Cryogenic & Cryostat for the CEPC MDI

Tongxian Zhao, Miaofu Xu,
Yongcheng Jiang

CEPC MDI Workshop

28-29, May, 2020

Outline

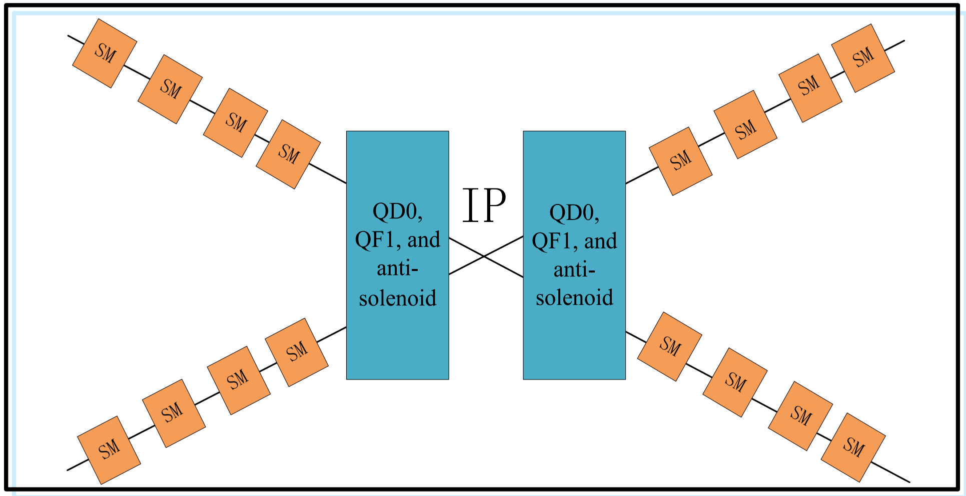
- Introduction
- Cryogenic cooling schemes and Cryogenic Layout for MDI
- Cryogenic system design considerations
- The Cryostat of MDI
- Cryostat Prototype Plan& Key technology
- Manpower
- Summary

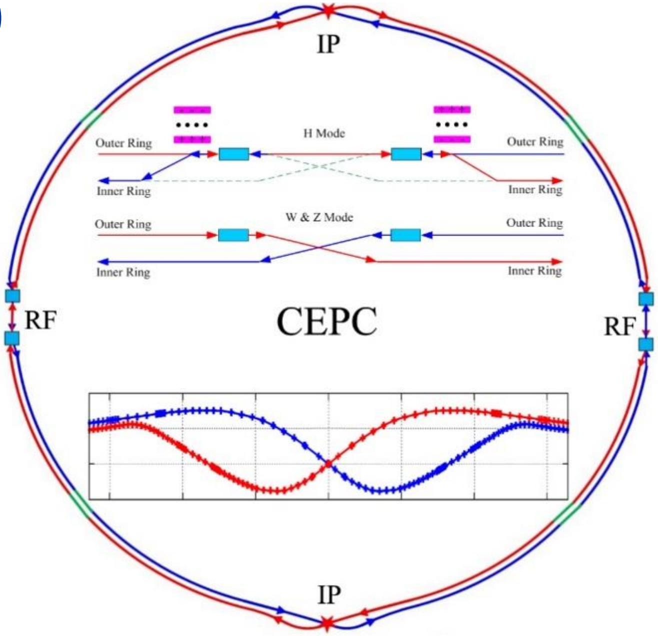
Introduction

The Machine Detector Interface (MDI)

IR magnets:

- 4 IR magnets
- 32 Sextupole magnets,
- 36 cryomodules/18 @each station
- Temperature: 4.5K (2K)

