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中国科学院
CHINESE ACADEMY OF SCIENCES

# Cryomodule development at IMP- lessons learned from operation of C-ADS and recent design for HIAF project

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**on behalf of IMP Cryogenic Department**

**TTC 2021, TESLA Technology Collaboration**
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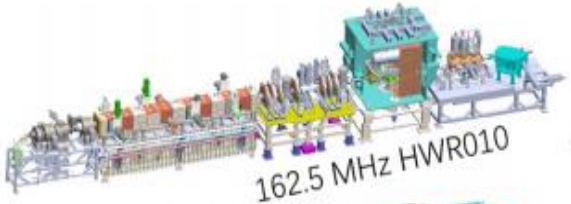
# Content

- ADS Front-end Demo Linac
- Cryomodule development at IMP
- Cryomodule operation
- Lessons learned from C-ADS
- Layout of HIAF cryomodules
- Mechanical design for HIAF cryomodules
- Cryogenics for HIAF cryomodules
- Summary

# ADS Front-end Demo Linac

1

- ECRIS + RFQ + MEBT + TCM1 (single HWR)
- Energy is ~2.5 MeV
- First beam October 1st, 2014




2

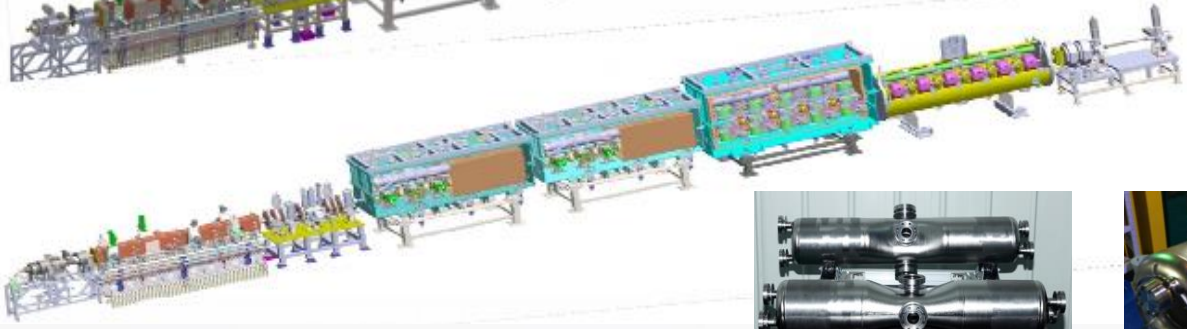
- ECRIS + RFQ + TCM6
- Energy is ~5 MeV
- First beam June 6th, 2015


3

- ECRIS + RFQ + CM1 + CM2
- Energy is ~10 MeV
- First beam September 15th, 2016

4

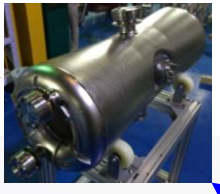
- ECRIS + RFQ + CM1 + CM2 + CM3 + CM4
- Energy is ~25 MeV
- First beam June 5th, 2017



