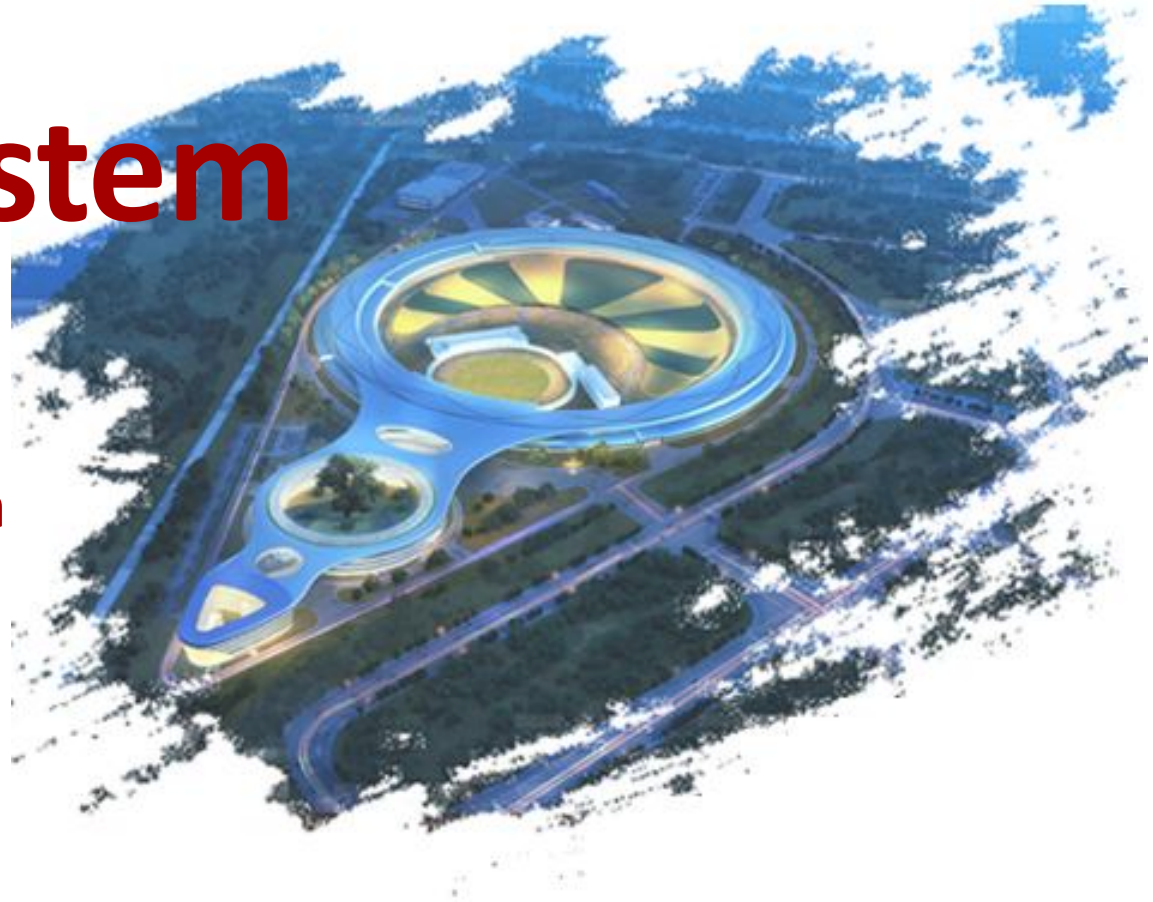
高能同步辐射光源
High Energy Photon Source

AFAD 2026

HEPS cryogenic system



Rui Ge, Changcheng Ma
On behalf of the Cryogenic system team
IHEP, CAS
15.10.2026

AFAD 2026 Shanghai China

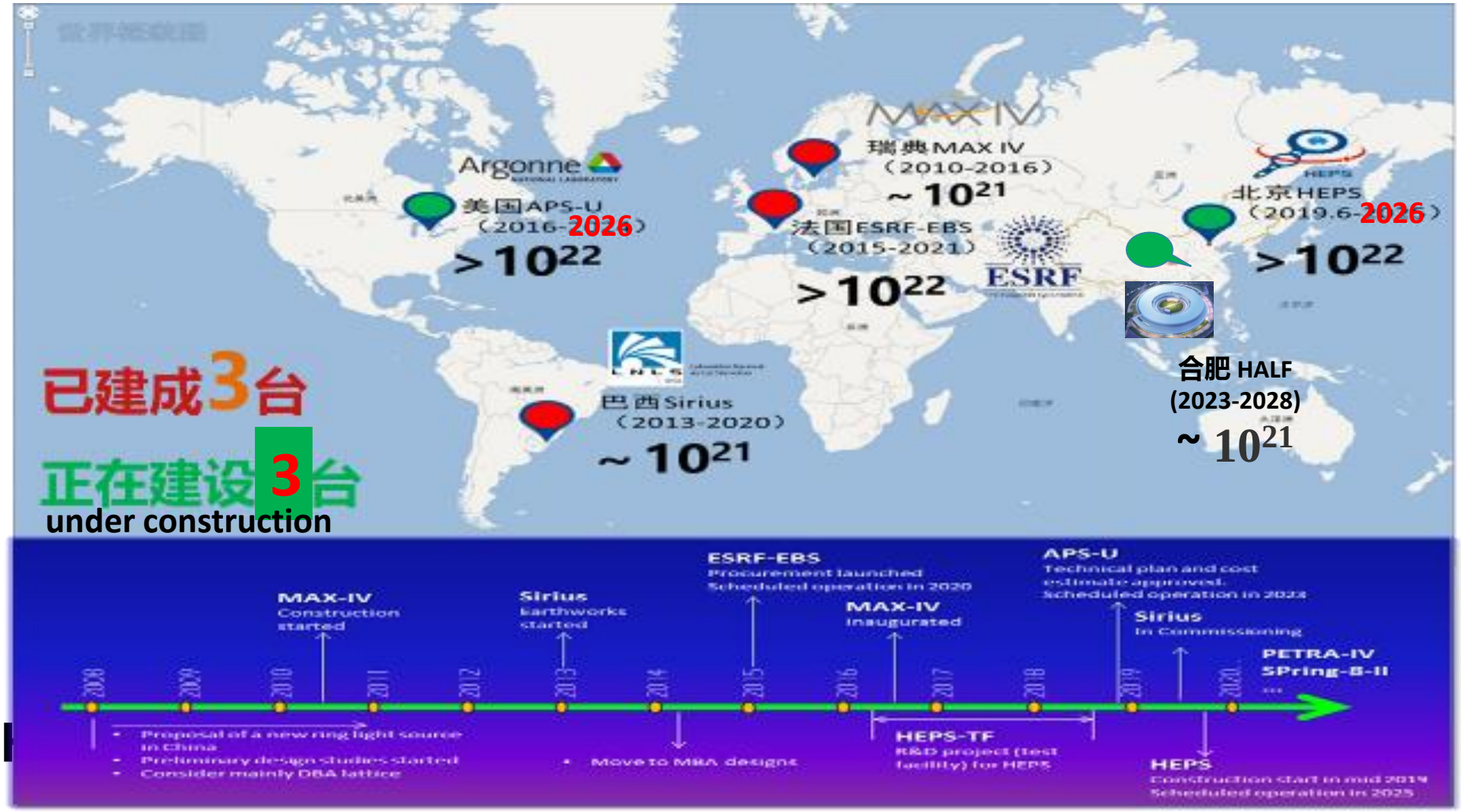
CONTENT

1. Overview
2. Development, Commissioning and Operation
3. Summary
4. Phase II plan

1 Overview

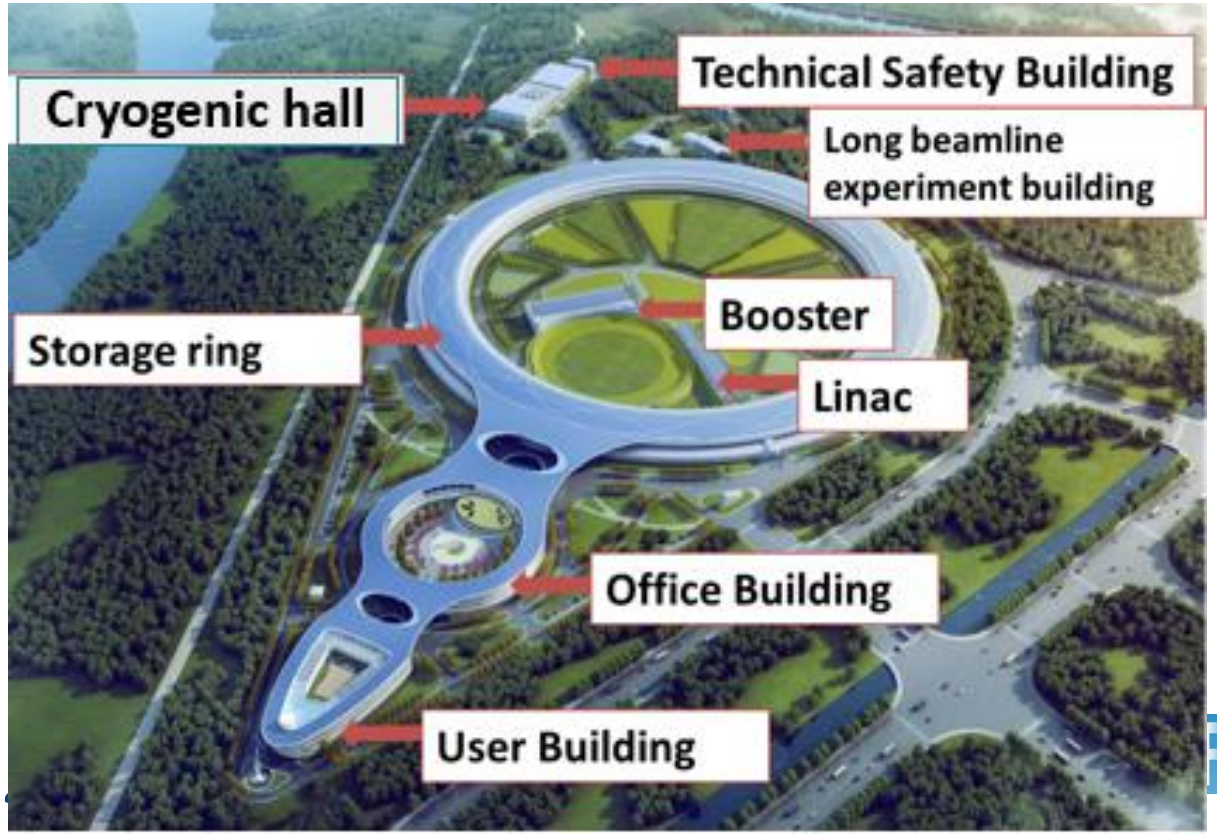
Overview ---HEPS

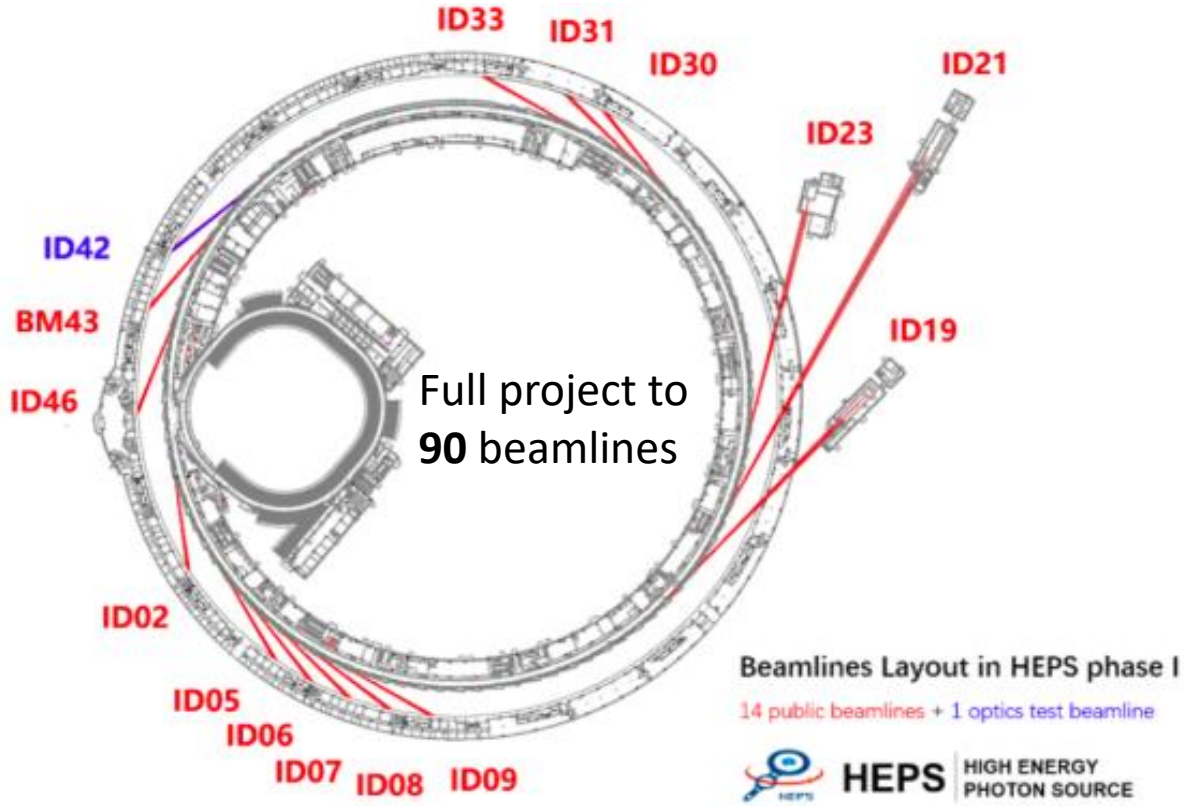
- The High-Energy Photon Source (HEPS) is Asia's first fourth-generation SR light source and one of the world's first light sources， high-energy X-rays up to 300 keV.



Overview---HEPS

- **Groundbreaking** took place in **June 2019**
- Vacuum sealing of the storage ring was completed in July 2024, and beam storage of the full ring was achieved in August 2024
- **The-first-photon beam output** from the initial beamlines occurred in **October 2024**
- **Technical-process acceptance was completed in October 2025**.





Overview---HEPS

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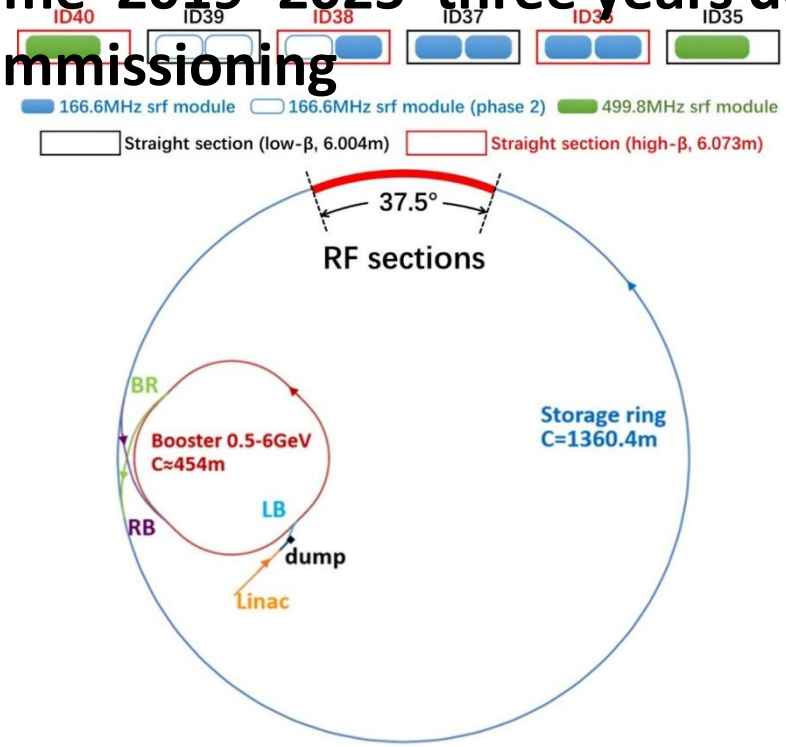


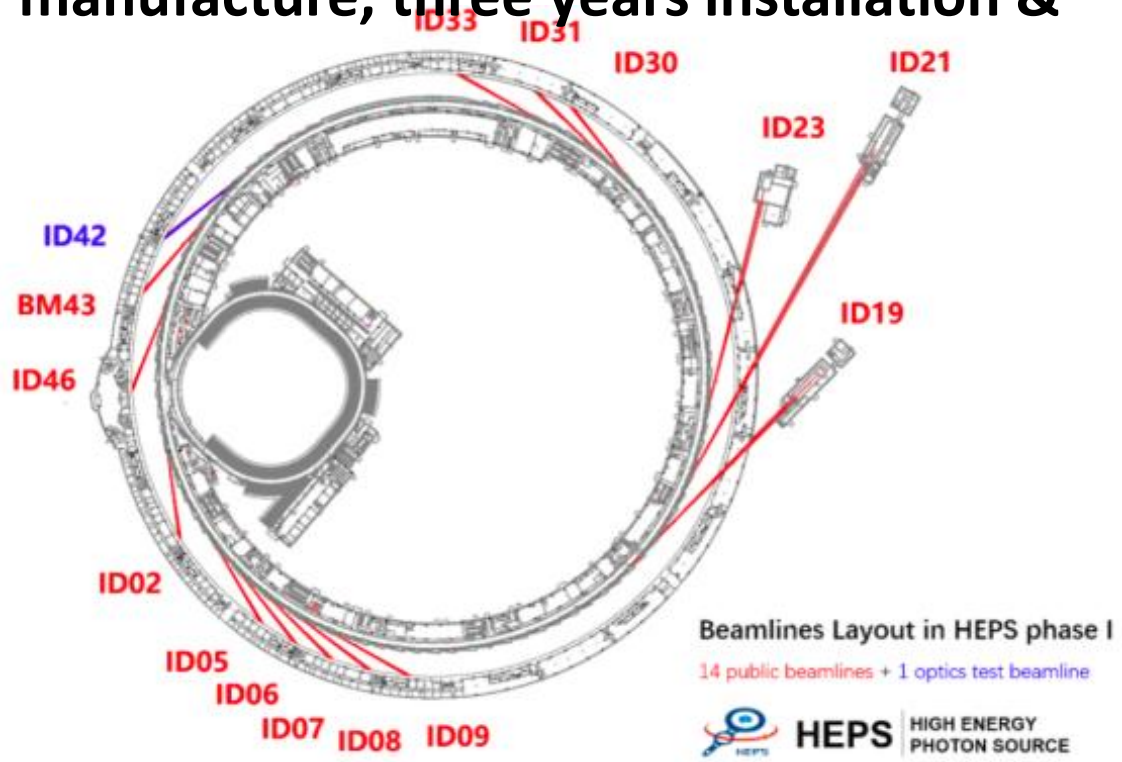
Overview---HEPS Cryogenic system objectives

1) To ensure the efficient and stable helium cryogenic conditions of SRF cavities modules (**max 10 SRF modules**)

2) To ensure stable **LN2 cryogenic conditions** for **Cryogenic insertion devices and beamlines cryogenic equipment in HEPS**

Time 2019~2025 three years design、manufacture, three years installation & commissioning





