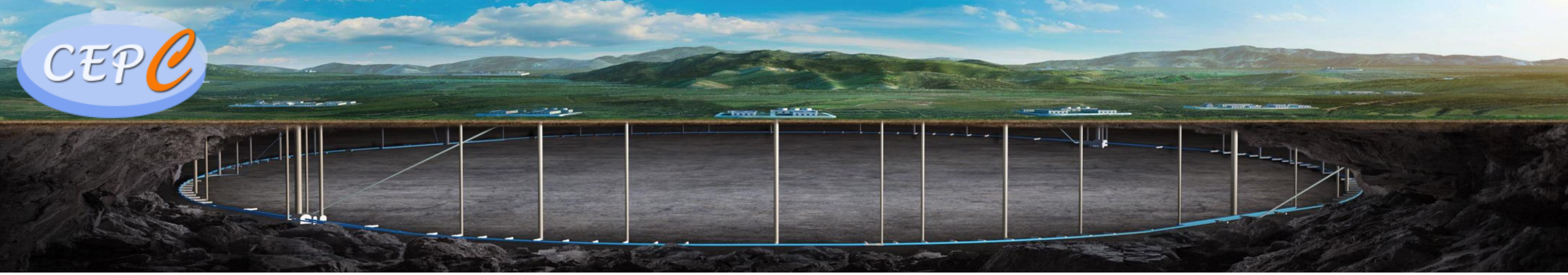


Detector common mechanics and cooling plan

Xiaoyan Ma
On behalf of the mechanical group

Overall R&D work plan

Based on IDRC, IHEP innovations, and DRD8

- **sCO_2 cooling** : IDRC, IHEP innovations,DRD8
- Research on the **mini-channel cooling device** : IHEP innovations, DRD8
- Ultra-thin walled vacuum **beam pipe** : IHEP innovations,DRD8
- Mock-up with **VTX** Detector and Services: IDRC, IHEP innovations,DRD8
- Inspection/Maintenance **Robot** in Detector Cavern Environment: DRD8

Others

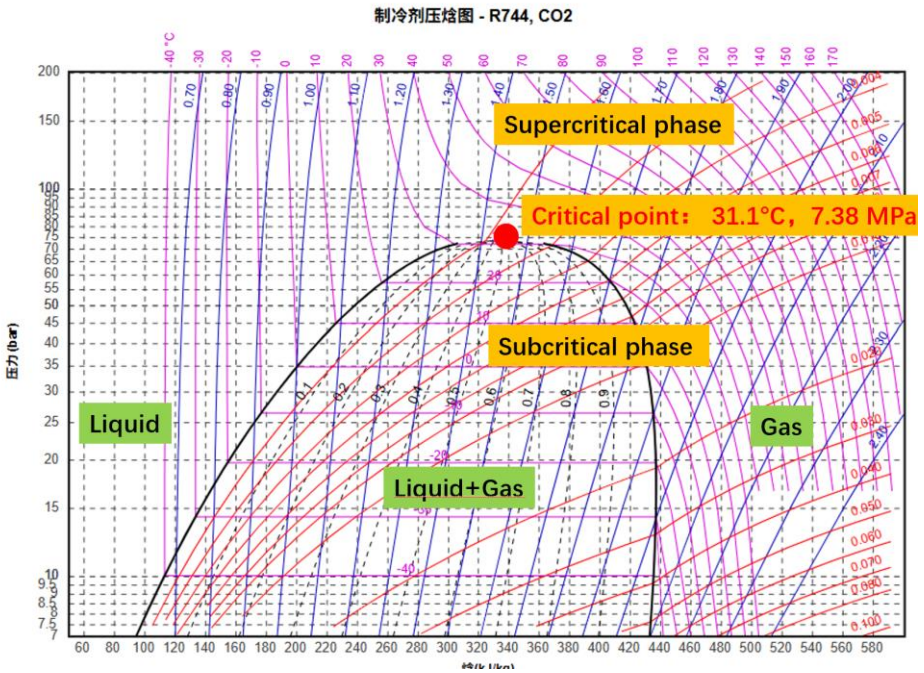
- **AI-accelerated FEA** simulation: Yoke
- Optimization of **detector design, installation and integration**
- **Research on Carbon Fiber**
- **Experimental hall layout**: Not a current priority

NSFC application

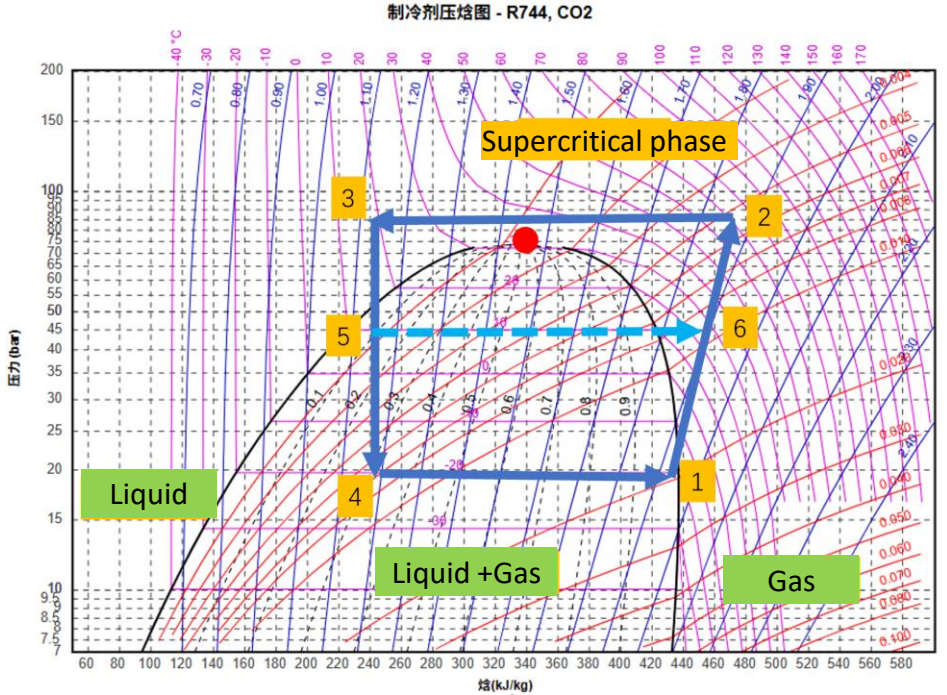
- CO_2 cooling: Xiaoyan Ma
- Beam pipe: Xiaohui Qian
- VTX : Jinyu Fu

