The Commissioning of a Hybrid Magnet at CHMFL

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Outline

1. Brief Introduction of CHMFL
2. A hybrid magnet at CHMFL
3. Summary and Perspective

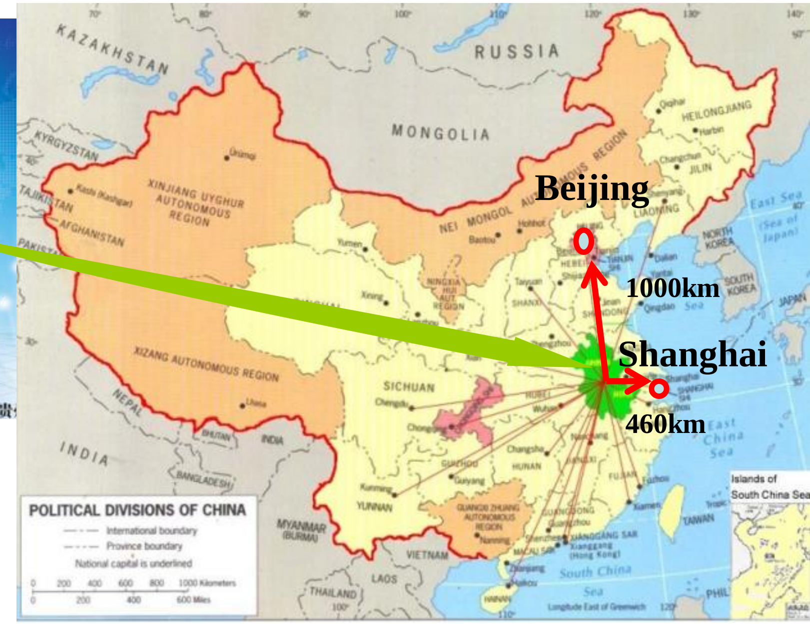
1. Brief Introduction of CHMFL

- The Steady High Magnetic Field Facility (SHMFF) was founded by the National Development and Reform Commission of China (NDRC) in 2008;

- The Project is undertaken by the High Magnetic Field Laboratory, Chinese Academy of Sciences (CHMFL).

Where is CHMFL ?

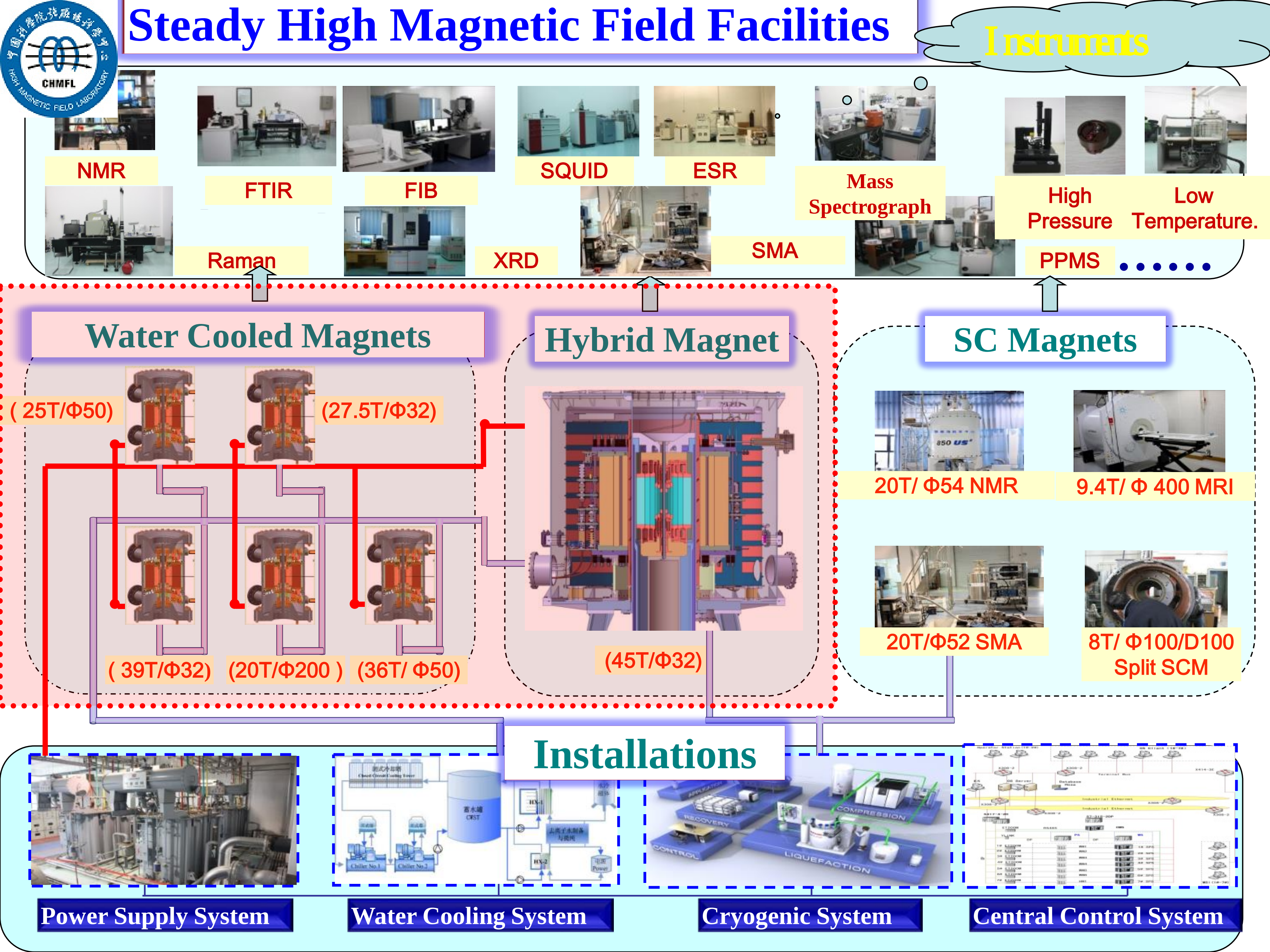
Science Island *Anhui Province* *P. R. China*