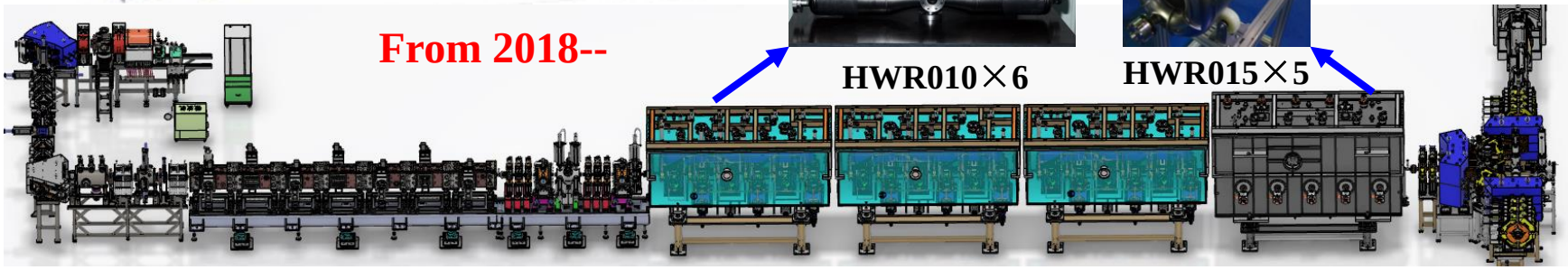
From 2018--



HWR010×6

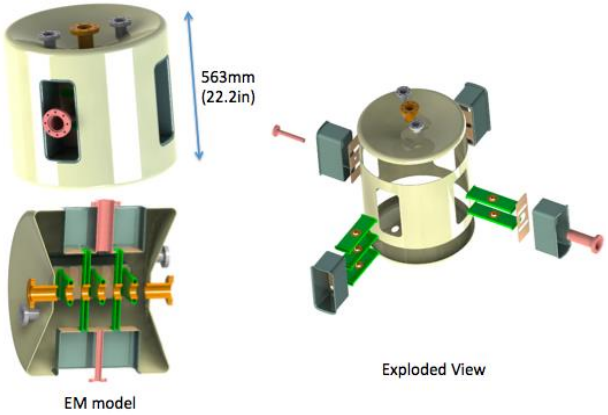


HWR015×5

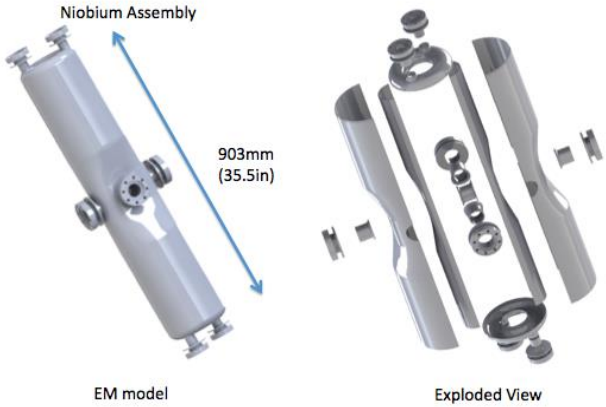


# Cavity development

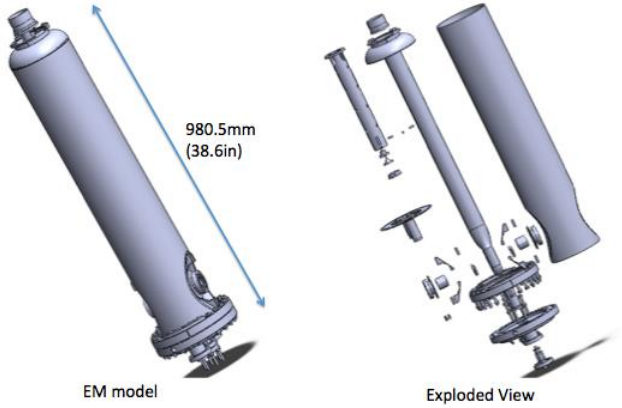
## 162.5 MHz CH cavity



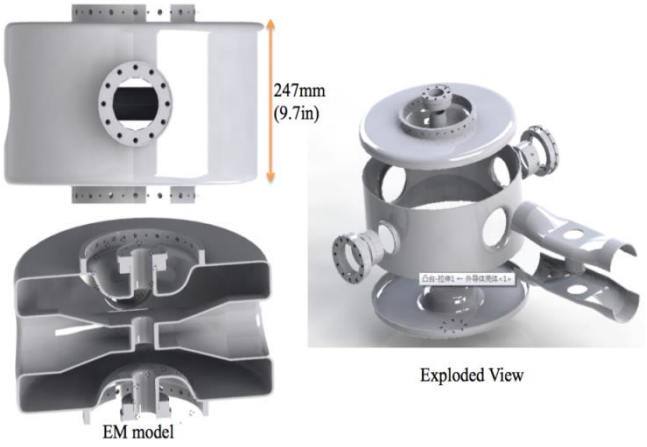

## 162.5 MHz Half-wave Cavity



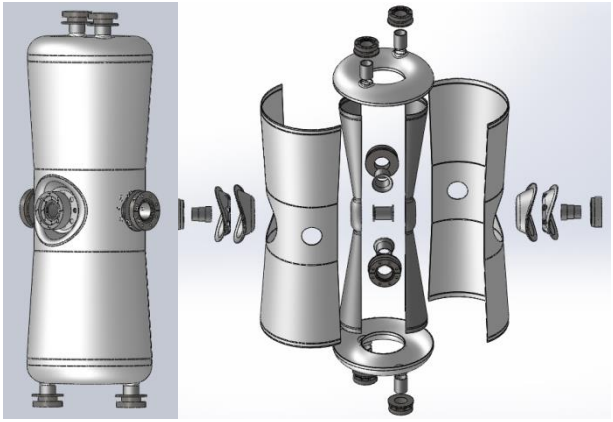

## 81.25 MHz Quarter-Wave Cavity



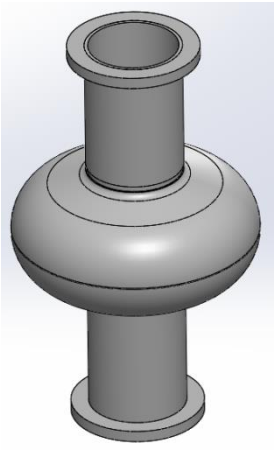

## 325 MHz Spoke cavity




## 162.5 MHz HWR015

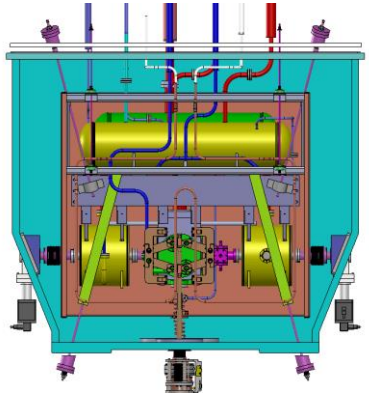


## 1.3 GHz Single-cell

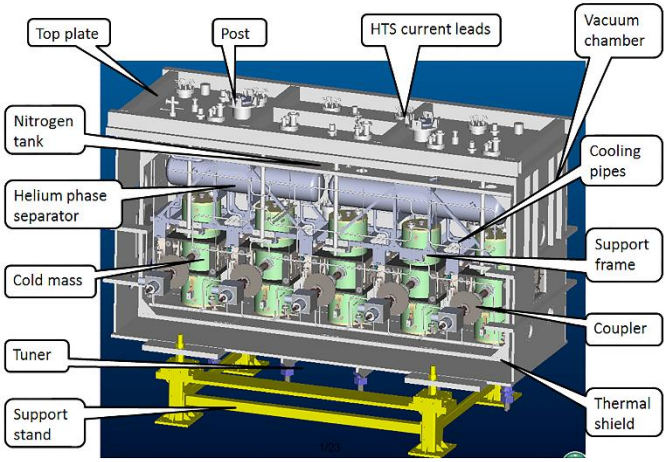


# Cryomodule development

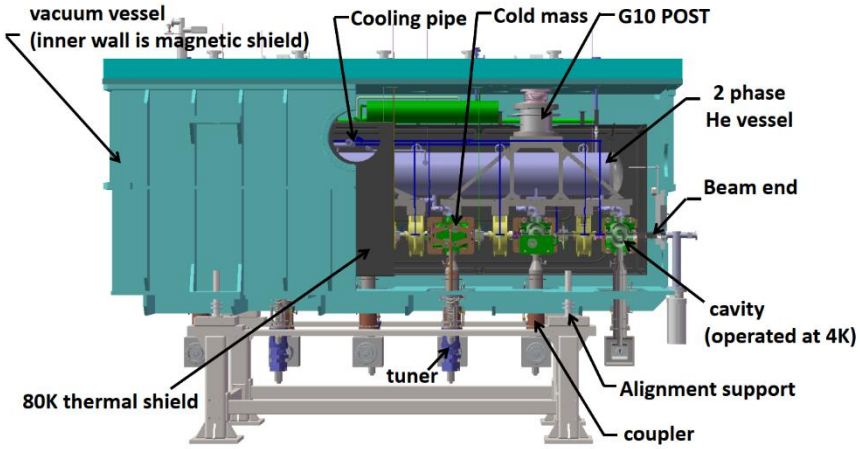
## ◆ Two Cavity Types, Totally Six Cryomodules, Four Cryomodules On-line