Research on CO_2 cooling

- Motivation: Water (TDR)Long-term water leak risk， Low-temperature capability
- Goal: Use thermomechanical mock-ups to compare water vs. CO_2
- CO_2 Critical point: T_c = 31.1° C | P_c = 7.38 MPa
- CO_2 cooling modes: Subcritical / Supercritical / Trans-critical



CO2 pressure-enthalpy diagram



Trans critical refrigeration

1→2: Compression (pressure and temperature rises)

2→3: Condensation (temperature drops)

3→4: Throttling/Expansion (pressure and temperature drop)

4→1: Evaporation (cools the R744 slice medium)

5→6: control pressure to obtain a different temperature

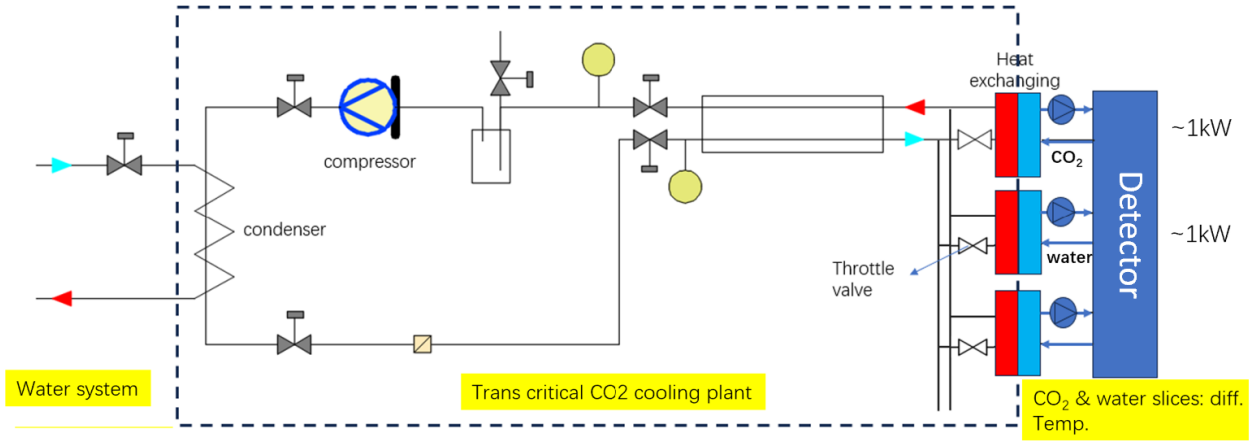
Research on CO_2 cooling

- Key tasks
  - 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

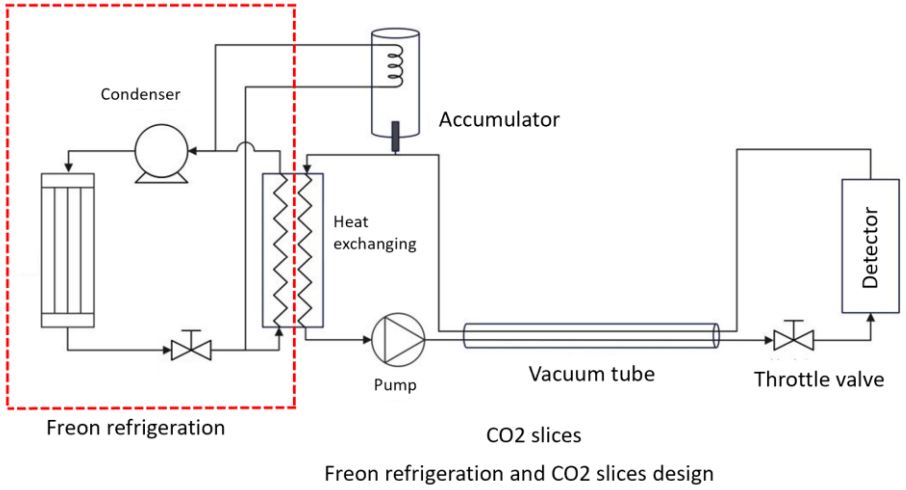
2026

  - Verification of key components function: accumulator, condensation, high pressure connector…
  - Small prototype

2027



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



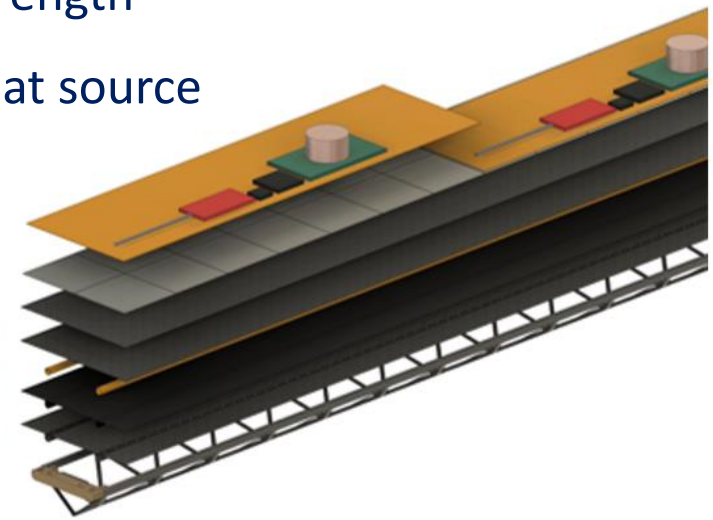
An ~1kW CO2 slices under development (Yan Qi group)

Research on ultra-low mass heat transfer device

- Goal: Ultra-light, extremely high thermal conductivity for sensor
  - Cold plate: Composite material (carbon fiber, graphene…)
  - Cooling channel: ~1 mm for CO2
- Potential applicable sub-detectors: ITK, OTK, TPC, Cherenkov, ECAL…
- Main issues
  - Composite thermal conductivity unknown
  - Interfacial thermal resistance & Composite strength
  - Contact resistance between cold plate and heat source