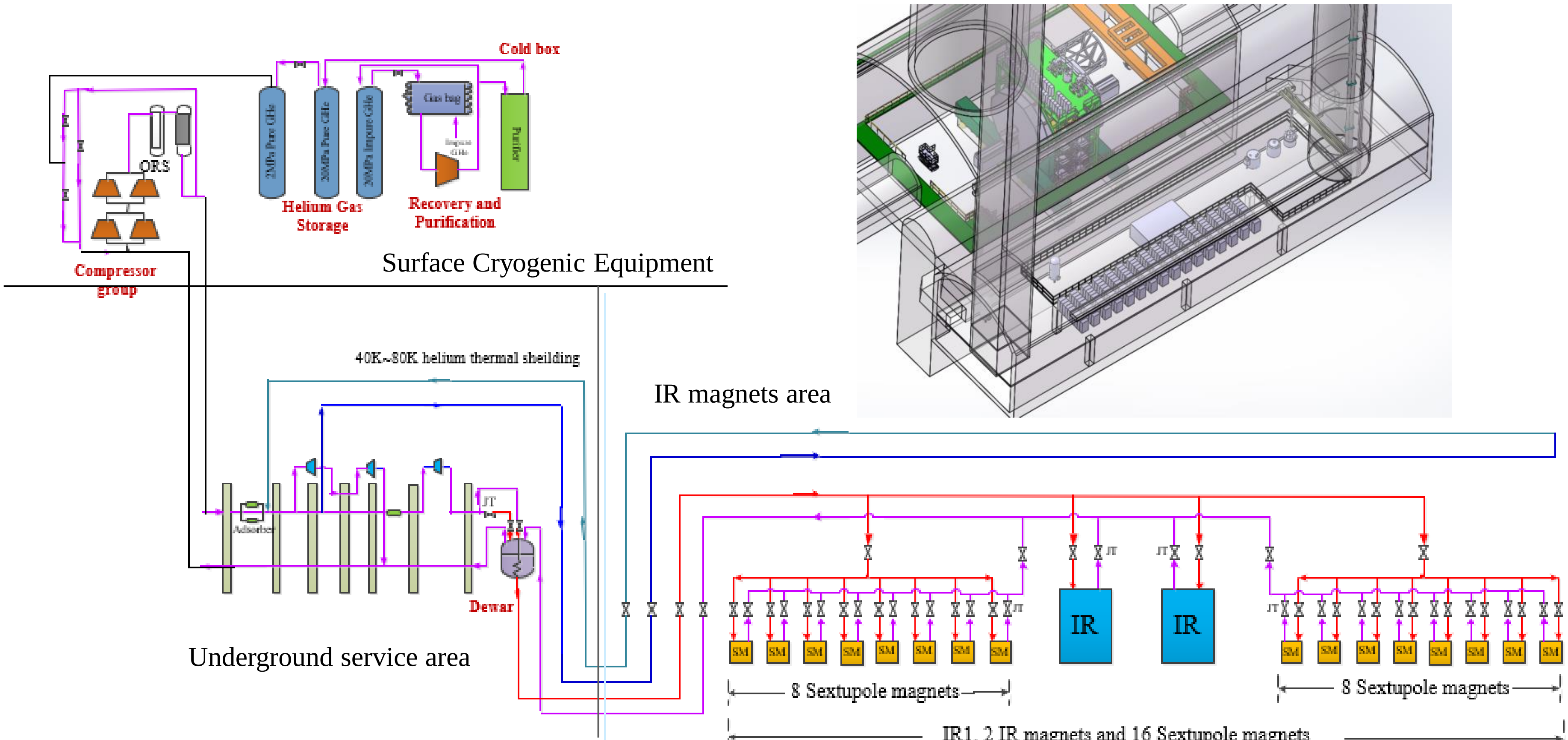




Sketch of CEPC Collider ring

CEPC MDI SC Magnets (superconducting QD0,QF1, anti-solenoid) in a helium vessel.