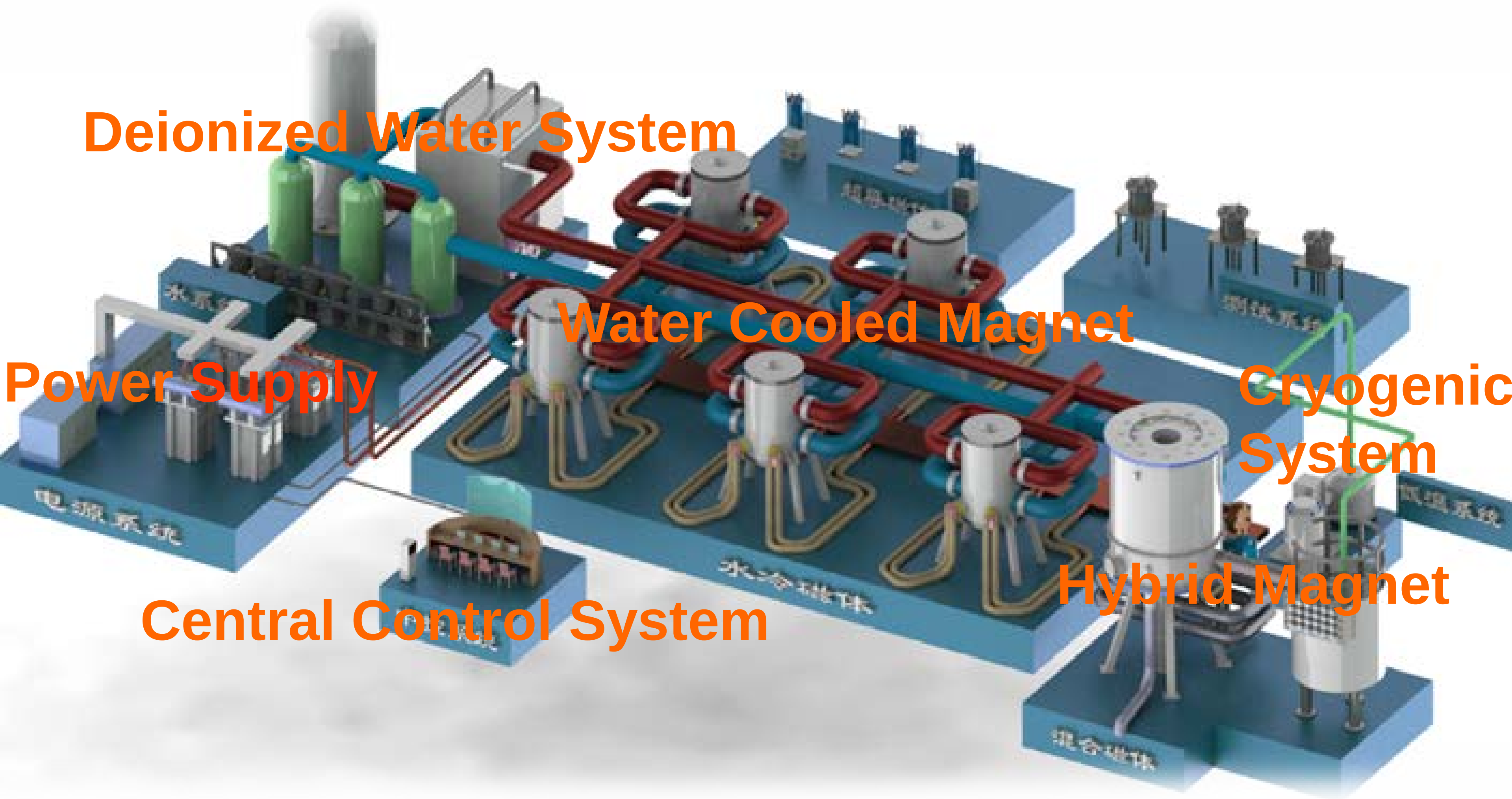
Science Island ---- a very beautiful peninsula!