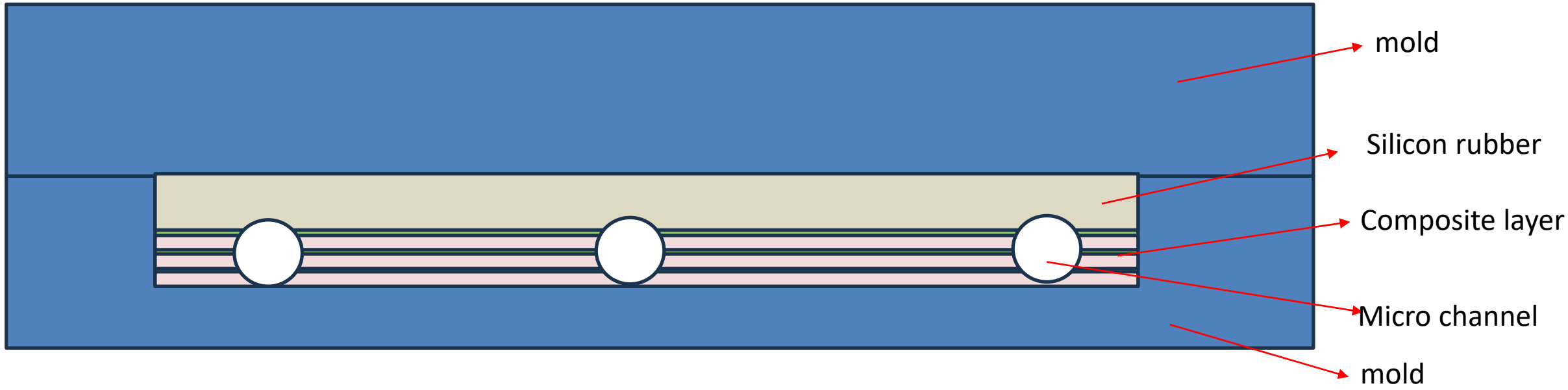
FPC: 250 μm →
Sensor(heat source) 芯片（热源）: 150 μm →
Cold plate
- Carbon fiber felt 碳纤维毡: 20 μm →
- carbon fiber plate 碳纤维板: 150 μm →
- Cooling pipe 冷却管 ID: 1.6 mm →
- Graphene film 石墨箔: 30 μm →
- Carbon fiber felt 碳纤维毡: 20 μm →

Triangular carbon fiber beam 桁架结构（缠绕技术）→



Research on ultra-low mass heat transfer device

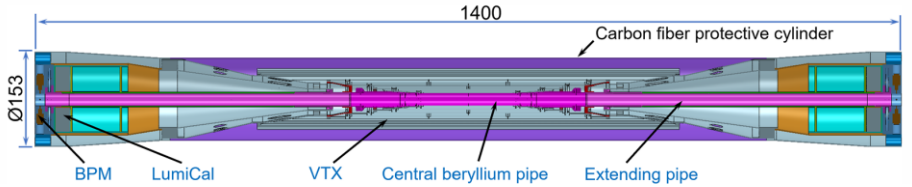
- Solution idea
  - Develop thermal conductivity measurement platform
  - Mold design for cold plate sample fabrication(with/without pipe)
  - Add high-conductivity filler powder to glue : AlN (~320 W/m·K), BN(300-600 W/m·K in-plane



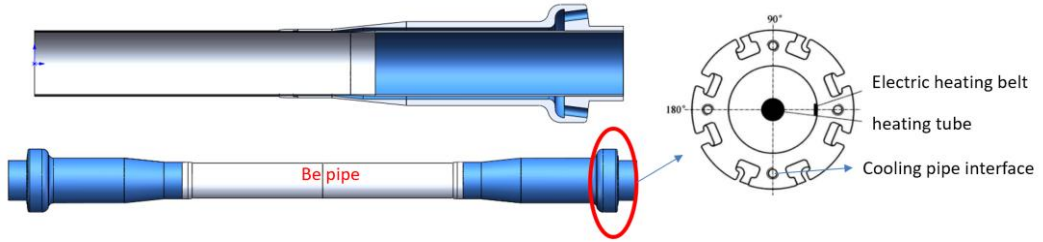
Mold for composite cold plate sample

Beam pipe

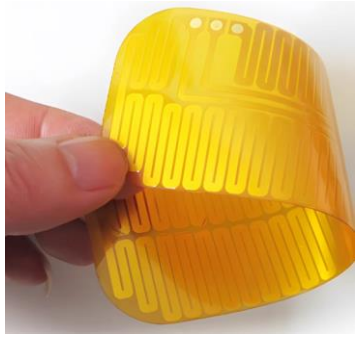
- Ultra-low mass, double-wall ultra-thin long pipe design
  - ID: Ø20 mm
  - Be pipe thickness: 0.15mm (outer layer), 0.2mm (inner layer)
  - Gap: 0.2 mm, mini cooling channel
- Key challenges
  - Heat dissipation in narrow channel structure
  - Fabricating issues: cracking (ultra-thin Be pipe), precision machining (roundness, coaxiality), Be–Al welding
- Al replaces Be for cooling prototype test
  - Cooling Simulation: Al vs. Be, uneven gap effect (in progress)
  - Test design & preparation (pump, pressure gage, Dummy heat source…)
  - Next (this year): Make prototype & Test
  - Goal: Validate design and cooling parameters (gap, flow velocity, coolant)