Cryogenic cooling schemes and Cryogenic Layout in the experimental Hall



SM Sextupole magnet IR IR magnet

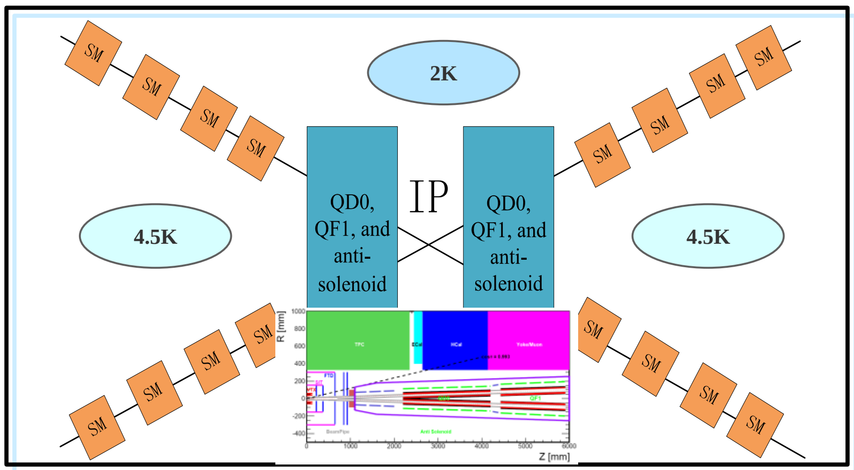
Interaction Region 1

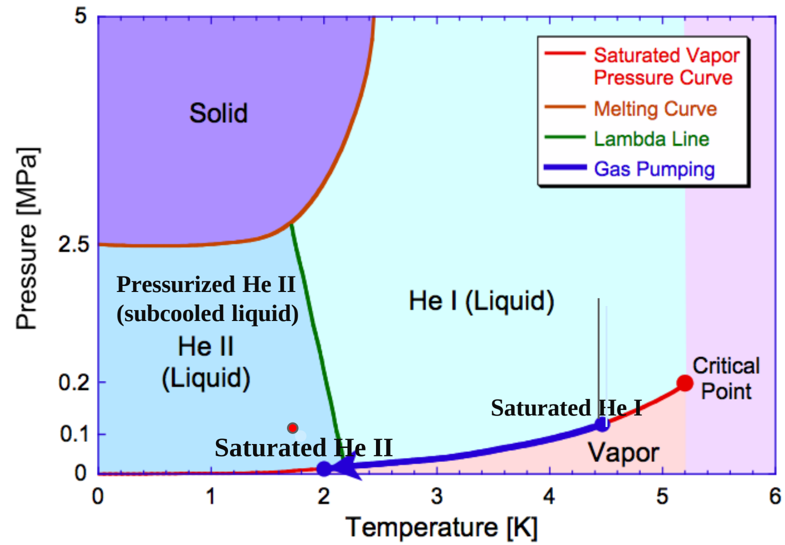
One Cold box and two MDI service cryostat are installed on each IP point, should be close enough to the user.

Sextupole magnets share a CB with MDI, they need to be considered together.

Refrigerator with the cooling capacity of 3kW@4.5K will be employed for each cryo-stations.

