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

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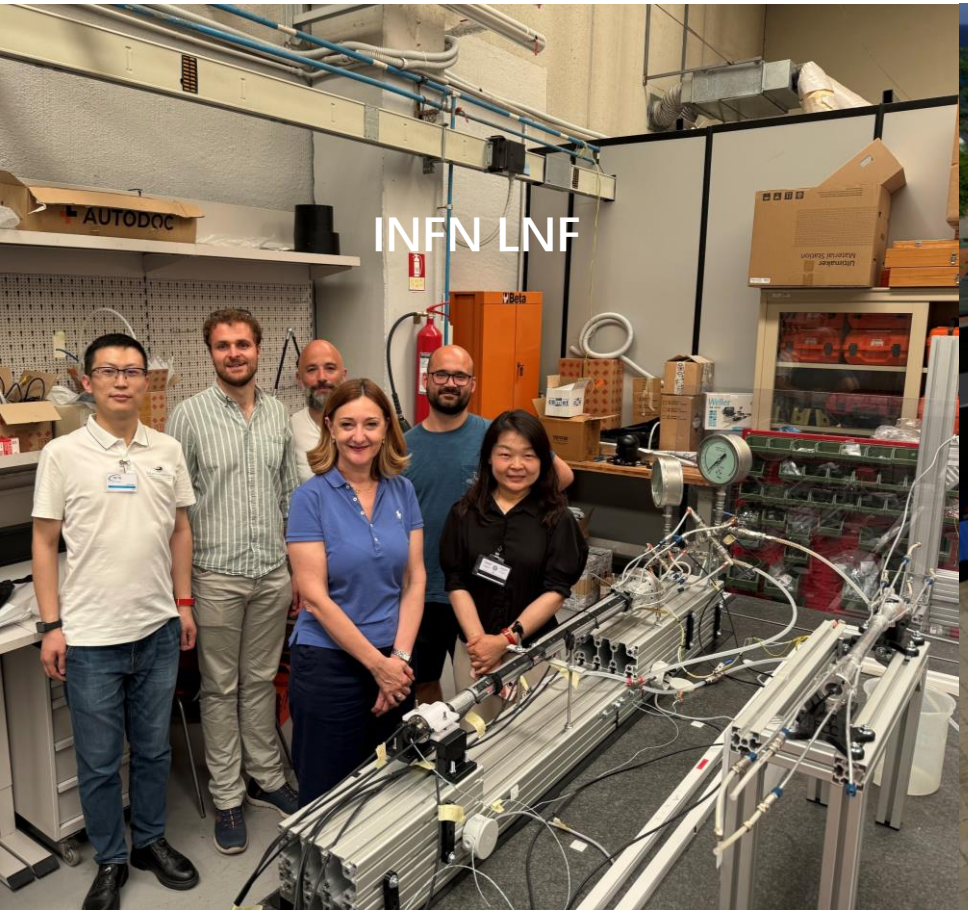
For CEPC day, IHEP

