Progress of CEPC Cryogenic System

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AFAD2018

2018.01.29

Outline

- Introduction
- Heat load
- Refrigeration
- Cooling scheme
- Cryomodules
- R&D
- Summary

Introduction

- The Cryogenic system will cool all the cavities in a liquid-helium bath at a temperature of 2 K to achieve a good cavity quality factor.
- The Cryogenic system lies besides the RF station, which provides helium for the collider ring and the booster ring.
- The Cryogenic system mainly includes the refrigerators, distribution boxes, compressor group, helium storage tanks and cryomodules.

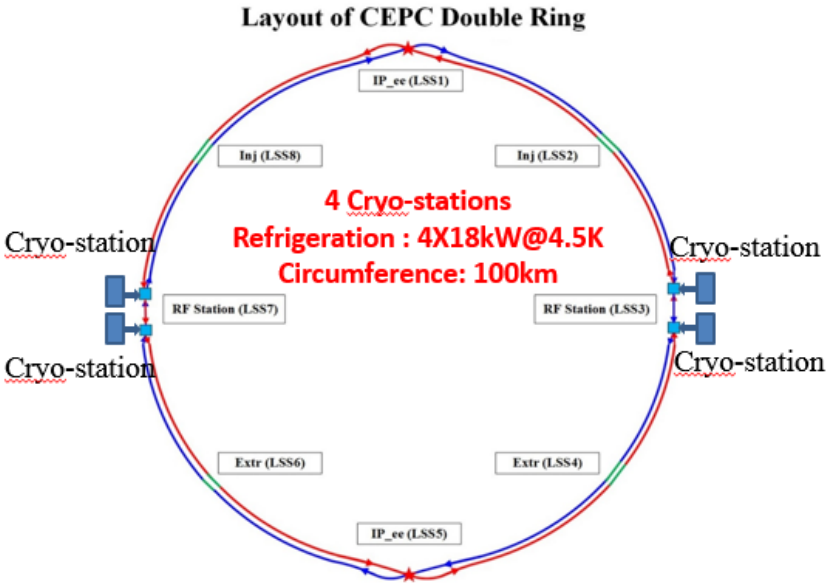
Introduction

Booster ring:

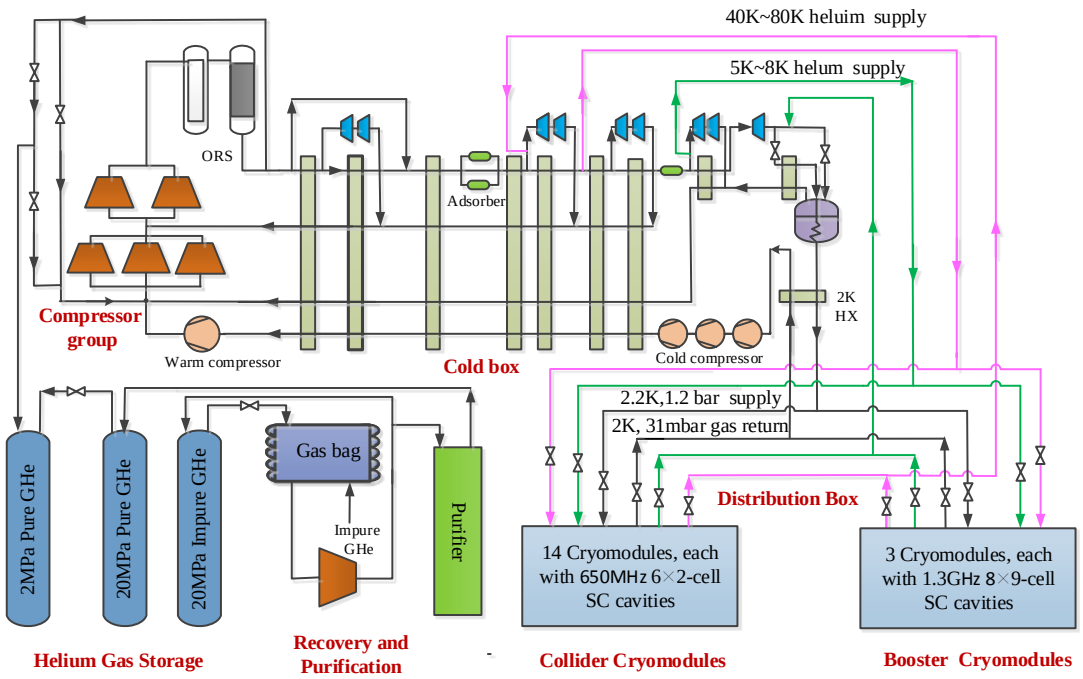
- 1.3 GHz 9-cell cavities, 96 cavities
- 12 cryomodules
- 3 cryomodules/each station
- Temperature: 2K/31mbar

Collider ring:

- 650MHz 2-cell cavities, 336 cavities
- 56 cryomodules
- 14 cryomodules/each station
- Temperature: 2K/31mbar