2K Cryogenic system

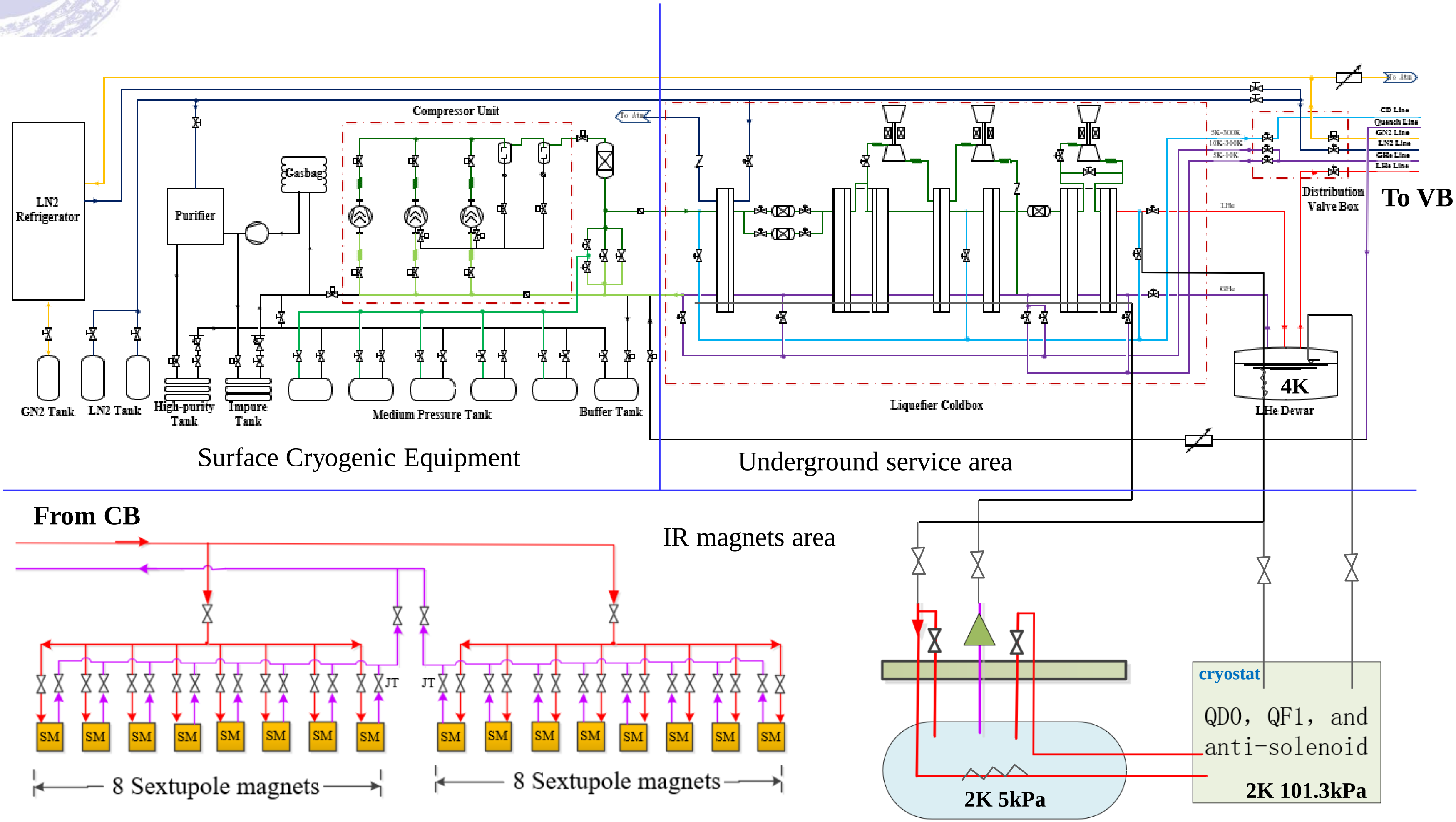




Superconducting equipment	Coolant condition	Heat Load
Sextupole magnets	4.5K(2K)	16*10W@4.5K(2K)
QD0, QF1 and anti-solenoid	Below 2K	4*30W@2K

- 2K helium has powerful stabilization against thermal disturbances(large C/excellent λ)
- Superfluid helium can permeate to the heart of magnet windings(low bulk viscosity)
- To determine actual cooling capacity safety factor and extra heat load has to be considered.
- With the change of operating temperature we also have to reconsider actual thermal load for these equipment.

Cryogenic cooling schemes @2K

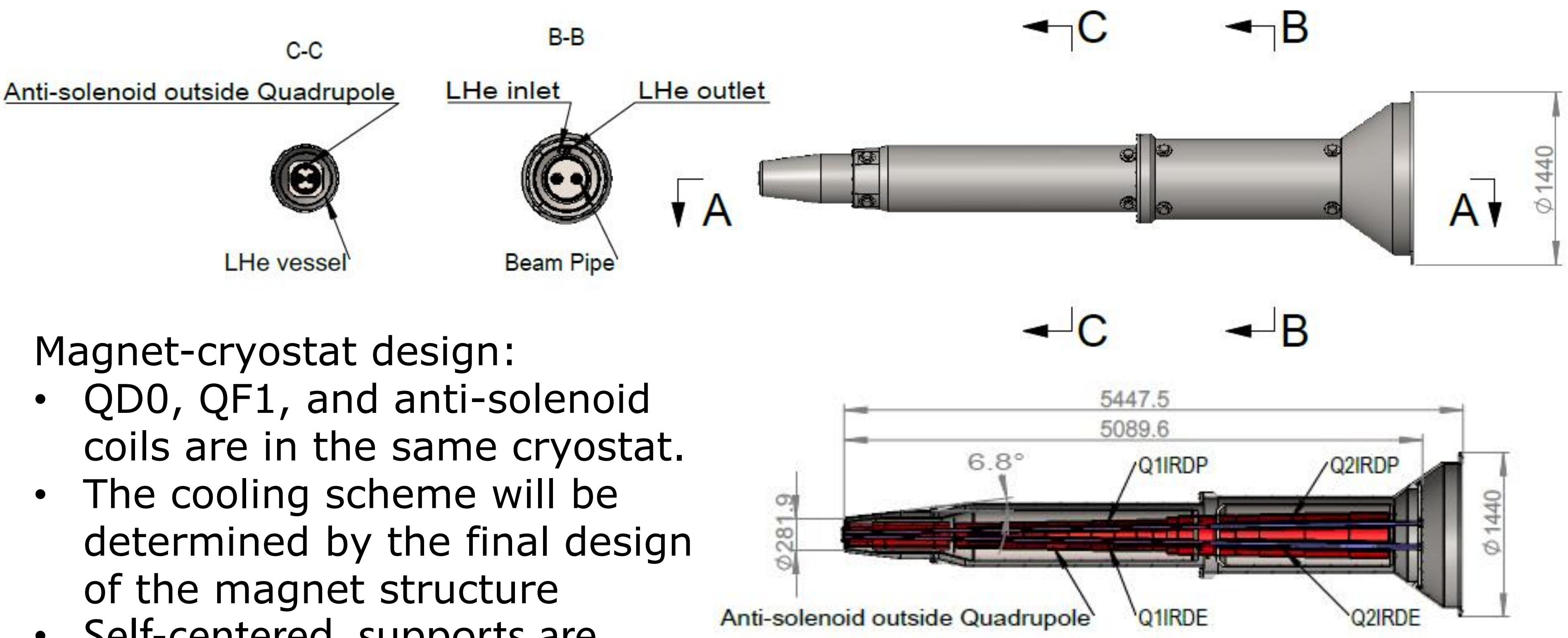


- The MDI cold masses will be cooled in a pressurized static superfluid helium bath at 101.3kPa and at a temperature of 2K, so we need a 2K refrigerator in the tunnel.
- The 5kPa vapor pressure is maintained by a cold compressor system
- The final operating temperature and pressure are determined by the cryogenic process calculation

