

CEPC Cryogenic System

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Outline

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- Heat load
- Refrigeration
- Cooling scheme
- Cryomodules
- Cryogenics for magnets
- R&D
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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.

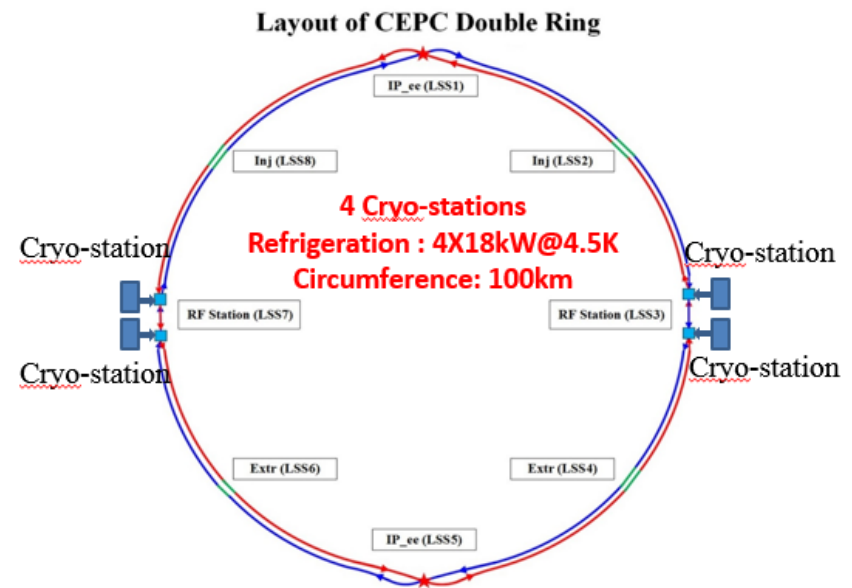
Introduction

Booster ring:

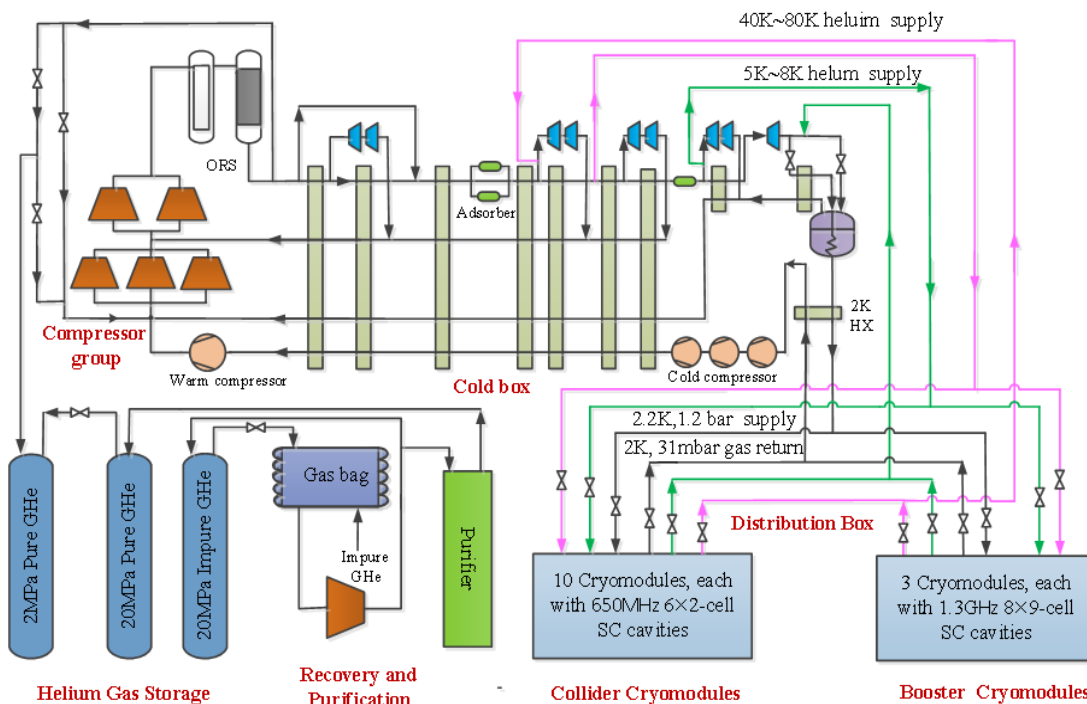
- 1.3 GHz 9-cell cavities, 96 cavities
- 12 cryomodules
- 3 cryomodules/each station
- Temperature: 2K/31mbar

Collider ring:


- 650MHz 2-cell cavities, 240 cavities
- 40 cryomodules
- 10 cryomodules/each station
- Temperature: 2K/31mbar



Flowchart of cryogenic system for one Cryo-station



- Each Cryo-station mainly includes Compressor, Cold box, helium gas storage tanks, cryomodules 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.



Parameters of SC cavities related for Cryogenic system

	Collider				Booster		
mode	H(50MW)	H(30MW)	W	Z	H	W	Z
Frequency(MHz)	650	650	650	650	1300	1300	1300
Cavity operating voltage (MV)	6.46	9.04	0.10	0.90	19.17	11.72	12.19
Duty factor	CW	CW	CW	CW	0.043	0.029	0.079
Total number of cavities	336	240	216	120	96	64	32
Total number of modules	56	40	36	20	12	8	4
Eacc (MV/m)	14.04	19.66	9.46	3.62	19.77	8.81	8.64
R/Q	213	213	213	213	1036	1036	1036
Q0	1.00E+10	1.50E+10	1.50E+10	1.50E+10	1E+10	1E+10	1E+10
Operation temperature (K)	2	2	2	2	2	2	2
Cavity dynamic heat load@ 2K (W/cavity)	19.58	25.59	5.93	0.87	1.75	0.23	0.61
Cavity dynamic heat load@ 2 K (W/module)	117.49	153.52	35.57	5.22	13.98	1.87	4.91