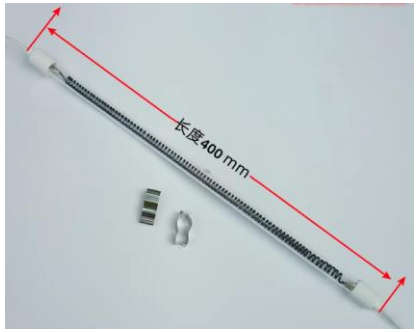
3D model of beam pipe assembly



Central beam pipe structure



Electric heating belt

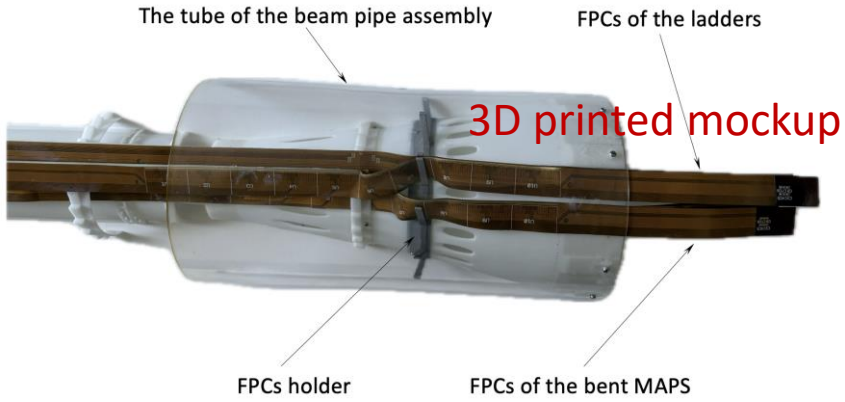


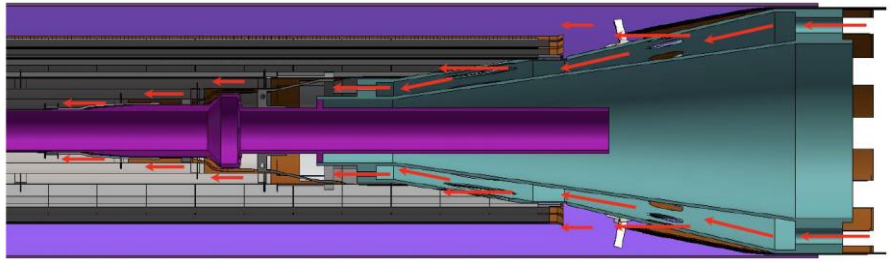
heating tube

VTX Mockup tests

- Goals
  - Validate the structure, forming & assembly process
  - Validate the cooling design & thermal management
- General plan
  - 3D printed VTX & beam-pipe mockup – space for cables & air channel verified (done)
  - Flat mockup: Preliminary verification of the measurement & heating layer (08/2026)
  - Single cylindrical barrel mockup: Cooling verification & system optimization (design & fabrication 12/2026, test 02/2027)
  - Multi-cylindrical barrel : beam pipe integration (08/2027)

Model of Vertex





VTX Mockup tests

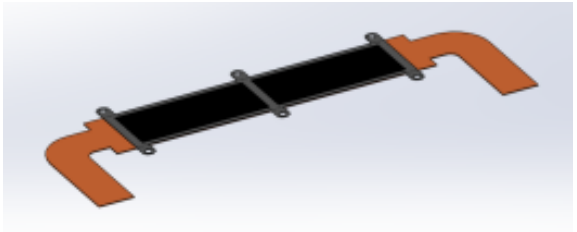
- Study on simulated heat source
  - Power density: 40 mW/cm² (stitching sensitivity area) / 485 mW/cm² (readout block)
  - First sample issue: Heat non-uniformity
  - Solution: Add thermal conductive layer

Thin-film heater

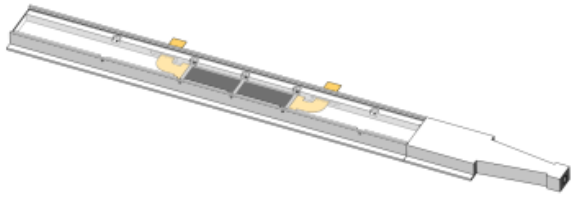
Thermal conductive layer(black)

Yiming: Dummy sensor with a resistance wire, potential for this test

- By June 2026
  - Optimize the design: mockup (CF support + double heater), air-cooled cavity
  - Mockup fabrication & test component purchase
  - System assembly and test platform setup



Thermal prototype

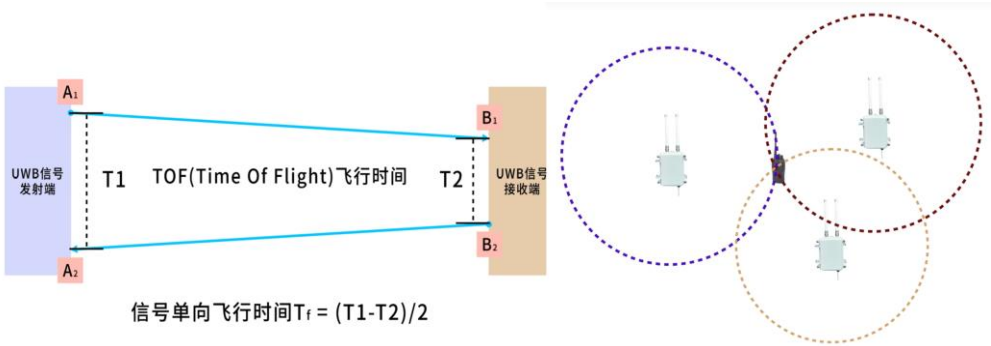


air-cooled cavity

Inspection/maintenance robots in detector environment

- Objectives
  - Goal: Autonomous inspection/maintenance in harsh environments: Radiation dose & magnetic field…
  - Develop robotic platforms, both ground and aerial: high-precision, anti-interference, self-locating
- Key challenges and environmental adaptability considerations
  - Electromagnetic Compatibility: stability under strong magnetic fields needs verification
  - Signal Occlusion & Reflection: Dense metal equipment areas may cause signal loss or multipath interference
  - Radiation Effects: Electronic devices require a certain level of radiation tolerance
- Indoor 3D self-locating Technology Comparison

解决方案 Solution	三位精度 3D Accuracy	硬件需求 Hardware Requirements	环境依赖 Environmental Dependence	成本 Cost
超宽带 UWB	5-10 cm	需部署基站	低	中
视觉 SLAM	1-5 cm	仅需相机	高 (需光照、纹理)	中/高
超声波	1-2 cm	需部署发射器	高 (怕遮挡、噪音)	低/中
激光 LiDAR	<1 cm	激光雷达	中	高