Trip Overview

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



INFN LNF

Forum and DRD8 meeting

INFN LNF visit

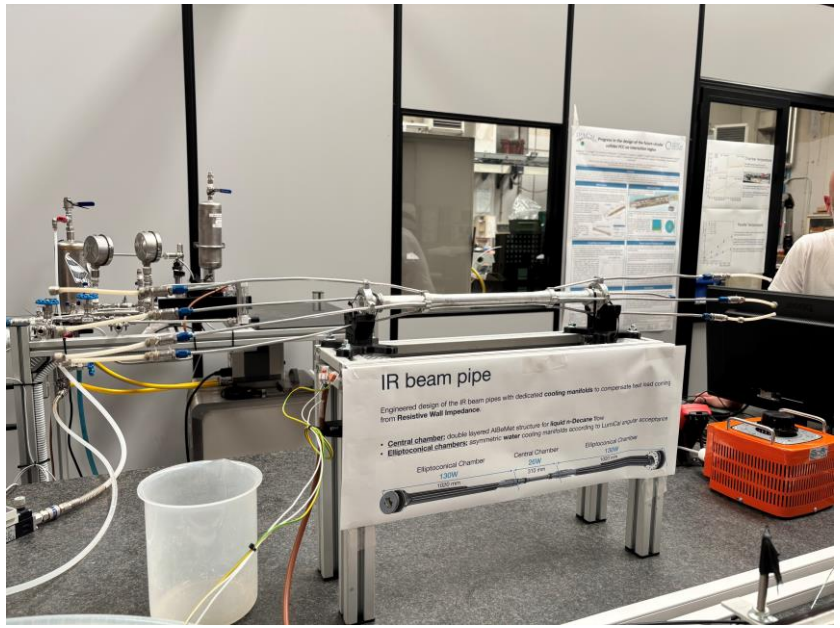
- Colloquium-style seminar in LNF

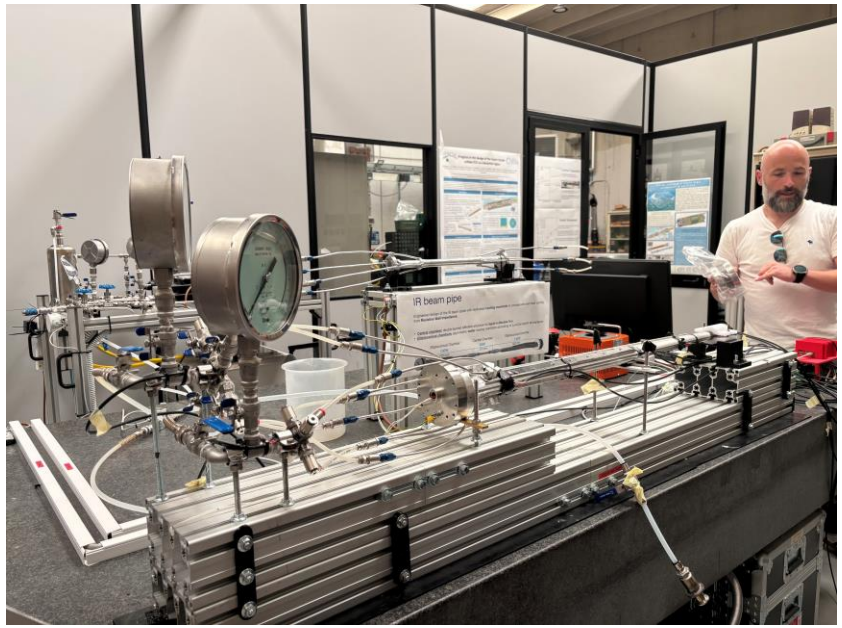
Talk “The baseline design of the CEPC”, by Haoyu Shi