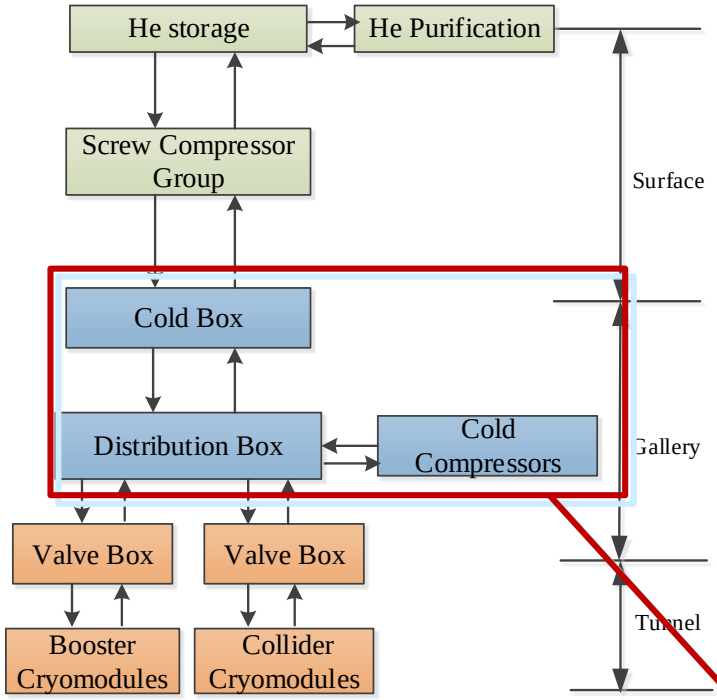


Flowchart of one Cryo-station



- Each Cryo-station mainly includes Compressor, Cold box, helium gas storage tanks, cryomudules and purification system.
- The cryomodules have two shields, a 40K~80K shield and a 5K~8K shield.
- A 2.2K, 1.2bar helium is supplied for the cryomodules and the 2K, 31mbar helium gas return to the cold box with the cold compressors.

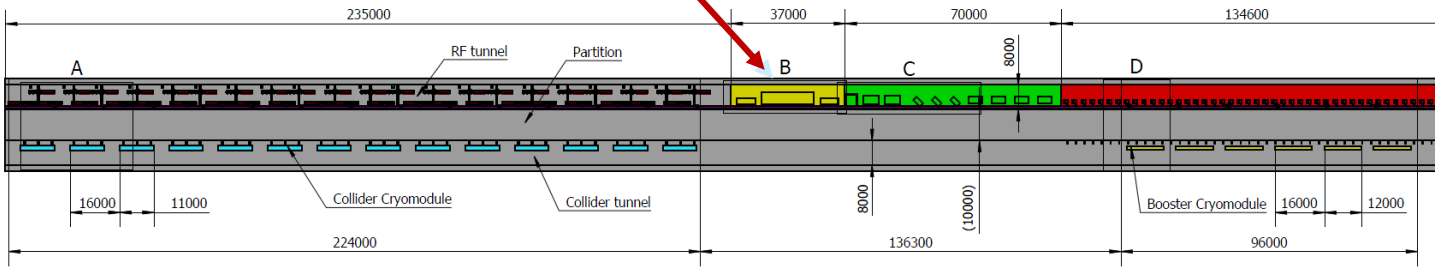
Infrastructure



Equipment:

- Warm equipment , on the surface
- Cold equipment, in the tunnel to decrease heat load

Each cryo-station has an underground plant in the gallery, the size is 37m * 8m.



Parameters of SC cavities related for Cryogenic system

100km RF parameters(From ZJY20171022)	Collider			Booster		
mode	H	W	Z	H	W	Z
Frequency(MHz)	650	650	650	1300	1300	1300
Cavity operating voltage (MV)	6.37	2.15	2.21	19.06	10.94	11.25
Duty factor	CW	CW	CW	0.17	0.10	0.04
Total number of cavities	336	192	24	96	64	32
Total number of modules	56	32	4	12	8	4
Eacc (MV/m)	13.8	9.4	9.6	18.4	10.5	10.8
R/Q	213	213	213	1036	1036	1036
Q0	1E+10	1E+10	1E+10	1E+10	1E+10	1E+10
Operation temperature (K)	2	2	2	2	2	2
Cavity dynamic heat load@ 2K (W/cavity)	19	8.7	9.2	6	1.2	0.5
Total dynamic heat load @ 2K(kW)	6.52	1.96	0.22	0.59	0.08	0.02