Area: 2.6 km^2

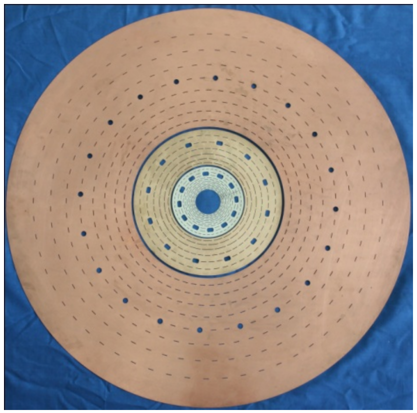
Steady High Magnetic Field Facilities

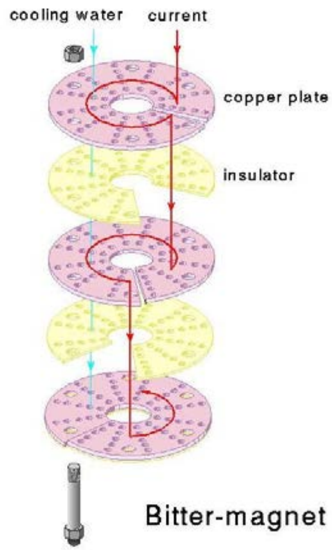


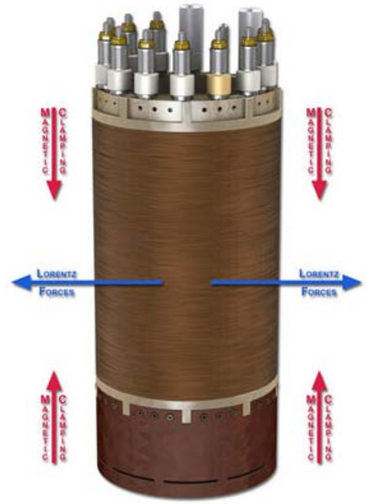
- **Layout of Magnet Hall**

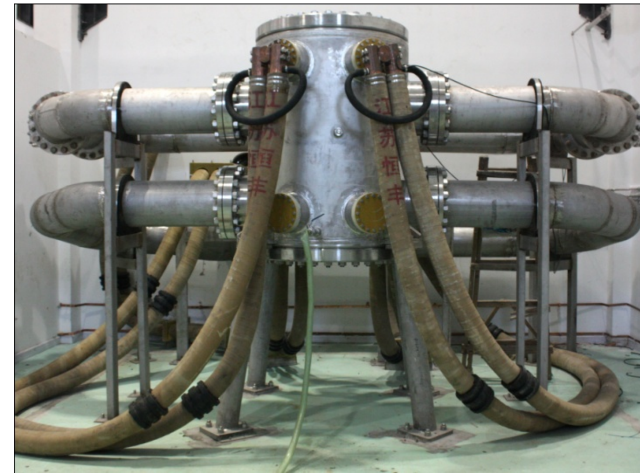


- **Water Cooled Magnets at CHMFL**





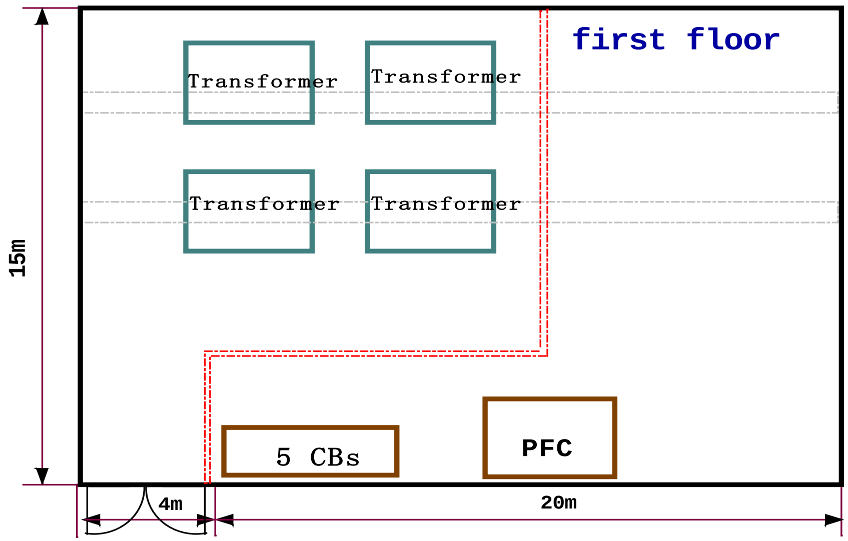


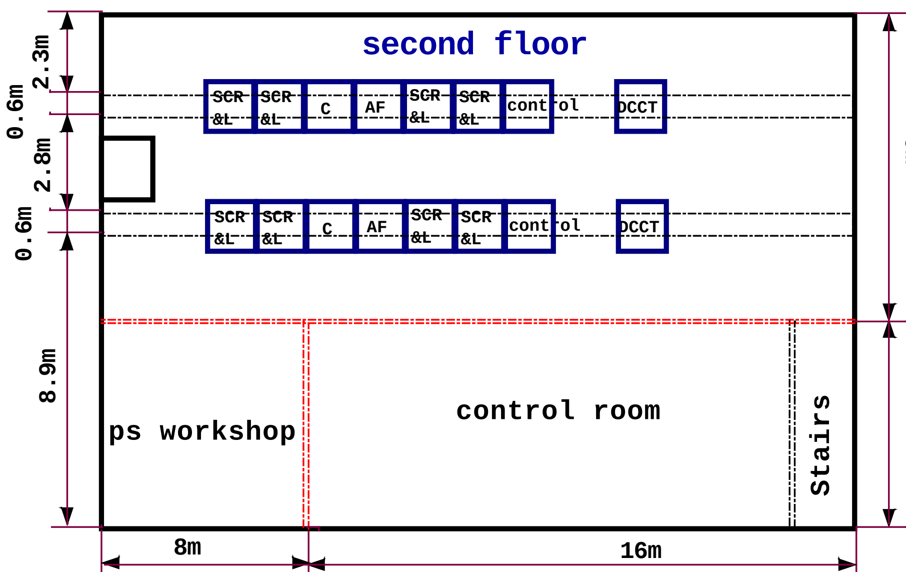


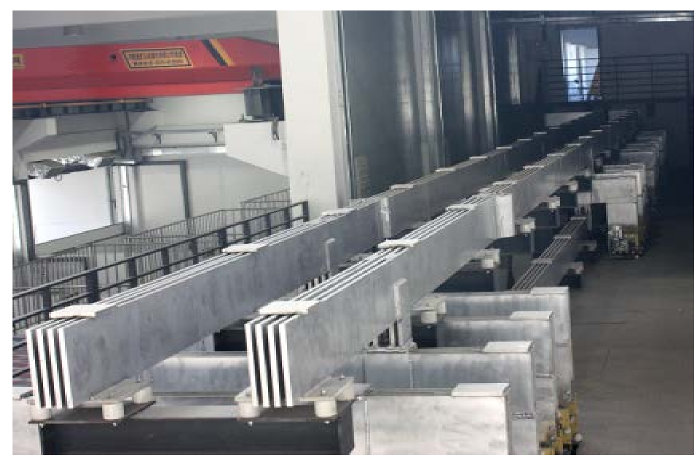
	Magnets	Magnet Field, T	Bore, mm	Power, MW	Current Status
Resistive Magnets	WM1	**38.5***	32	25.2	Open for users
	WM2	25	50	15	Open for users
	WM3	19.55	200	20	Open for users
	WM4	**27.5***	32	10	Open for users
	WM5	**35***	50	24	Open for users