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

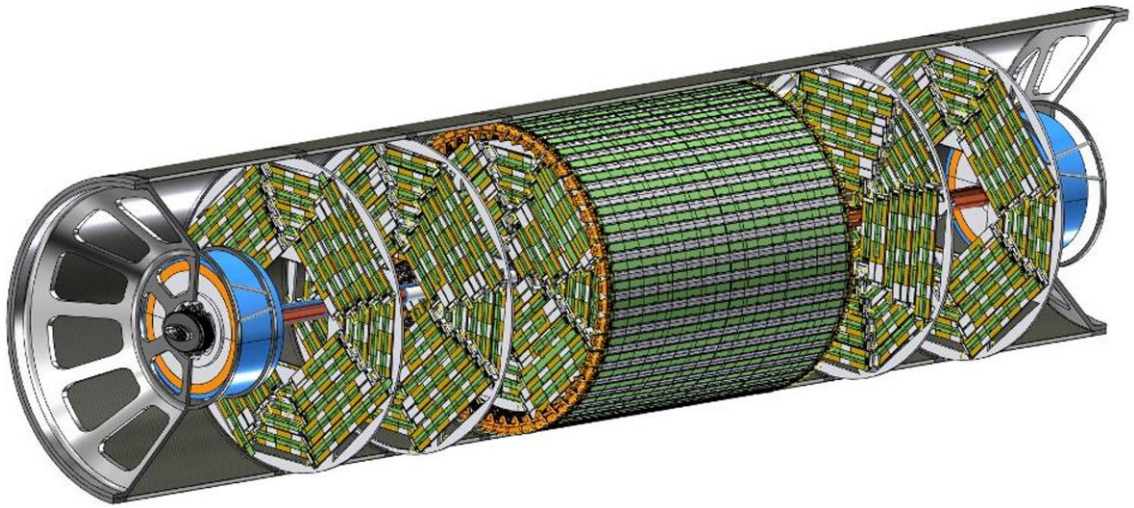
Potential further optimization

- 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

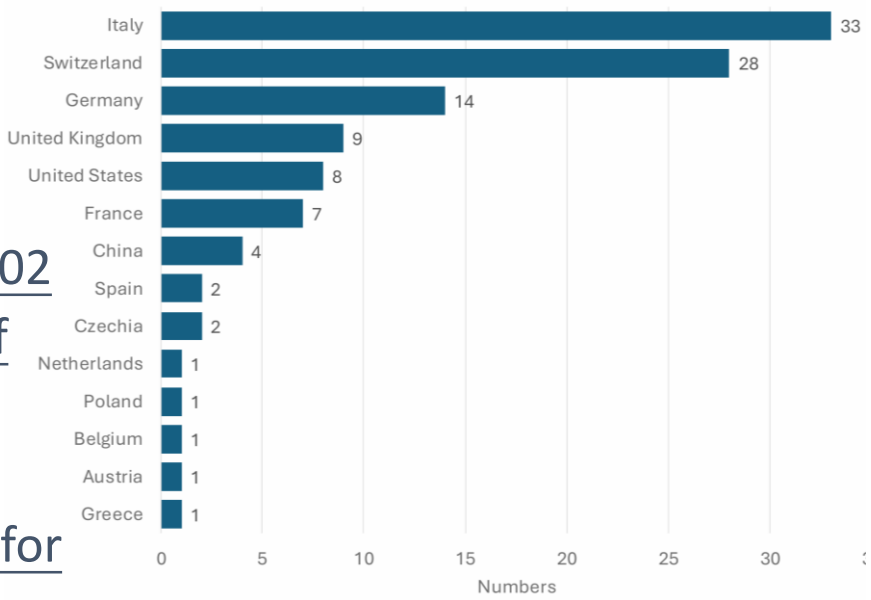
D1.1.1	Ultra-thin beam pipe	Deliver an ultra-thin beam pipe compatible with vacuum operational requirements.	July 2025	July 2027	CH-CERN, CN-IHEP, IT-INFN.LNF
D1.1.2	Alignment system prototype	Develop and evaluate hardware alignment prototype system	July 2025	July 2028	DE-UNI-FR, CH-CERN
D1.1.3	Retractable 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 characteri-sation 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

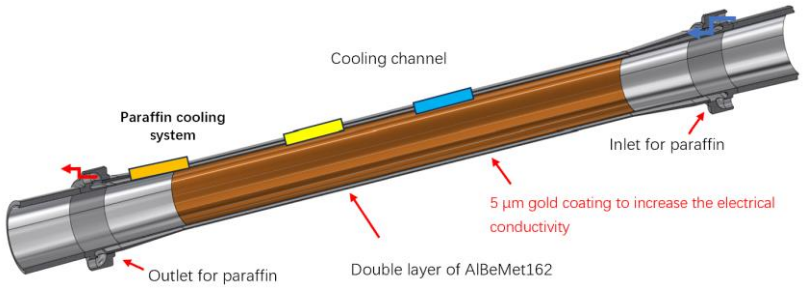
- Record number of participants
  - 112 attendants
  - 3+1 (online) from IHEP
- Record number of contributions: stimulating fruitful discussions
  - 4 talks from IHEP
    - Xuhao Yuan: The upgrade of the silicon tracking detector at AMS-02
    - Xiaoyan Ma: Structural Design and Thermal Performance Study 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
  - A notable gap 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



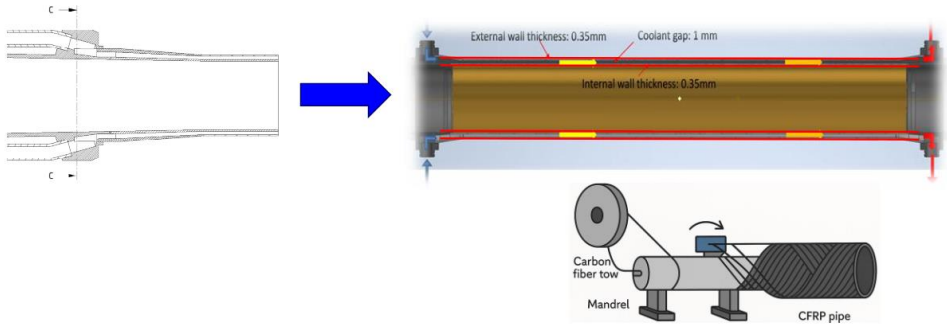
AlBeMet 162 (62% Be, 38% Al) as main material

- 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 Reiforced 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 trail and breakthroughs in the process
  - Encourage them to apply for funding support to continue process research.