Heat load

H mode	Collider			Booster		
	40-80K	5-8K	2K	40-80K	5-8K	2K
Module static heat load (W)	140	20	3	300	60	12
Module dynamic heat load (W)	300.00	60.00	113.51	140	10	48
HOM loss per module (W)	86.4	8.64	2.88	2	1	1
Connection boxes (W)	50	10	10	50	10	10
Total heat load (kW)	41.24	7.76	7.75	3.98	0.49	0.74
Total predicted mass flow (g/s)	**197.62**	**242.24**	**365.76**	**19.1**	**15.4**	**35.1**
Overall net cryogenic capacity multiplier	1.54	1.54	1.54	1.54	1.54	1.54
4.5K equiv. heat load with multiplier (kW)	4.77	10.81	38.18	0.46	0.69	3.67
Total 4.5K equiv. heat load with multiplier (kW)	**53.77**			**4.81**		
Total 4.5K equiv. heat load of booster and collider (kW)	**58.58**					

Installed power requirement

	40-80 K	5-8 K	2 K
Booster heat load（kW）	6.14	0.76	1.15
Collider heat load（kW）	63.51	11.96	11.94
CEPC TOTAL（kW）	69.64	12.71	13.08
COP（W/W)	16.4	197.9	700.2
Install power（MW）	1.14	2.52	9.16
Total installed power（MW）	**12.82**		

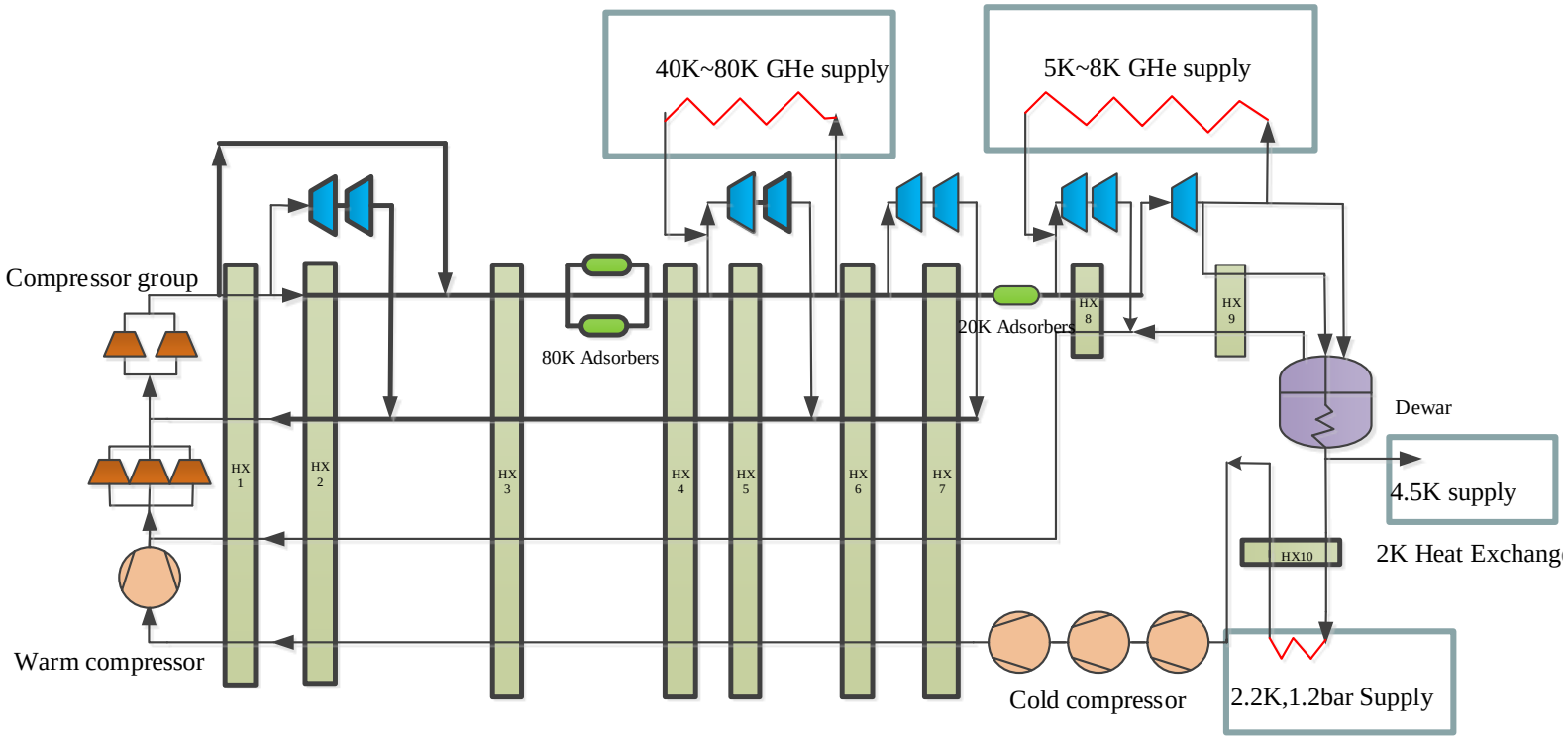
- The required total 4.5K equiv. heat load is 58.58kW and total installed power is 12.82MW.
- Four individual 18kW@4.5K refrigerators will be employed for the CEPC cryogenic system.
- Referred to LHC 18kW refrigerator, the corresponding installed power is 16.6MW.