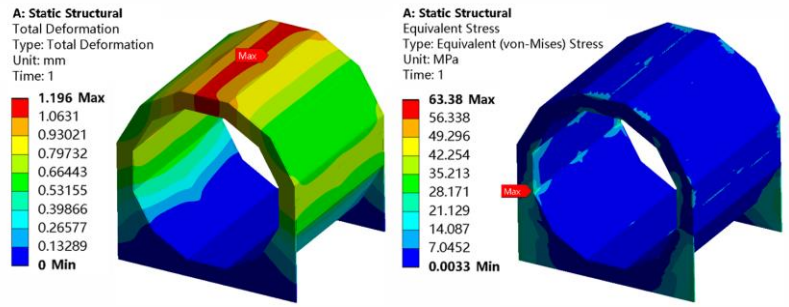


UWB: accuracy slightly lower but sufficient for need

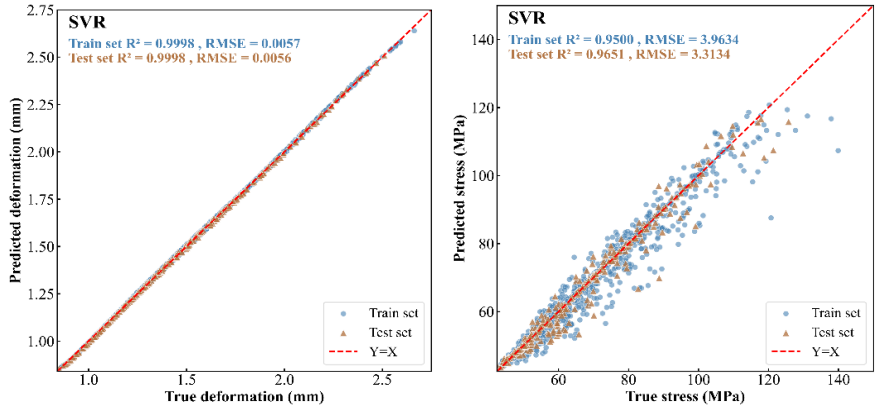
- Next Plan
  - Purchase UWB module → Field testing→ Algorithm optimization→ System integration
  - Involved person: Xiaohui, Zhuo Liu, Shaojing, Haoyu,

AI-accelerated FEA simulation

- Motivation： Traditional FEA is time-consuming
- Proposed approach: Deep learning (DL) surrogate models → replace FEA
- Significance: Enables multi-parameter & multi-objective optimization
- Initial Trial in Yoke Structural Optimization
  - Goals: Significantly improve efficiency with acceptable accuracy
  - Workflow: Data Collection → Model Design → Model Training → Model Validation
- Current progress
  - Preliminary feasibility validated
  - DL models show better accuracy and efficiency
- Next : Further model optimization, extend to other sub-detectors



To be discussed with software team



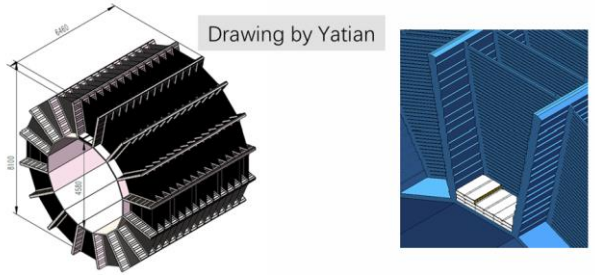
Nonlinear Models Excel, with SVR Best

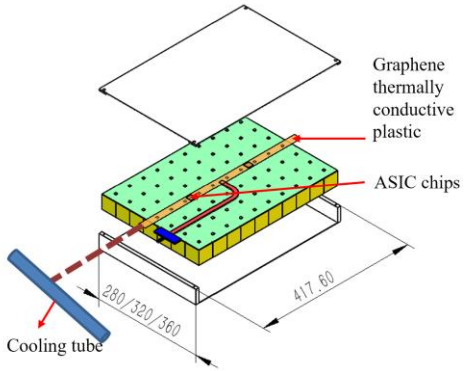
Design adapts to sub-detector's change

- As the design of sub-detectors deepens
- Calorimeter : with glass scintillators
  - New structure design
  - Cooling consideration

Work with sub-detector group
Responsible engineer:
HCAL: Yatian Pei
ECAL: Shaojing Hou
TPC&ITK: Xiaohui Qian
VTX: Jinyu Fu
Cherenkov: Jian Wang
Beam pipe: Xiaohui Qian, Jian Wang

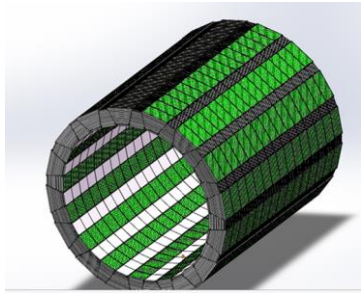
HCAL

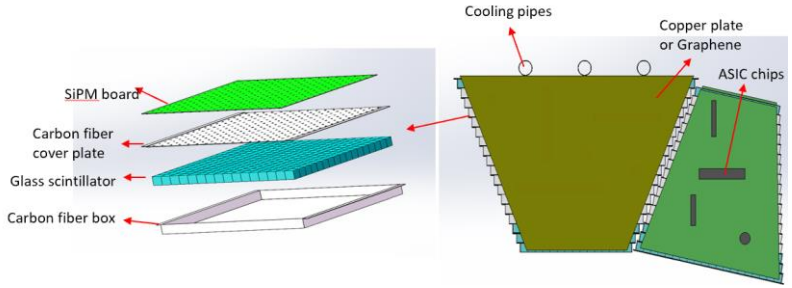


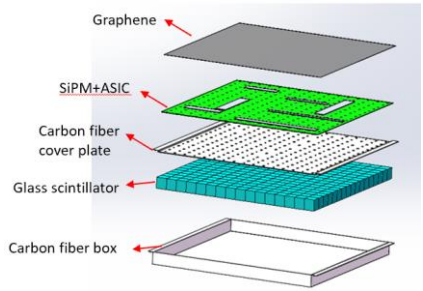


- Graphene thermal plastic contacts ASIC chips top surface to extract heat
- Connects to cooling tubes at both barrel HCAL ends