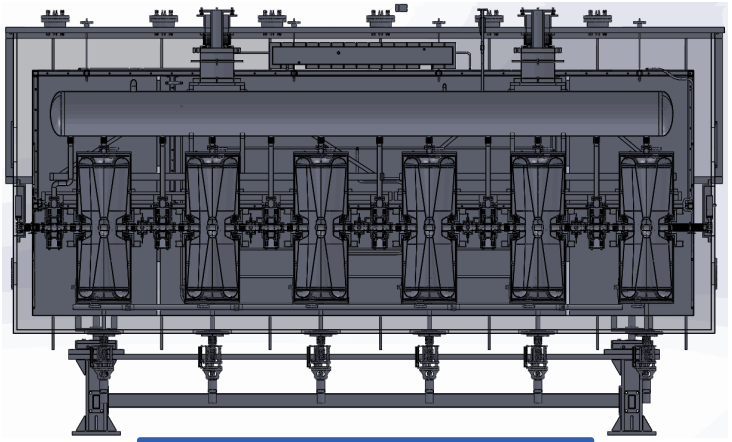
TCM1×1




HWR015-CM(5)×1



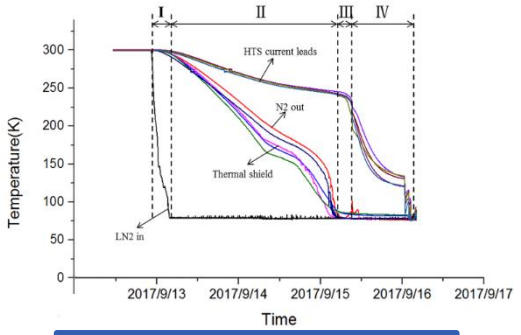

HWR010-CM×3



HWR015-CM(6)×1

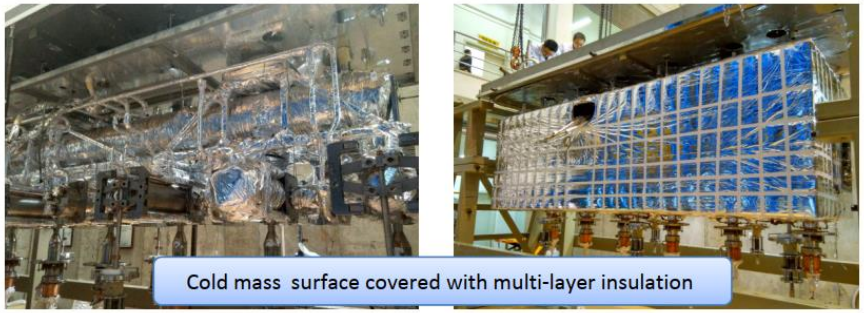
# Cryomodule operation

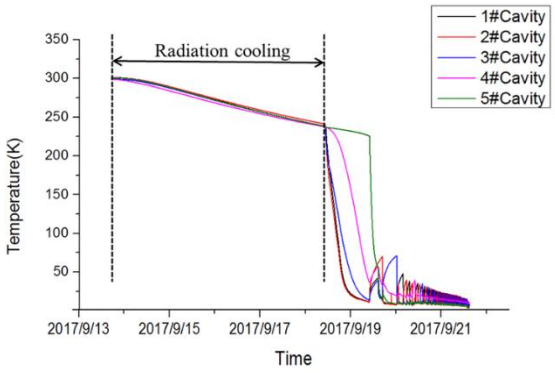



## LN2 cooling process

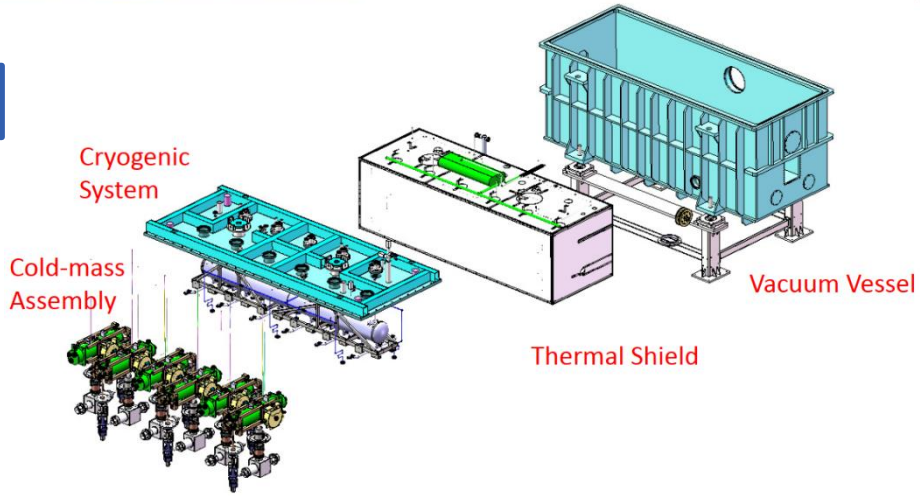
- I. Cryogenic transmission line cool-down stage.
- Ⅱ. Thermal shield cool-down.
- Ⅲ. Accumulation of liquid nitrogen in the LN2 tank.
- Ⅳ. HTS current leads cooling.

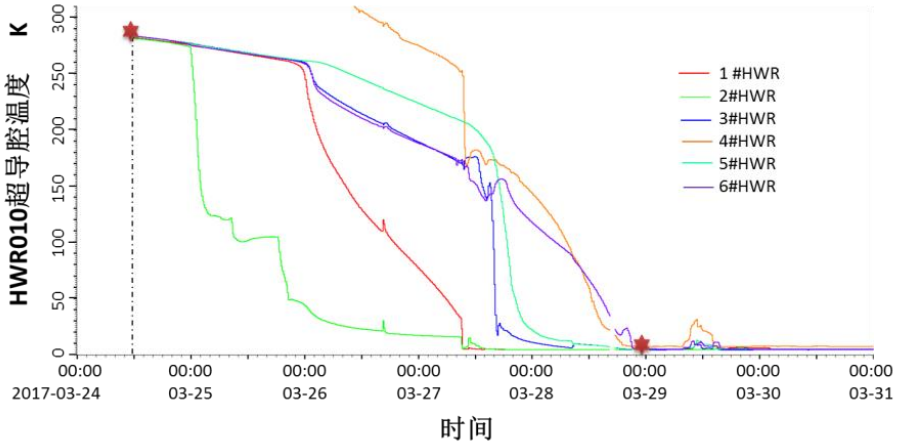

## LHe cooling process

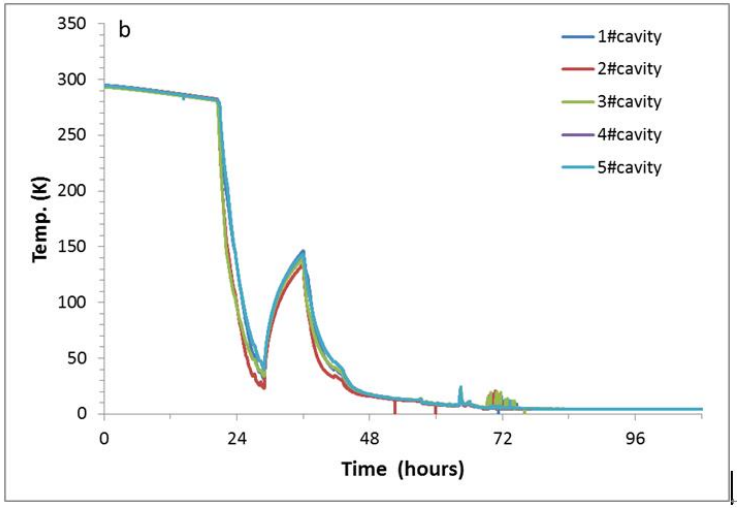
- Radiation cooling. (300K-220K)
- Liquid heliun cooling. (220K-4.5K)
- Temperature difference, need to optimize)

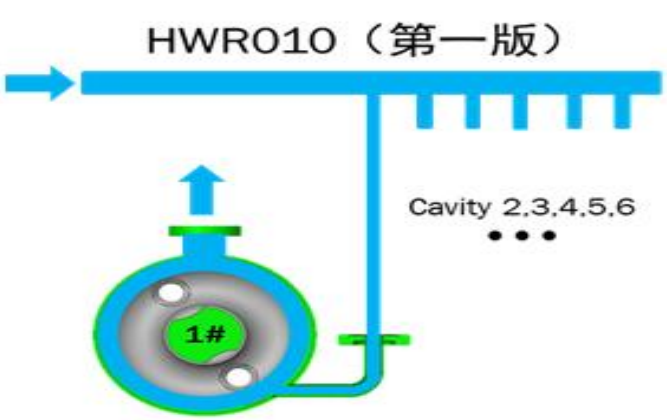


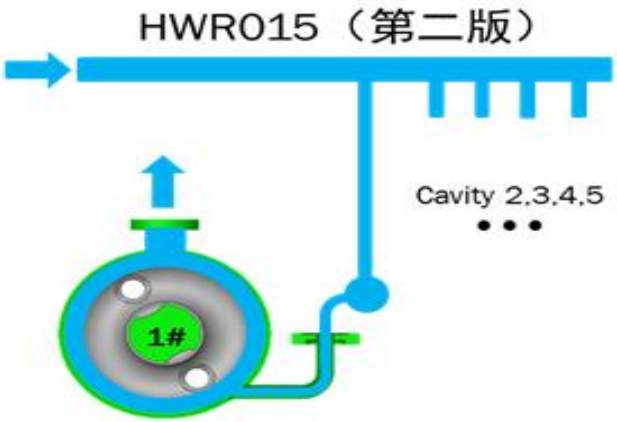
# Lessons learned from C-ADS

- **In the precooling process, the temperature of superconducting cavities in CM is not uniform and the temperature difference is relatively large.**