Helium Inventory

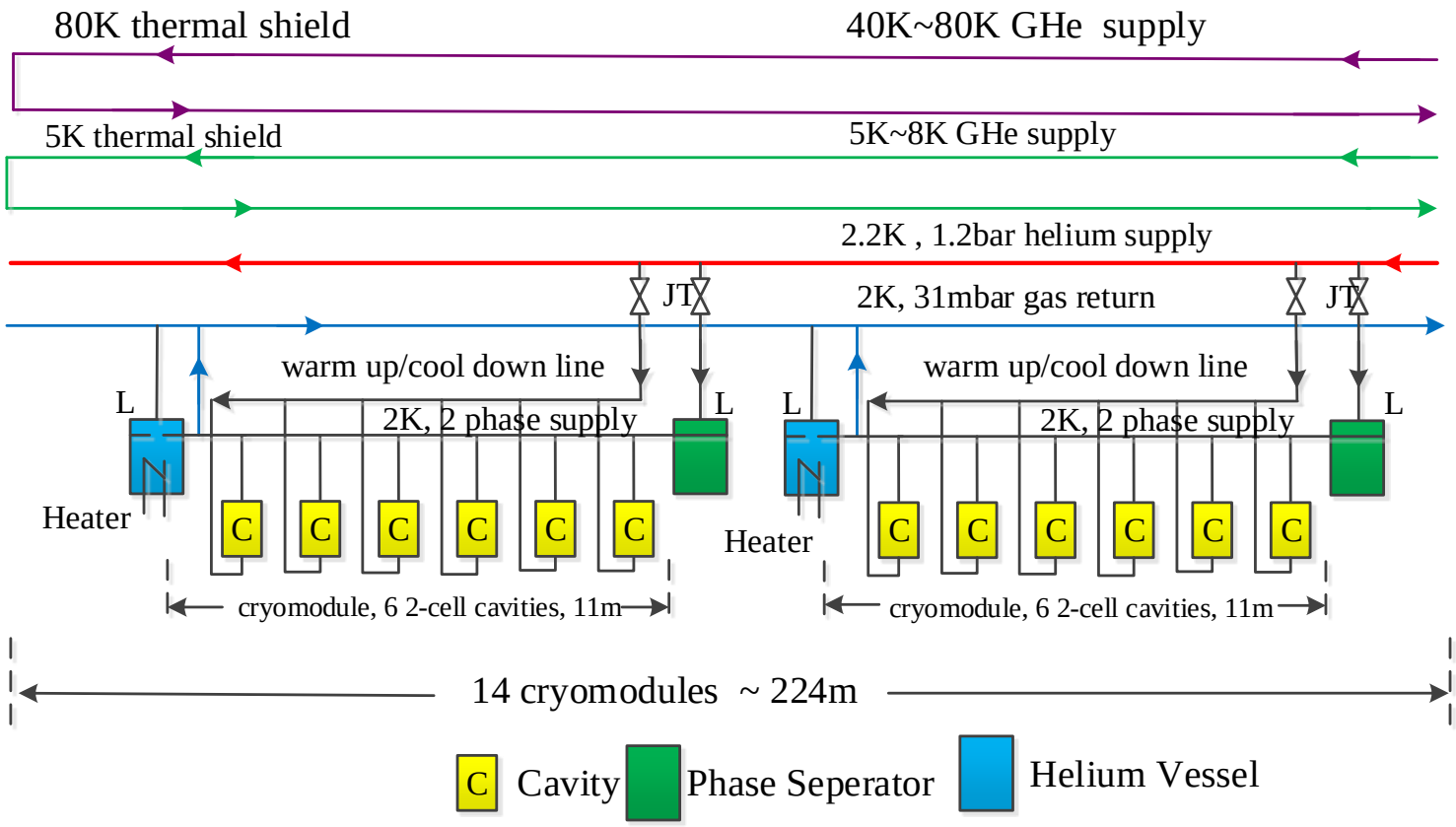
- The volume of one 1.3GHz and 650MHz module is about 320 liters and 346 liters, respectively.
- The total liquid helium volume in the system will be **33,166** liters.
- To safely operate the cryogenic system, a coefficient factor 60% is added, so CEPC needs a standard **4.5E4 m^3** helium inventory system.