Cryogenic system design considerations

- The cryogenic systems incorporate high efficiency helium refrigeration (liquefaction) at 4.5 K, a distribution system with low heat-in leaks ,a large helium inventory (storage) and the cryogenic users (cryostat).
- The design of the cryostat and cryogenics system allowed the prior testing of the full cryogenic loop without magnet.
- CEPC cryogenic system should allow for rapid cool-down and warmup of limited lengths of the strings, e.g. for repairing or exchanging a defective unit.
- To ensure reliable operation, it should provide reasonable redundancy of functions among its components and sub-systems
- Personnel and equipment safety

The Structure of Cryostat



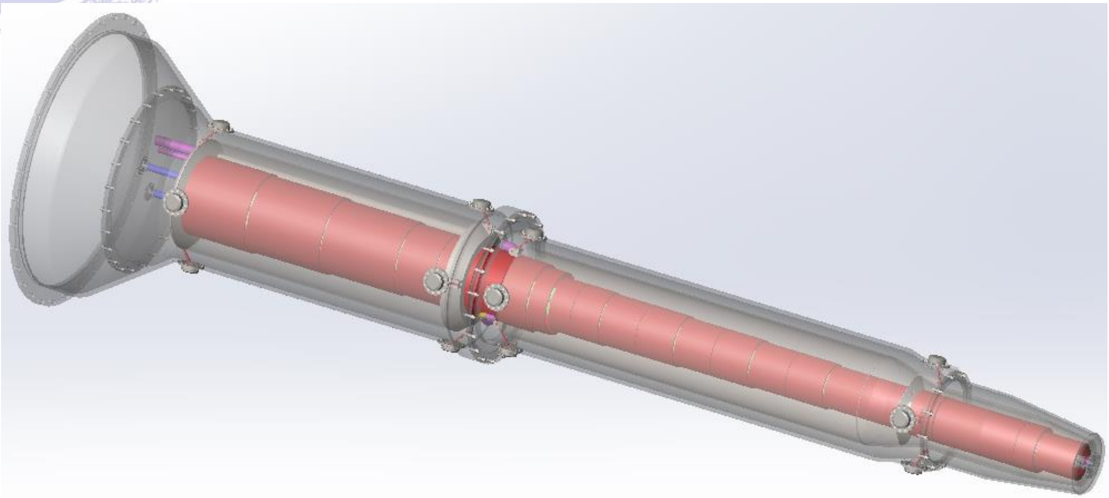
Magnet-cryostat design:

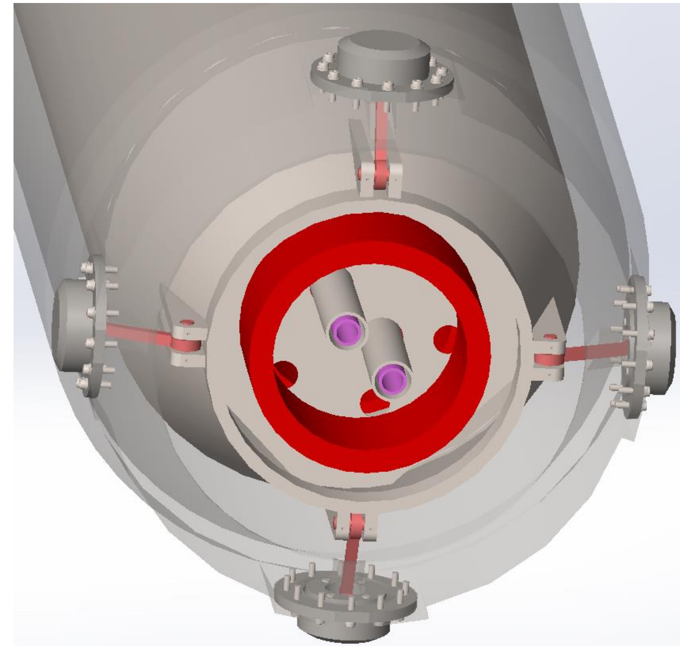
- QD0, QF1, and anti-solenoid coils are in the same cryostat.
- The cooling scheme will be determined by the final design of the magnet structure
- Self-centered supports are designed to make the magnet positions after cool-down the nominal positon for the beam operation.
-