*New Record

A. power supply modules Installations



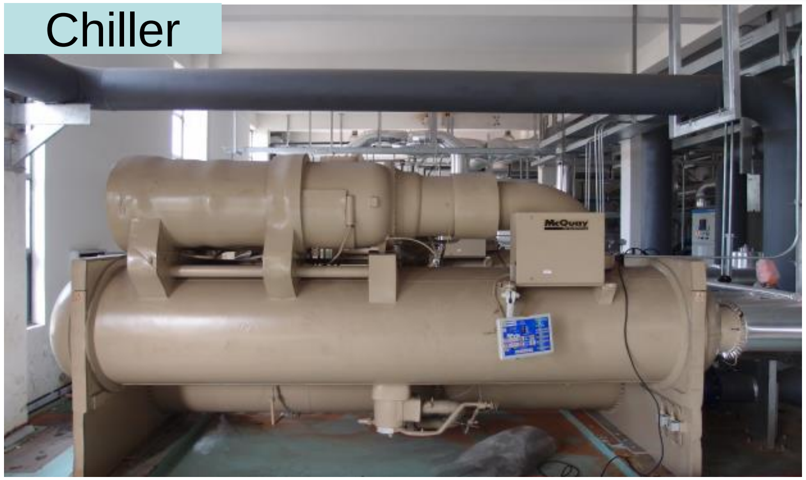




B、Water cooling system

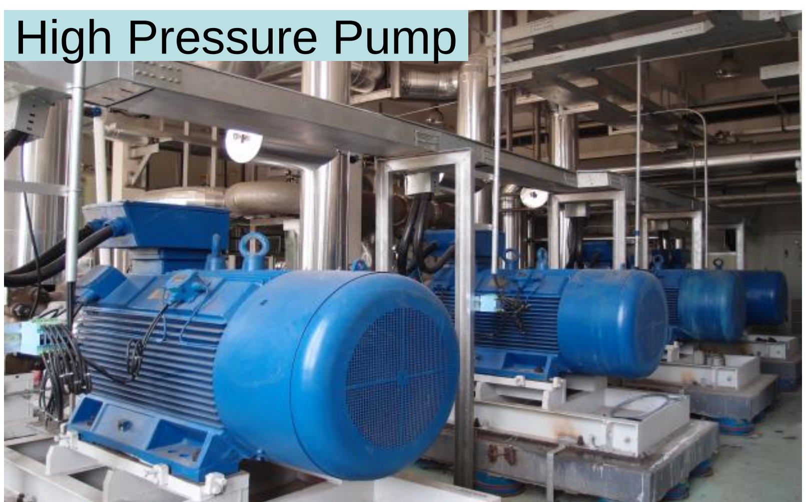
Main Equipment

Chiller



Cooling Tower

High Pressure Pump



Storage Tank

C. Helium Cryogenic System

Helium Refrigerator