Refrigeration

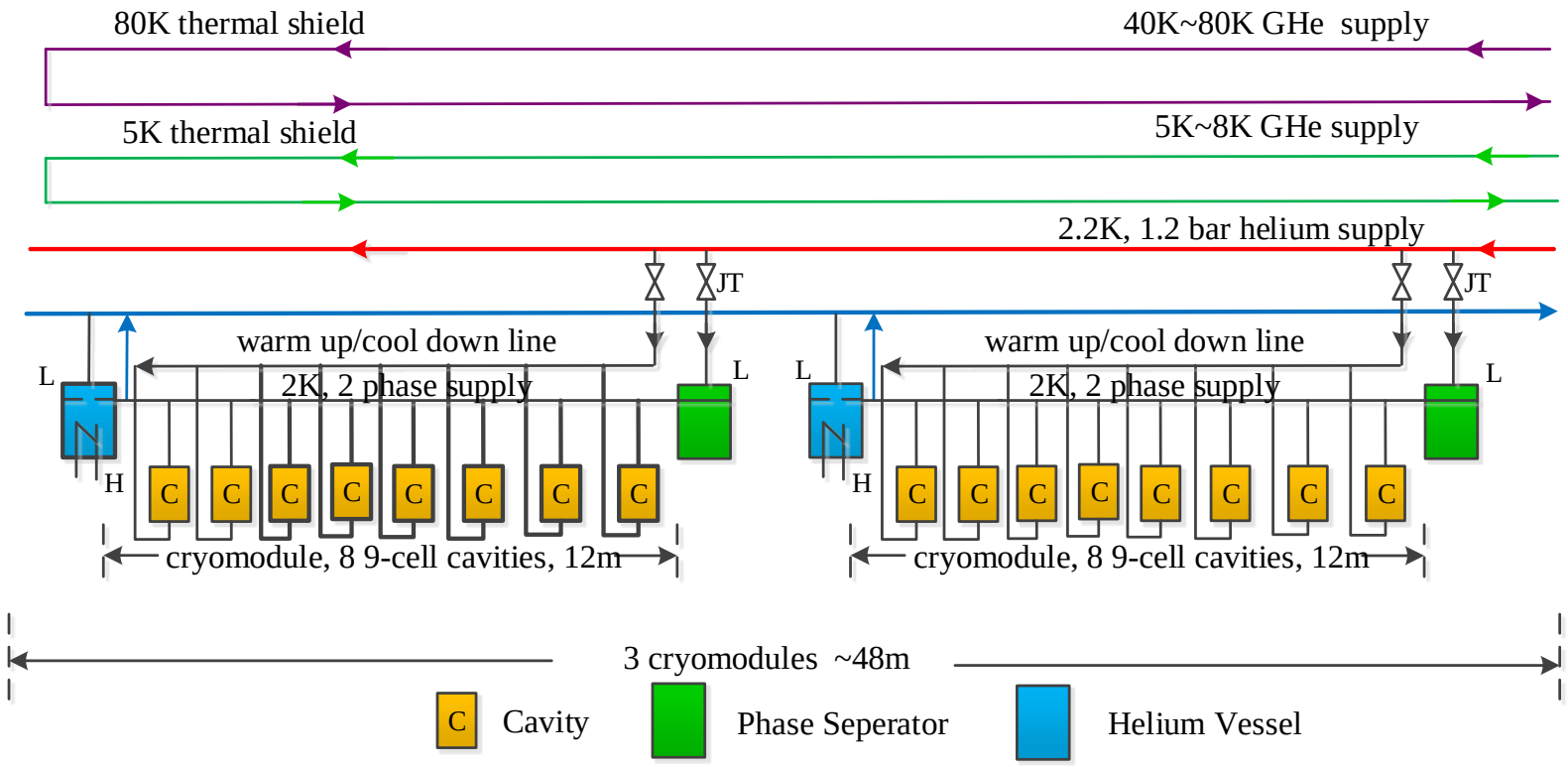
- **With a 20% margin**, four individual 18kW@4.5K refrigerators will be employed.
- The total cryogenic capacities are equivalent to 72kW at 4.5K.