Heat load of cryogenic system

Higgs Mode (30MW)	Unit	Collider			Booster		
		40-80K	5-8K	2K	40-80K	5-8K	2K
Static heat load per cryomodule	W	300	60	12	140	20	3
Cavity dynamic heat load per cryomodule	W	300	60	153.59	140	10	13.98
Input coupler dynamic heat load per cryomodule	W	20	12	2	40	3	0.4
HOM dynamic heat load per cryomodule	W	60	40	6	2	1	1
Module dynamic heat load	W	380	112	161.59	182	14	15.38
Connection boxes	W	50	10	10	50	10	10
Cryomodule number		40			12		
Total heat load	kW	29.20	7.28	7.34	4.46	0.53	0.34
Total mass flow	g/s	139.93	227.15	346.58	21.39	16.47	16.07
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	3.38	10.14	36.18	0.52	0.74	1.68
Total 4.5K equiv. heat load with multiplier	kW	49.70			2.93		
Total 4.5K equiv. heat load of booster and collider	kW	52.63					

Heat load and installed power with different working modes

	Collider				Booster		
	H(50MW)	H(30MW)	W	Z	H	W	Z
Total heat load @ 4.5 K (kW)	59.62	49.7	24.07	11.61	2.93	1.75	1.35
Total installed power (MW)	13.05	10.88	5.27	2.54	0.64	0.38	0.30

	H(50MW)	H(30MW)	W	Z
Total heat load @ 4.5 K (kW)	62.55	52.63	25.82	12.96
Total installed power (MW)	13.69	11.52	5.65	2.84

- 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.