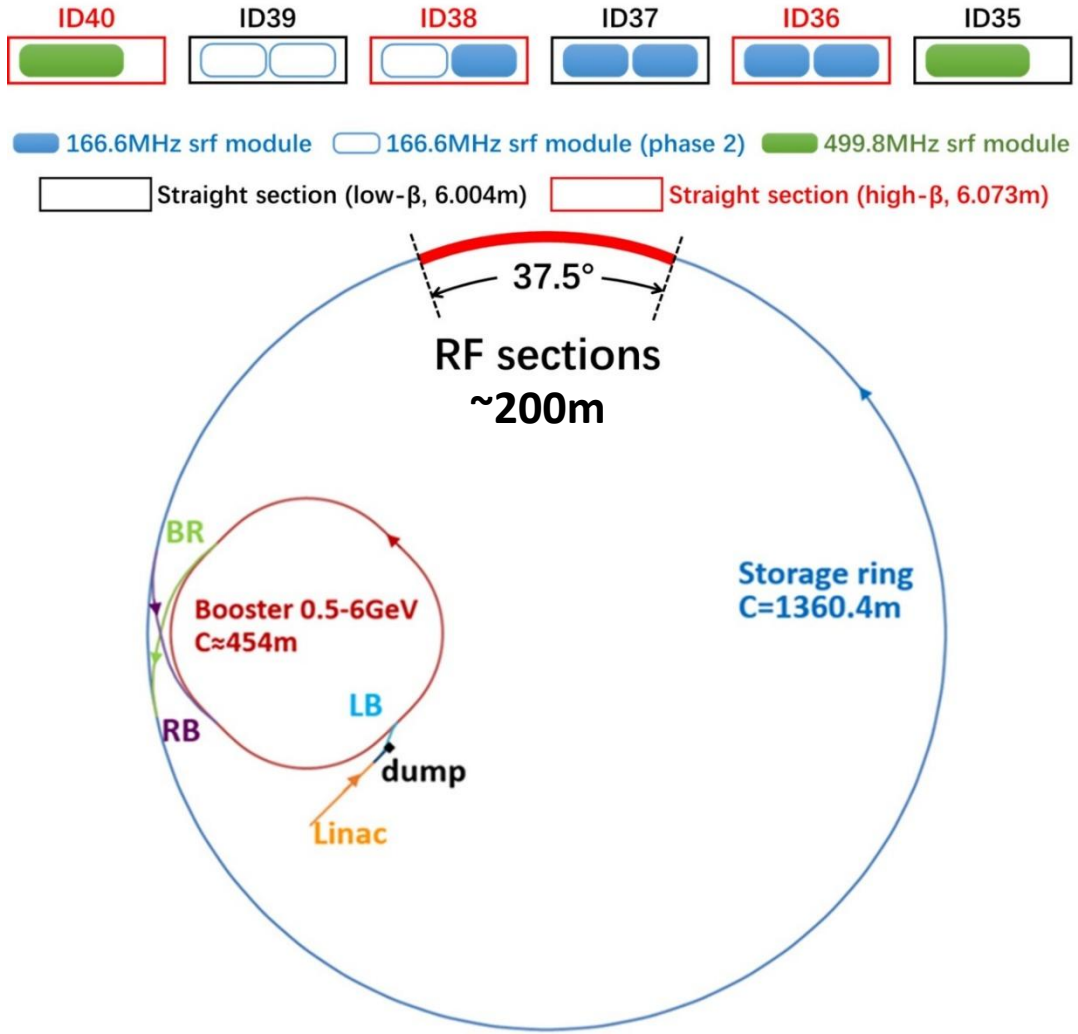
2 Development, Commissioning and Operation

---1) Helium cryogenic system

---2) Nitrogen cryogenic system

---3) Cryogenic control system

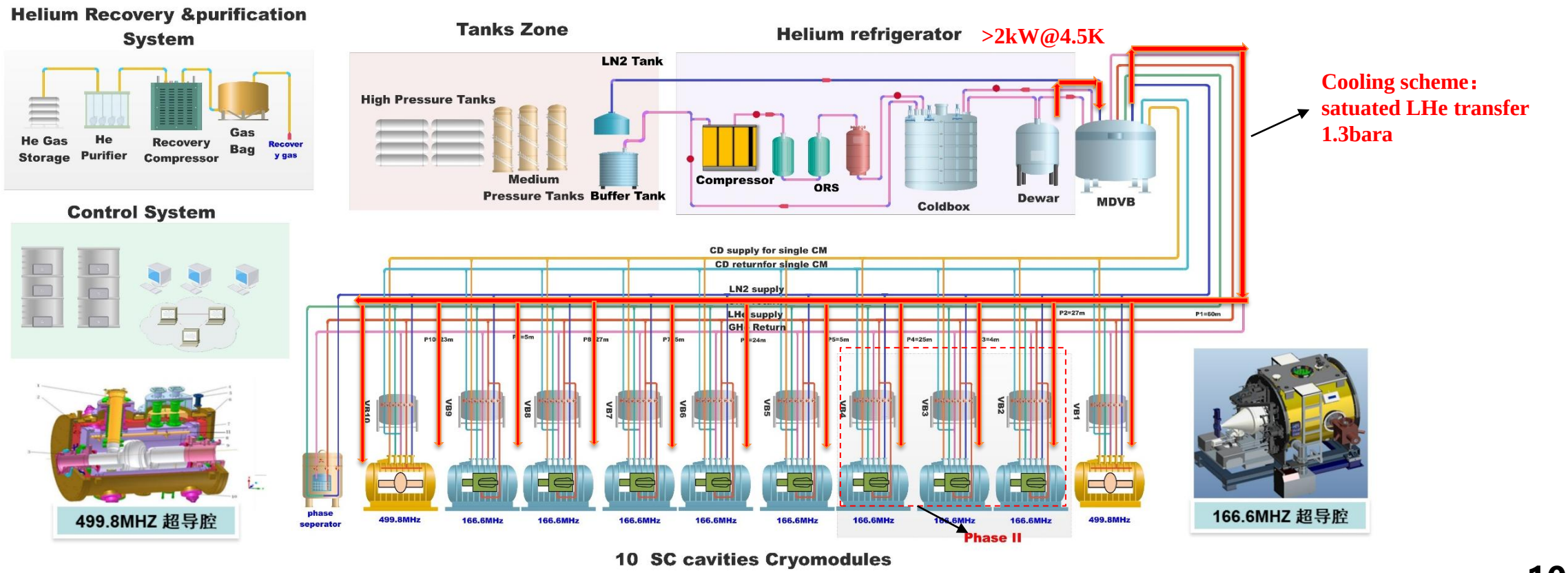
Helium Cryogenic System---SRF Cavities Requirement



- **Five 166.6MHz** SRF cavities, **two 499.8MHz** SRF cavities in **HEPS Phase I**
- **Develop** Low static **heat leak cryomodule** for the SRF cavities
- To ensure the efficient and stable cryogenic conditions
- **Requirement parameters**: Liquid helium immersion cooling, **the pressure stability ±3mbar, liquid level stability ±1%**
- **To fulfill various operating modes**, including pre-cooling mode, warm-up mode, normal operation mode and quench protection, etc.

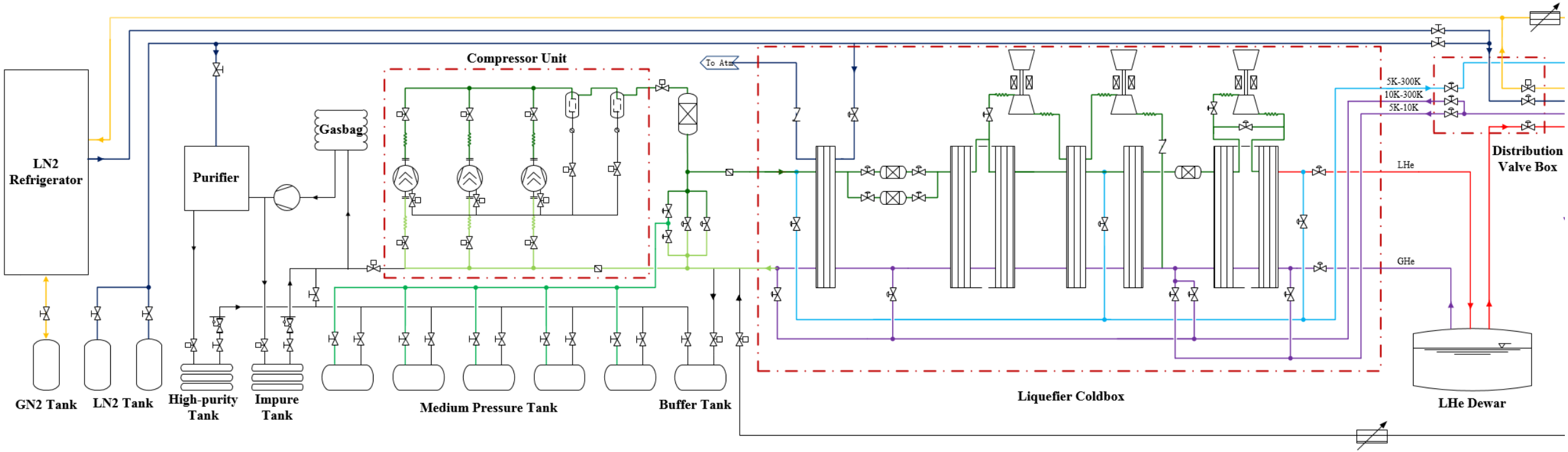
Helium Cryogenic System---overall composition

- Helium Compressor units
- Helium cold box
- Liquid helium Dewar
- Helium recovery and purification system
- Helium gas storage
- Cryogenic distribution system
- SRF cavity cryomodules
- Control system



Helium cryogenic system---helium refrigerator

- Provide one 2.0kW@4.5K **helium refrigerator**
- the cooling capacity for ten SRF cavity cryomodules
- **Core 1:** Operation with low failure rate
- **Core 2:** Fast recovery ability of faults



Helium cryogenic system---helium refrigerator

Duty name	Period	Start time	Complete time	Status
Cryogenic helium refrigerator				
Manufacturers Research and Report	59 WDs	**2019年10**月24日	2020年1月14日	Completed
Technical Program Review (IHEP)	1 WD	2020年1月15日	2020年1月15日	Completed
Technical requirements clarification discussion	21 WDs	2020年5月1日	2020年5月29日	Completed
Pre-bidding preparation	110 WDs	2020年6月1日	2020年10月31日	Completed
Pre-bid evaluation meeting (IHEP)	1WD	2020年9月14日	2020年9月14日	Completed
Formal bidding	21 WDs	2020年11月1日	2020年11月30日	Completed（Nov. 12, 2020）
Signing a contract	23 WDs	2020年12月1日	2020年12月31日	Completed（Dec. 18, 2020 digital version，Jan. 6, 2021, Paper version）
Letter of credit processing, down payment effective	23 WDs	2021年1月1日	2021年3月4日	Completed（March, 2021 ）
Manufacturing	346 WDs	2021年3月	2022年7月3日	Completed
Shipment	45 WDs	2022年7月4日	2022年9月4日	Completed
Equipment Arrival	1 WD	**2022年9**月5日	2022年9月5日	Completed
Commissioning & acceptance (Dewar load)	46 WDs	**2023年10月**	2023年11月	Completed

Helium cryogenic system---helium refrigerator

- Provide 2.0kW@4.5 +150L/h, **Type: Linde LR700**
- Three compressors on line
- Two units independent UPS for protection against unexpected power outages



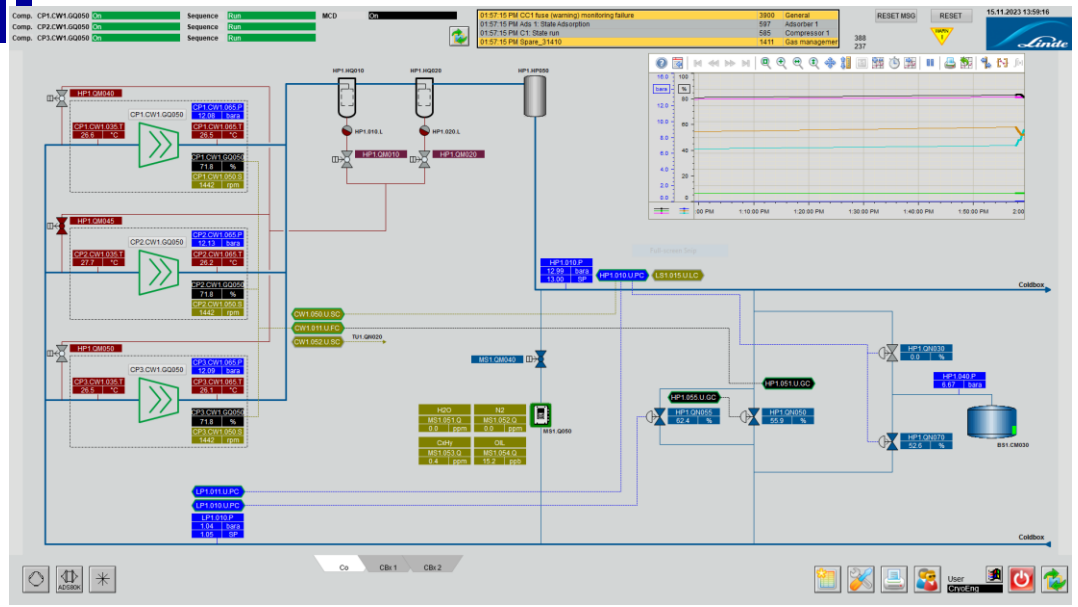
Helium compressors

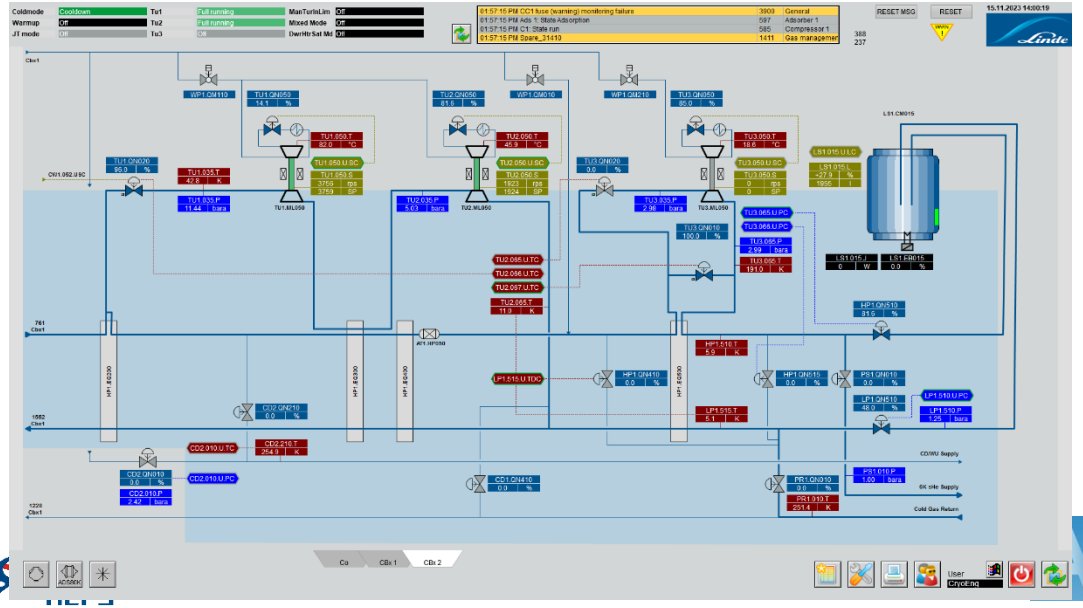

Helium ORS

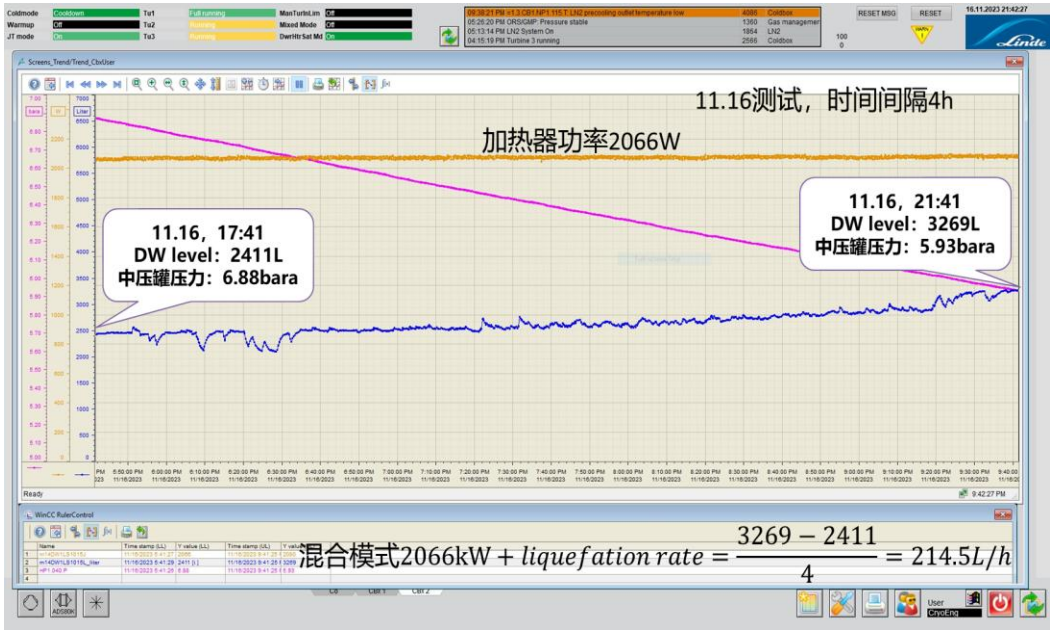


Helium coldbox and dewar

Helium refrigerator commissioning



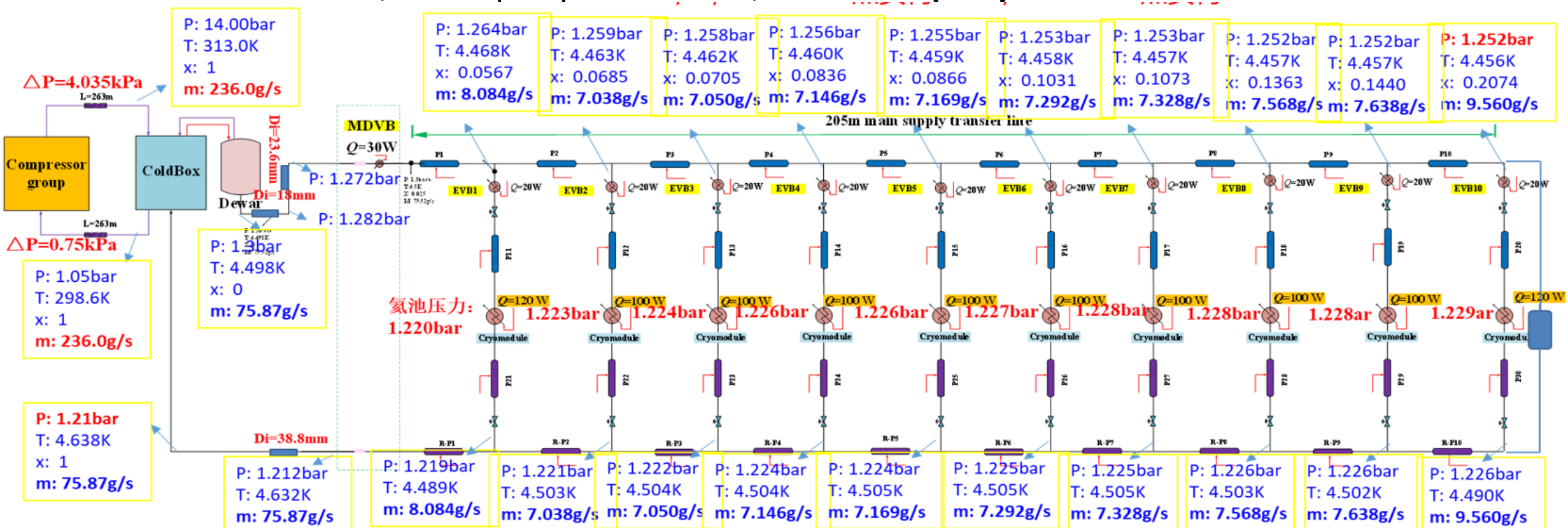




- The helium refrigerator commissioning has been **started at 2023.11**
- Complete the overall acceptance test at 2023.11.16~18. **Success on the first start-up**
- **The cooling capacity** has been tested at **2066W+214.5L/h** with liquid nitrogen precooling