Cooling scheme for Collider



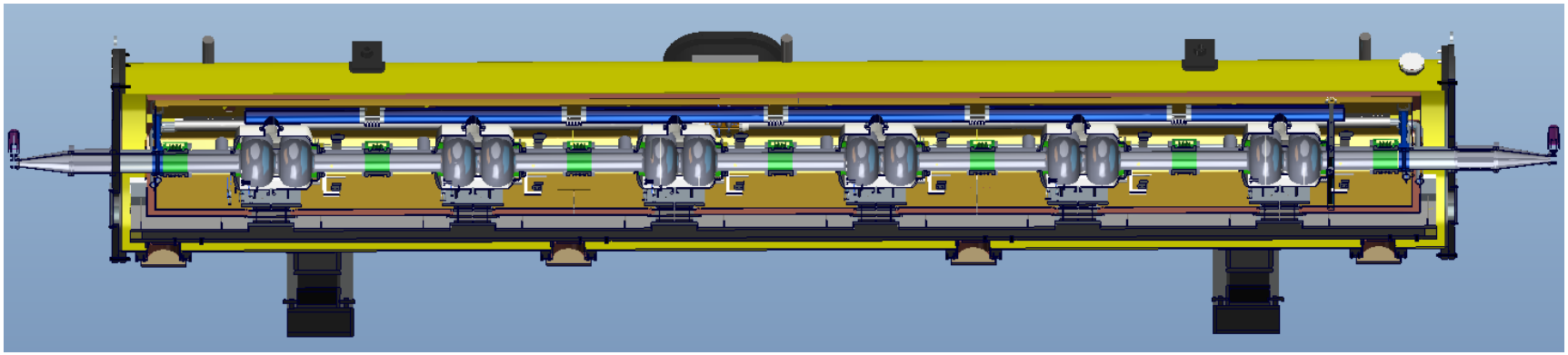
Cooling scheme for Booster



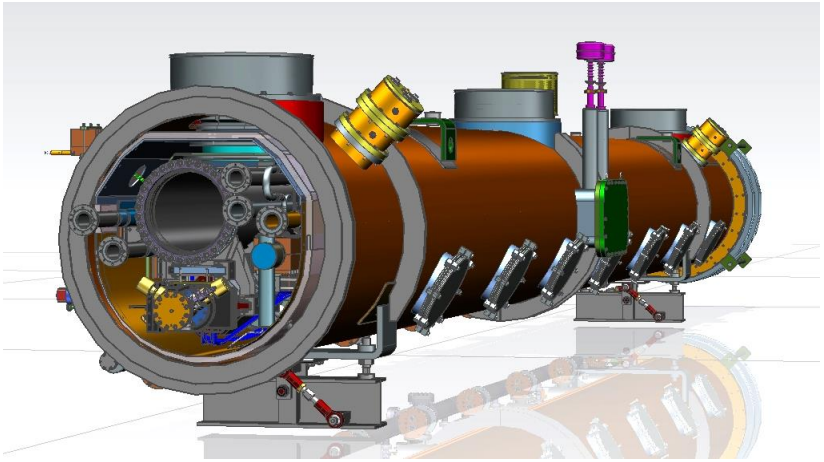
Cryomodule for 650MHz 2-cell cavities

From Ruixiong Han

- Including six 2-cell 650 MHz superconducting cavities, six high power couplers, six mechanical tuners and two HOM absorbers
- Fast Cool-down is introduced, means 10K/minute below 45K.
- The static heat load of whole cryomodule is 5W at 2K.



Cryomodule for 1.3GHz 9-cell cavities

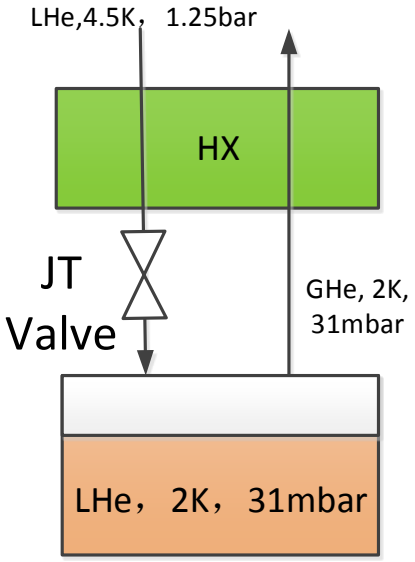


Design Goals:
- **Low heat loss**
- **Fast cool down**

XFEL / LCLS-II type Cryomodule for High Q Cavity

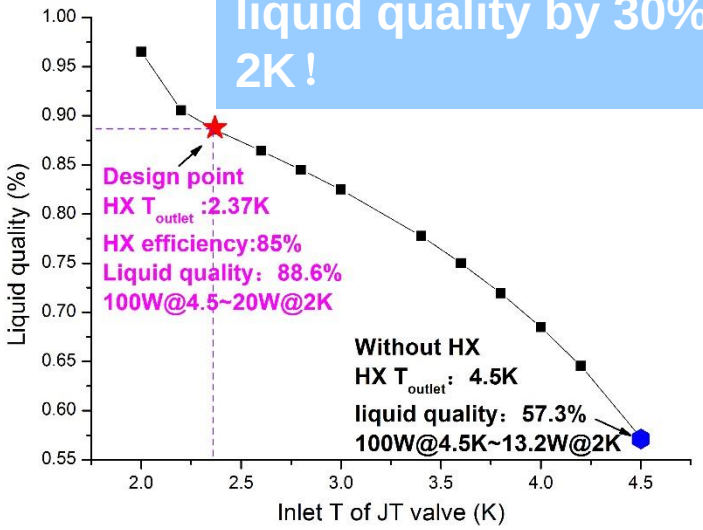
- Cryogenic Group in IHEP has manufactured 58 1.3GHz 9-cell Cryomodules for EXFEL cooperated with domestic companies.
- It's a good foundation for the optimization design for the CEPC cryomodules.