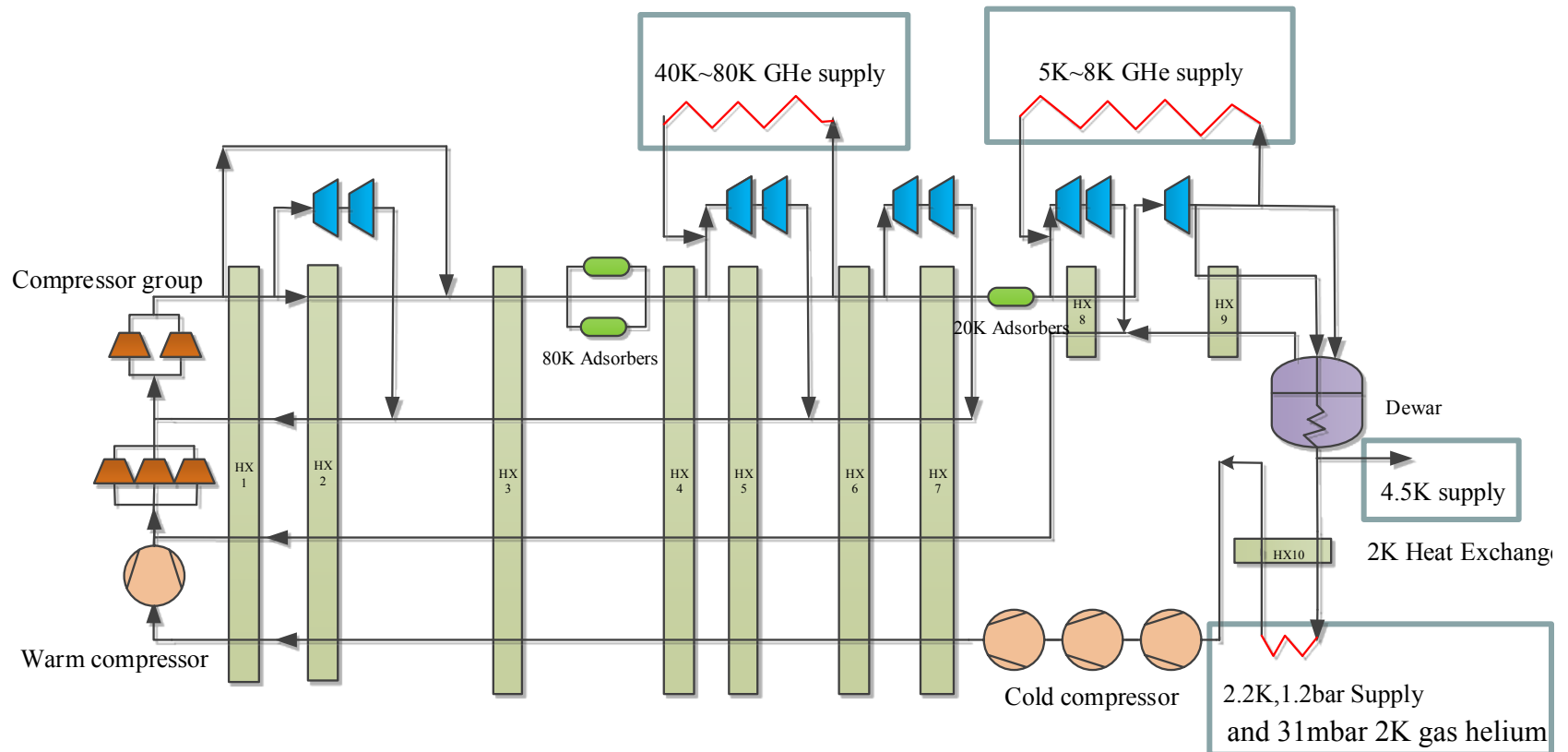


Helium Inventory

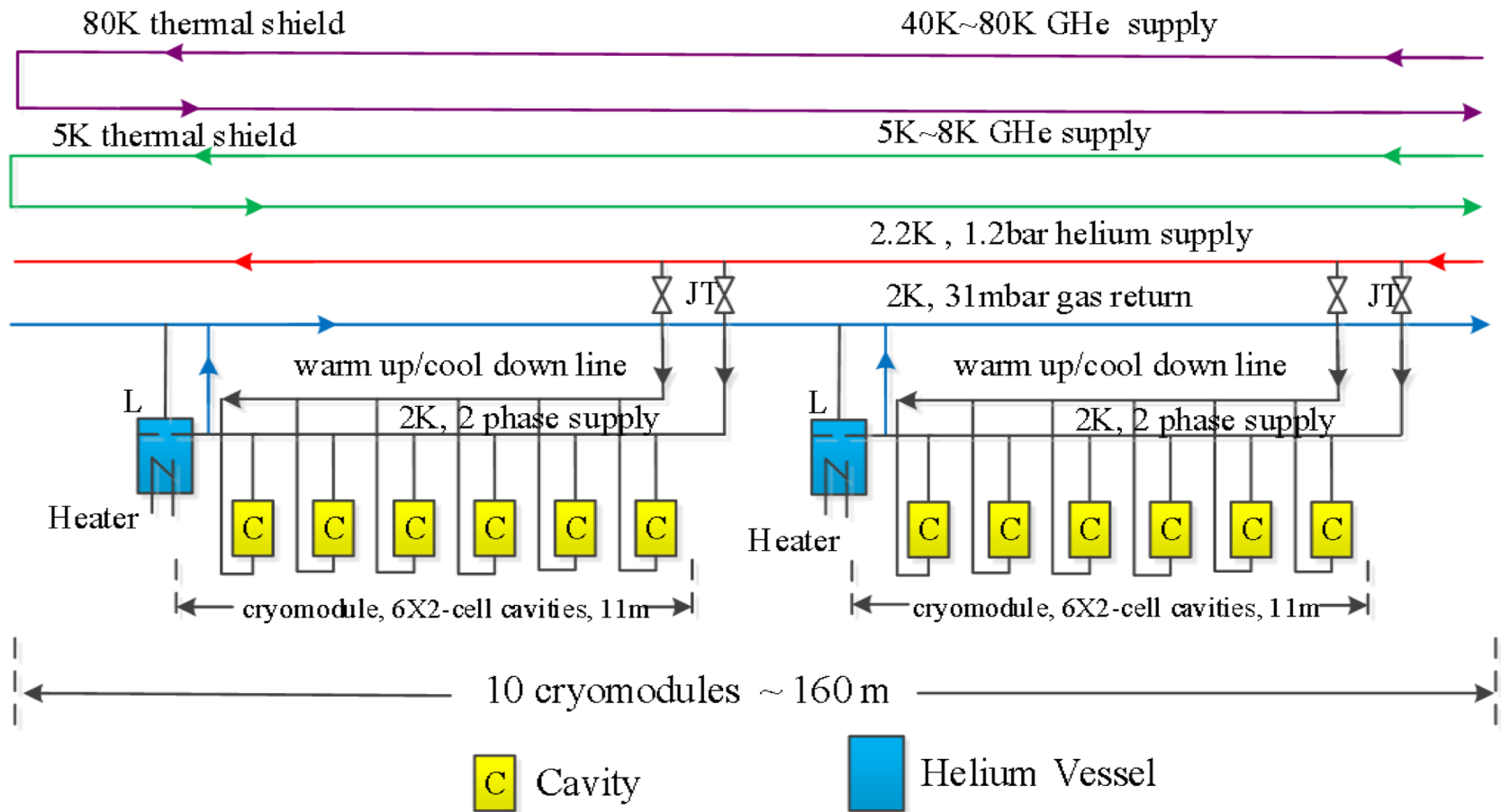
- The volume of one 1.3GHz module and one 650MHz module is about 320 liters and 346 liters, respectively.
- Accounting for the liquid in the Dewar and in the transfer lines, the total liquid volume in the system is about 25,257 liters, or about 3,137 kg
- To safely operate the cryogenic system, a coefficient factor 60% is added, so CEPC needs a standard 3.2E4 Nm³ helium inventory, or about 5,228 kg.

Flowchart of refrigerator

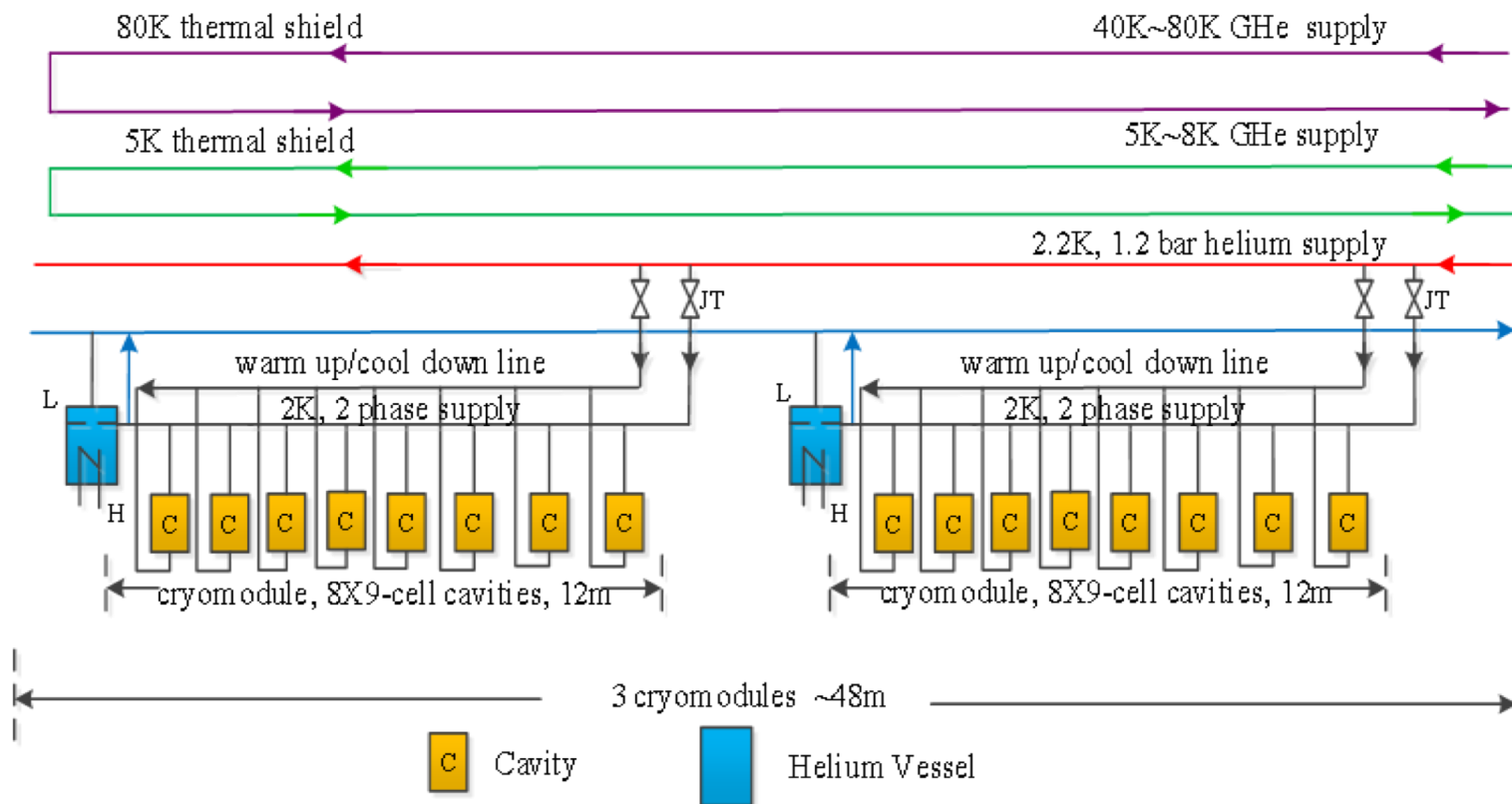
- **With a 27% margin**, four individual 18kW@4.5K refrigerators will be employed.
- The total cryogenic capacities are equivalent to 72kW at 4.5K.