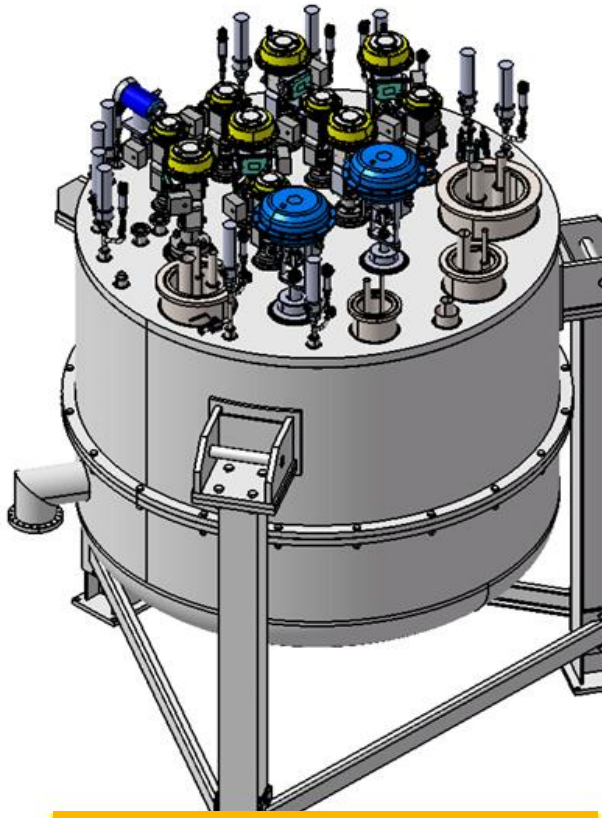
Helium cryogenic system--- transfer & distribution

- **A multi-objective parameter method** is adopted, to deeply analyze the specific effects of multiple factors on the pressure drop
- **Integration of helium-specific properties into the software** to improve design accuracy
- **After multi-objective parameter evaluation: 1.3 bara saturated liquid helium supply** scheme is selected, 95% liquid yield for CM1, and **80% liquid yield for CM10**

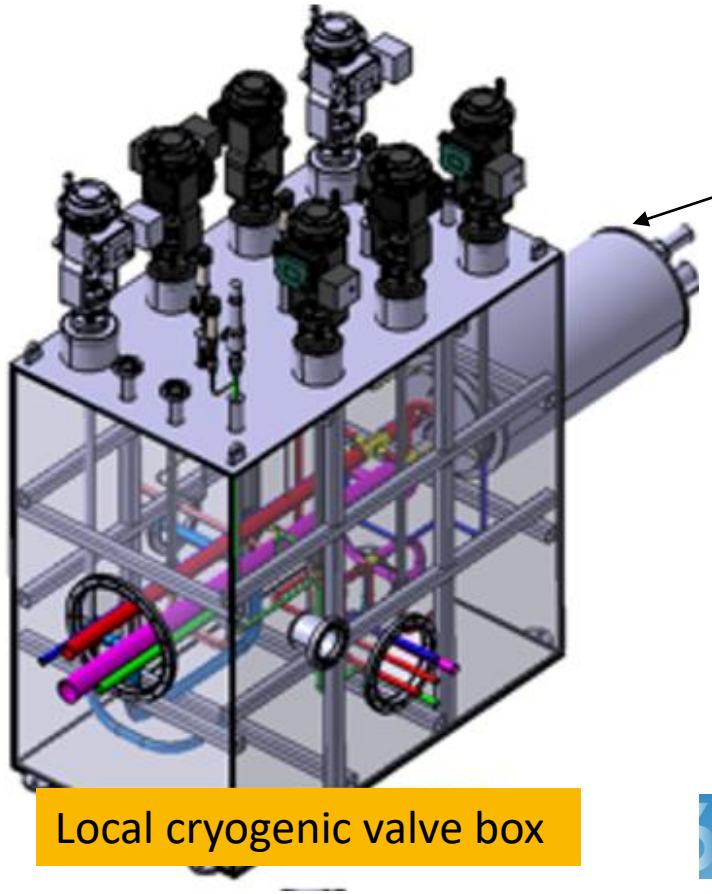


Helium cryogenic system--- transfer & distribution

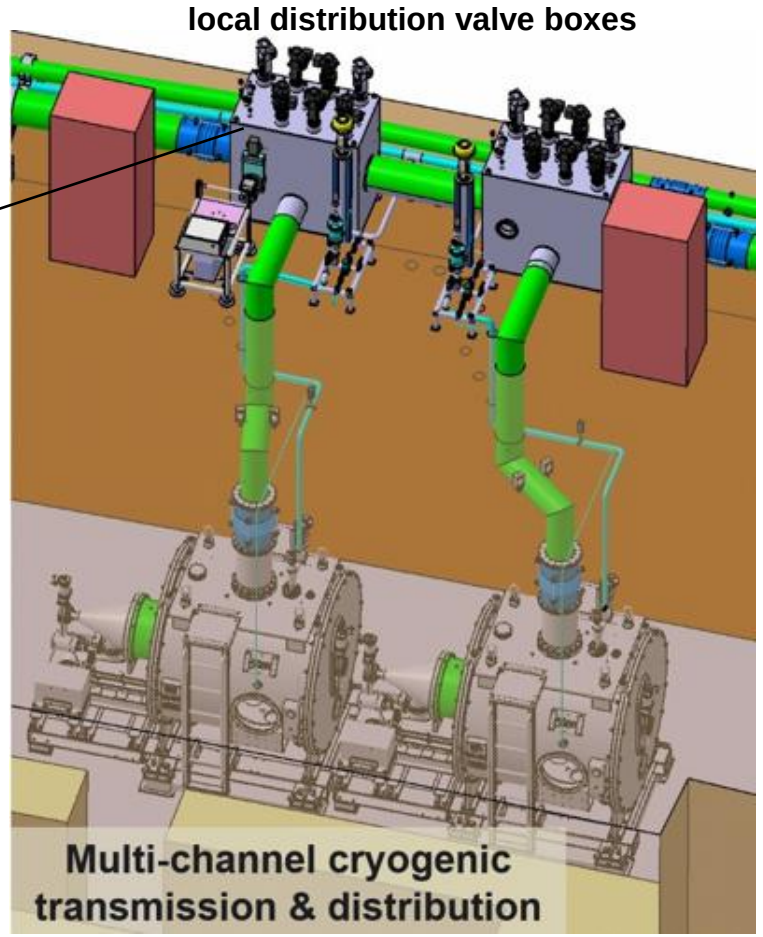
- **Equipment**: **One main cryogenic valve box, seven local distribution valve boxes** located above SRF cavity cryomodules, **about 200m long multi-channel cryogenic line**. To distribution liquid helium, cold helium gas and liquid nitrogen, also equipped with safety units for faults



Main cryogenic valve box



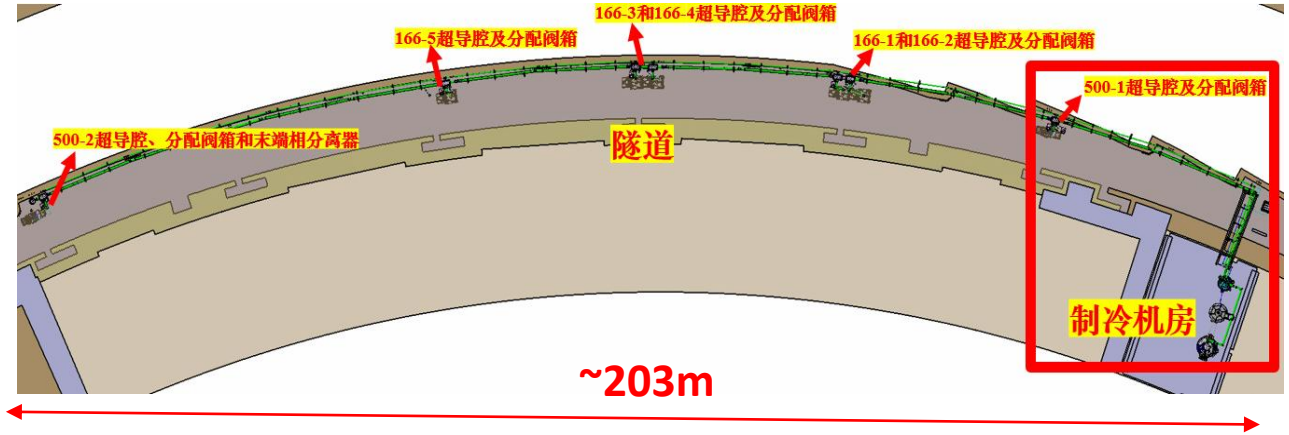
Local cryogenic valve box

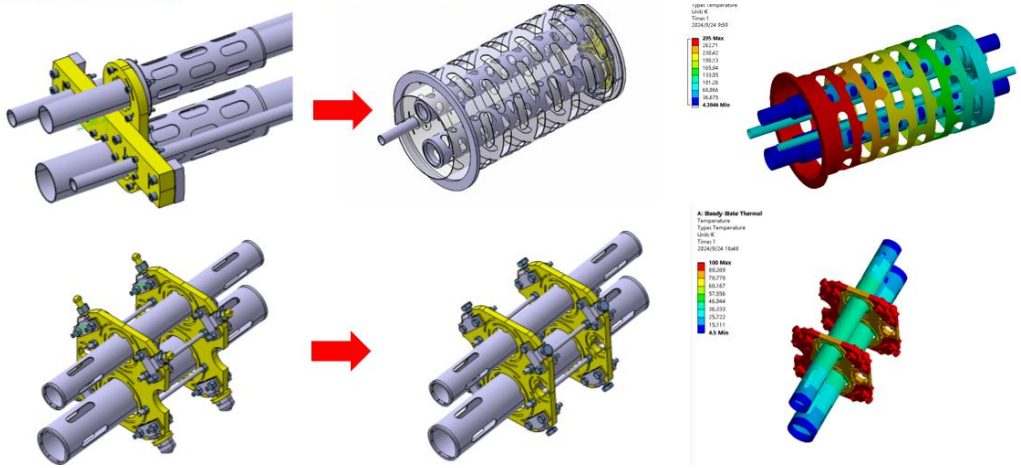


Helium cryogenic system--- transfer & distribution

- **Multi-channel cryogenic pipeline**

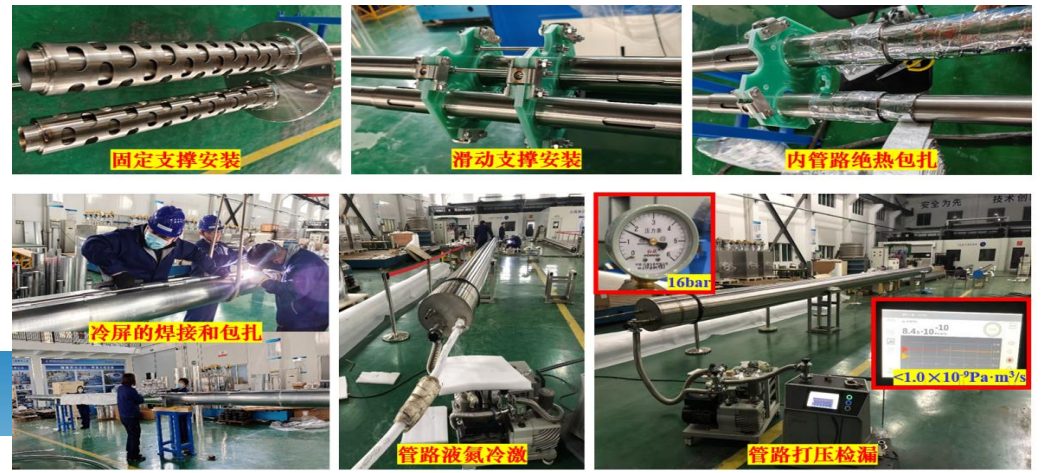
- Design and calculations started in October 2024
- Commissioning was completed in July 2025
- Operation in August 2025, with a successful first start-up





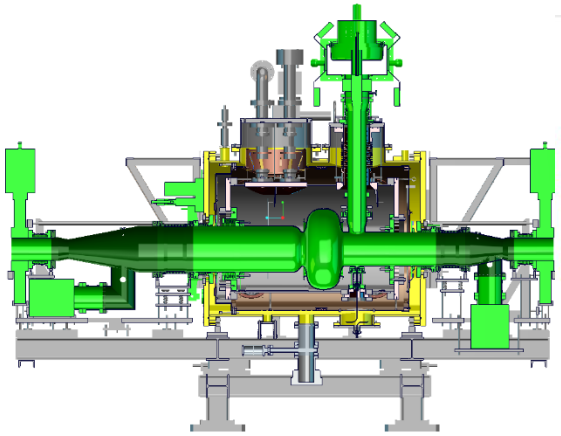


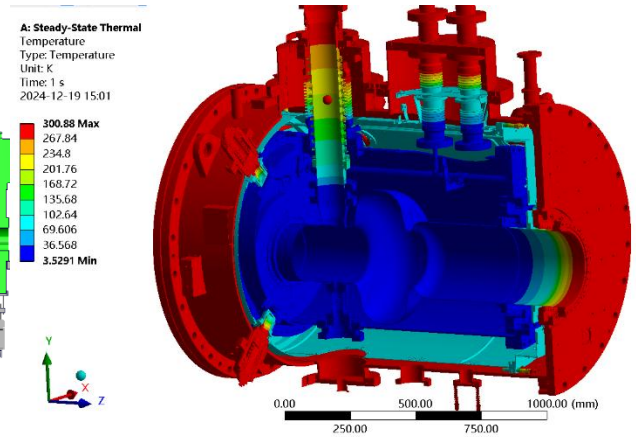


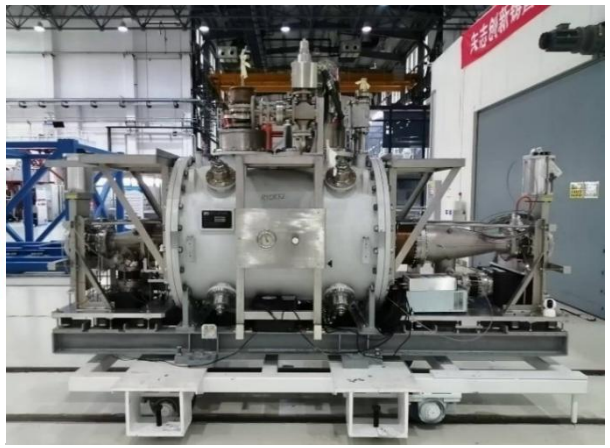


Helium cryogenic system--- SRF cavity Cryomodule

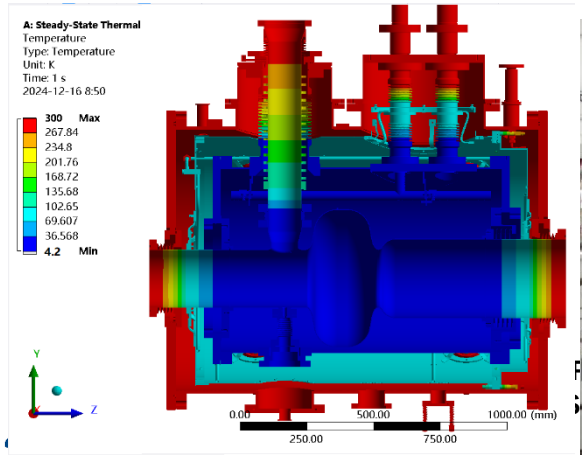
- Take the BEPCII **499.8MHz SRF cavity** CM as **the basic framework (KEKB type),** and improve the design scheme to enhance the cryogenic thermodynamic performance
- Improvement scheme: sealing structure, cold screen material, brazing process, multiple measures to reduce thermal resistance etc. **Static heat load ~ 23W@4.5K**