Magnet cryostat	Weight(Kg)
Total cold mass	≈1097.87
Lhe vessel	≈537.87
Magnet	≈560

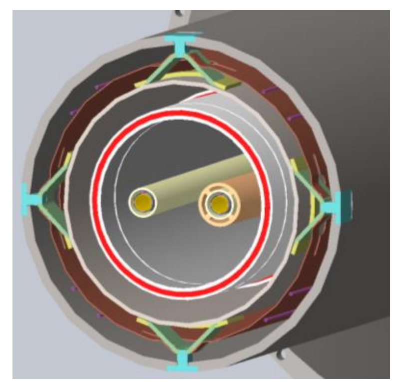
From Miaofu Xu

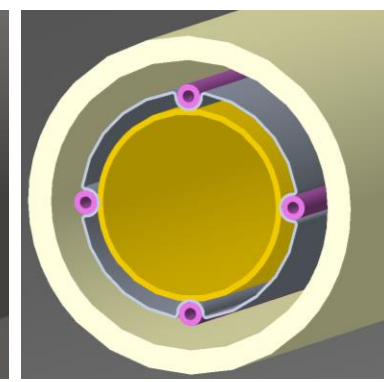
The Structure of Cryostat





- The helium vessels, in which the SC magnets are assembled, are supported by the 8 rods from the vacuum vessel.
- To be made of non-metallic materials such as Carbon fiber (CFRP, T300)
- The multilayer insulation material and it's dressing process is very important to decrease the heat load