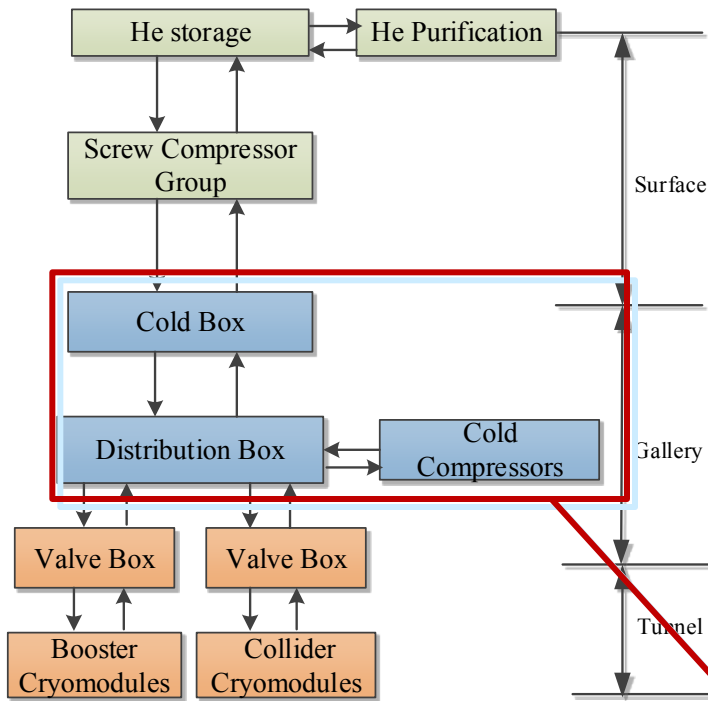
Cooling scheme for Collider



Cooling scheme for Booster



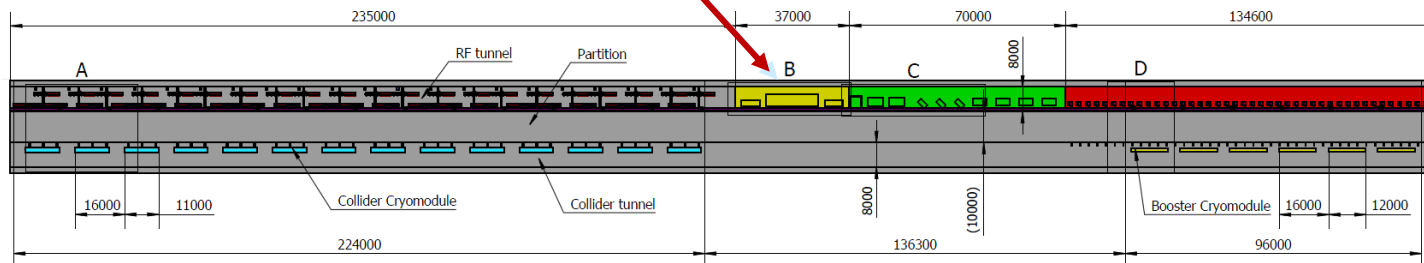
Infrastructure



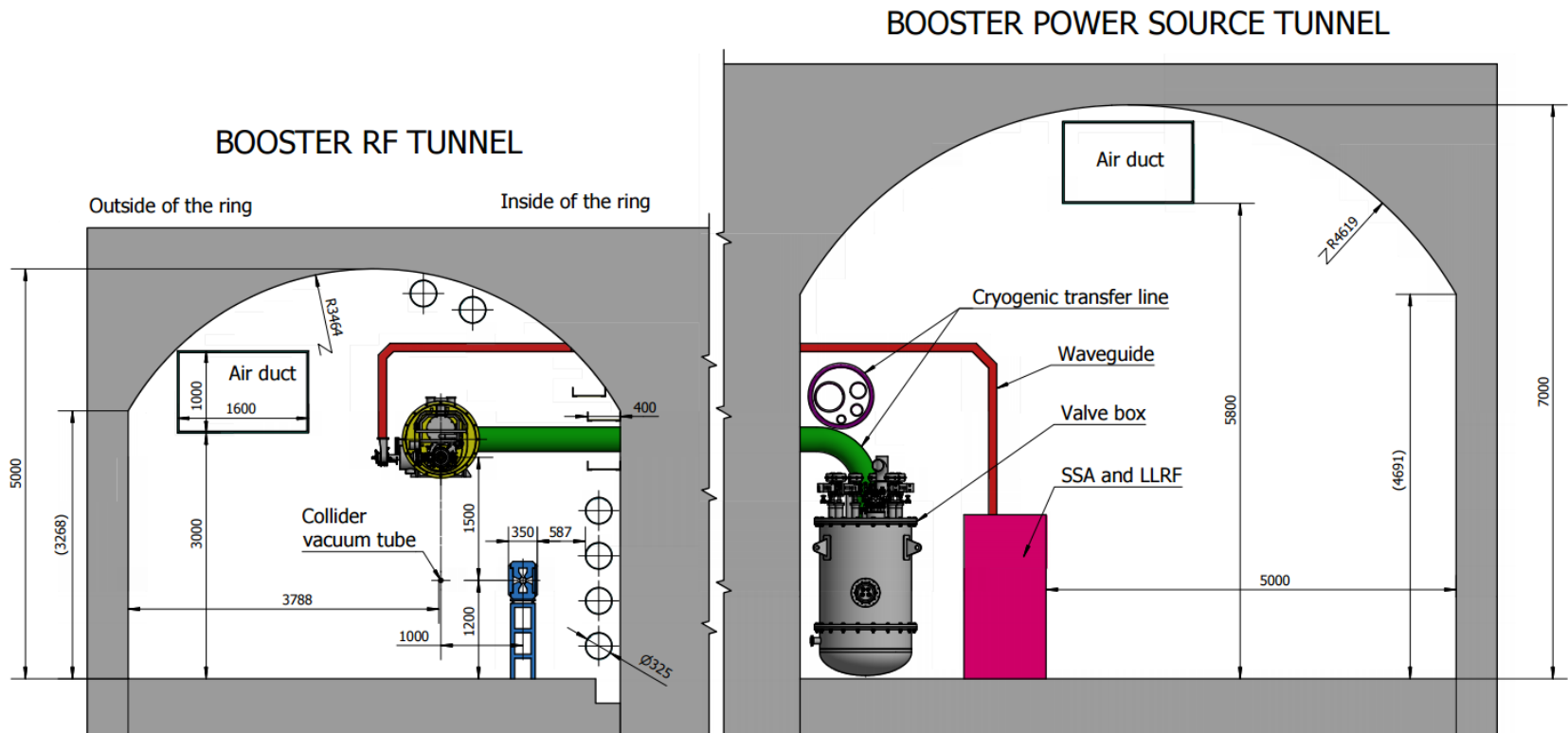
Equipment:

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

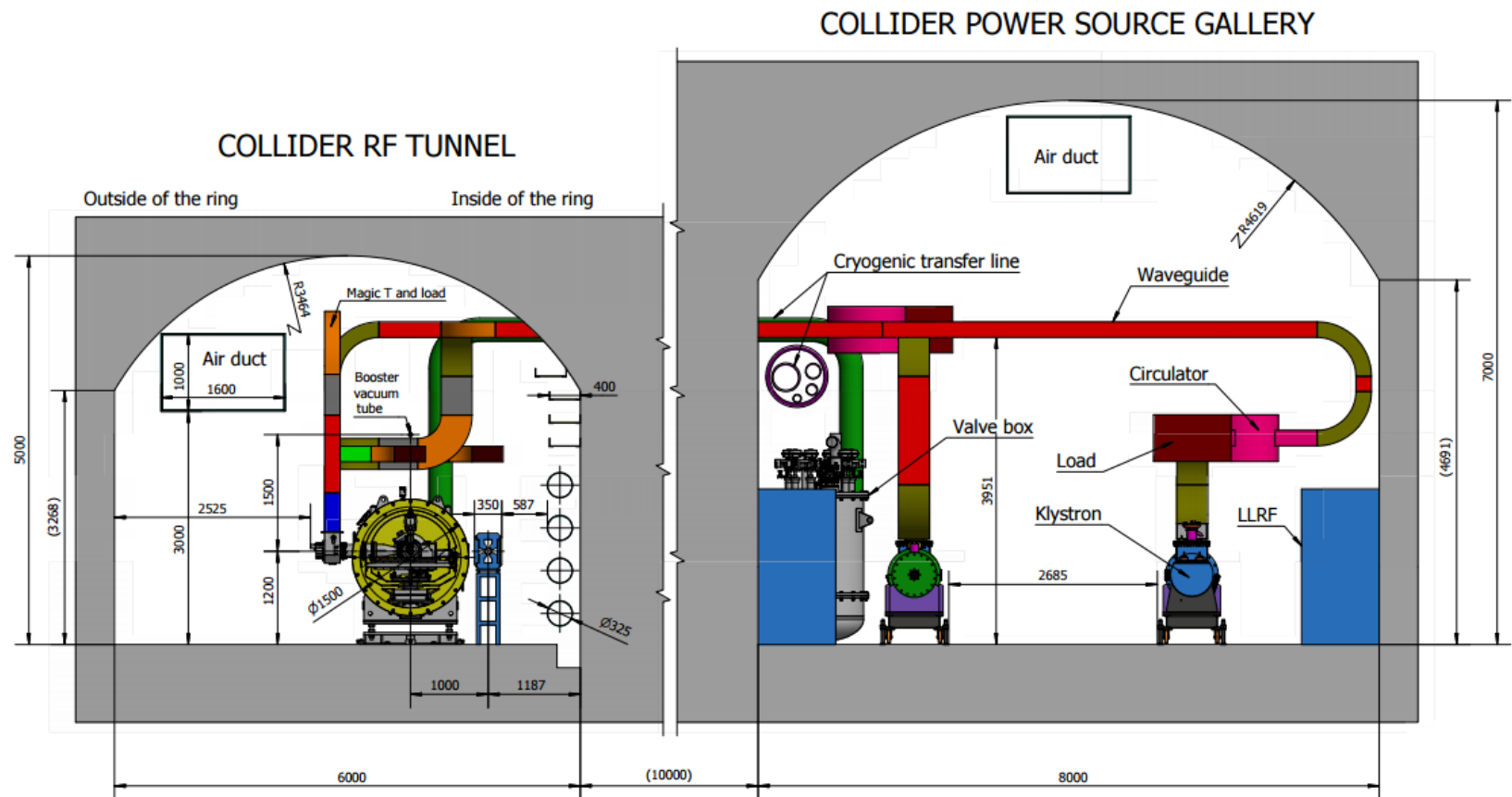
Each cryo-station has an underground plant in the gallery, the size is 37m * 8m.