ECAL



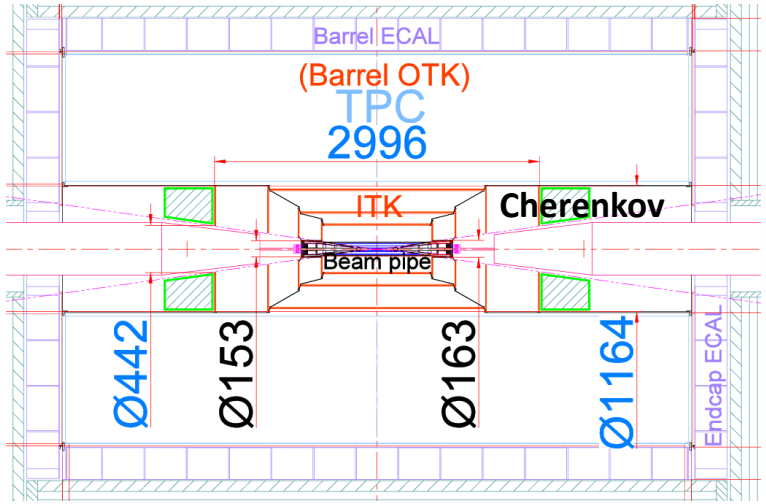




- Cooling method of ASIC chips on the surface of module
- Cooling method of ASIC chips in each layer

Optimization of integration and installation

- How to mount Cherenkov (30kg*2)? Fixed to ITK? To TPC endplate?
- Can we directly mount ITK & Cherenkov to the nearby inner cylinder of TPC?
  - For ITK, Cherenkov,: reduce the material budget, reduce the deformation
  - For TPC inner cylinder: need improve the design to increase the strength & stiffness



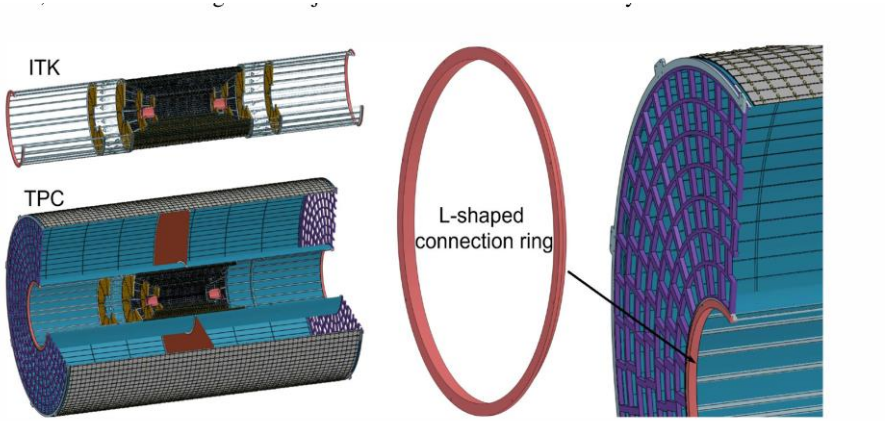
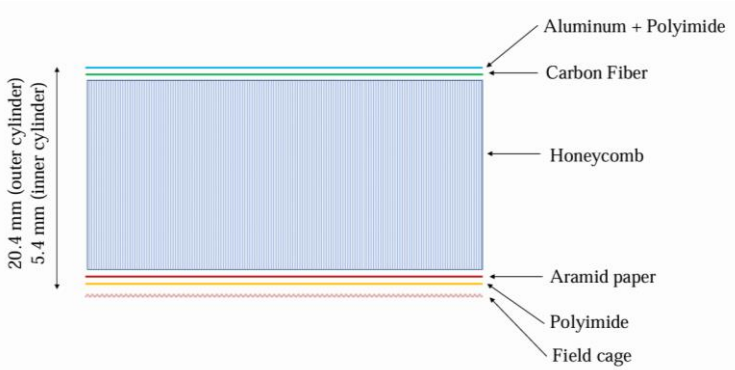


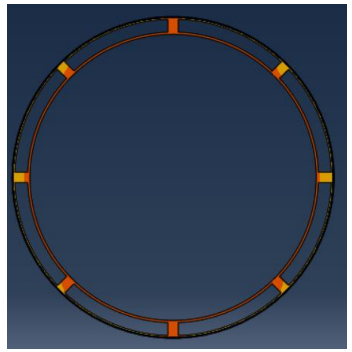
Figure 14.28: Connection structure of the ITK. The L-shaped connection rings at both ends connect the ITK to the TPC



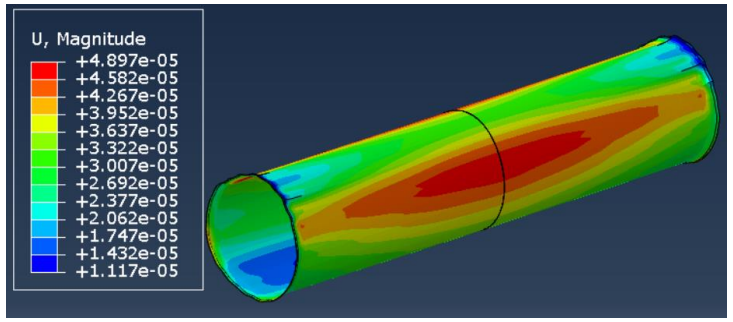
TPC inner cylinder in TDR: a thinner Nomex honeycomb core of about 5 mm, 0.2mm CF

Optimization of integration and installation

- Quick preliminary comparative calculation of deformation
  - Adding 2 rings to TPC, 8 points (at one end) for connecting ITK to TPC inner cylinder
  - Circumferential ribs contribute little to deformation reduction
- Continue the optimization: add axial ribs, increase honeycomb thickness…
  - What is the maximum allowable deformation of the TPC?