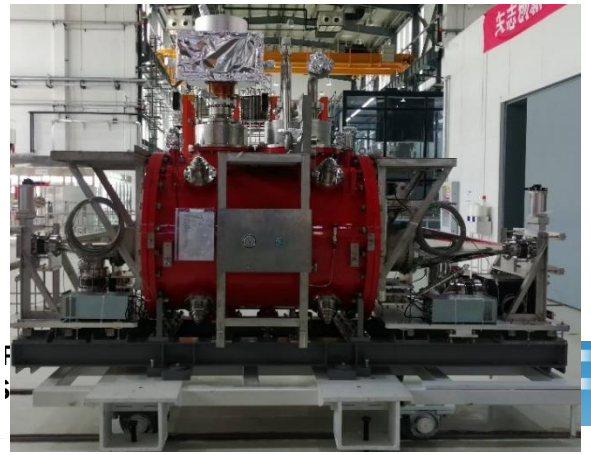




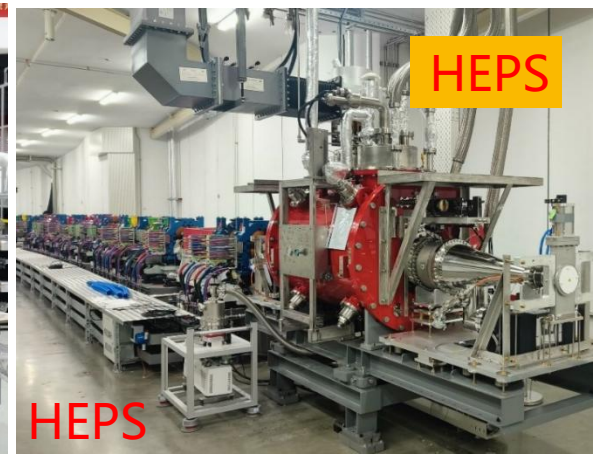






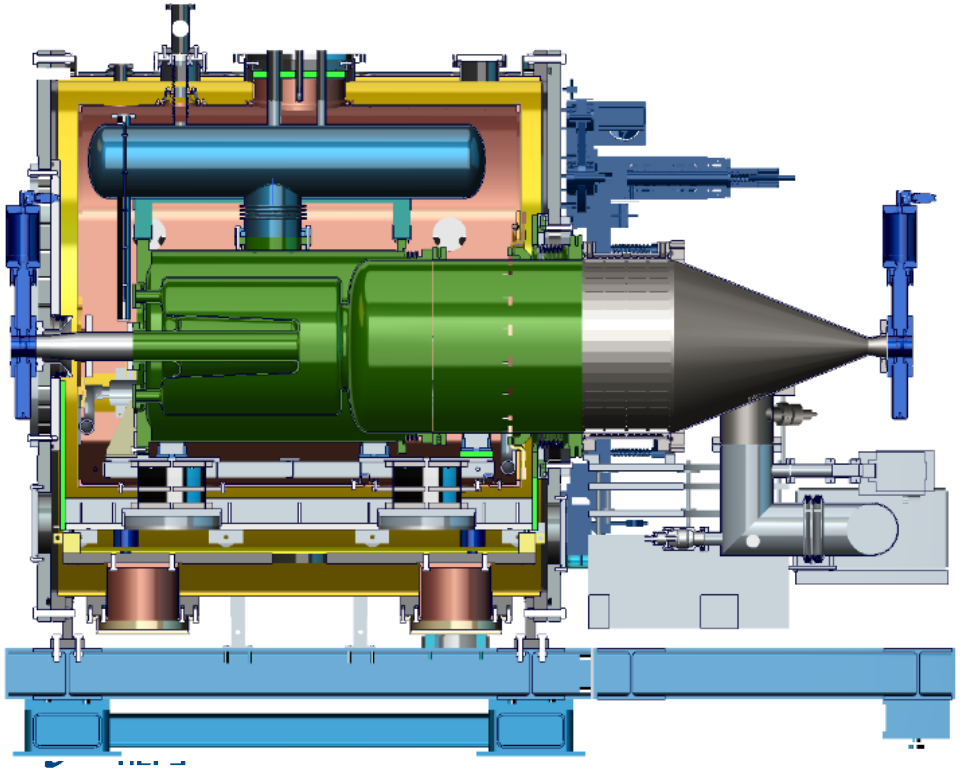


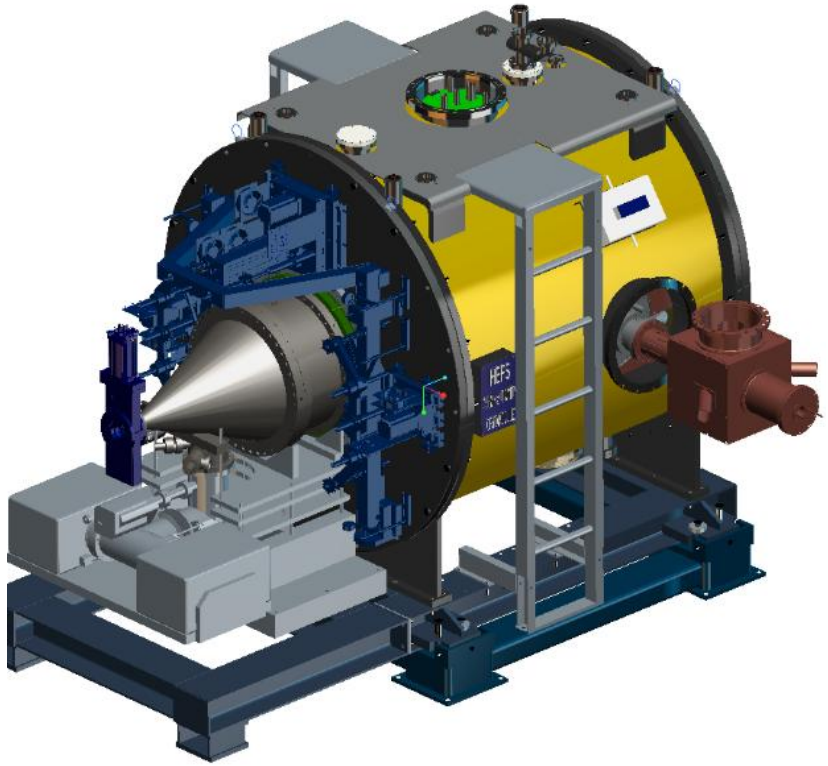


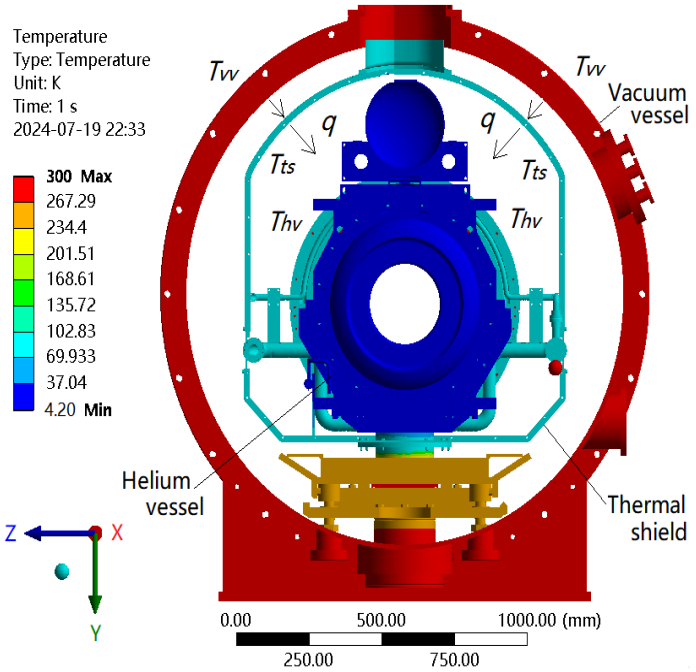


Helium cryogenic system--- SRF cavity Cryomodule

- Low frequency **166.6MHz SRF cavity** **requires new cryomodule, total five cryomodules**
- **Detailed Mechanical Design**: Structural Design, Assembly Design, Material Selection, 3D Modeling, Reliability Design etc. **The development** was quite challenging
- **Thermal performances** of the cryomodule are analyzed to account the main contributors
- Cool down, operating with RF power, **accomplish static heat load ~ 40W@4.5K**



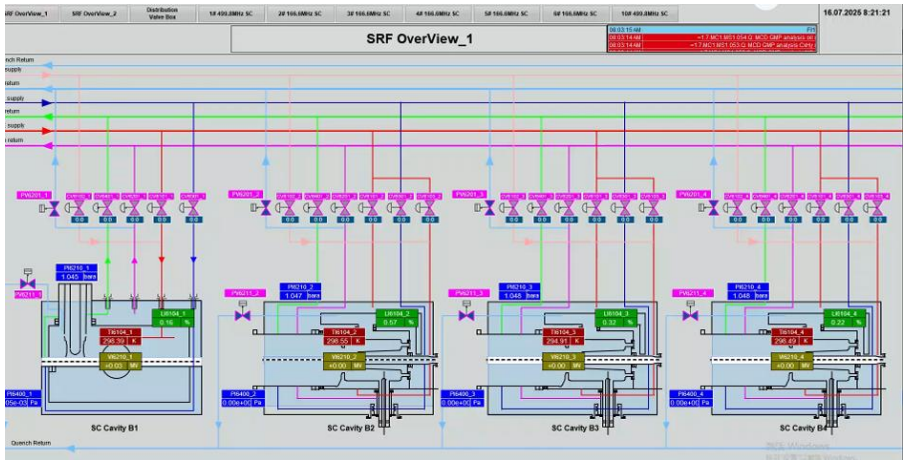


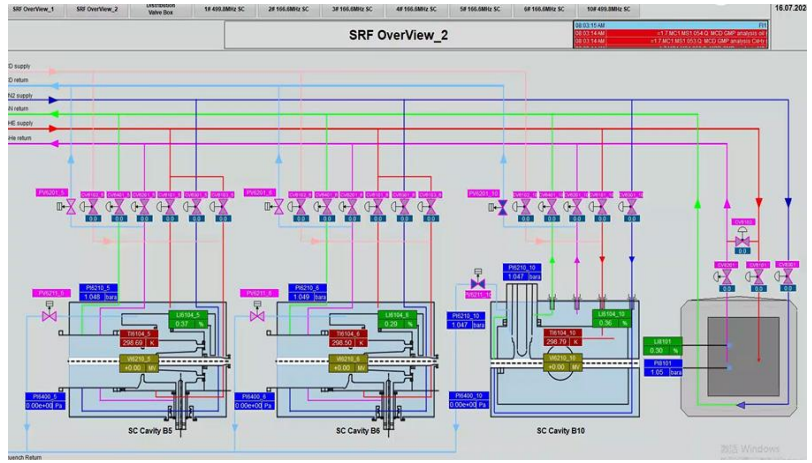


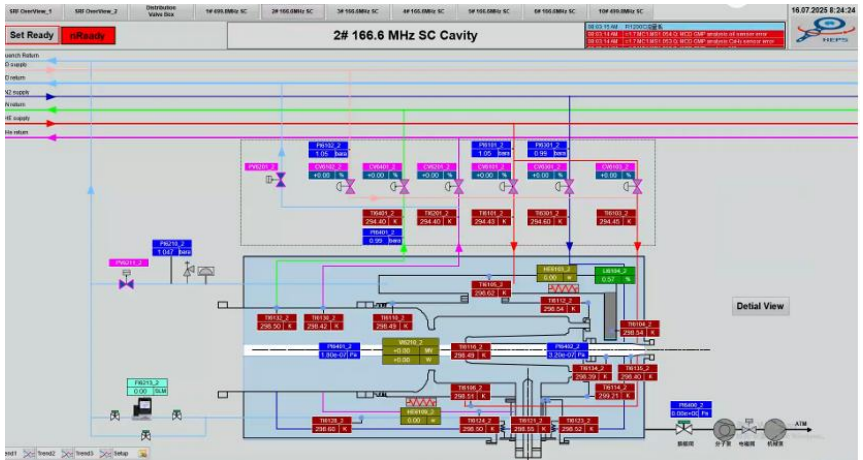
Helium cryogenic system--- CM Control system

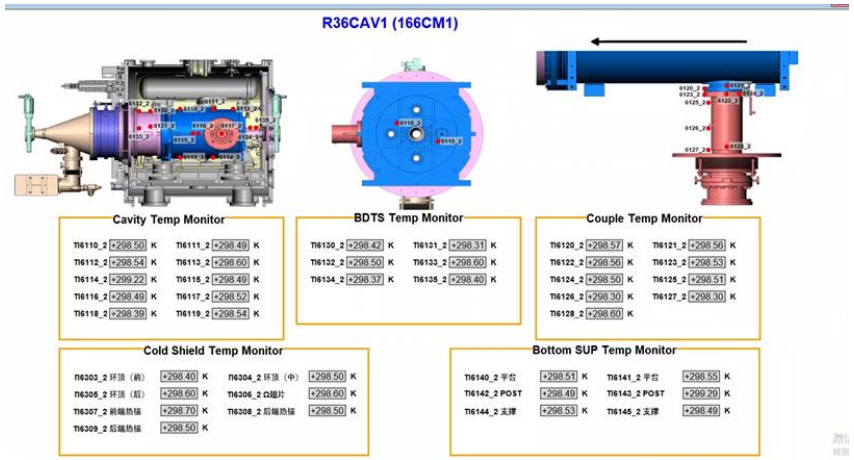
- **After cryomodules installation, Only half a month time,** completed **cryomodule Control system** of software and hardware installation and commissioning for seven cryomodules**, about 2000 signals**, **cabinets and the remote control interface**

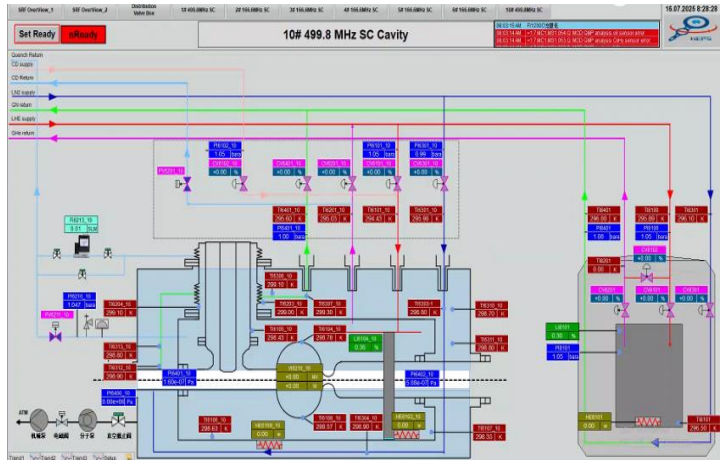










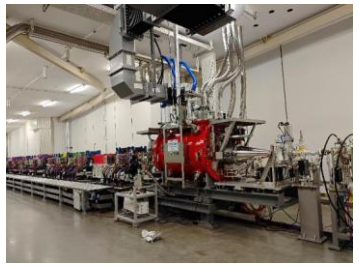


SRF cryomodule milestones

- SRF cavity cryomodule **assembly first started** on **28 September 2023**.
- Horizontal testing, installation and commissioning lasted until **1 August 2025**.
- All cryomodules were ready for beam on **8 August 2025** and have been in operation up to now.



First Cryomodule assembly
2023.9.28



Second Cryomodule Ready
2024.11.30



All Cryomodules installation
2025.7.20

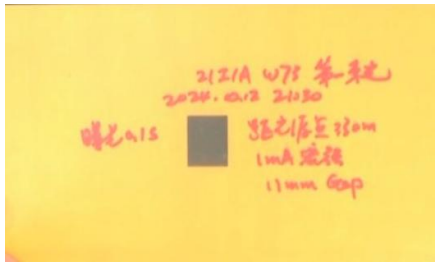


HEPS mission completed
2025.10.29

2024.7.6
First Cryomodule Ready



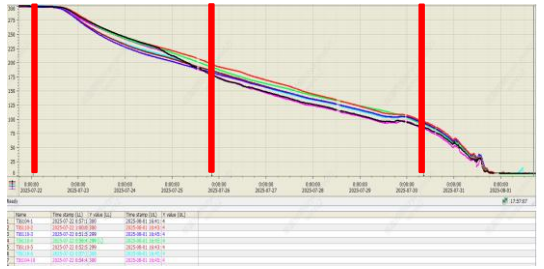
2024.10.12
HEPS First light



2025.6.20
Six Cryomodules test



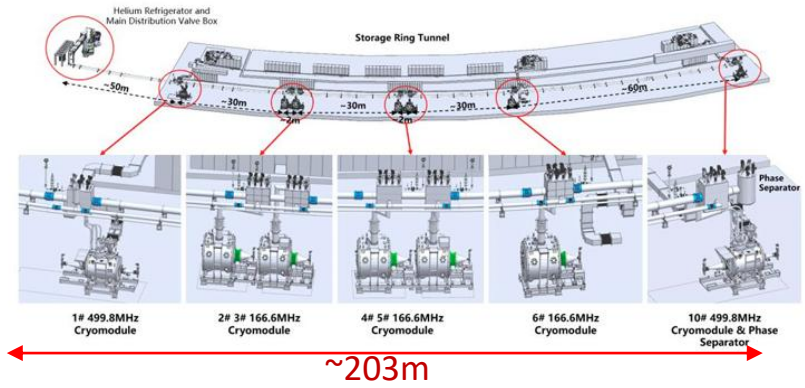
2025.8.1
All Cryomodules Ready

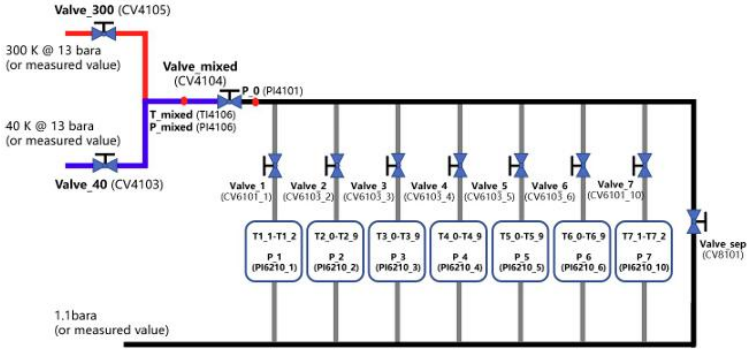


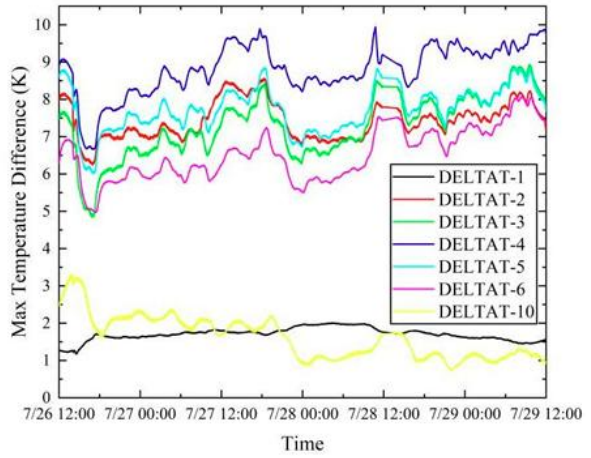
Automatic cooldown of Cryomodules

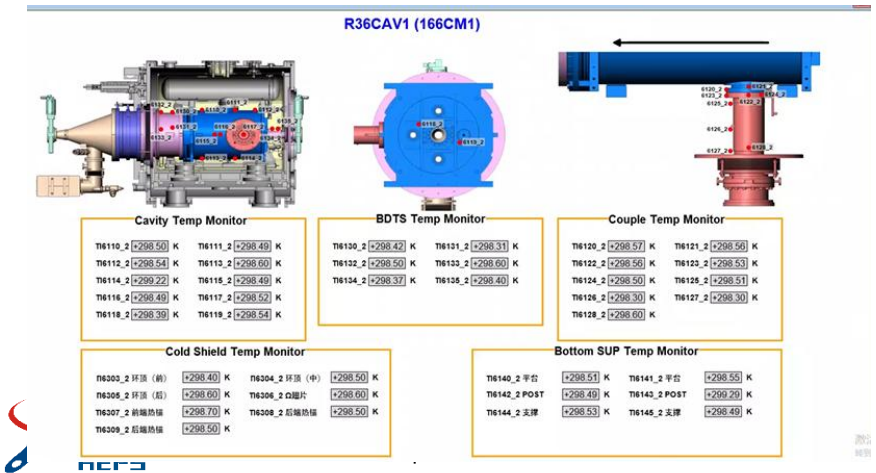
Extremely stringent control of cooling rate and cavity temperature difference(T<5K/h，ΔT<10K/h)

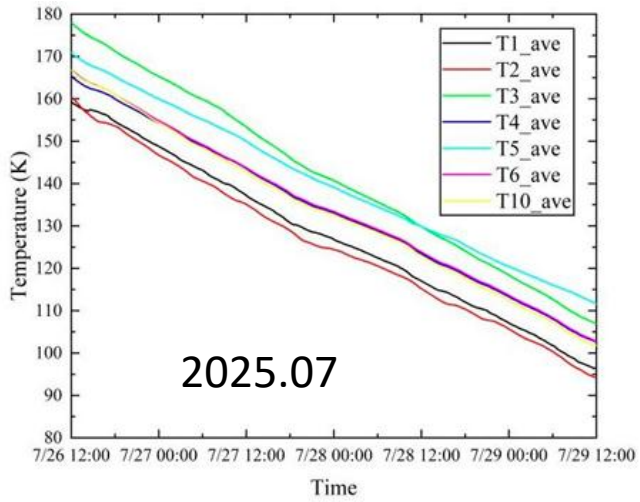
- The innovative introduction and promotion of the multi-cavity, 203-meter-level long-distance online
- **Automatic cooldown technology was successfully tested** on 7 SRF cryomodules
- Greatly reduces manual operations and enables digital construction of the system.