Infrastructure



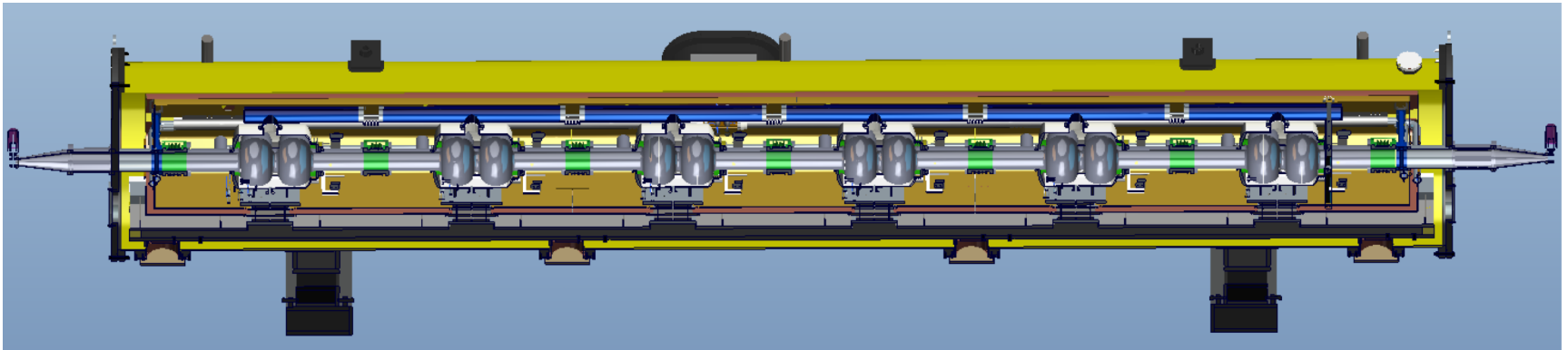
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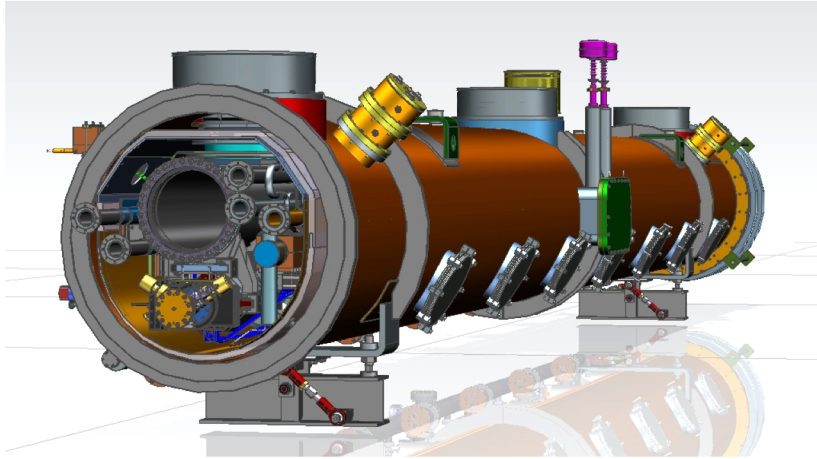
Cryomodule for 650MHz 2-cell cavities

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

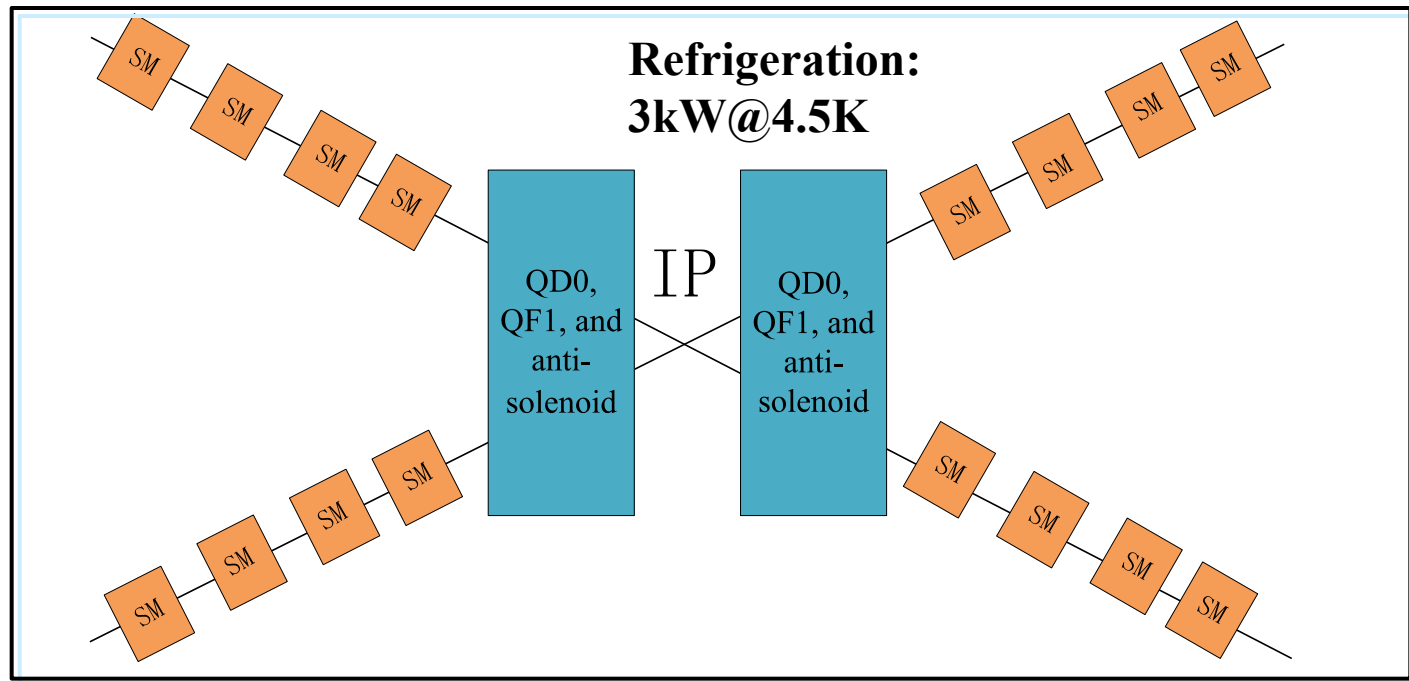
XFEL / LCLS-II type Cryomodule for High Q Cavity

- 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.



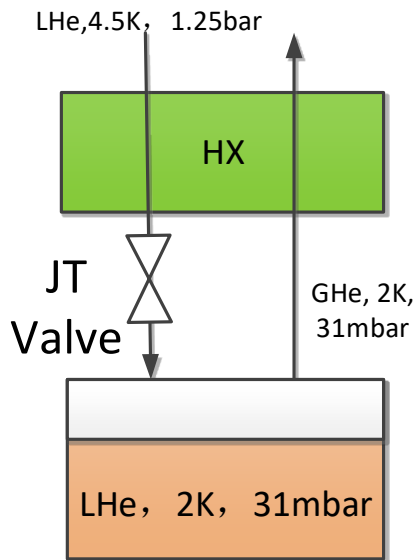
Cryogenics for SC magnets

- 2 IPs in CEPC Interaction Region, there are 4 insertion quadrupole magnets and 32 sexupole magnets.
- There are 2 cryo-stations, each one with a refrigerator of 3kW@4.5K.