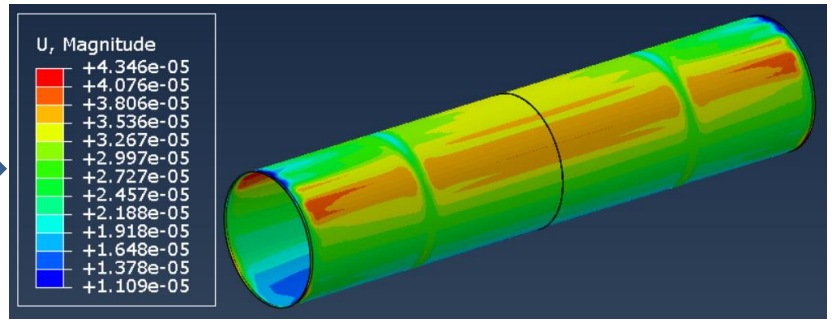


By Xiaohui



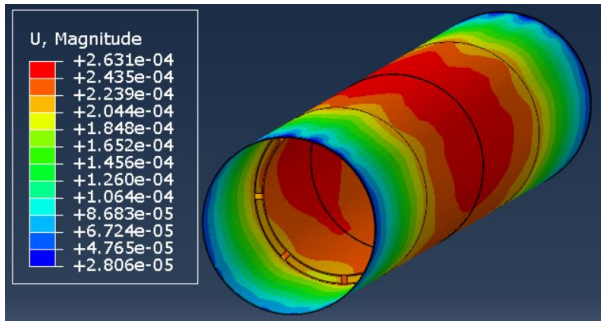
TPC Original deformation: 0.05mm (without load)

Adding 2 rings



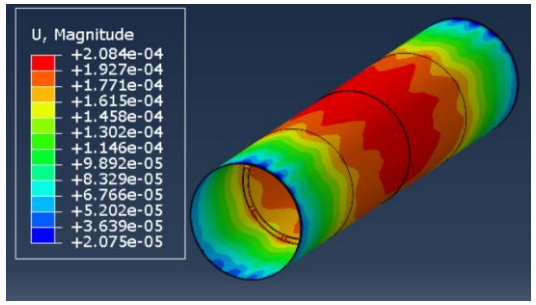
TPC: 0.043mm

With load

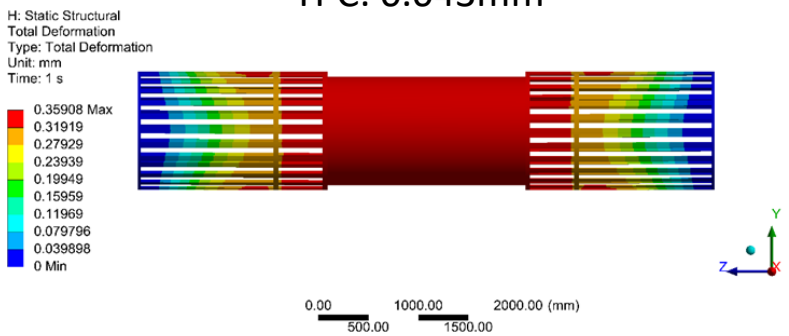


TPC: 0.26mm

TPC inner CF: 0.2→0.3mm



TPC: 0.21mm

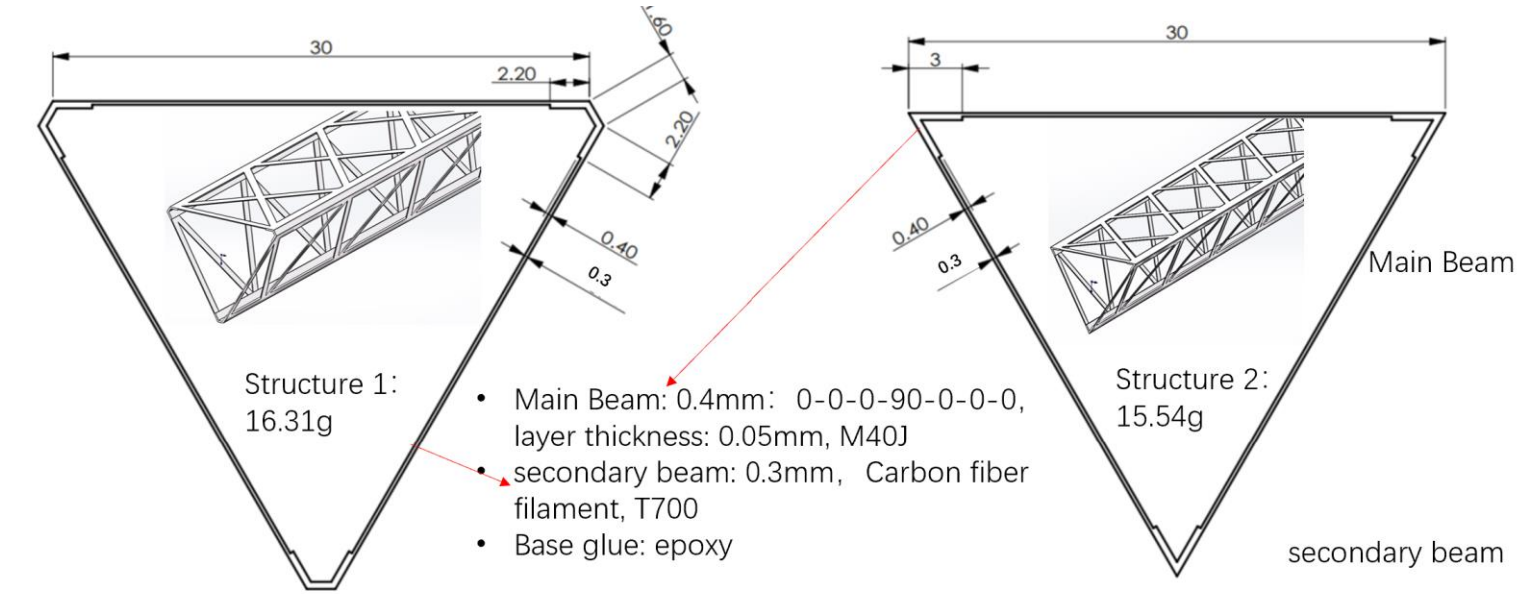


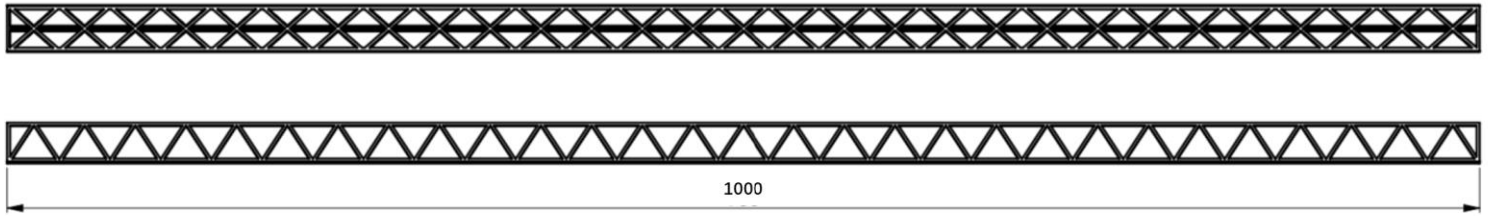
ITK deformation: 0.36mm (fix to TPC endplate)→0.23mm (fix to TPC inner cylinder)