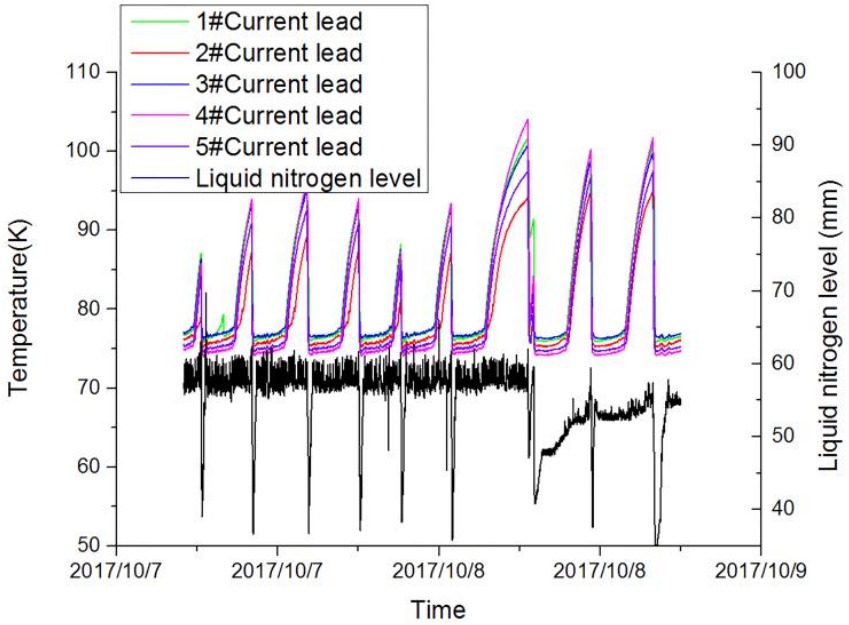



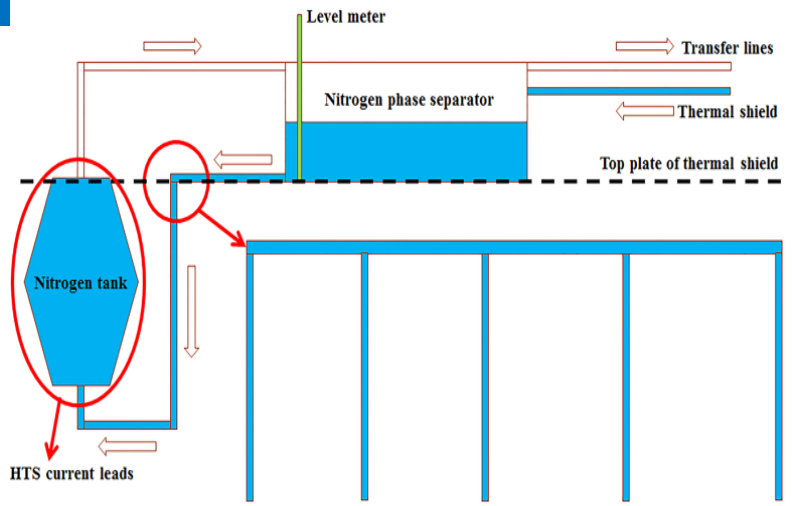
# Lessons learned from C-ADS

## ◆ Temperature fluctuation of HTS current leads

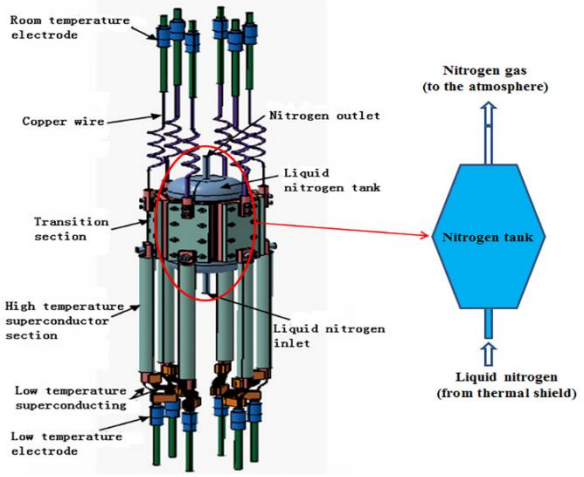



**Temperature fluctuation curve of HTS current leads**

- HTS current leads repeat uniform temperature fluctuation in the absence of any operation.
- The volume change of liquid nitrogen in the nitrogen phase separator tank just is equal to the sum of five HTS current leads nitrogen tanks.
- Blockage in the main nitrogen return pipe caused the temperature fluctuation.