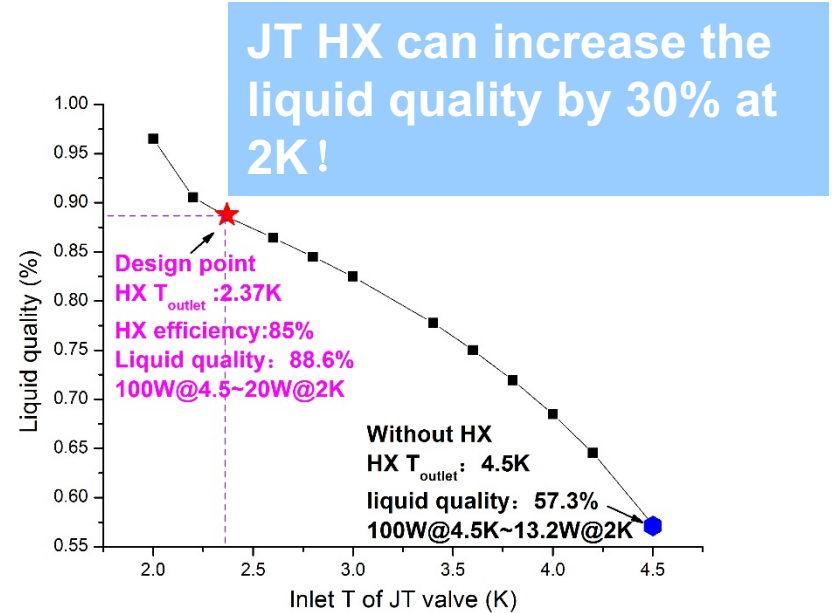
R&D

2K JT heat exchanger



Key points:

- efficiency $\geq 85\%$
- Pressure drop $\leq 100\text{Pa}$
- Low heat loss



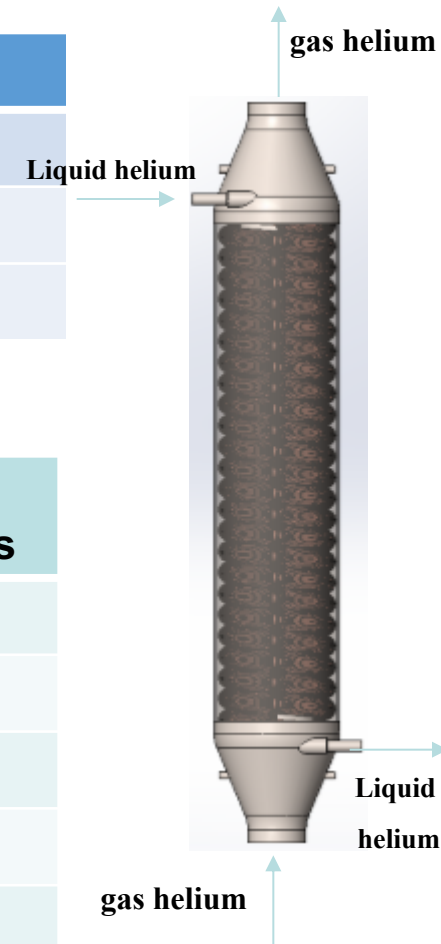
- ✓ The 2K JT heat exchangers (HXs) were designed, the flow is 2g/s, 5g/s and 10g/s.
- ✓ 2K JT HX test stand will be built in **PAPS** in 2018.
- ✓ The 2K JT HX with high efficiency will be used in the CEPC cryogenic system.

Design of 2K J-T heat exchanger

Fluid	Liquid helium	Gas helium
Inlet temperature (K)	4.45	2
Inlet pressure (Pa)	1.25E+05	3100
Outlet temperature (K)	2.2	3.36

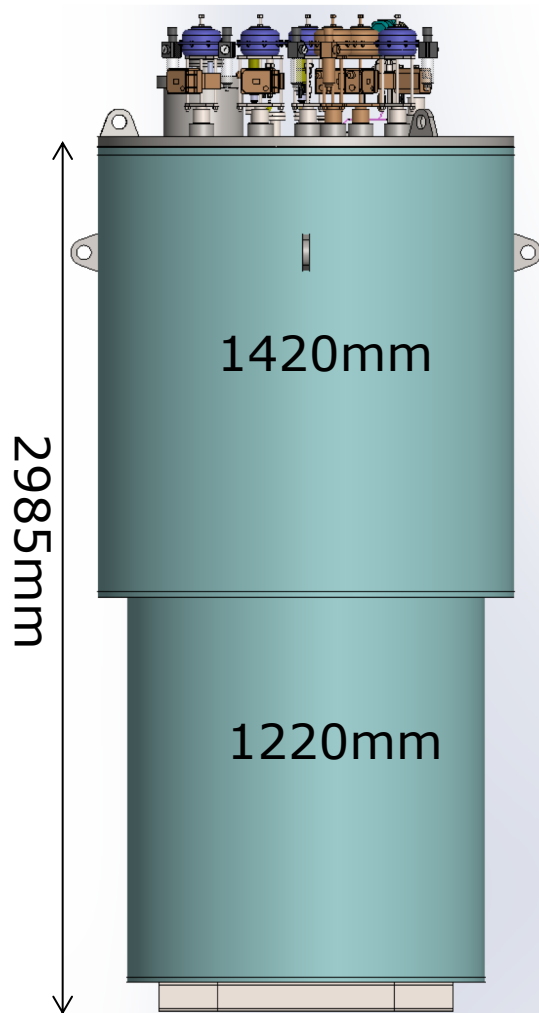
Mass flow rate	m=2g/s	m=5g/s	m=10g/s
Axial length of coil finned tube (m)	0.52	0.603	0.691
Axial length of heat exchanger (m)	0.72	0.803	0.891
Pressure drop for the shell side (Pa)	6.1	30.6	70.2
Pressure drop for the tube side (Pa)	36.2	242	388.9
Heat exchanger efficiency	91.8%	91.8%	91.8%