R&D
2K JT heat exchanger



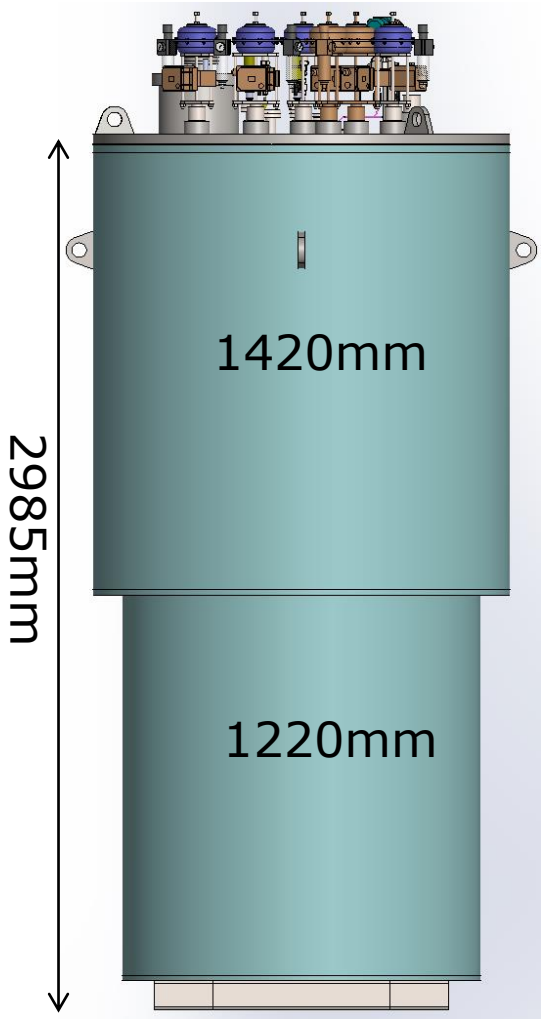
Key points：
- efficiency ≥85%
- Pressure drop ≤100Pa
- Low heat loss

JT HX can increase the liquid quality by 30% at 2K !

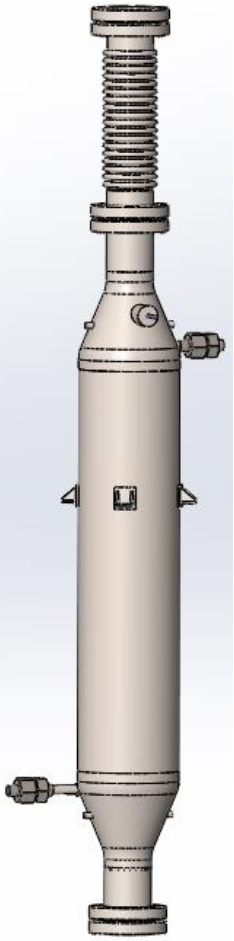


✓The 2K JT heat exchangers(HXs) were designed, the flow is 2g/s , 5g/s and 10g/s.
✓2K JT HX test stand will be built in **PAPS** in 2018.
✓The 2K JT HX with high efficiency will be used in the CEPC cryogenic system.