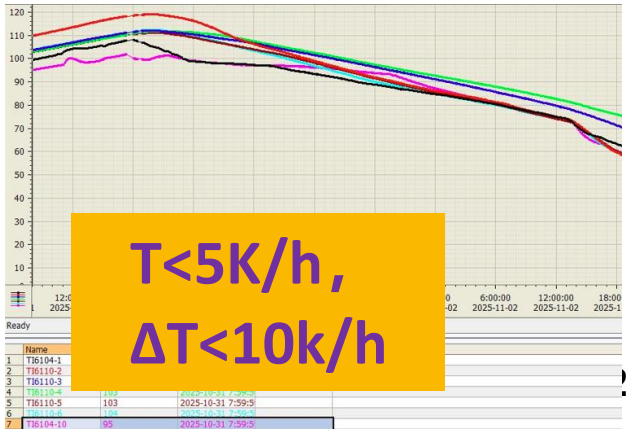






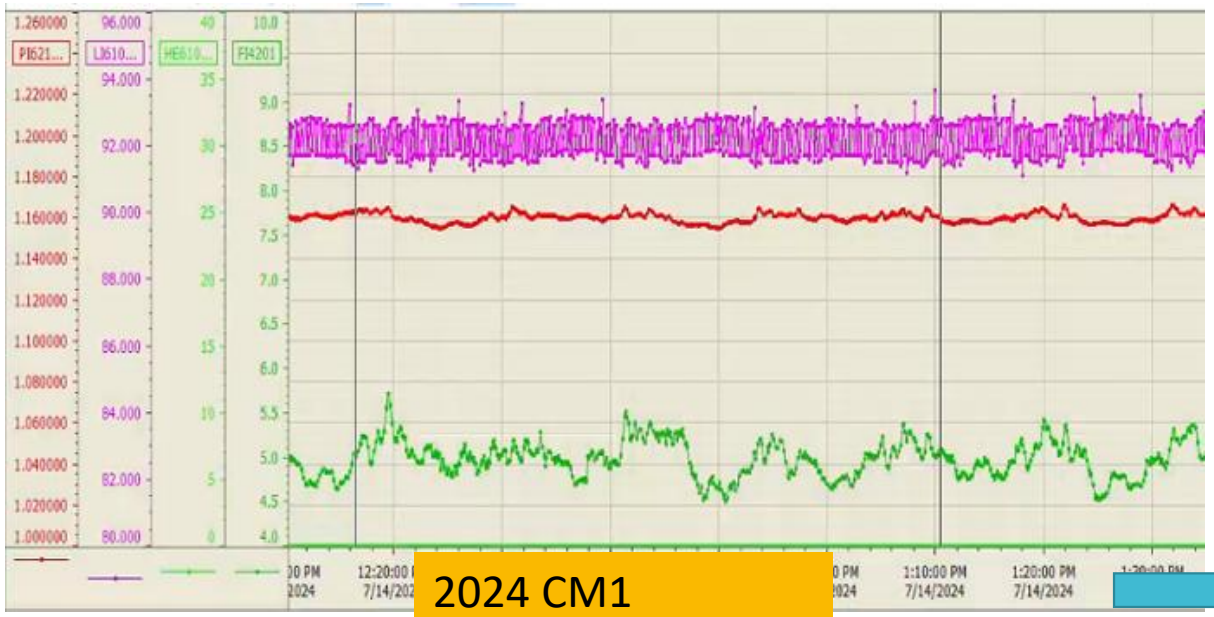




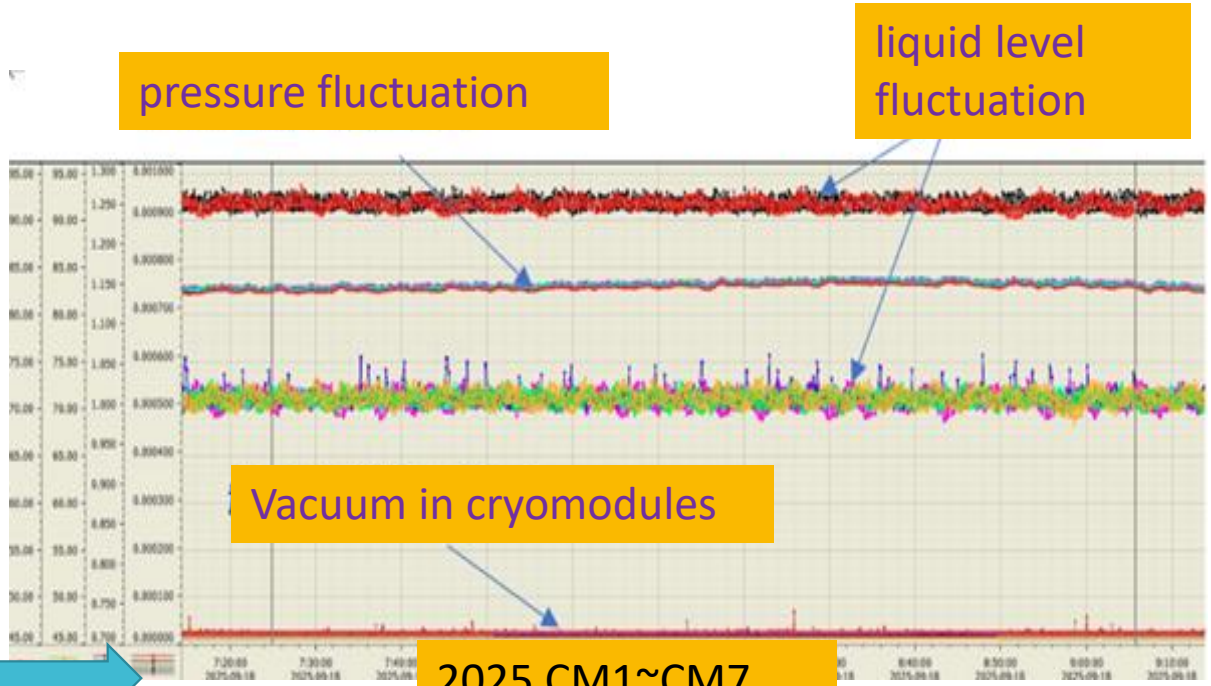


Helium cryogenic system operation

- Helium cryogenic system **has operated more than** year from October, 2025
- Performance is good: pressure fluctuation < ±3mbar
  ±1% liquid level fluctuation of liquid helium in SRF cavity cryomodules



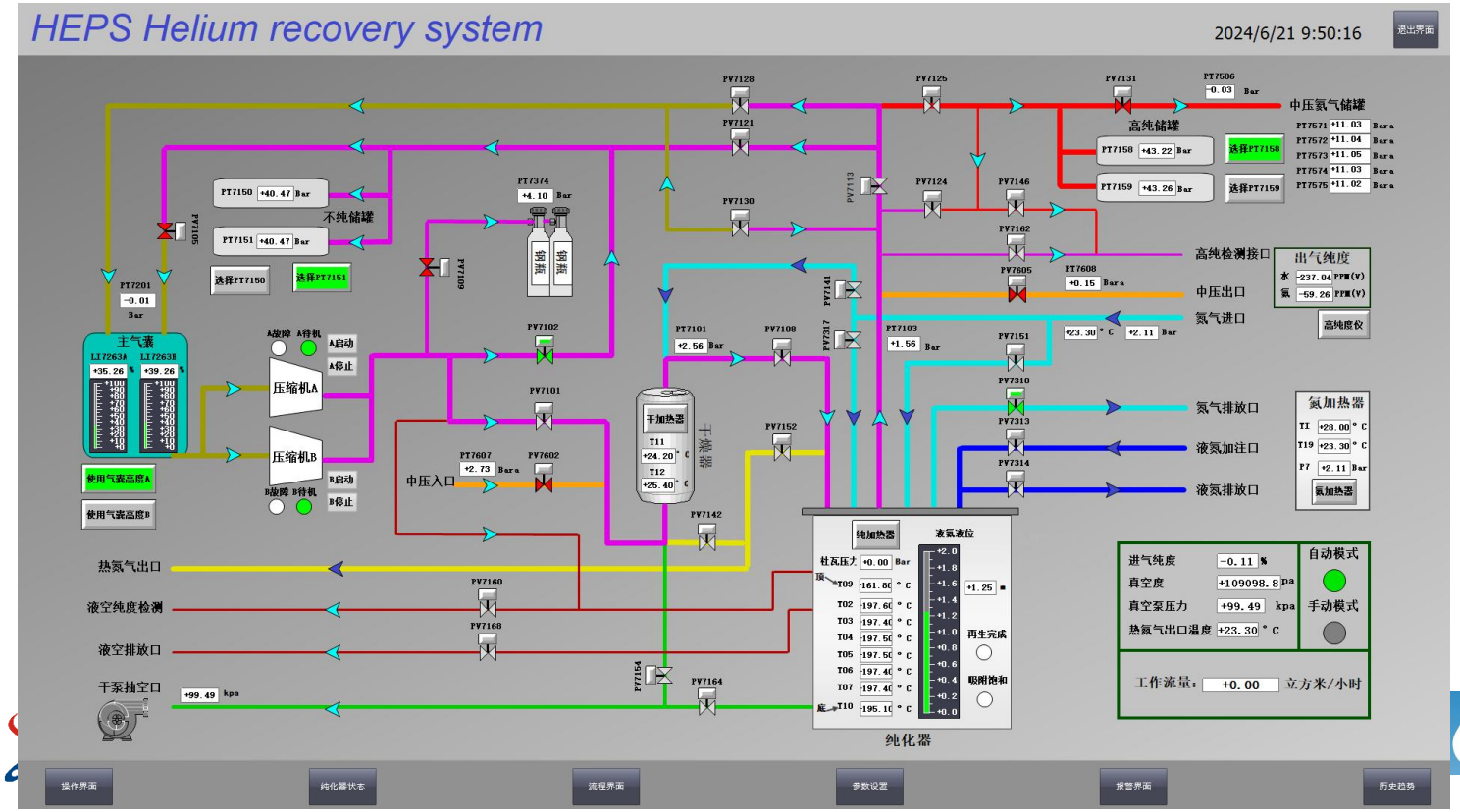
2024 CM1

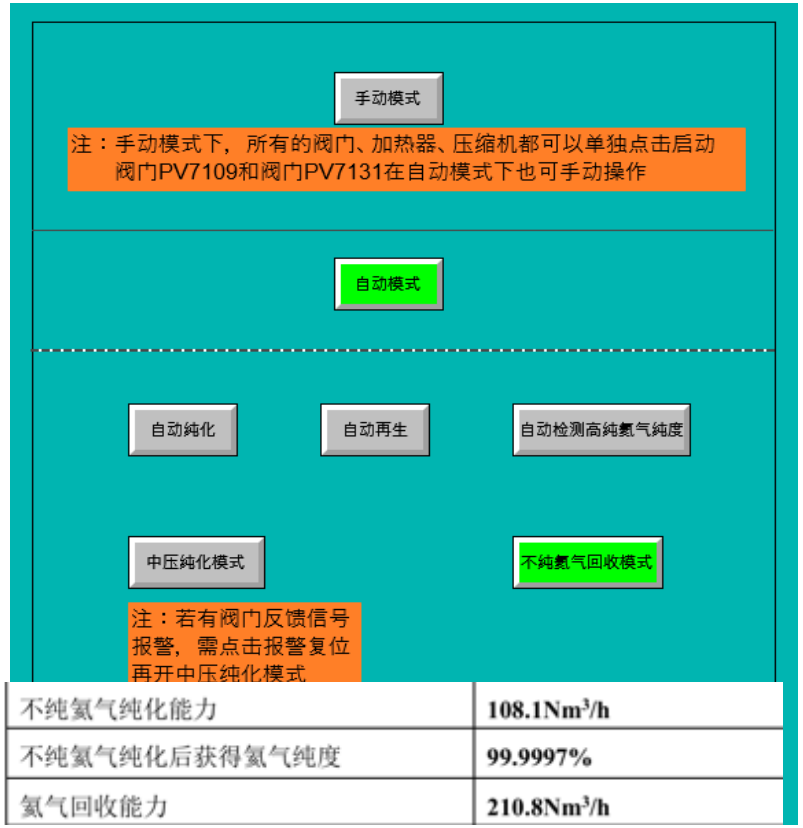


2025 CM1~CM7

Helium recovery and purification system

- **Operates fully automatically**, supporting multiple operating modes: **Purification mode**, Regeneration mode, automatic helium purity detection mode, medium-pressure purification mode, impure helium recovery mode, etc.
- **Fully guarantees the supply, purification and storage of high-purity helium** with a purity of **>99.999% & 200NM3/h** for the HEPS cryogenic system throughout the year





不纯氦气纯化能力	108.1Nm³/h
不纯氦气纯化后获得氦气纯度	99.9997%
氦气回收能力	210.8Nm³/h

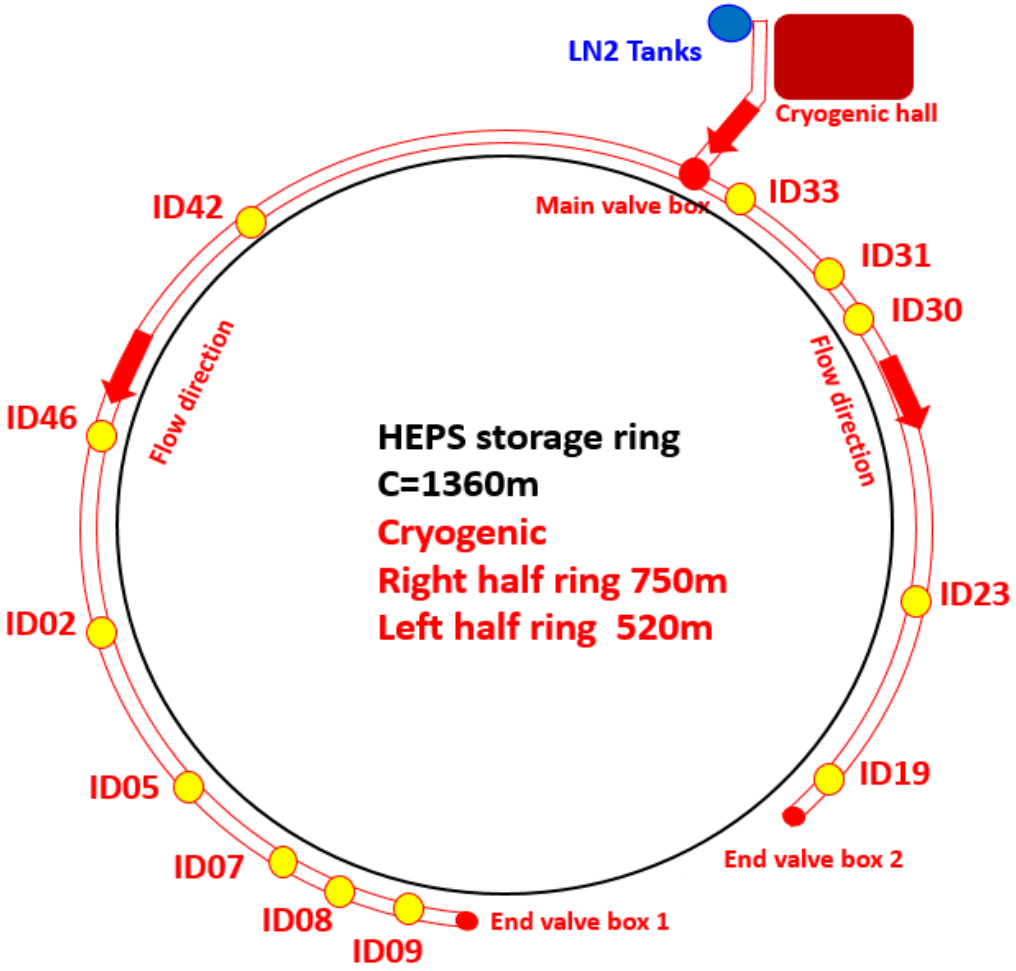
2 Development, Commissioning and Operation

---1) Helium cryogenic system

---2) Nitrogen cryogenic system

---3) Cryogenic control system

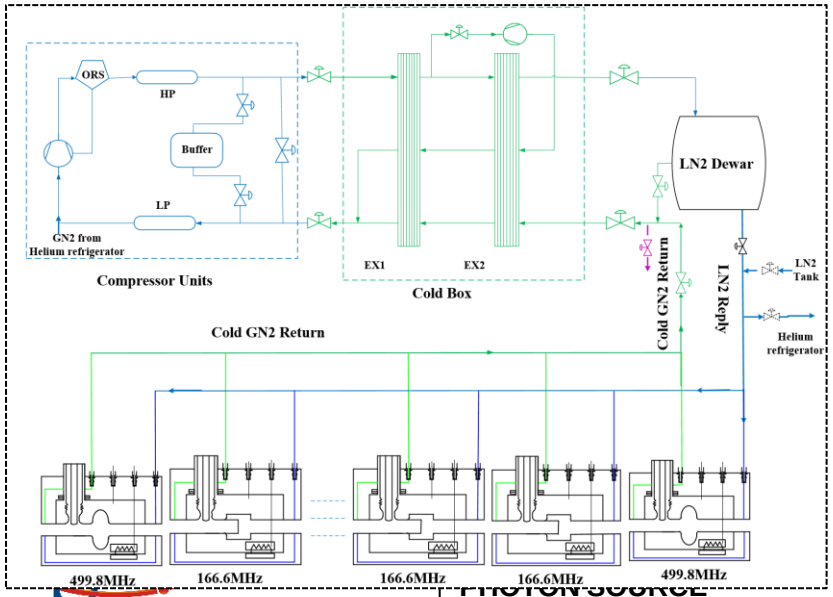
Nitrogen cryogenic system--- LN2 equipment requirement

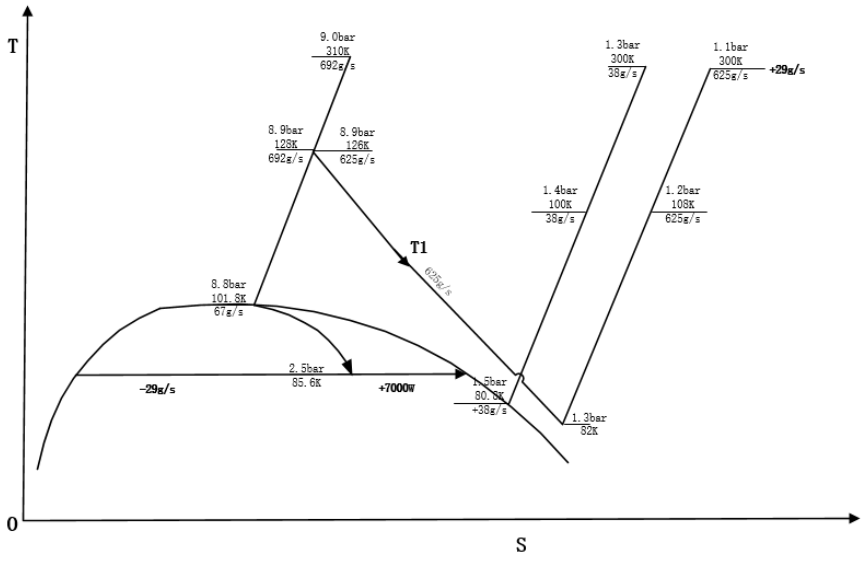


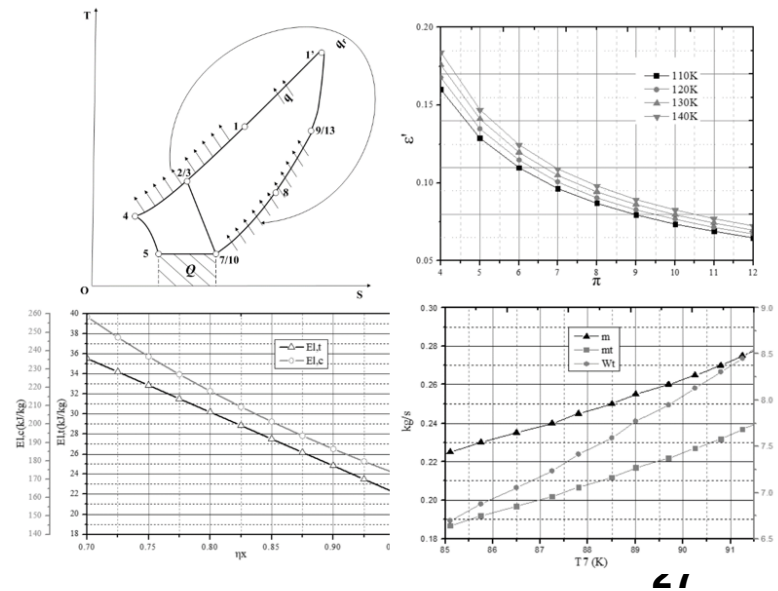
- 6 CPMU in storing line and 14 beamlines cryogenic equipment, precooling 1 helium refrigerator, thermal shield of SRF cavity cryomodules, multi-channel cryogenic transfer line, etc
- **To ensure stable liquid nitrogen cryogenic conditions, ~45kW@80K**
- **To fulfill various operating modes**: pre-cooling mode , warm-up mode, normal operation mode and safety protection.
- **Requirement parameters**: Liquid nitrogen cooling, **temperature gradient <1.5K/m**, **Pressure stability RMS1.0mbar**, cooling temperature 80~100K, Low static heat leakage