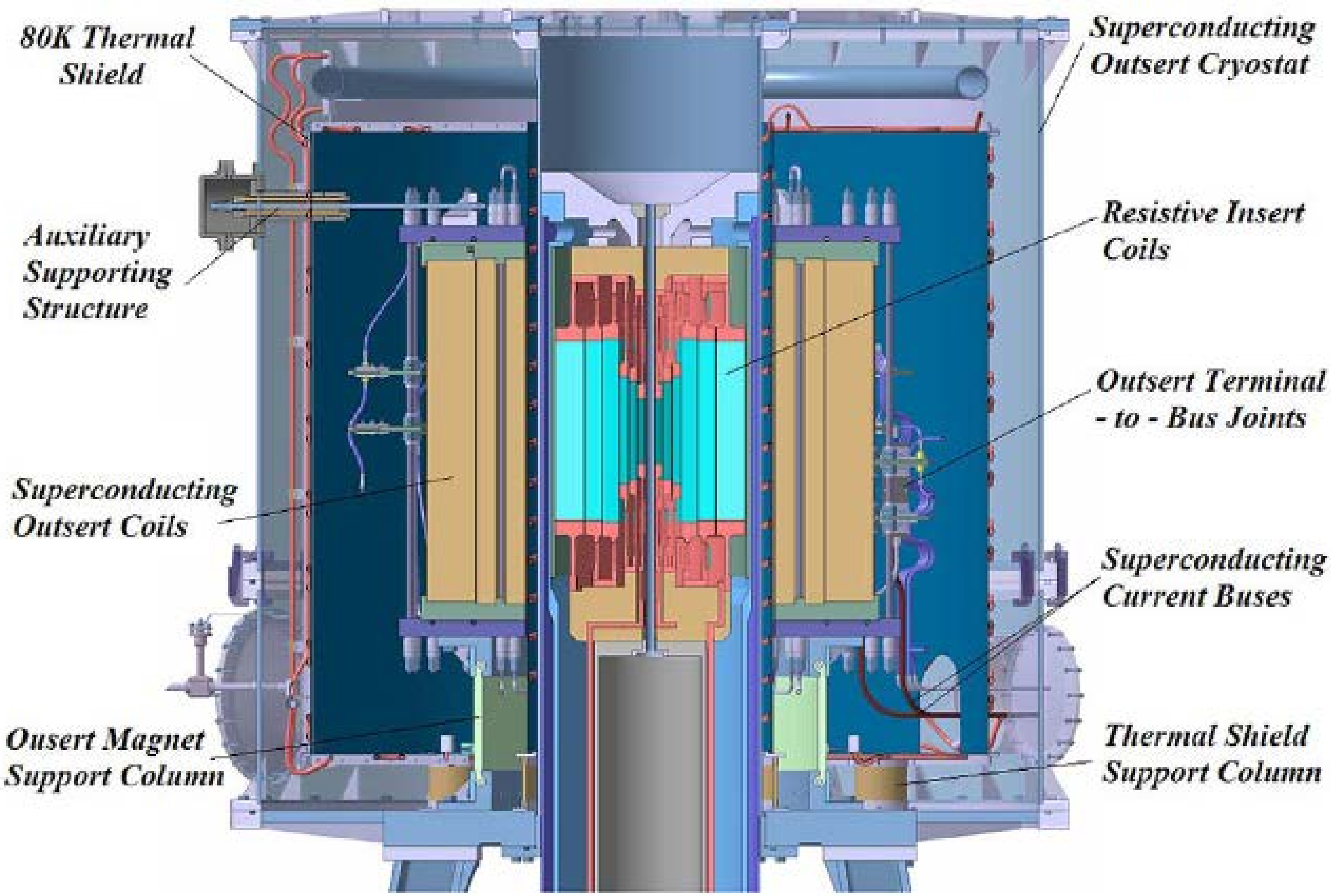
Storage Tanks

Gas Bag

LHe Dewar

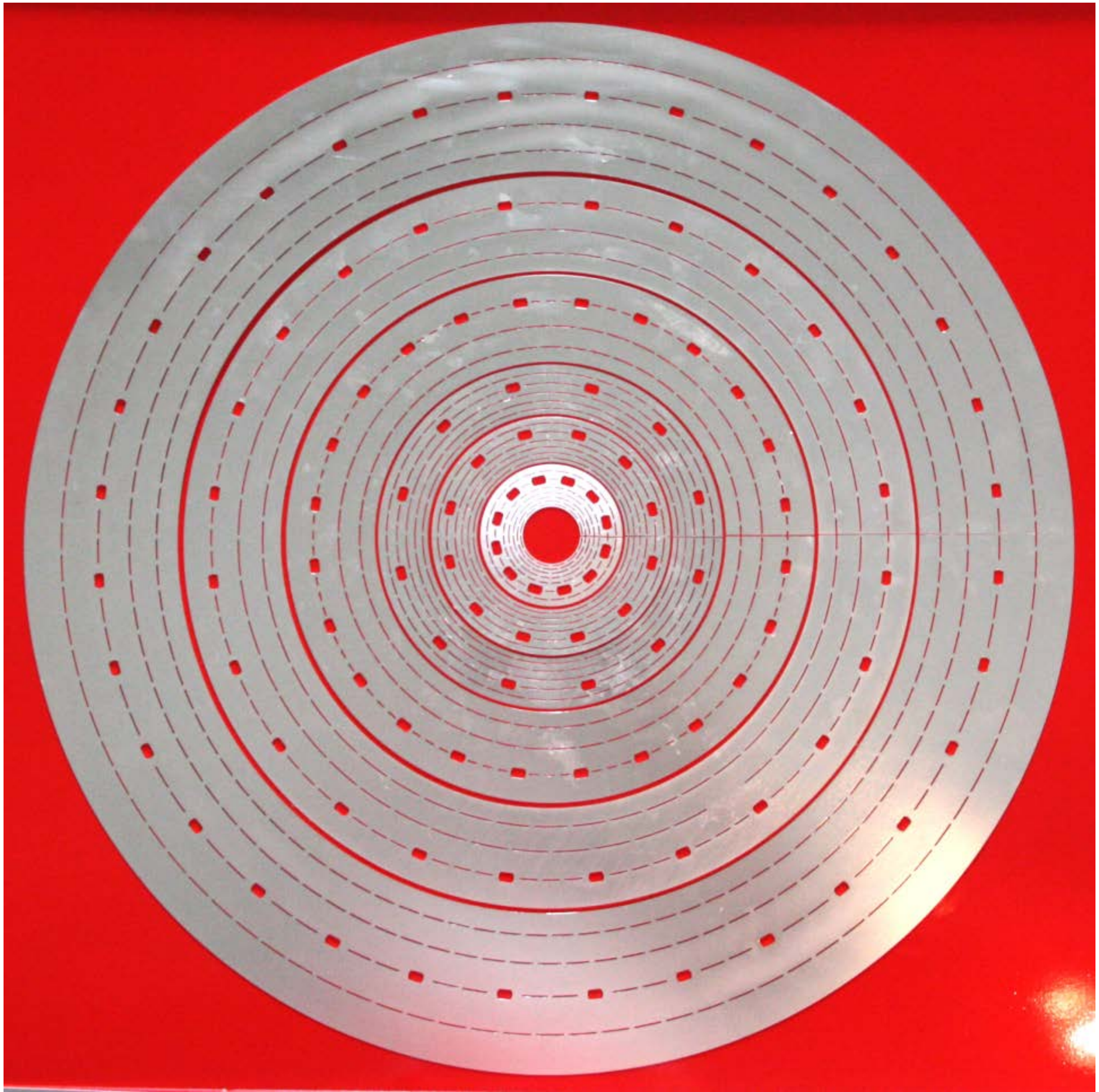
Compressor

2. A Hybrid Manget at CHMFL



A hybrid magnet has been designed, manufactured, assembled and tested at CHMFL, it consists of a superconducting outsert and a water-cooled insert.