R&D
2K JT heat exchanger

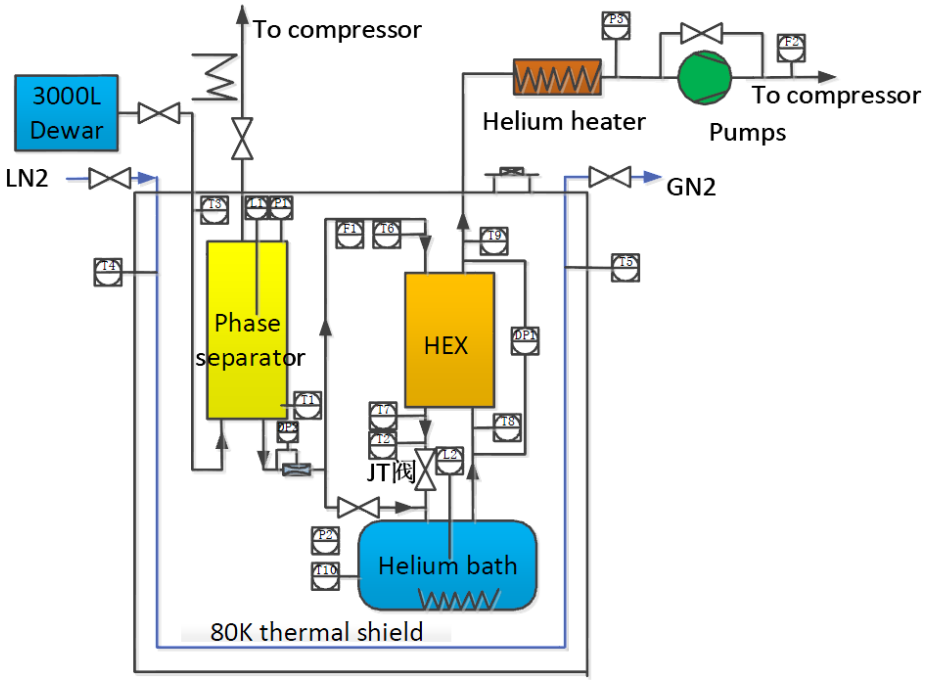


HEX Test Cryostat



HEX

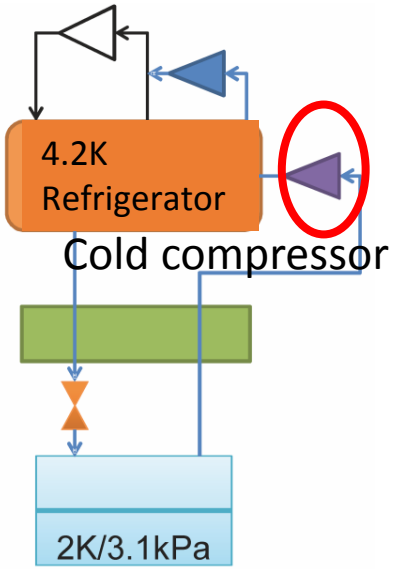
Pmax	Pmin	Tmax	Tmin
1.25bara	3kPa	4.5K	2K



R&D
Cold compressor

- Cold compressor is the key equipment for large 2K cryogenic system (mass flow> 10g/s).
- Only a few core manufacturers abroad have the design and manufacturing capacity.

The research of cold compressor is ongoing and supported by Key independent deployment project of Particle Accelerator Physics and Technology Key Laboratory .

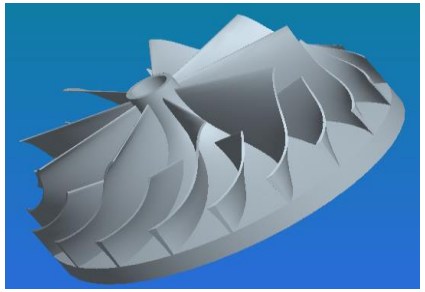


Technical parameters:

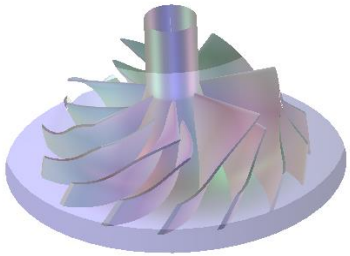
- adiabatic efficiency: ≥60%
- Compression ratio: ≥2
- Leakage rate: 10-9 Pa•m3/s
- A high-speed motor output power: ≥1 kW
- High speed motor speed: ≥36krpm

R&D
Cold compressor

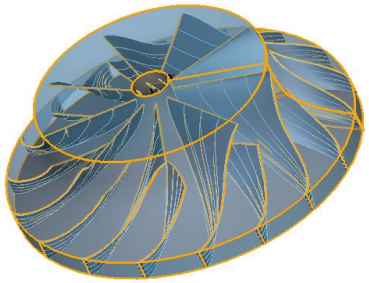
- Impeller is the key part of the cold compressor.
- Four types of impellers have been designed and numerically simulated with 3D software.



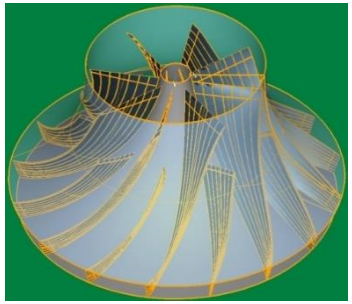
CC-IHEP01



CC-IHEP02



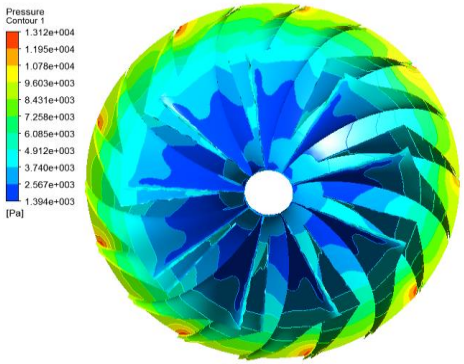
CC-IHEP03



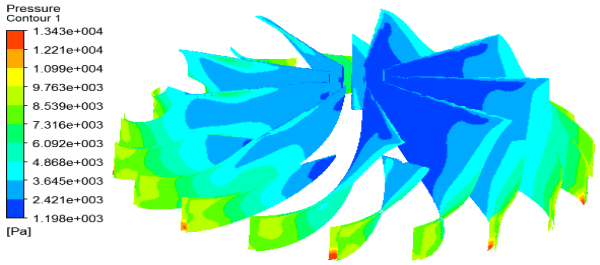
CC-IHEP04

- Manufacturing and dynamic balance test has been done.

CC-IHEP01



P distribution on blade and hub



P distribution of blade surface

Summary

- The heat load is evaluated, the required total 4.5K equiv. heat load is 58.58kW and total installed power is 12.82MW.
- There are four cryo-stations and each station has an individual 18kW@4.5K refrigerator.
- The R&D of 2K JT heat exchanger and cold compressor is under way.