (L1 & L4), both using L1 width	Test basic system functionality	Designed and under fabricated
2. Single-layer cylindrical	Performance evaluation	Integrate heating layer + CF support	Evaluate cooling performance under real geometry	2026-2027
3. Multi-layer cylindrical	System validation	Multi-layer + beam pipe mock-up + air cavity	Validate overall VTX thermal management	2027

■ Progress of the first phase test

- Test system & platform : components purchased and mostly ready (Air compressor, piping, fittings...)
- Temp. acquisition: 2×7-channel modules purchased; interface design in progress
- Air cavity (inner layer): order placed
- CF support sample (inner layer): manufactured
- Heating layer (2nd version): in progress

冷干机下游至减压阀上游气路采用铝管



空压机散热口专门的排风管道



Plan to give a presentation at next year's Forum with more testing results

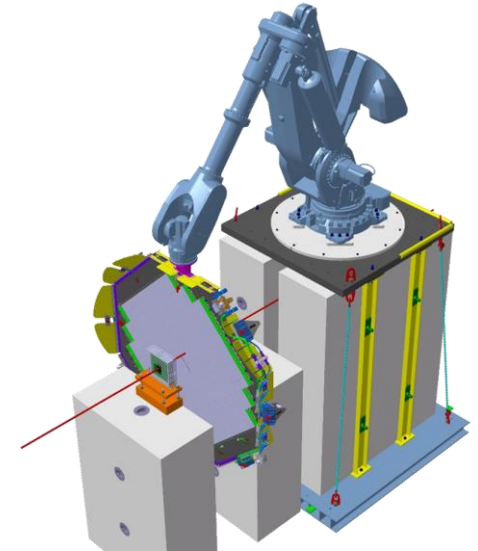
Robotic (others' research)

■ Overall Objectives

- Robotics as core component of FCC safety & availability: space reserved from design phase
- Improve availability & reduce human risk via automation & teleoperation

■ Key use cases

- Robotic arms for installation, maintenance and other
- Deploying robots for detector caverns inspection



Use Case	Description	Impact
Girder alignment	Fully autonomous alignment	Proof of concept completed
Smoke alarm validation	Robot inspection to avoid false stops	+2.9% availability
Power converter swap	Automated module replacement in racks	+3.4% availability
Haptic teleoperation	Virtual 3D objects guide operator	Avoid contact with delicate hardware
Human detection & vital signs	Heart rate, respiration, temperature monitoring	Improved teleoperation awareness



Robotic (CEPC status)

- IHEP currently focused on D1.2.2, to fulfill the schedule of DRD8

D1.2.2	Legged robots and robotic airships in cavern	Deliver robots able to perform an autonomous inspection/monitoring of the detector cavern environment.	July 2025	July 2028	CN-IHEP, CH-CERN
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- Motivation

- The robotic arms used in detector installation
- The monitors for radiation or magnetic fields with robots
- The network and positioning system

- Progress

- Positioning sensor has been purchased and test

- Next Plan and goal (2026-2028)

- Validate positioning in real caverns (e.g., BESIII)
- Upgrade from cart to robotic dogs
- Adopt mobile mesh network for navigation via industry collaboration
- Make the monitor and robots workable in high-radiation fields



- USB positioning accuracy better than 10cm
- WIFI wireless data transfer validated on auto-lifting cart with dosimeter

Summary

- Gained valuable insights from the forum: fruitful presentations and discussions
- Expanded professional network: met many mechanical engineers and international colleagues, which will benefit future communication and collaboration
- Encourage team members to attend this forum regularly
- Invited the international colleagues to CEPC workshop

Next joint Forum and DRD8 Meeting

- Many thanks for those who expressed interest to host the joint Forum and DRD8 Collaboration Meeting in the coming years:
 - Beijing, Heidelberg and Paris (in alphabetic order...)
- We aim to have the meeting again in the first part of June (2027), avoiding conflicts with other major conferences (e.g. Pisa meeting).
- The proponents are collecting more information to host the meeting, so that we can conclude by our DRD8 meeting in October.

Thanks!