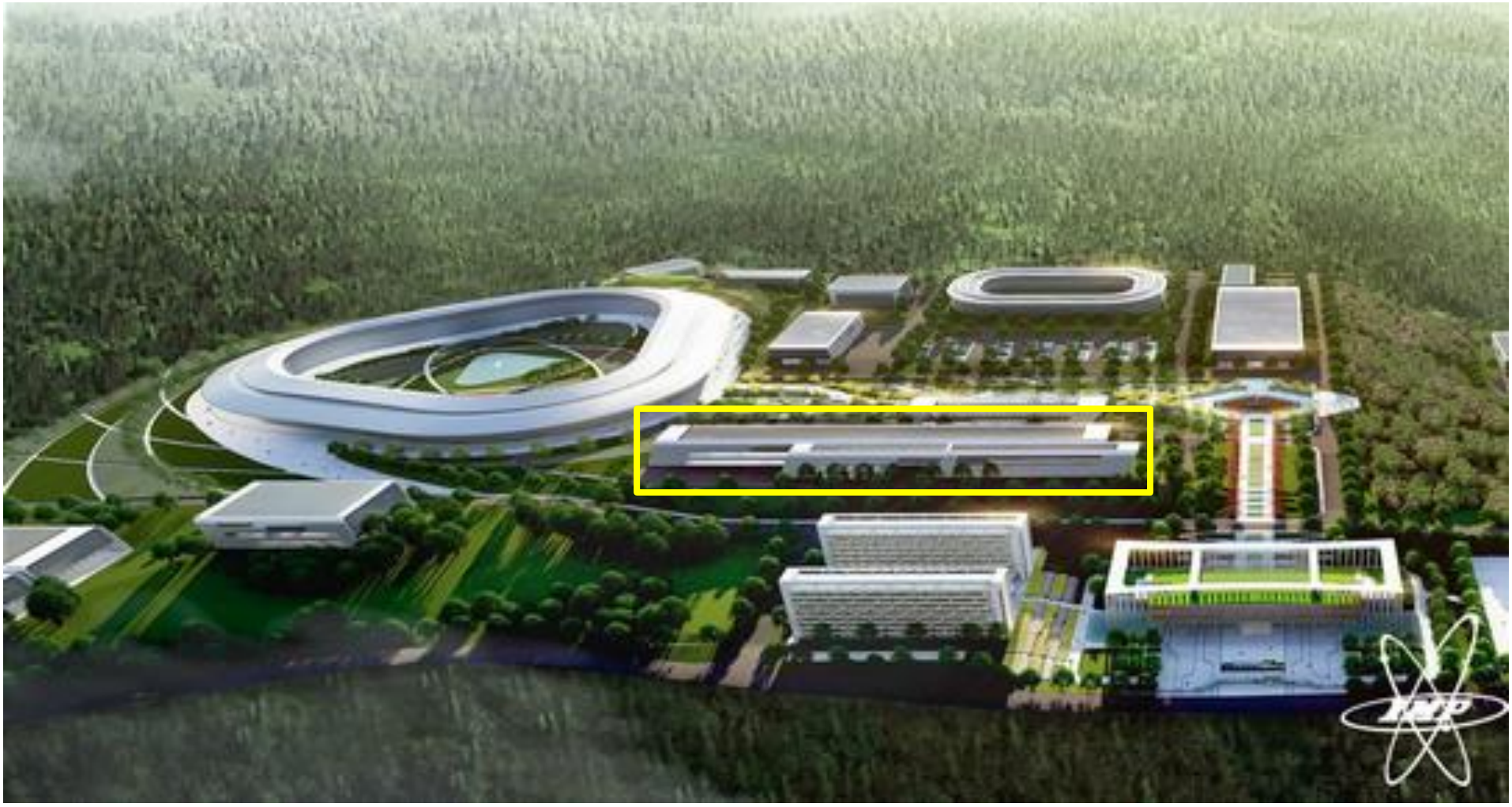

**LN2 cooling system for HTS current leads**




**HTS current leads**

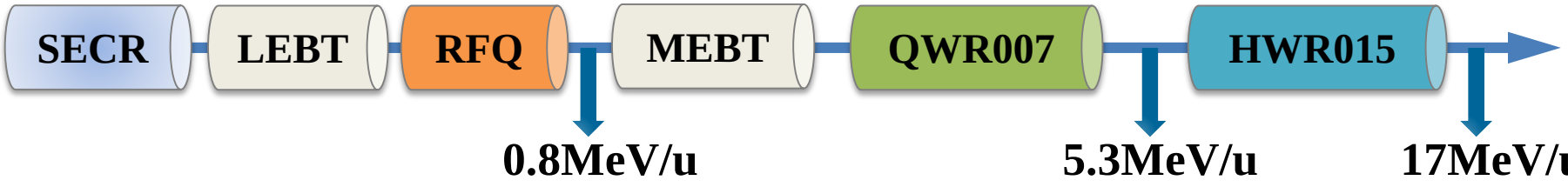
# HIAF Project at Huizhou, GuangDong

◆ High Intensity heavy-ion Accelerator Facility

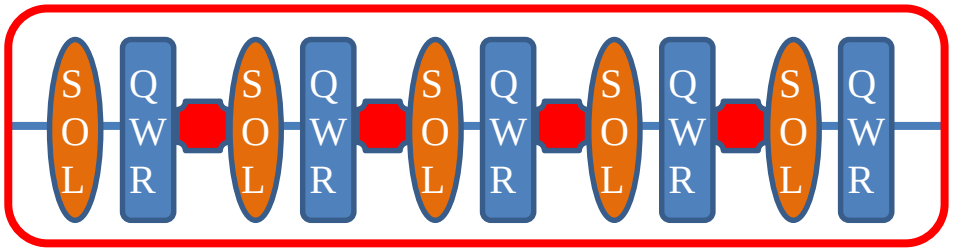


# Layout of HIAF cryomodules

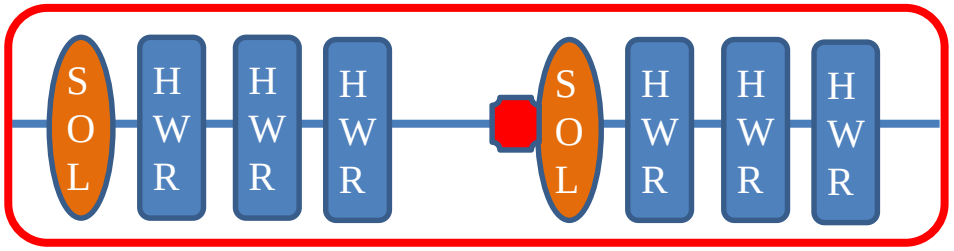
◆ High Intensity heavy-ion Accelerator Facility




| | QWR007 | HWR015 |
|---|---|---|
| CM Quantity | 6 | 11 |
| CM Length | 5073 | 5836 |
| CM Width | 2000 | 2000 |
| CM Height | 3800 | 3800 |
| Cavity Quantity | 5 | 6 |
| Solenoid Quantity | 5 | 2 |
| BPM Quantity | 4 | 1 |



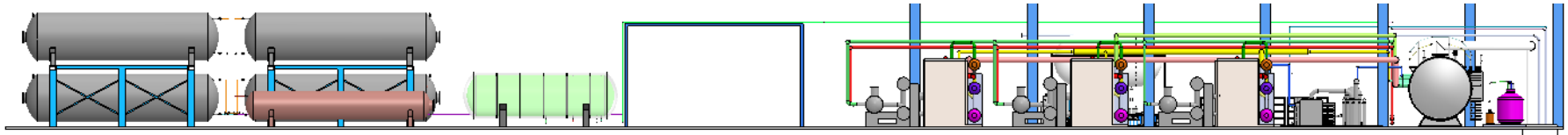

CM-QWR007




CM-HWR015

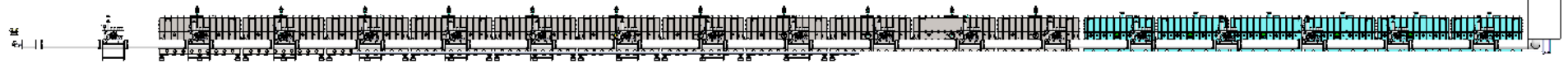
Cavity Quantity: 96 → Cryomodule Quantity: 17 → CM Total Length: 99.6m