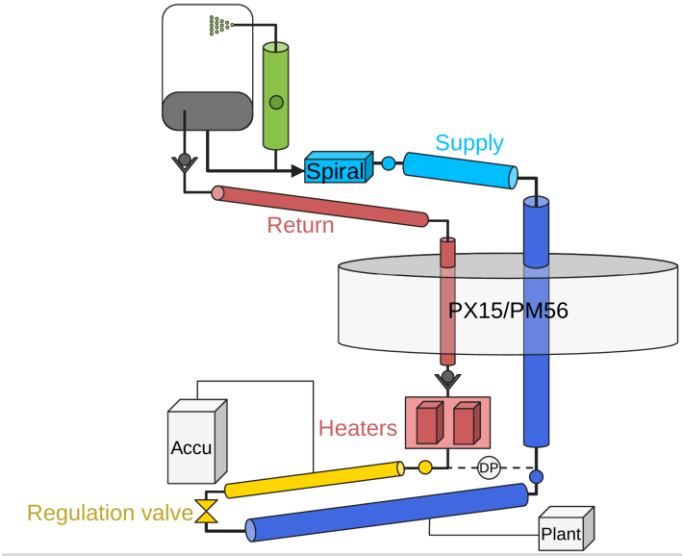
Challenges of ultra-thin and long Be pipe: crack, machining precision, Be-Al welding

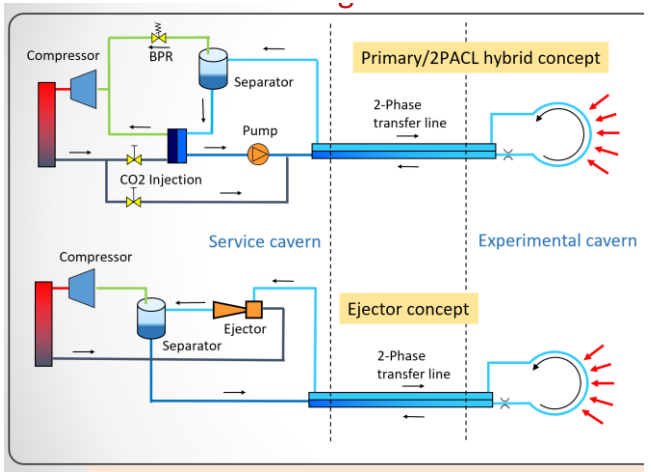
- Cooling mockup validation plan
  - Be→Al
  - Simulation finished
  - Mockup design and manufacturing investigation in progress
  - Cooling test: 2027

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

CO_2 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 (≈ -40°C minimum)
  - Vertical risers cause significant static pressure loss
  - Oil-free compressors lack industrial maturity and funding.
- Development
  - Surface storage & thermosiphon: Pump-free CO_2 circulation achieved using gravity and buoyancy over ~70 m vertical drop
  - Ejector cycle developed: replaces mechanical pump, enables operation near CO_2 triple point (-55℃) and surface plant placement





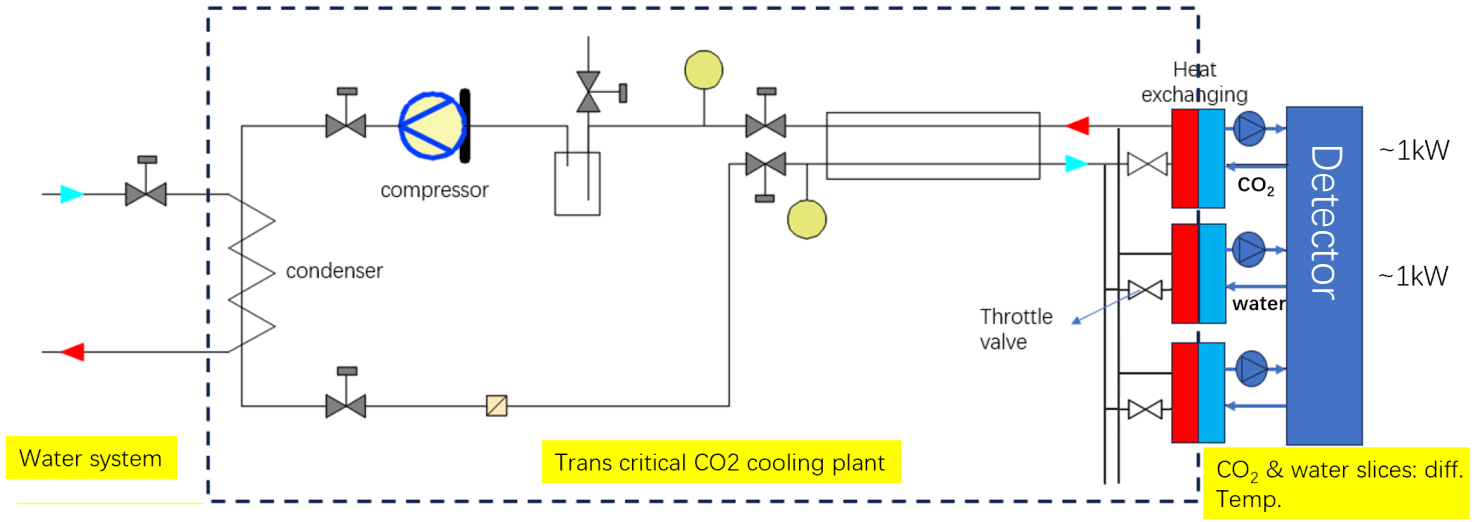
2PACL: Two-Phase Accumulator Controlled Loop