- **Water Cooled Insert of Hybrid Magnet**



Bitter Disks

Six Coils

Inner diameter

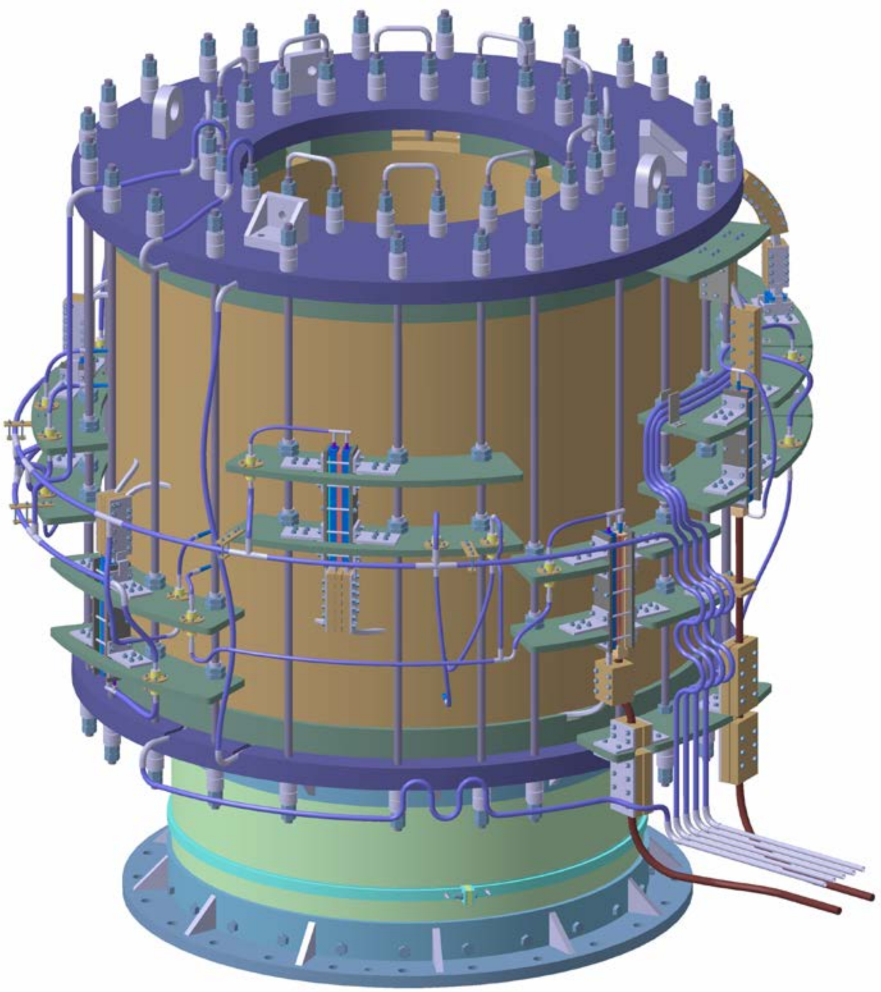
38 mm

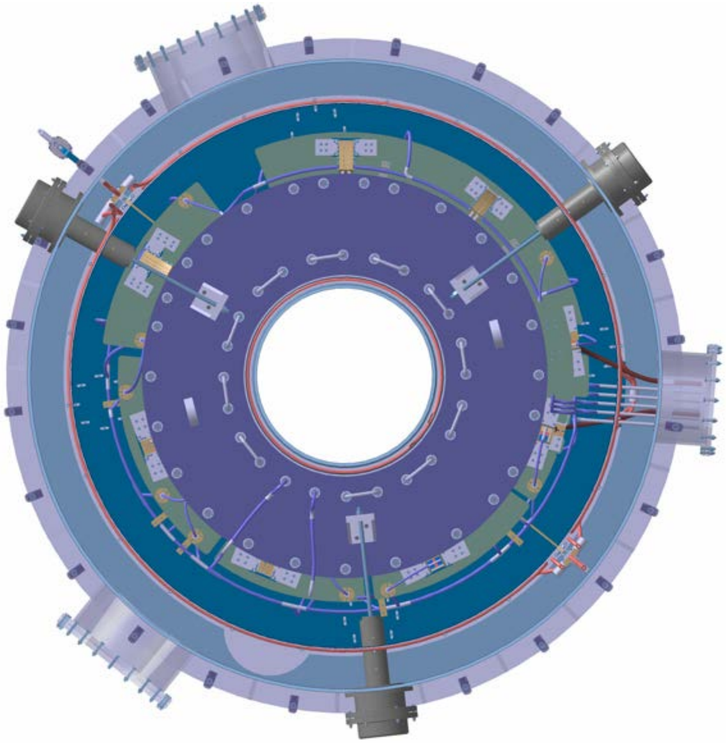
Outer diameter

710 mm

- **Coils A,B,C,D,E,F of insert of hybrid magnet**

- **Superconducting Outsert of Hybrid Magnet**





CICC Three Coils

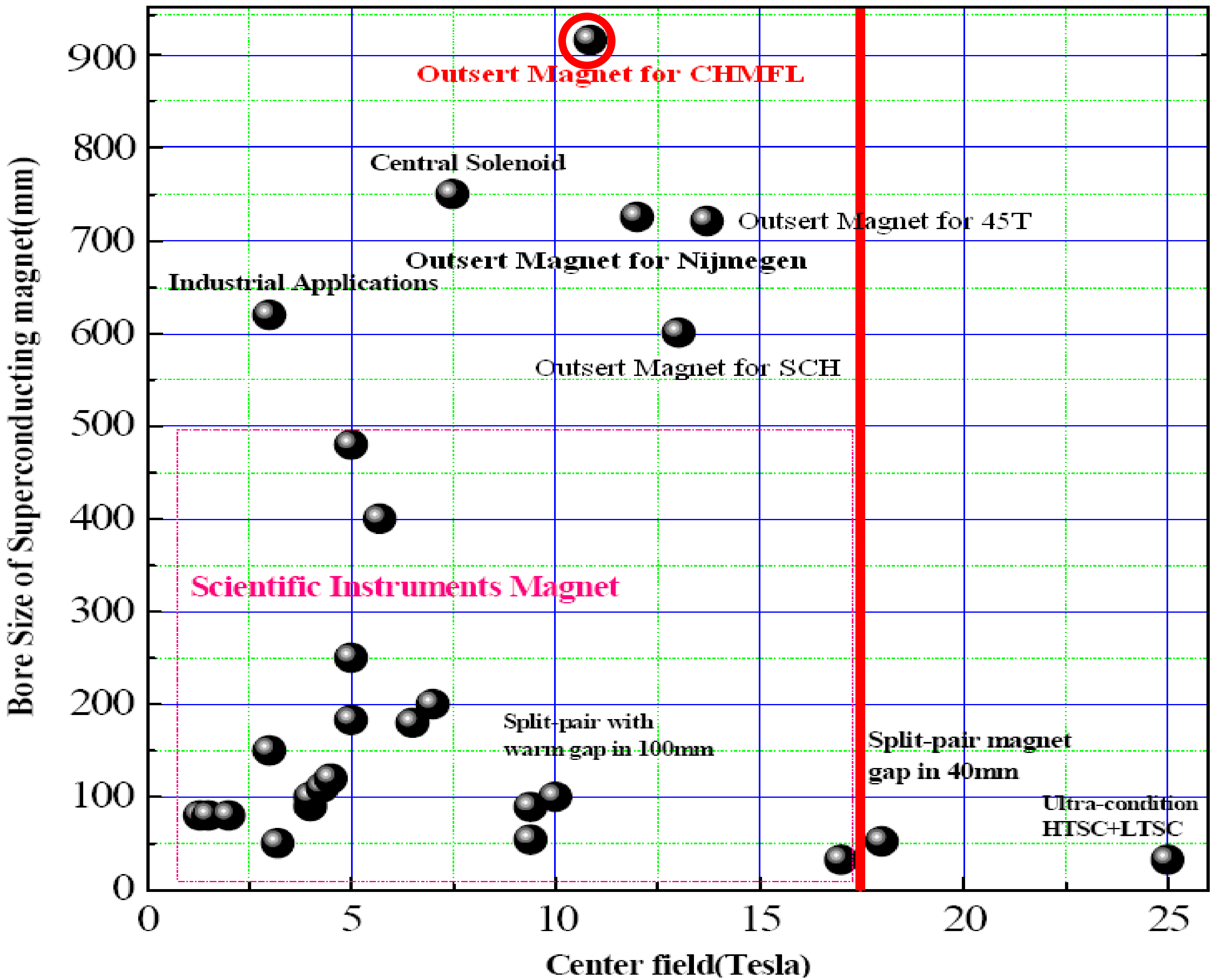
Inner diameter 920 mm

Outer diameter 1297 mm

• Parameters of Superconducting Outsert

	Coil A		Coil B	Coil C
	Grade I	Grade II		
Type of winding	layer	layer	layer	pancake
Conductor type	Nb_3Sn CICC using "insulate-wind-and-react" route			
Conduit material	modified 316 LN			
Strands configuration	(2SC+1Cu)×4×4×5	((2SC+1Cu)×3 + (1SC+2Cu))×3×5	(1SC+2Cu))×3×4×5	((1SC+2Cu)×3 +3Cu)×3×4
CICC size (mm×mm)	22.0×15.0	20.2×13.4	20.2×13.4	15.0×14.4
Conduit thickness (mm)	2.2	2.2	2.2	2.0
Void fraction of conductor (%)	~ 30	~ 30	~ 30	~ 30
Compressive peak load [a], (MPa)	10.20	10.13	8.87	10.30