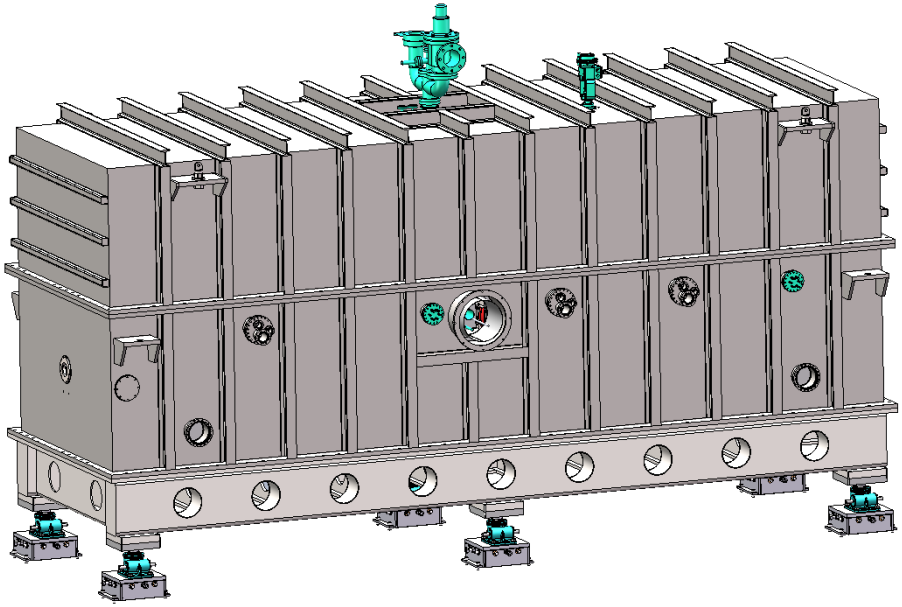
# Layout of HIAF cryomodules



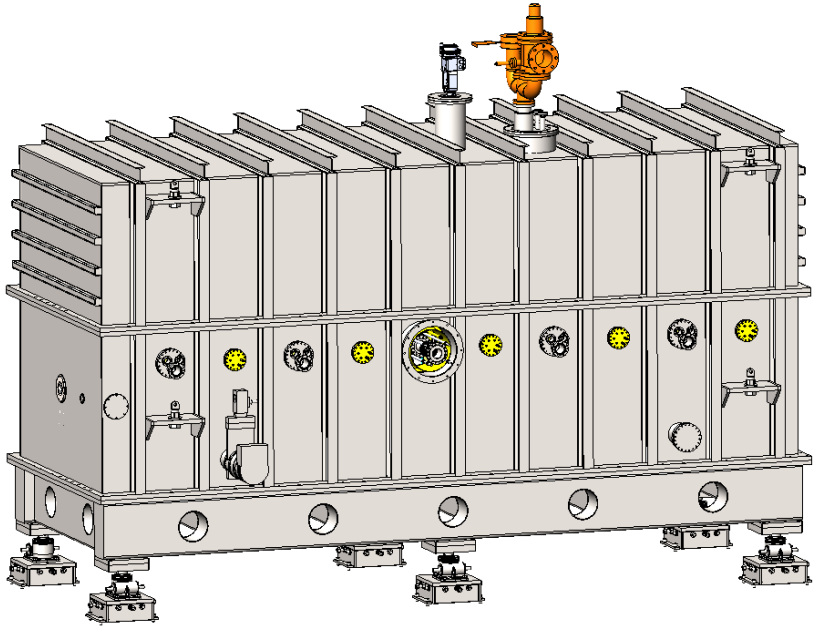
**CM-HWR015 (Quantity：11)**

**CM-QWR007 ( Quantity：6 )**



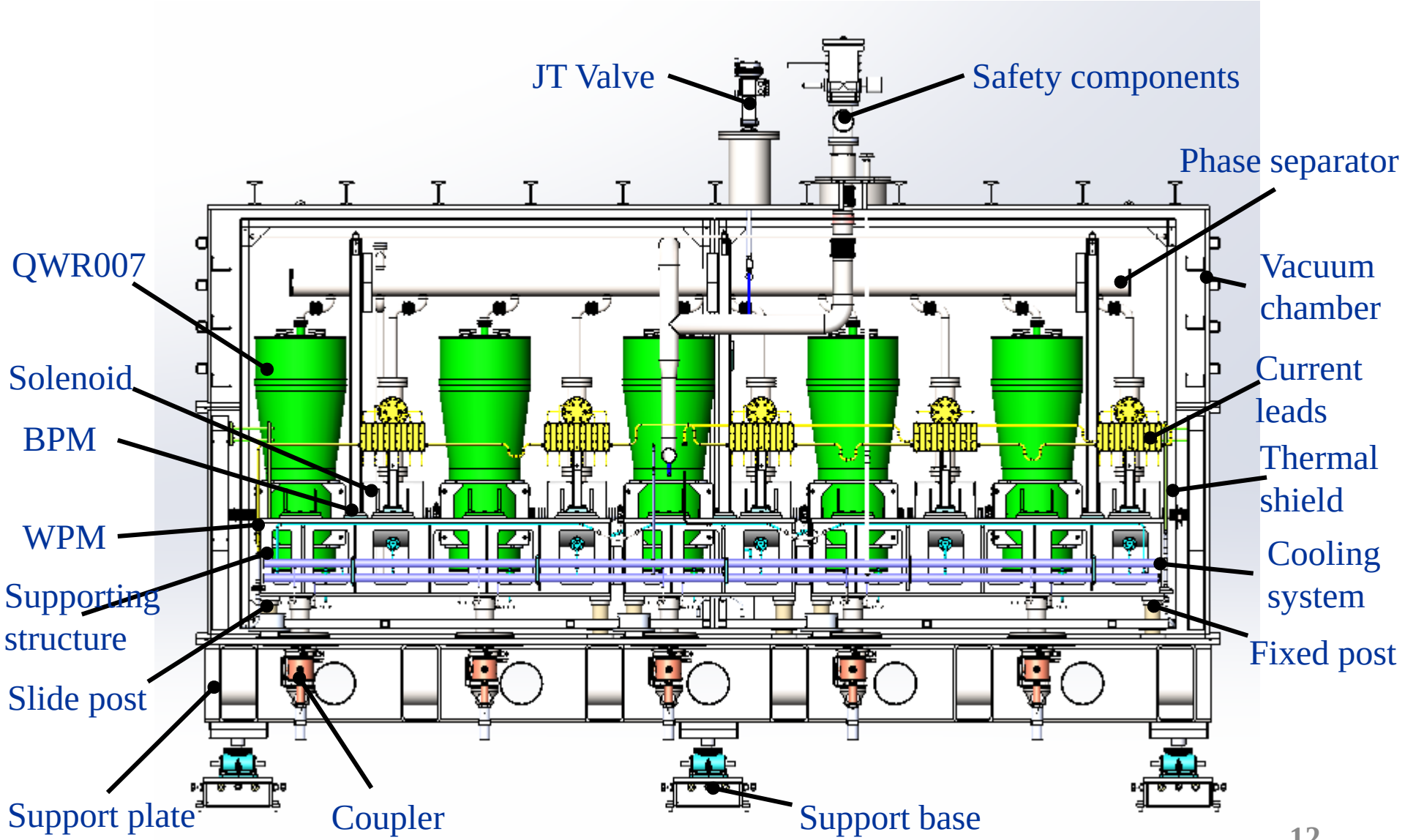


CM-HWR015



CM-QWR007

# Mechanical design of HIAF CM

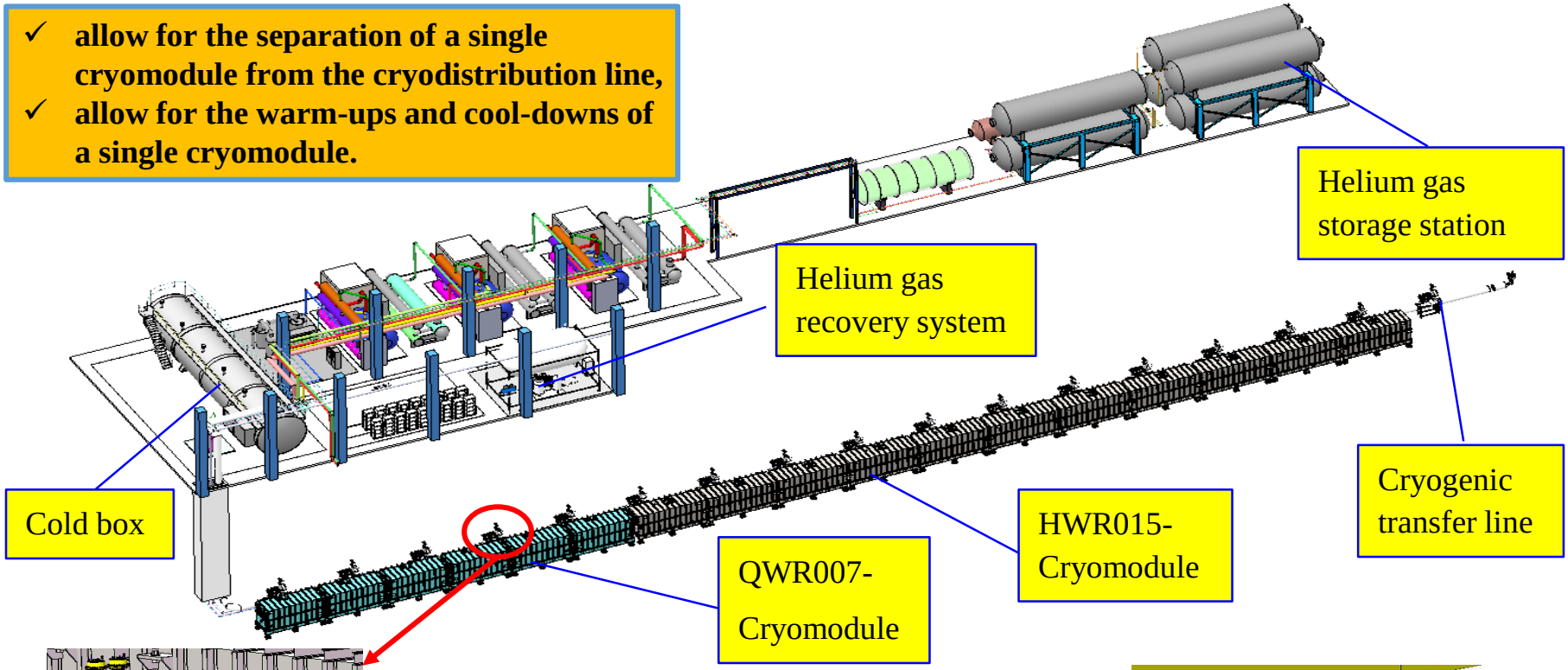


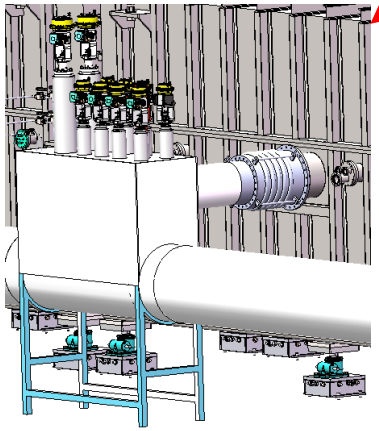
# Heat load(QWR007)

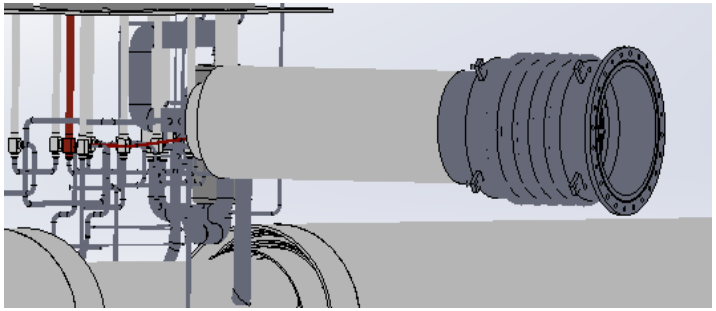
| Component | Qty. | 2K（W） | | | 4.5K-75K（W） | | 50K-300K（W） | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Static | Dynamic | Total | Dynamic | Total | Static | Dynamic | Total |
| Cavity | 5 | 0.09 | 2.96 | 15.25 | | | | | |
| Solenoid | 5 | 0.05 | | 0.25 | | | | | |
| Tuner | 5 | 0.31 | | 1.55 | | | 0.74 | | 3.7 |