Nitrogen cryogenic system---refrigerator

- To achieve ultimate "self-sufficiency" in nitrogen cold energy , one 7kW@90K+140L/h **nitrogen refrigerator** are developed **for cryomodules and helium refrigerator** in HEPS Phase I
- A steady-state system thermodynamic calculation model, the influences of the performance of the nitrogen compressor and the cryogenic turbine on the exergy efficiency of the nitrogen refrigeration system were obtained
- **Core features：** Operation with low failure rate and high COP





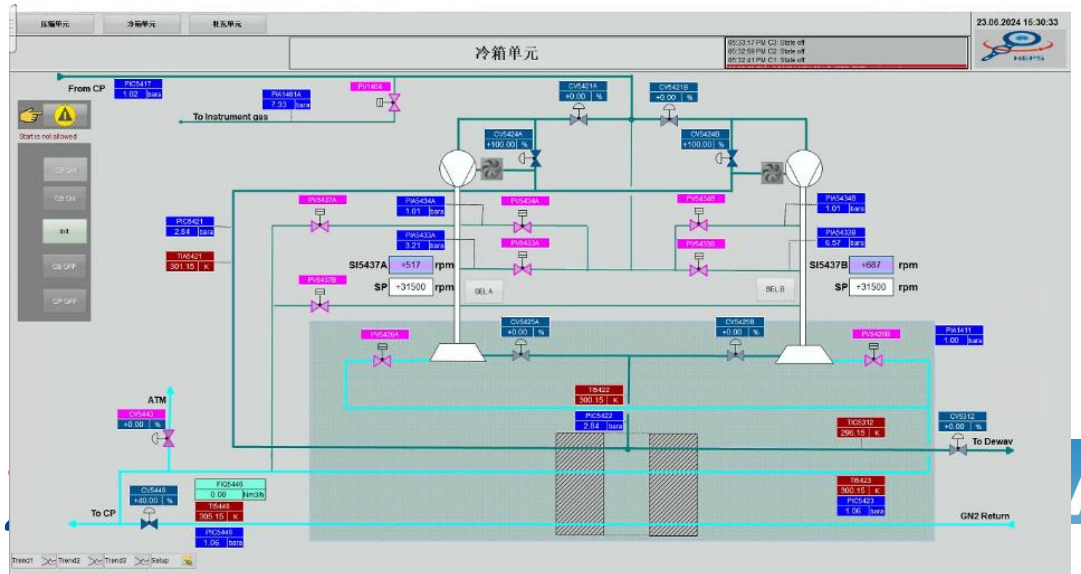


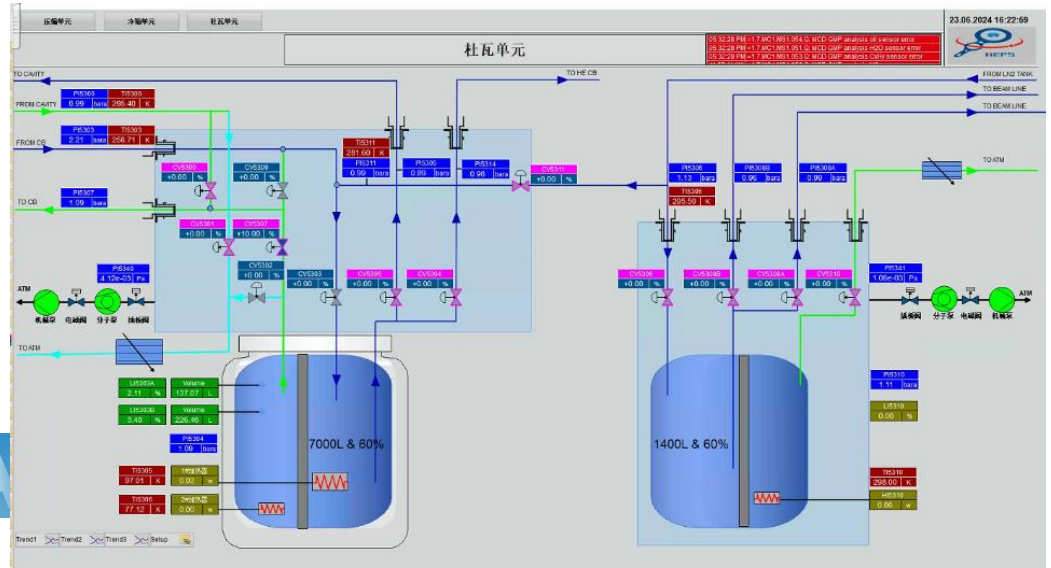
Nitrogen cryogenic system---refrigerator

- In February,2022, **Control strategies** for the nitrogen cycle refrigerator system, including startup, cool-down, liquid accumulation, variable operating conditions, and shutdown, have been formulated.
- In **October, 2023 staged commissioning was carried out**



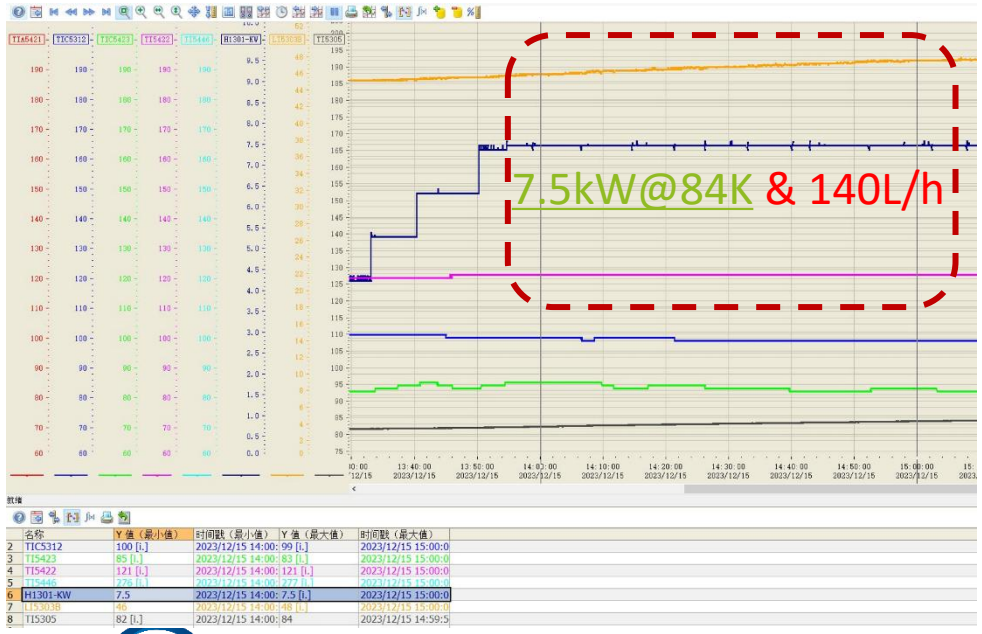






Nitrogen refrigerator commissioning

- In **December 2023**, all commissioning of individual equipment and the complete system was finished. The entire development work was completed over a period of 3 years.
- The measured cooling capacity in mixed mode **is 7.5 kW @ 84 K & 140 L/h**,which exceeds the acceptance specifications.
- Now, the system has been operating stably and has participated in HEPS operating, providing a reference for the construction of similar light source facilities.

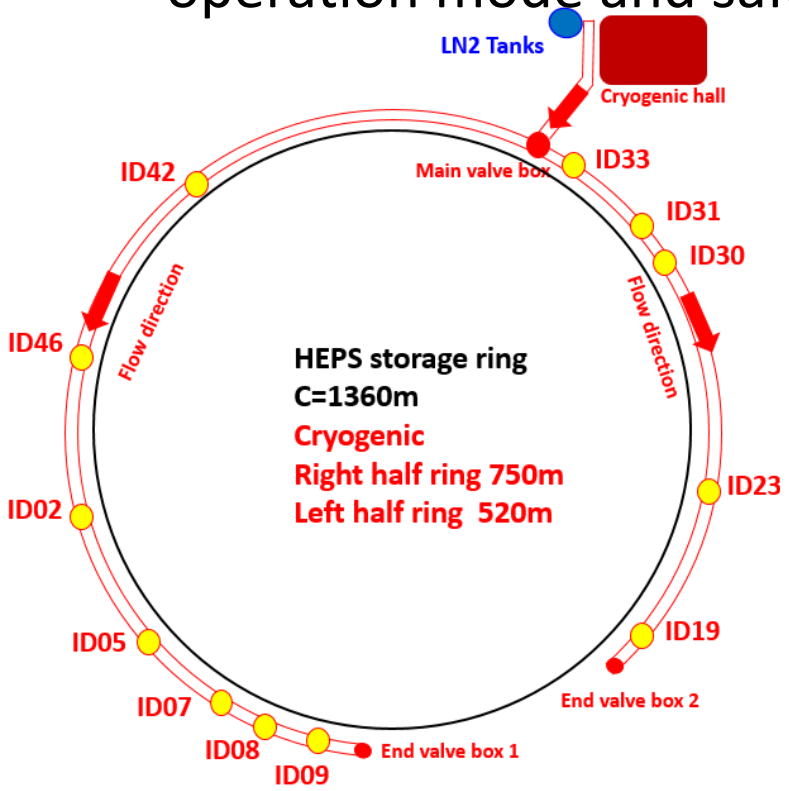


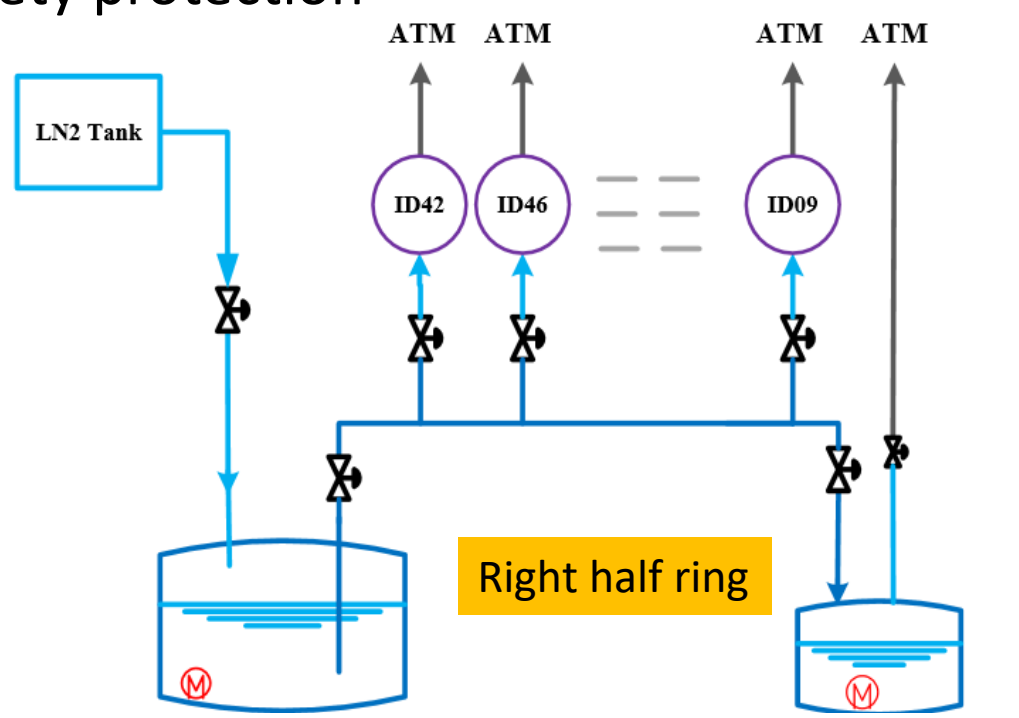


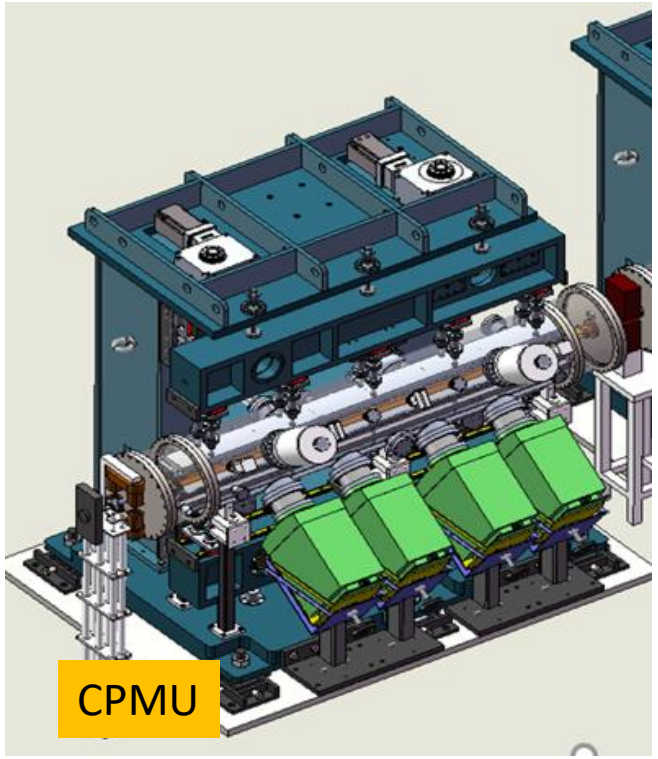


Nitrogen cryogenic system---transmission and subcooled LN2

- To ensure stable **liquid nitrogen cryogenic** conditions for **six CPMU in storage line and 14 beamlines cryogenic monochromator in** HEPS experimental hall
- **Kilometer-scales** high-quality liquid nitrogen transmission and Subcooled liquid nitrogen coldbox
- **To fulfill various operating modes**: pre-cooling mode, warm-up mode, normal operation mode and safety protection

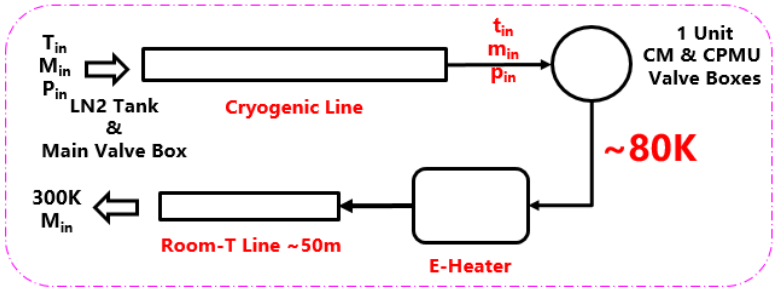


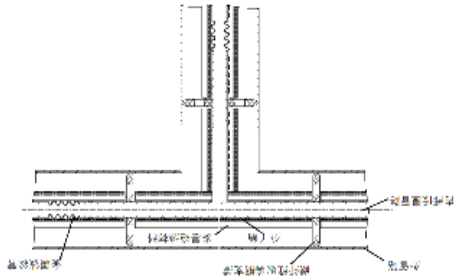


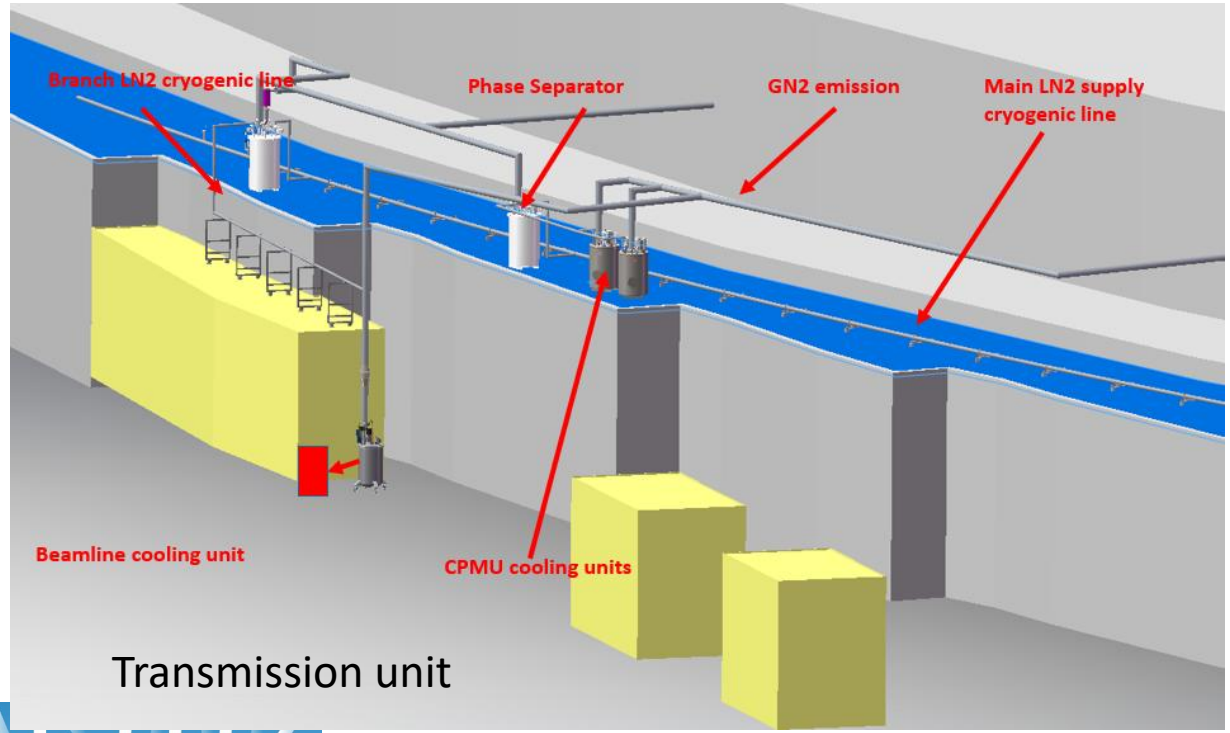


Liquid nitrogen transmission unit

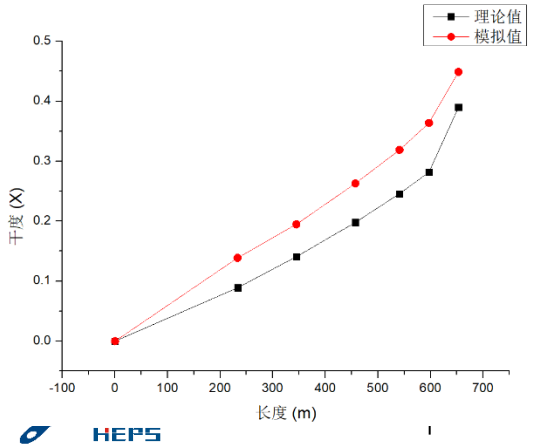
- **Detailed Mechanical Design:** 3D Modeling, Assembly Design, Reliability Design etc.
- **Thermal performances** of the cryogenic line are analyzed to account the main contributors of Cool down, operating, worm up
- **Challenges :** Kilometer-scale long-distance and year-round high-quality liquid nitrogen transmission and distribution were solved