Number of turns	104 (2 layer × 52 turns/layer)	114 (2 layer × 57 turns/layer)	228 (4 layer × 57 turns/layer)	720 (72 pancake × 10 turns/pancake)
Inner diameter of winding (mm)	930.0	998.0	1147.6	1296.8
Outer diameter of windings (mm)	996.0	1057.6	1268.8	1604.8
Height of windings (mm)	1196.0	1208.4	1208.4	1223.0
Turn insulation (mm)	0.5	0.5	0.5	0.5
Layer/pancake insulation (mm)	1.0	1.0	1.0	1.0
Nominal current (A)	14100 [b] (13410) [c]			
Operation temperature (K)	4.5			
Maximum field at the windings (T) [b]	12.732	11.353	10.051	7.745
Temperature margin w/o degradation (K) [b]	2.15	2.58	2.30	3.64
Temperature margin with 15 % degradation (K) [b]	1.91	2.30	1.90	3.22
Total length of the superconducting wire (km)	66.7	51.2	68.8	156.6
Field contribution at center (individual coils) (T)	1.20 [b] (1.14) [c]	1.27 [b] (1.21) [c]	2.37 [b] (2.25) [c]	6.73 [b] (6.40) [c]
Field contribution at center (combined coils) (T)	11.566 [b] (11.0) [c]			
Combined inductance (H)	1.02975			
Combined stored energy (MJ)	102.362 [b] (92.589) [c]			