| Coupler | 5 | 0.07 | 0.09 | 0.8 | 0.05 g/s | 0.25 g/s | | | |
| Cooling pipes | 1 | 0.23 | | 0.23 | | | 10.6 | | 10.6 |
| Current Leads | 5 | 0.36 | | 1.8 | | | 14.2 | 30.4 | 223 |
| Cold to warm | 2 | 0.5 | | 1 | | | 1.3 | | 2.6 |
| Support structure | 3 | 0.2 | | 0.6 | | | | | |
| Post | 9 | 0.2 | | 1.8 | | | 7.8 | | 70.2 |
| Thermal shield | 1 | 1.75 | | 1.75 | | | 52 | | 52 |
| Valve | 1 | 0.2 | | 0.2 | | | 1 | | 1 |
| Instruments | 1 | 1 | | 1 | | | 1 | | 1 |
| Total | | 10.9 | 15.3 | 26.2 | | | 212 | 152 | 364 |

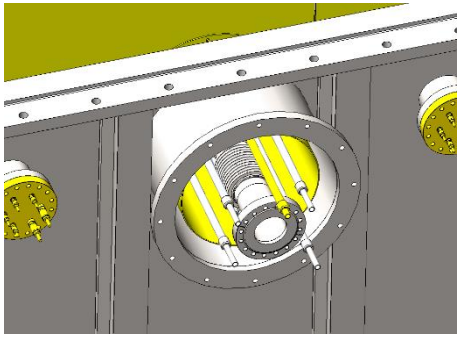
# Cryogenics for HIAF CM

- ✓ **allow for the separation of a single cryomodule from the cryodistribution line,**
- ✓ **allow for the warm-ups and cool-downs of a single cryomodule.**