Table 2 The design results of J-T heat exchanger for m=2g/s, m=5g/s and m=10g/s

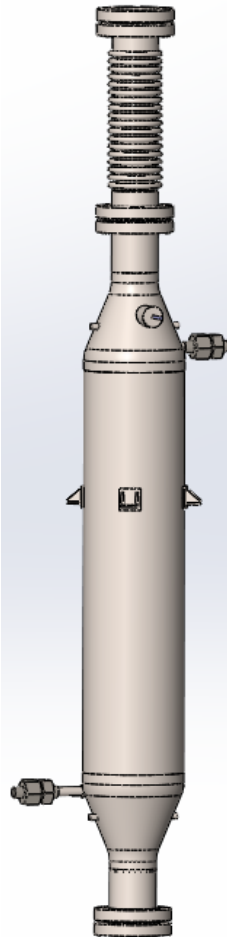


R&D

Test platform for 2K heat exchanger

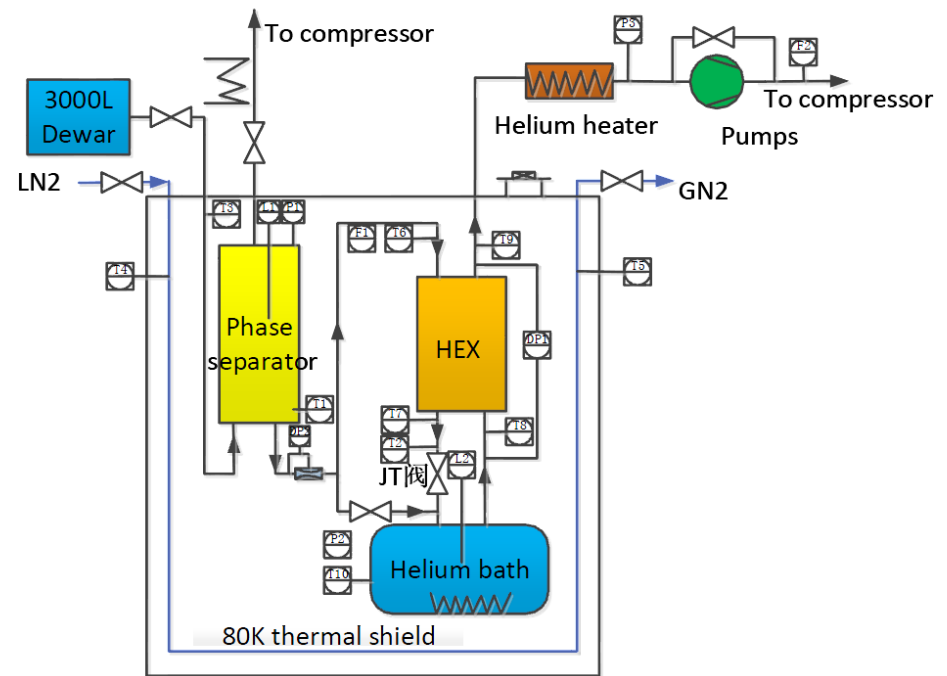


HEX Test Cryostat



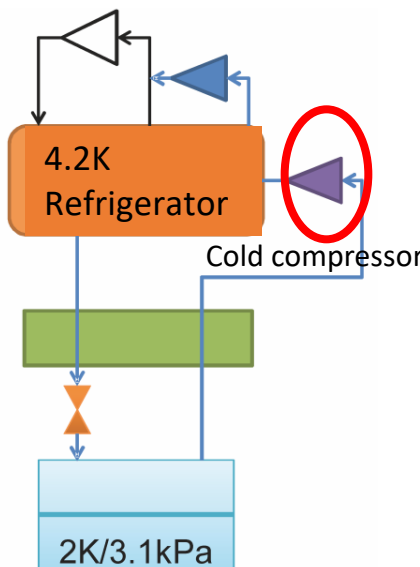
HEX

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



R&D of Cold compressor

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

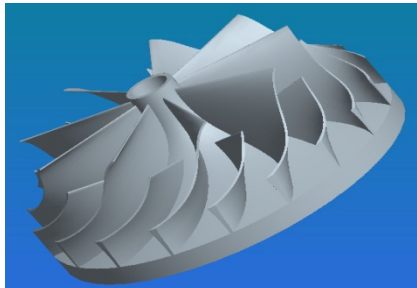


Technical parameters:

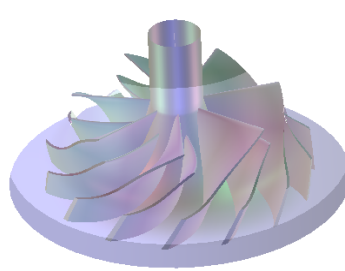
- adiabatic efficiency: $\geq 60\%$
- **Compression ratio: ≥ 2**
- Leakage rate: $10^{-9} \text{ Pa} \cdot \text{m}^3/\text{s}$
- A high-speed motor output power: $\geq 1 \text{ kW}$
- High speed motor speed: $\geq 36 \text{ krpm}$

R&D of Cold compressor

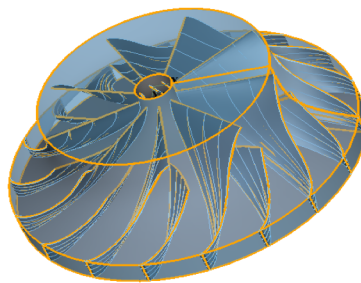
- Impeller is the key part of the cold compressor.
- Four types of impellers have been designed and numerically simulated with 3D software.



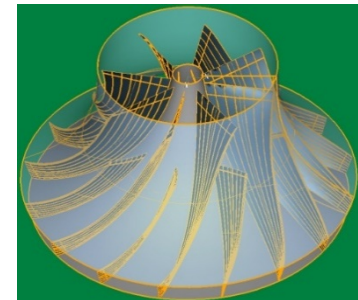
CC-IHEP01



CC-IHEP02

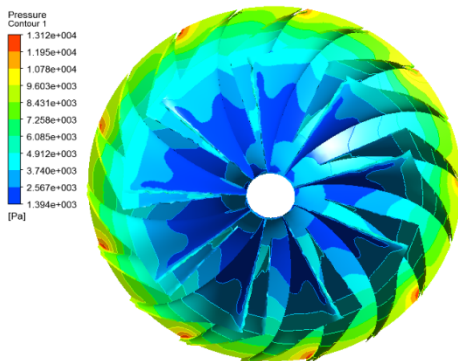


CC-IHEP03

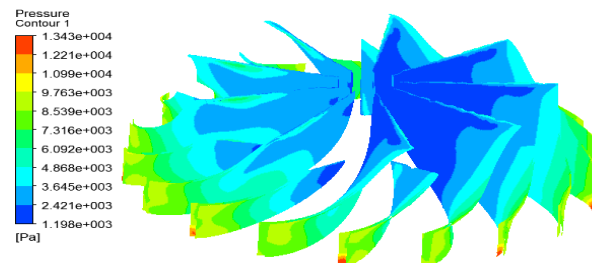


CC-IHEP04

- Manufacturing and dynamic balance test has been done.



CC-IHEP01



P distribution on blade and hub

P distribution of blade surface



Summary

- The cryogenic system is currently in the conceptual design stage, and the CDR report has been basically completed.
- The heat load is evaluated, the required total 4.5K equiv. heat load is 56.2kW and total installed power is 12.3MW.
- 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.