Transmission unit



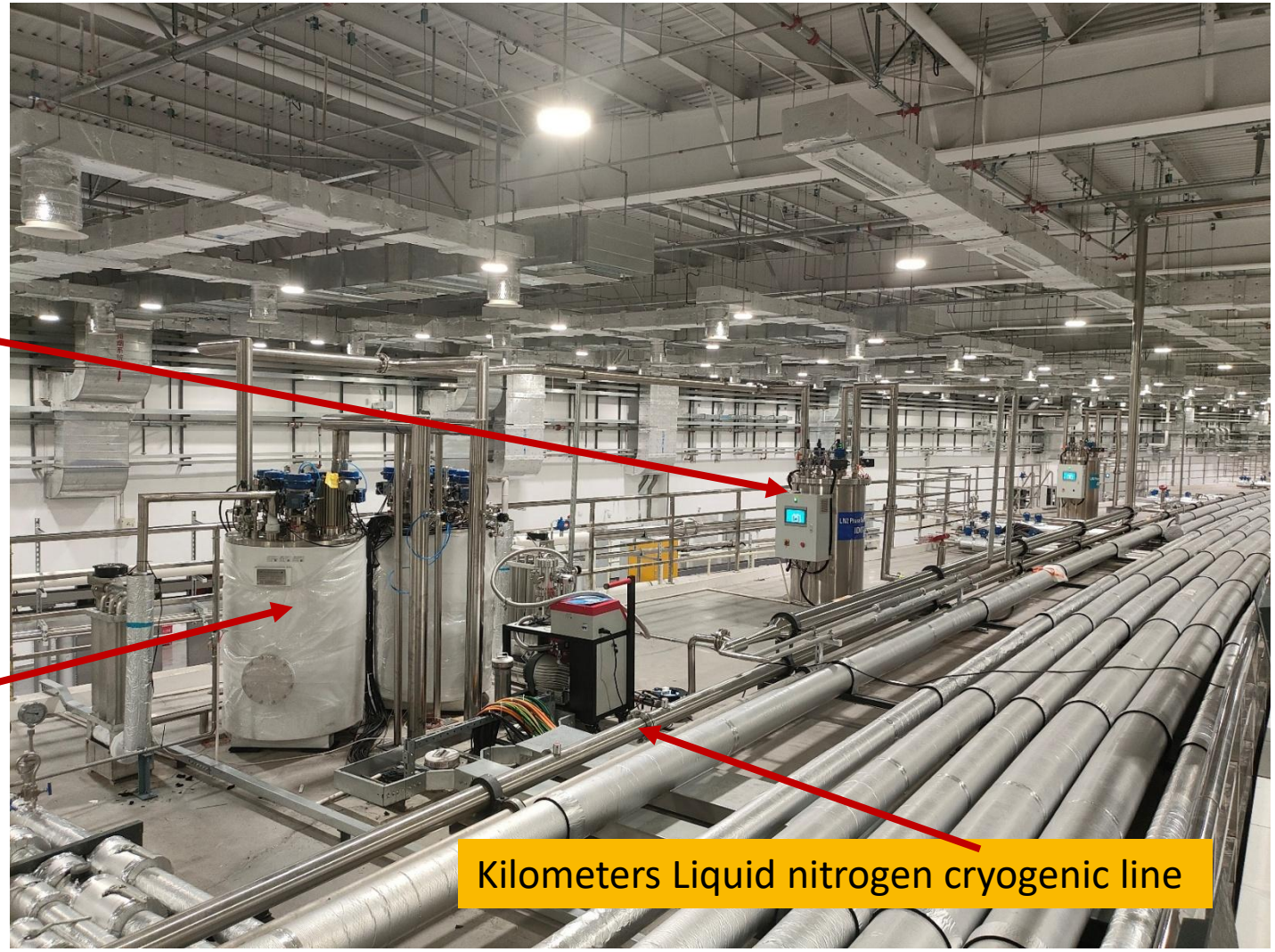

Testing sample section

Liquid nitrogen cryogenic---batch-produced, commissioning

- **Long** cryogenic pipelines**, multi-point equipment, micro-vibration**
- **Batch-produced, commissioning** LN2 phase separators and subcooled nitrogen units in 6.2025


Seventeen Nitrogen phase separators

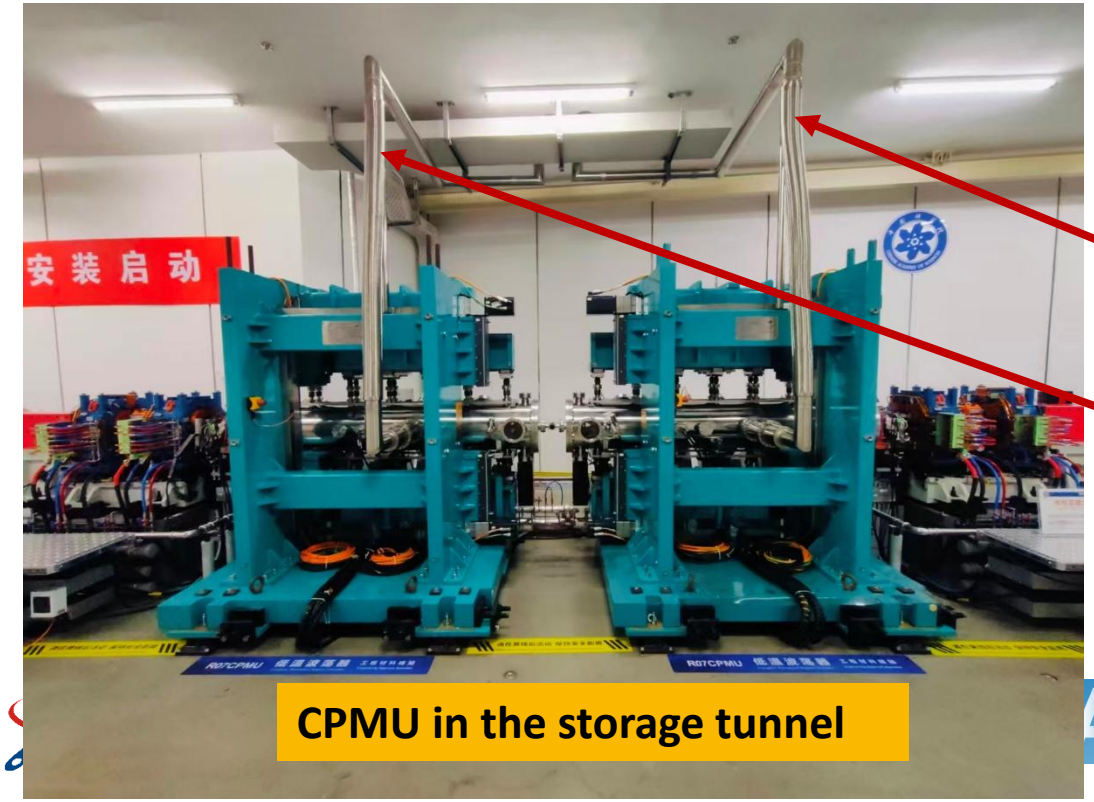

Six Subcooled liquid nitrogen units


Kilometers Liquid nitrogen cryogenic line

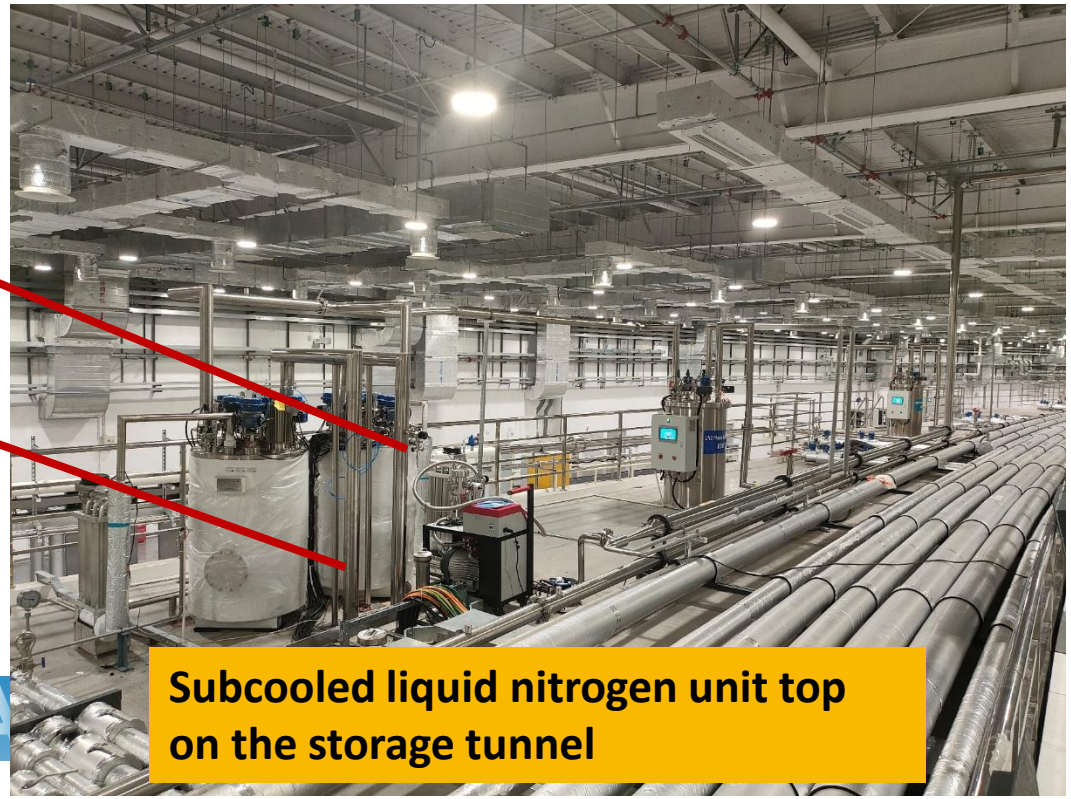
Subcooled liquid nitrogen units

- CPMU and Subcooled liquid nitrogen units perform well in field operation

Parameter	Average temperature	Temperature gradient	Pressure stability	Heat loads	Cooling capacity
Design	＜85K	＜1.5K/m	RMS 1.0mbar	＜220W	＞1000W
Operation	80K	1.0K/m	0.9mbar	208W	1024W



CPMU in the storage tunnel

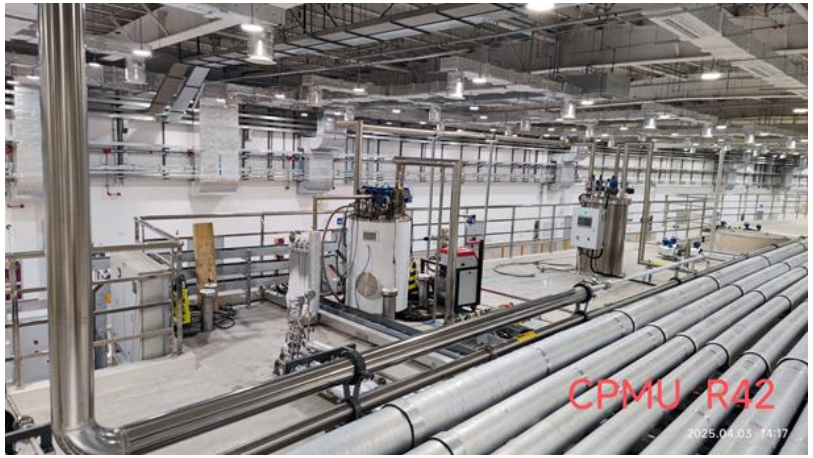


Subcooled liquid nitrogen unit top on the storage tunnel

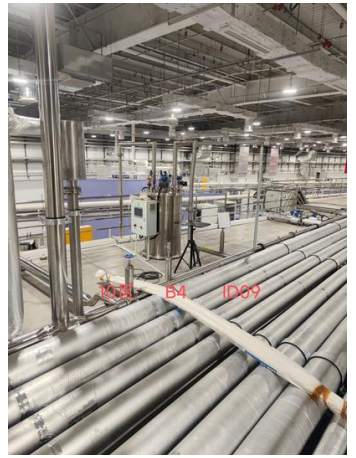
Liquid nitrogen cryogenic

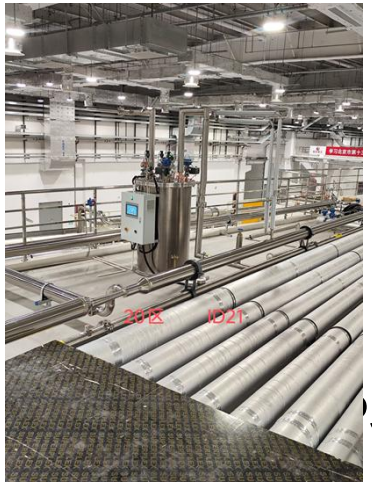
- **Kilometers nitrogen** cryogenic pipelines, seventeen LN2 PS, **six CPMU** and **15 beamlines**
- In a **Short time window, all cryogenic equipment have been finished commission**
- **Operating about one year since October 2025**

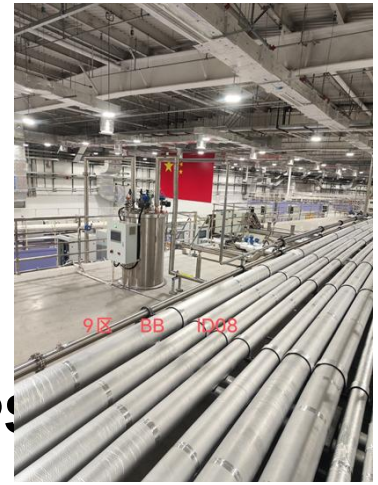
















2 Development, Commissioning and Operation

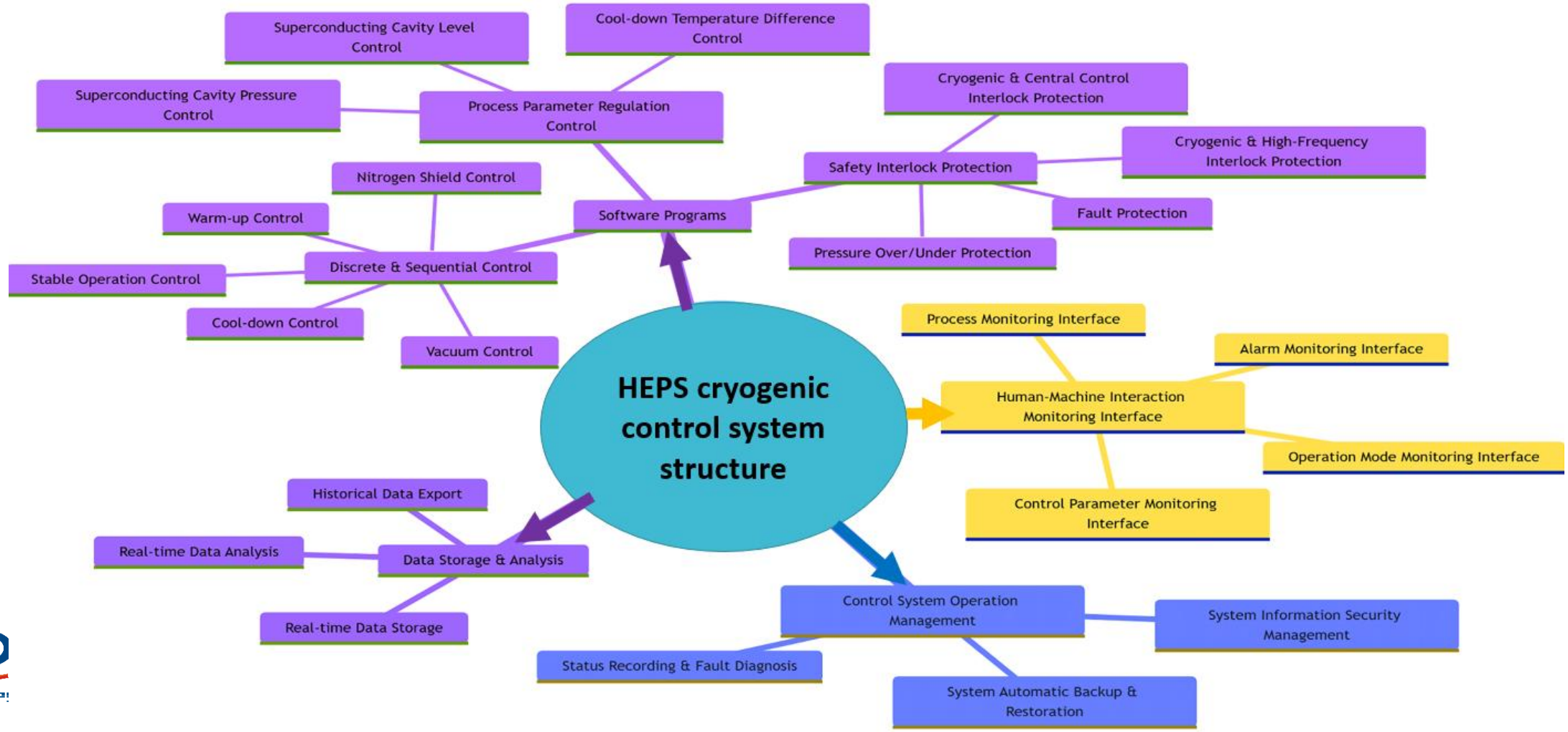
---1) Helium cryogenic system

---2) Nitrogen cryogenic system

---3) Cryogenic control system

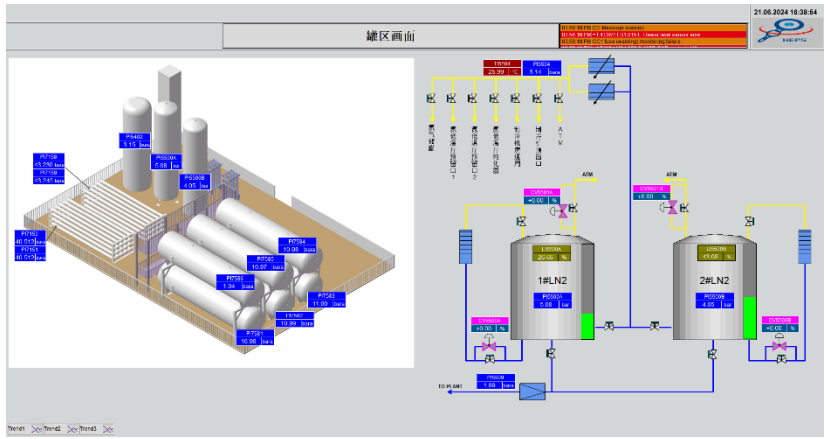
Control System

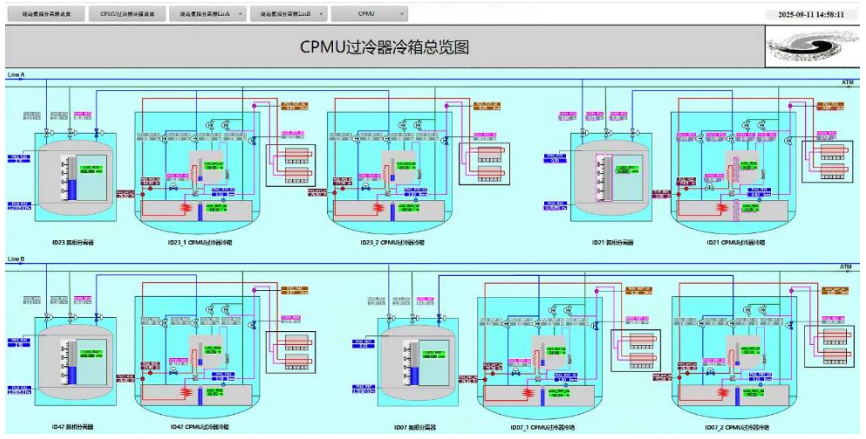
- Cryogenic control system including: Software programs、HMI、monitoring interface、control system operation and data storage & analysis, etc
- Supports single-person operation of all cryogenic equipment