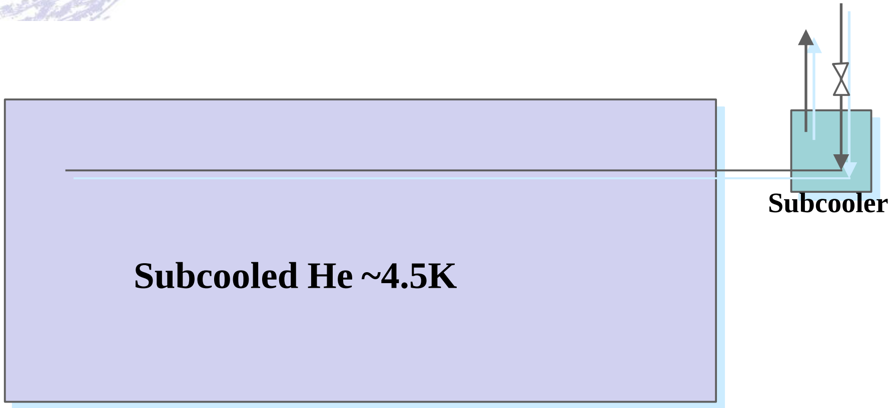


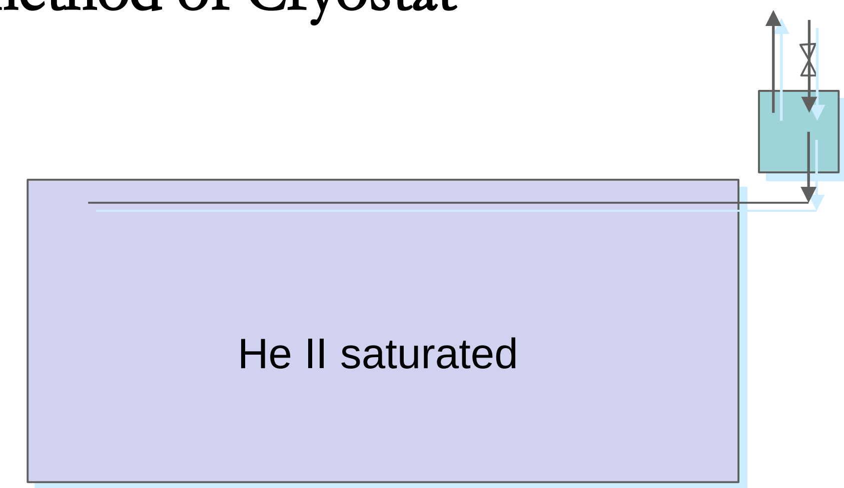


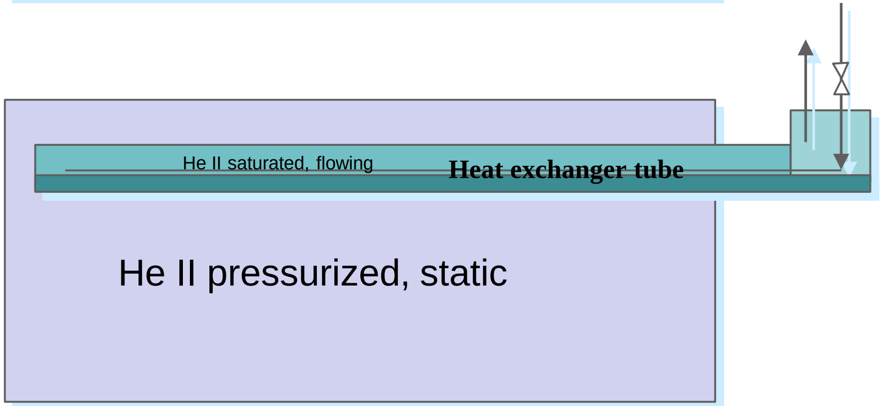
From Miaofu Xu

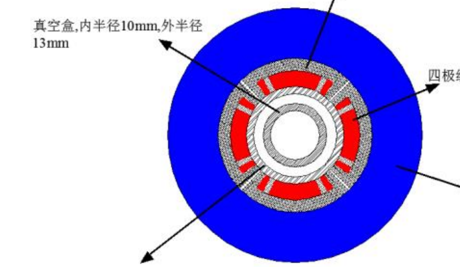
***Study on heat leak of multilayer insulation(MLI)**

The Cooling method of Cryostat









- Subcooled helium ~4.5K
- Pressurized saturated superfluid helium
- Forced-flow convection of pressurized superfluid helium
- Two-phase flow of saturated superfluid helium

The Refrigerator

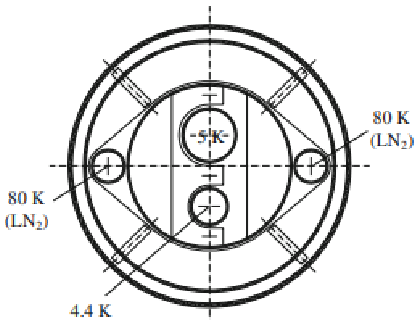
- **Plan A . Large refrigerator**
  - There are 2 cryo-stations, each one with a refrigerator of 3kW@4.5K
  - low cost of daily maintenance.
  - The CTL is long and the cost is high（~214 million）
- **Plan B. Large refrigerator +GM refrigerator**
  - There are 2 cryo-stations, each one with a refrigerator of 500W@4.5K
  - Each sexupole magnet is equipped with a GM refrigerator unit, totally 32 groups.
  - If GM refrigerator is adopted, there is no cryogenic transfer line (SM),
  - But the maintenance of the GM refrigerator is more difficult.
  - Low cost（~174 million）, no long-distance CTL.
  - 128 GM refrigerators and 2*500W(4*250W) refrigerators, high cost of daily maintenance and high failure rate.
- **Plan C . 2K Refrigerator**

Cryostat Prototype plan

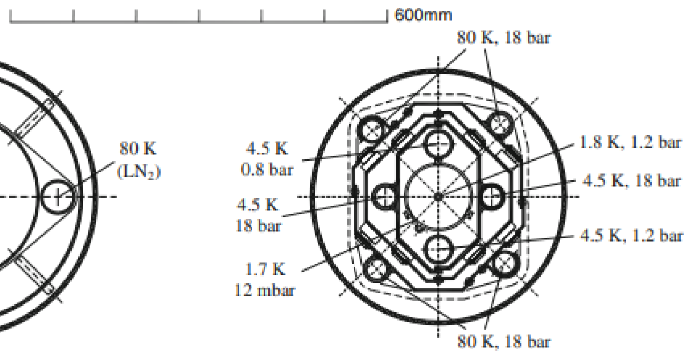
No	Name		Price （RMB10000）	Tatol Price （RMB10000）
1	Budget for development of cryostat prototype (without current leads)			398.90
1.1	Cryostat			341.60
1.1.1	Mechanical	1	180	180.00
1.1.2	Offline performance test of key components			18.00
	Performance test of pull rod assembly	16	0.5	8.00
	performance test of metal hose and displacement compensator	1	2	10.00
1.1.3	measurement			67.60
1.1.3.1	Temperature sensor and instrument	1	45	46.00
1.1.3.2	Liquid level meter and instrument	2	1.8	3.60
1.1.3.3	FEEDTHROUGH	1	5	5.00
1.1.3.4	multi-channel cryogenic transfer line	1	13	13.00
1.1.4	Cryogenic test			74.00
1.1.4.1	Liquid Nitrogen	1	2	2.00
1.1.4.2	Liquid Helium	4000	0.018	72.00
1.1.5	Pump system	1	20	20.00
1.2	Control Unit			12.3
1.2.1	Control PC	1.00	2.50	2.50
1.2.2	PLC	1.00	1.30	1.30
1.2.3	Cabinet	1.00	1.50	1.50
1.2.4	Software	1.00	5.00	5.00
1.2.5	Other componets	1.00	2.00	2.00
1.3	Deawr for Pressurized Lhe/ Heat exchanger	1	45	45