CO_2 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

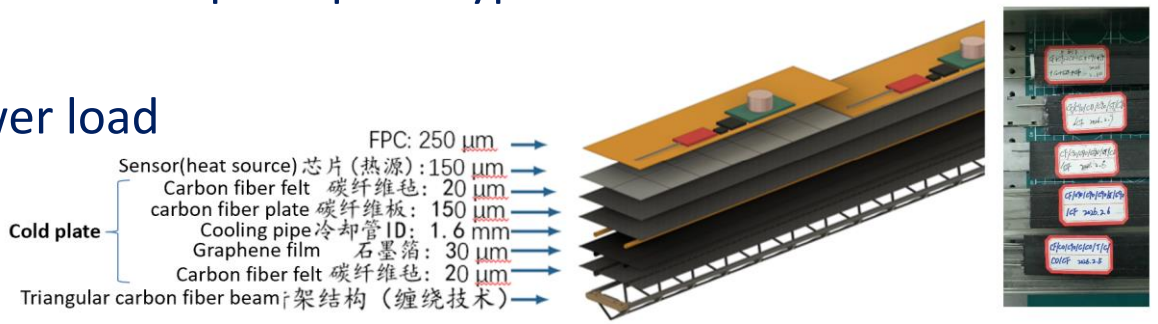
Project	Material solution	Key features
FCC-ee / ALICE ITS2	Carbon fiber + polyimide pipes	High thermal conductivity, embedded tubes
Belle II oVTX	CFRP skins + foam core + Kapton	Ω-shape, ultra-low mass
Belle II iVTX	Thermal Pyrolytic Graphite (TPG)	No fluid, in-plane k = 1500 W/m·K
HENAPIX	Silicon vapor 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: CO_2 boiling microchannels, carbon-fiber embedded tubes, TPG (Thermal pyrolytic graphite) conduction, and nanofiber heat pipes
- Most are in prototype testing & simulation stage

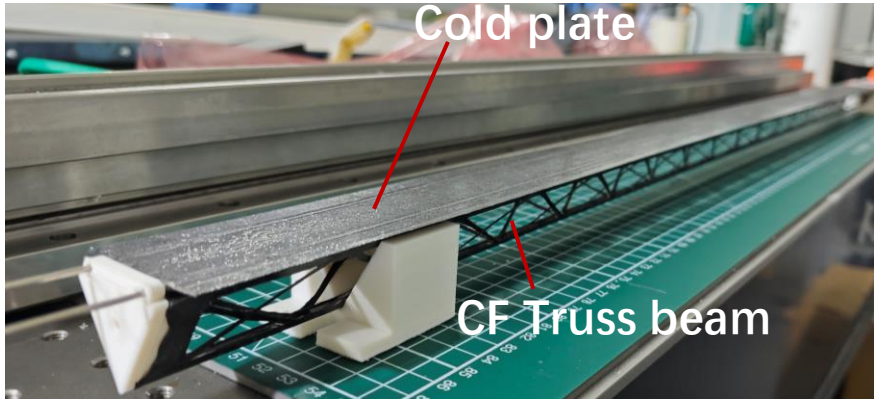
Cold plate (CEPC status)