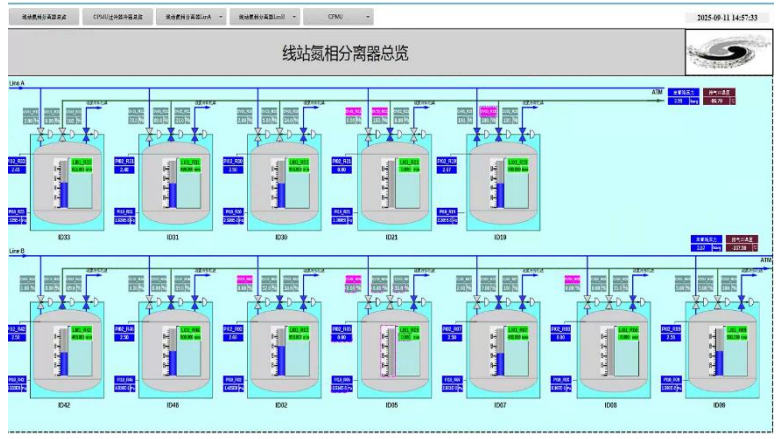


Control System

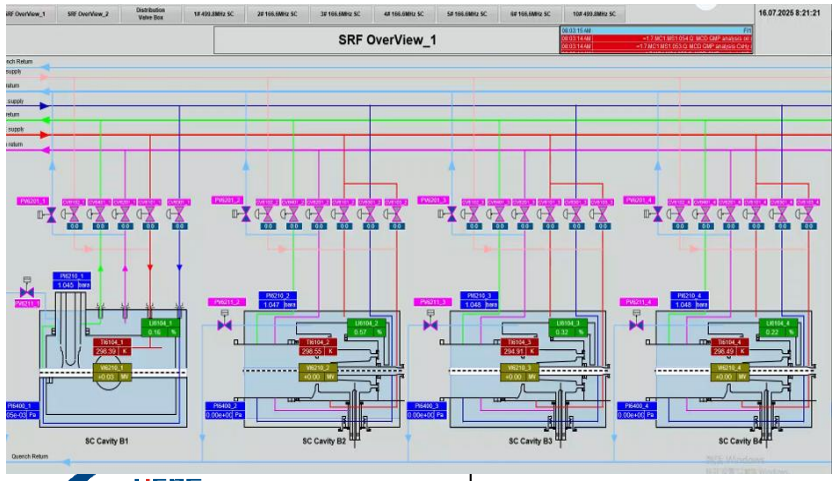
- **Fully automatic control** of cryogenic equipment was realized. **Operation very stably more over one year since October 2025**

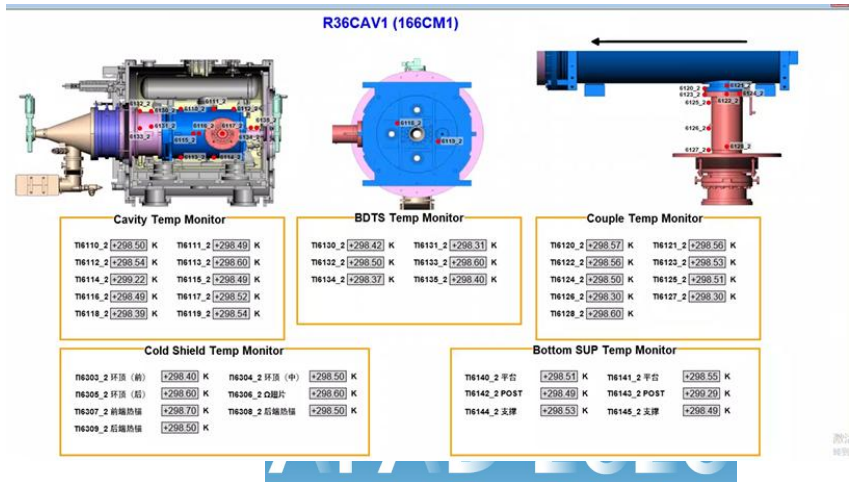


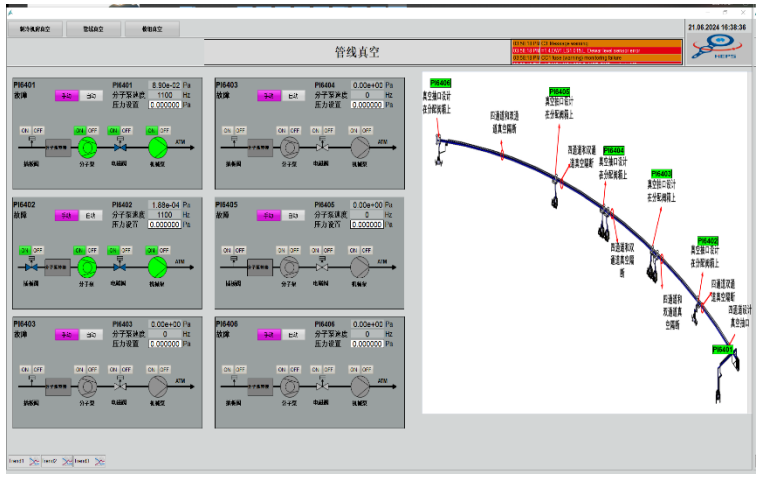




Screenshot of the control interface







3 Summary

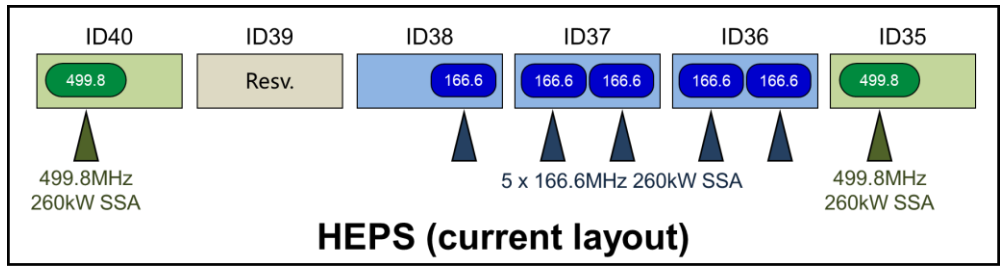
Summary

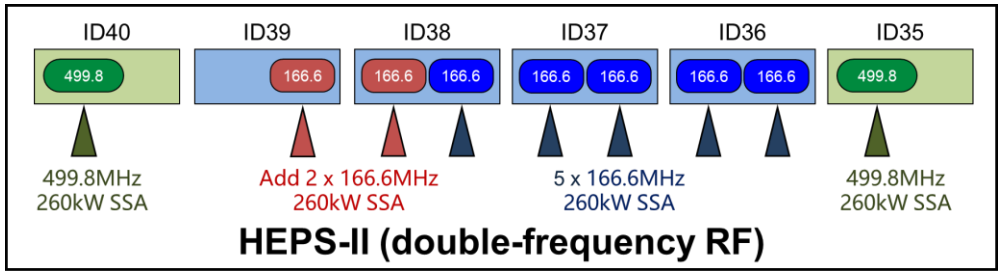
- **A sound plan must be formulated**
- Strong in-depth **cooperation** with relevant systems is essential.
- Special attention shall be paid during the cool-down and warm-up of the SRF cavities in the temperature range of 300 K to 40 K
- **Automatic control should be paid much more attention. Maybe AI technology in future**
- As a user facility, stability and reliability are the most important factors of the cryogenic system.
- Sufficient patience, **spare parts,** contingency plans and **sufficient budget** must be prepared **to address potential emergencies**.
- With the progress of the project, new difficulties will arise.

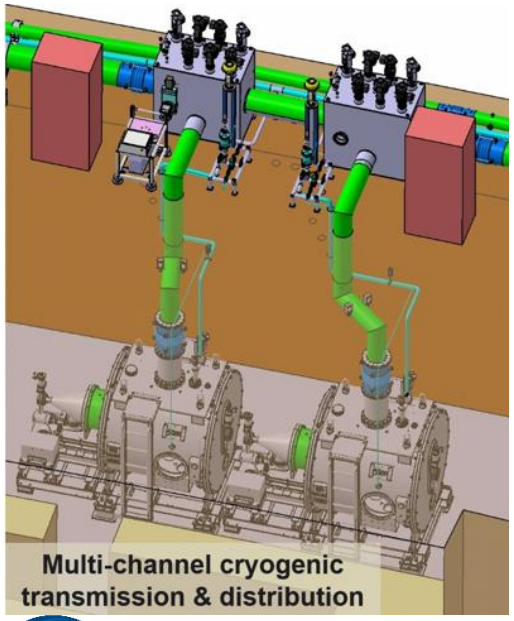
4 Cryogenic system Phase II Plan

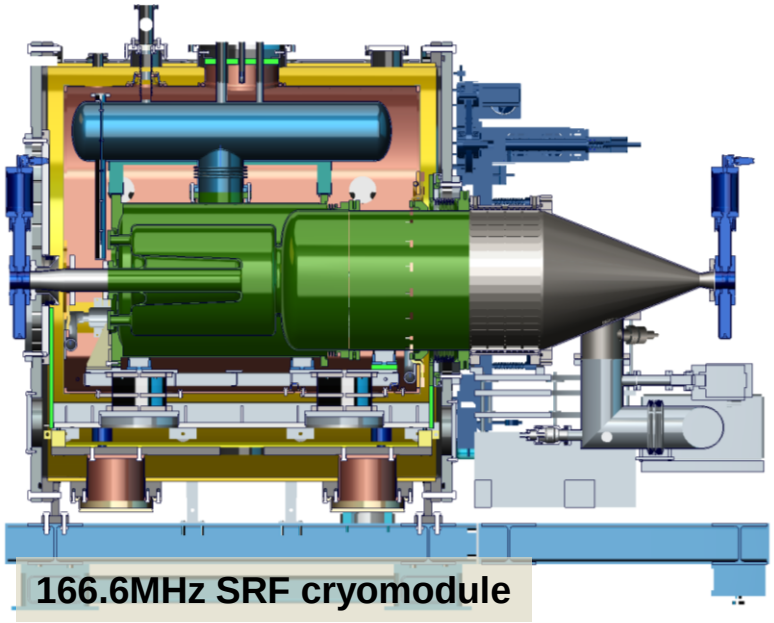
HEPS Phase II plan--Updates on cryogenic devices

- To cavity voltage, add **two or three high performance 166.6MHz SRF cavity cryomodules** and two multi-channel cryogenic transmission and distribution system





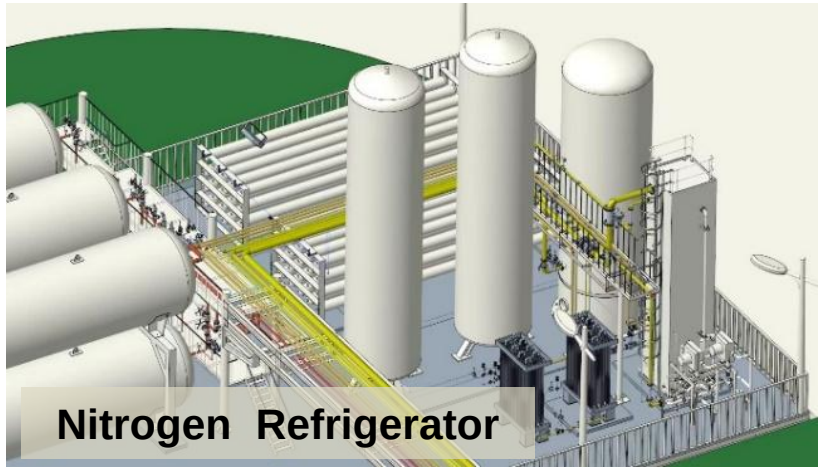


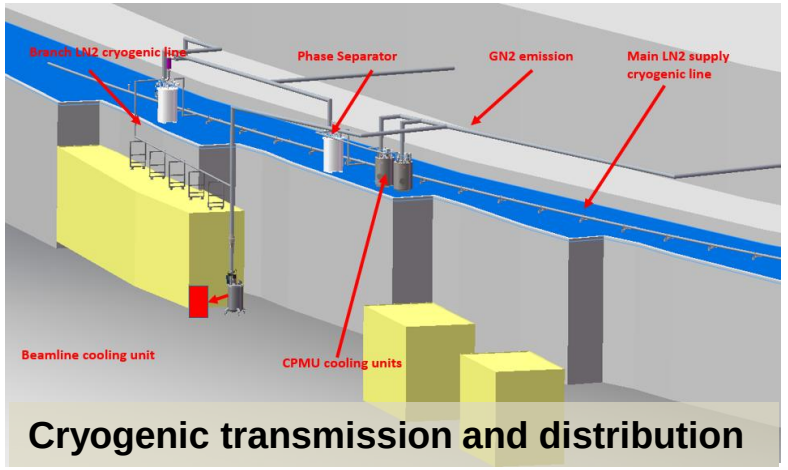




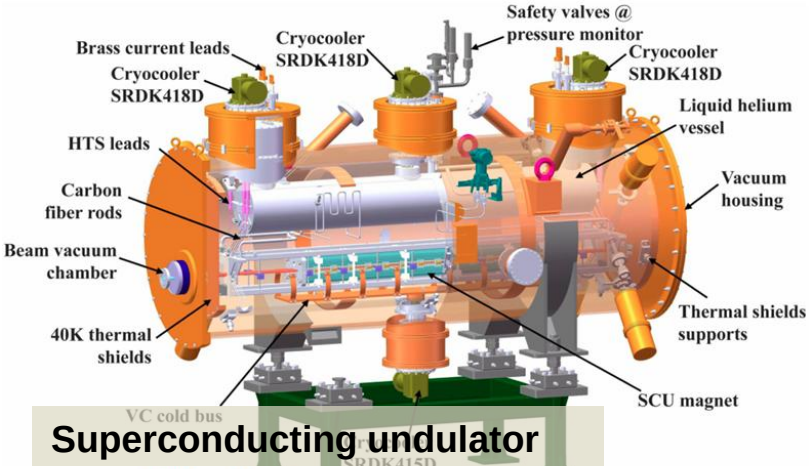
HEPS Phase II plan--Updates on cryogenic devices

- **Two Superconducting** Insertion Devices, **nine CPMU** and **twenty-two Cryogenic monochromators** in HEPS-II.
- To ensure the efficient and stable cryogenic conditions

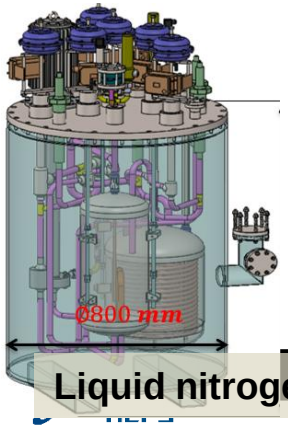

Nitrogen Refrigerator

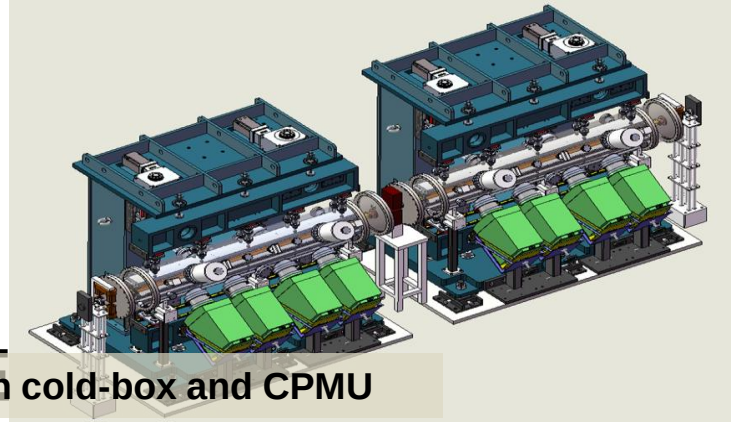


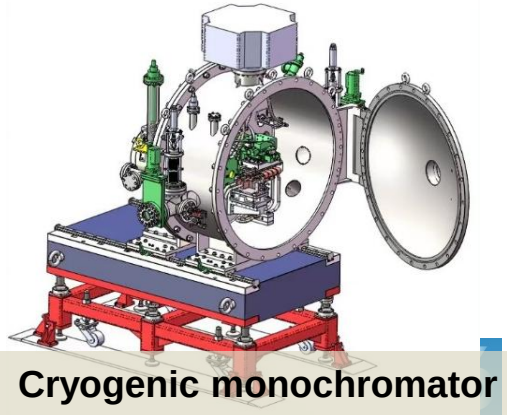
Cryogenic transmission and distribution

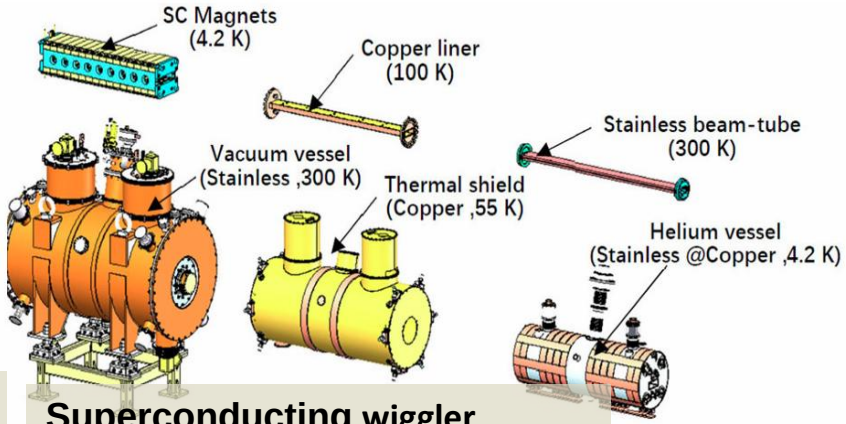


Superconducting undulator




Liquid nitrogen cold-box and CPMU


Cryogenic monochromator



Superconducting wiggler


Thanks for you attention !