- **We needs to make a cryostat prototype to find many unforeseen problems.**
- **Heat exchange for the cryostat.**
- **High-performance cryogenic transfer line.**
- **The pressurized static superfluid helium bath technology.**
- **Cold compressor station.**

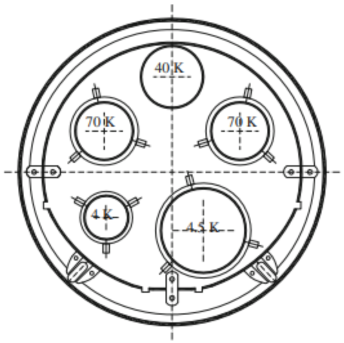
Cryogenic Transfer Lines



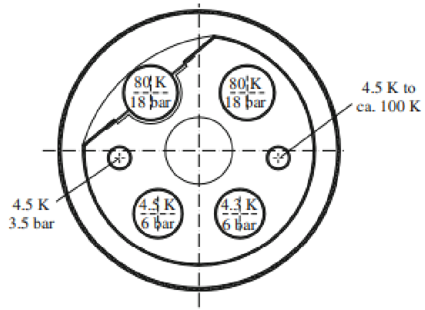
TRISTAN CTL



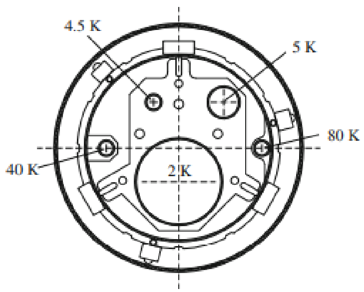
Tore Supra CTL



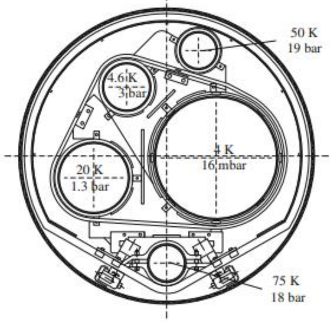
RHIC VJRR CTL



ITER prototype CTL



XFEL/Injector CTL



LHC/QRL CTL

Cryogenic transfer lines are typical components of almost all cryogenic systems.They are intended for transferring cryogenic fluids between two cryogenic devices. We need high-performance cryogenic transfer lines for reduce the heat leak.

We will build a test stand for the CTL heat loss measurement, design CEPC CTL.

manpower

- Cryostat design | Miaofu Xu
- Cryogenic system | Yongcheng Jiang
- Thermodynamic simulation | Tongxian Zhao
- Layout design | Jiang， Zhao
- Cryostat Prototype Development | Xu, Zhao
- Key technology of cryogenics | Jiang, Zhao
- Cryogenic Transfer Line | Jiang
- Cryogenic Measurements | Zhao
- Cryogenic Control system | Cryogenic Group

Summary

- The cryostat will be optimized follow the process of magnets.
- MDI Dynamic heating should be provide.
- Precision Thermometry.
- Test Stand for the CTL.
- Cryostat Prototype is necessary.
- Research on 2K cooling scheme.

Thanks for your attention

Heat loads for SC magnets

Name	Unit	No.	Heat load for each	Heat load
IR SC sextupole magnet	W	32	10	320
Valve Box of IR SC sextupole magnet	W	32	20	640
Current lead of IR SC sextupole magnet	g/s	32	0.1	3.2
IR SC magnet	W	4	30	120
Valve Box of IR SC magnet	W	4	30	120
Current lead of IR SC magnet	g/s	4	0.5	2
Main distribution valve box	W	2	50	100
Cryogenic transfer-line	W	4000	0.5	2000
Total equiv. heat load @4.5K	W	/	/	3820
Total equiv. heat load @4.5K with multiplier 1.5	W	/	/	5730
Cooling capacity of refrigerator@4.5K	W	2	3000	6000
Installed power (COP(300W/1W))	MW	/	/	1.8

***No contingency**