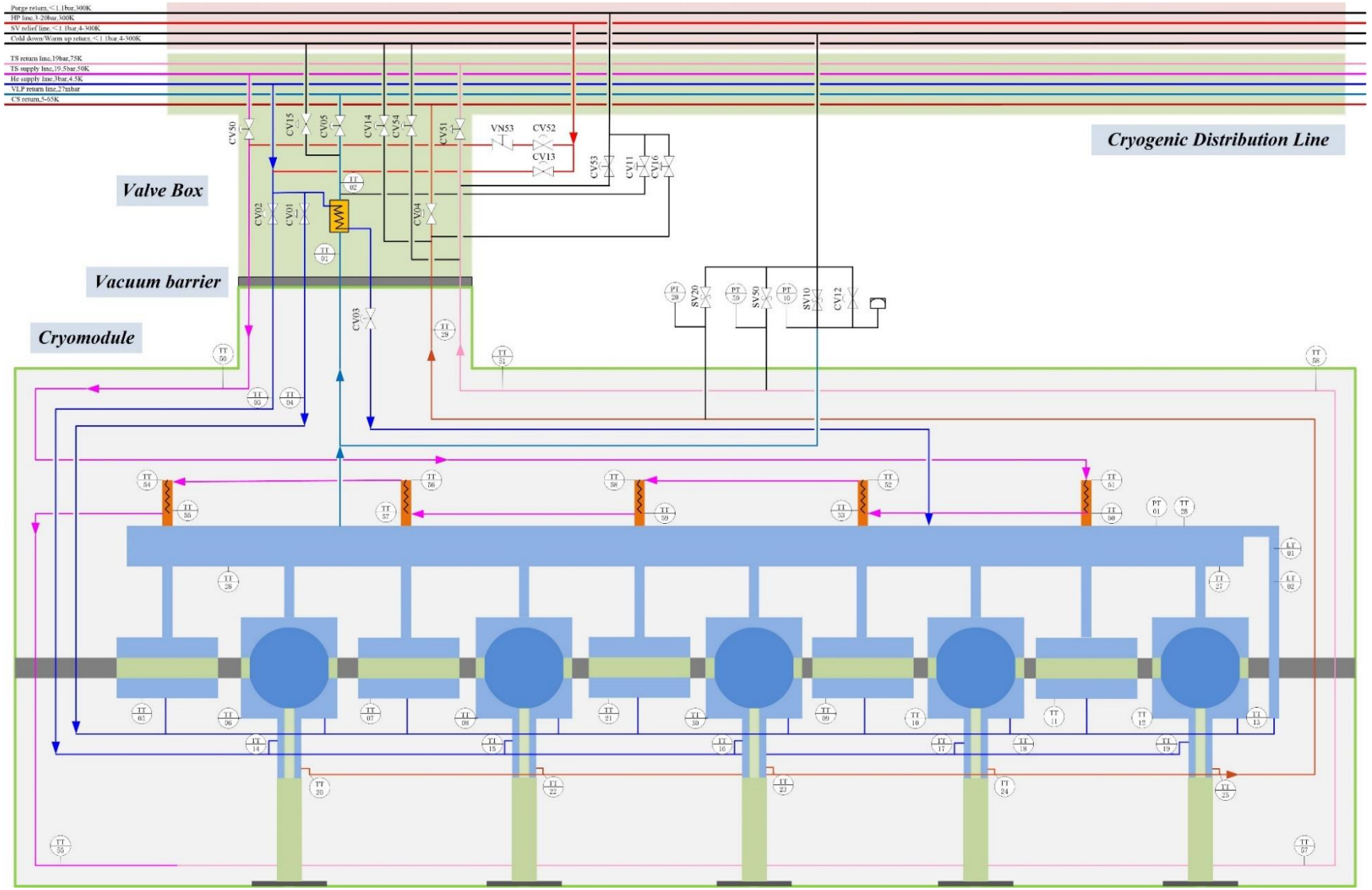





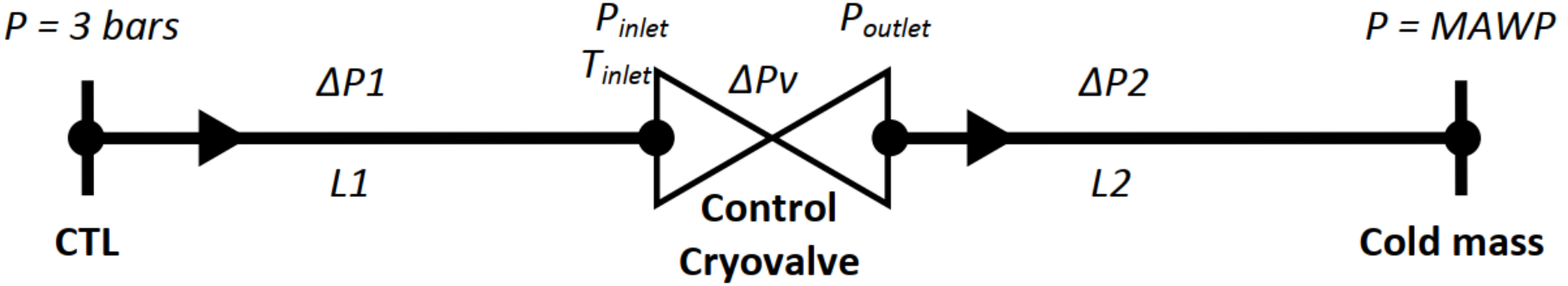


**Interface to the cryomodule**

# Process and instrumentation diagram



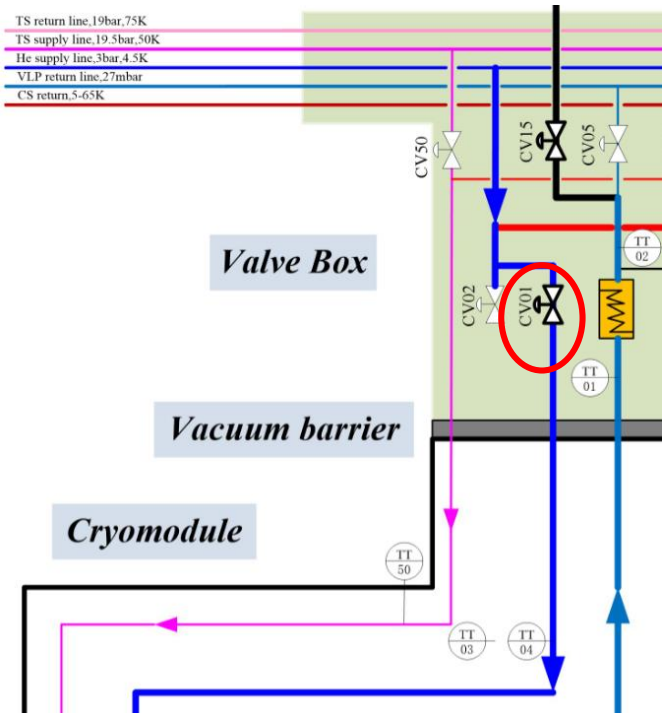
# Fast cool-down




## Cooling requirements of cavity

- 300K-150K cooling rate, 5K/h（mixed helium gas）;
- 150K-50K cooling rate, >1K/min;
- 15K-5K cooling rate, >4K/min(He mass flow=26g/s);
- 300K-4K total cooling time, 32h;
- With a large He mass flow at 15-5K，need to select Kvmax（＞30g/s）。

| m (g/s) | $T_{inlet}$ (T) | $T_{out}$ (T) | Φ (mm) | L1 (m) | ΔP1 (mbar) | L2 (m) | ΔP2 (mbar) | Kv ($m^3/h$) |
|---|---|---|---|---|---|---|---|---|
| 2.3 | 4.5 | 4.5 | 10 | / | / | 4.5 | 0.28 | 0.054 |



# Summary

- **C-ADS cryomodule has been validated and many issues have been identified along the way but solutions have been found.**
- **HIAF cryomodule design has been completed and two prototypes will been fabricated in the next year.**

## Plan for 2021:

- **Two cryomodule prototypes processing and manufacturing**
- **The alignment of the cryomodules need to confirm**
- **Others: ready for cryomodule testing conditions**

# Thanks for your attention and welcome to Lanzhou !