load added on TPC: 150Kg
- ITK:80kg
- VTX+ Beam pipe:10kg
- Cherenkov: 30kg*2

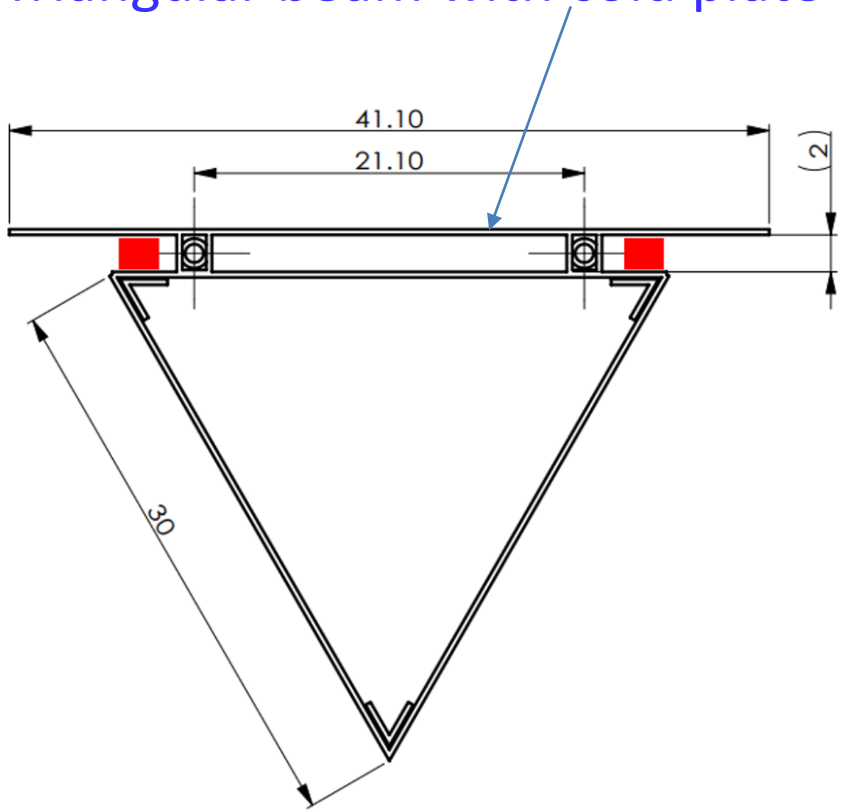
Research on Carbon Fiber

- Structure of triangular carbon fiber beam for ITK





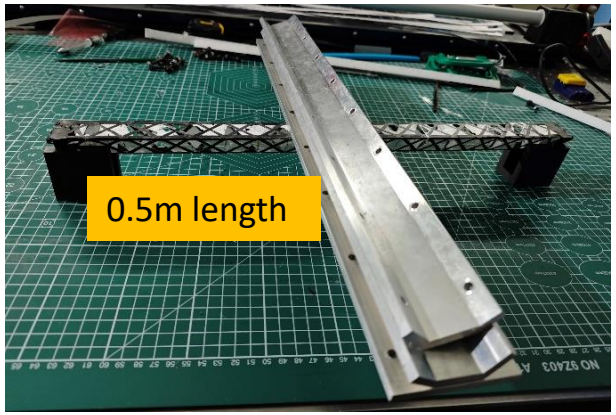
- Triangular beam with cold plate



Research on Carbon Fiber

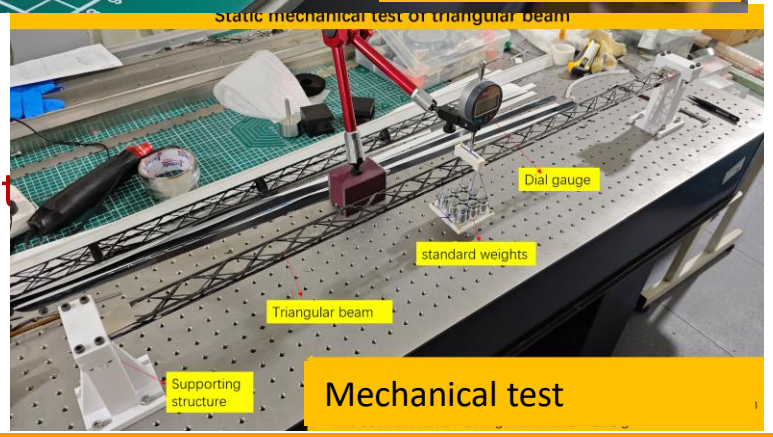
- Lab fabrication of CF beam samples for ITK
  - Involved persons: Xiaohui Qian, Jian Wang, Yujie Li, Jiajian Zhang, Qi Yan
  - 0.5m beam→1m beam→ cold plate
  - Mold & process optimization → Significant quality improvement →Static mechanical test

Mold for CF beam and cold plate




CF beam and cold plate assemble

- Progress and next plan
  - Successfully fabricated 1m triangular CF beam: ~15g weight
  - Deformation measurement: ~ 35um @50g concentrated load, FEA result can match well with measurement results
  - FEA: ~20um @ 80g Uniformly Distributed Load
  - Continue to improve the mold, integrate with cold plate



Mechanical test

Summary and next plan

- From TDR to R&D→ Focus on critical technologies → Mitigate risks for detector
- Key R&D Trends
  - New thermal management: CO2 cooling
  - Cooling tests on some critical sub-detectors
  - Ultra-low lightweight engineering: sub-mm precision component
  - Development on composites: CF, graphene low mass & high thermal conductivity
  - AI-accelerated simulation
  - Development on CF fabrication in lab
- Interfaces further checking and coordination
  - Detector internal interface
  - With accelerator
- Installation & Integration: Further Deepening and Refinement

Thanks!