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

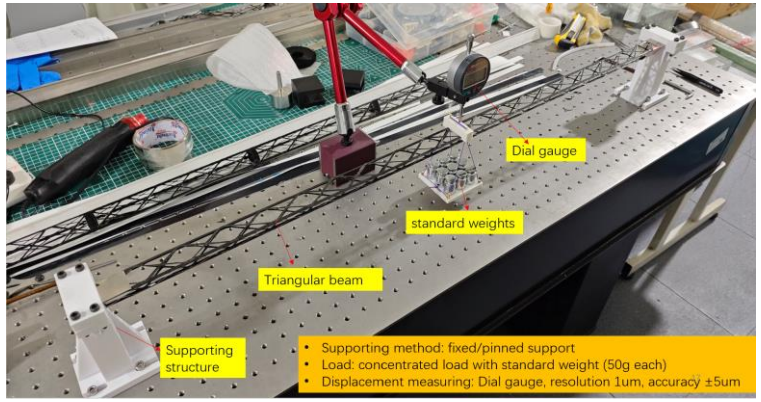
- Successfully manufactured the triangular CF truss beam and cold plate prototypes
- Process addressed
- Deformation: Test & FEA results matches well under lower load
- Cold plate research on ITK
  - Could be use in TPC, ECAL, HCAL…
  - **Progress:** mold is under design, candidate powders to increase thermal conductivity: Boron nitride, aluminum nitride
  - **Manufacturing and preliminary test**: 2026
  - **Process optimization to increase thermal conductivity** :2026-2027



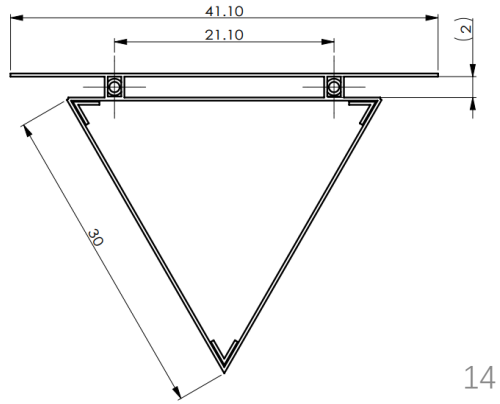
- People were quite interested in the talk
- Consulted Xiaohui on technical details
- Suggestion: pay attention to flatness issue–lessons from CMS



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, ΔT<5-7℃
  - 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, ΔT < 7°C, sub-μm vibration
FCC-ee Vertex	Air (sealed ducts)	50 mW/cm², 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 W/m·K	Passive, no fluid, X_0 = 0.202% per 0.38 mm
Belle II oVTX	Single-phase liquid	10°C supply, ΔP = 0.36 bar	Kapton tubes, T_peak < 29°C
FCC-SEED	Air (R&D)	50 mW/cm², R ≥ 17 mm	Curved sensors + mechanical integration

Air cooling validated, RMS displacement<0.4um

challenges: dust, conductivity, CTE

Curved sensors successful, R = 20 mm, 50–60 μm thick, power similar to flat

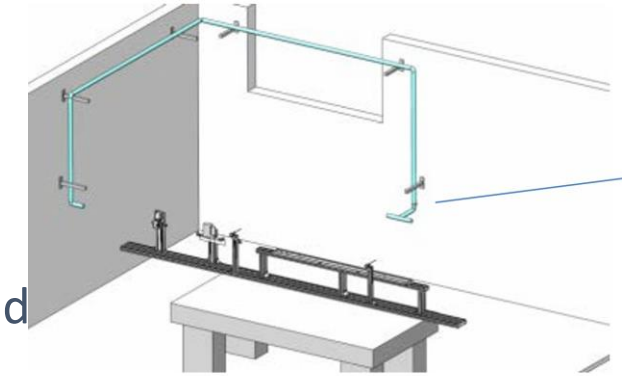
VTX cooling (CEPC status)

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

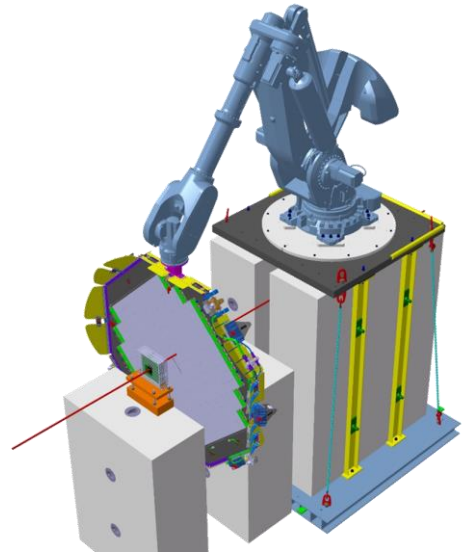


空压机散热口专门的排风管道

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

- 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!