- **Large Cold Bore with 920 mm of Outsert**

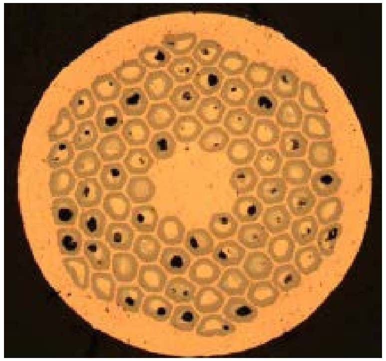


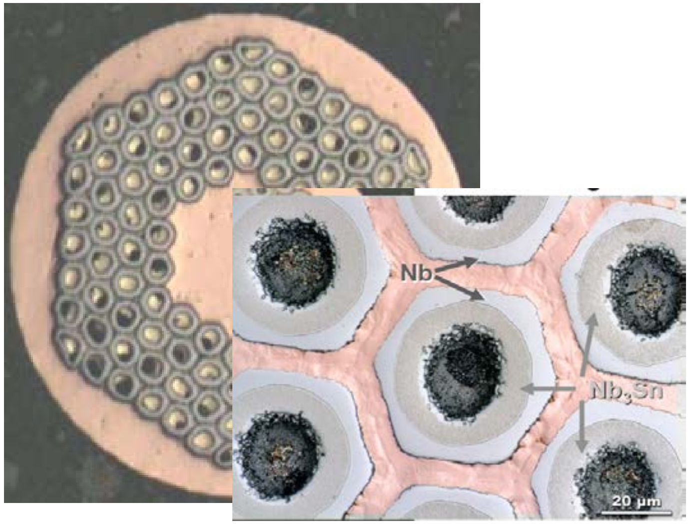
• Fabrication Process of Superconducting Outsert

• Superconducting Strands for the Outsert

Stand parameters

Wire diameter (mm)	Ø0.81±0.005
Bare wire diameter (mm)	0.806
Cr plated (μm)	1-2
Cu/non-copper	1.0±0.1
d_{eff}（μm）	≤80
Critical current, Ic (A)（4.2K,12T,0.1μV/cm）	≥540A (non-Cu Jc≥2100A/mm^2)
RRR	≥ 100
n value	≥20
Twist pitch (mm)	15 ± 3
Hysteresis loss (7T-0-7T cycle) (kJ/m^3)	≤1600



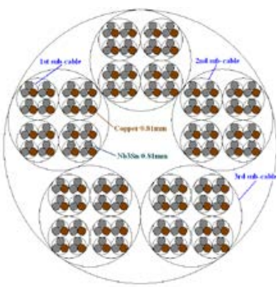


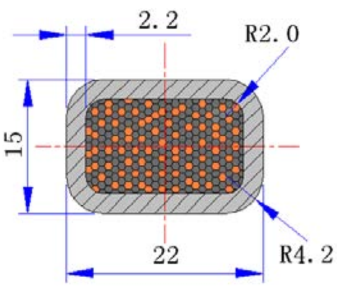
To achieve the central field requirements and keep the overall magnet size compact, Nb3Sn strands must have the critical current density Jc above 2100 A/mm2 at 12 T and 4.2 K. We selected a Ti-doped restacked-rod process (RRP) Nb_3Sn wire made by Oxford Instruments Supercond. Tech. (OST).

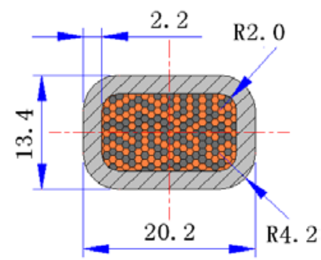
- # CICC Design for the Outsert

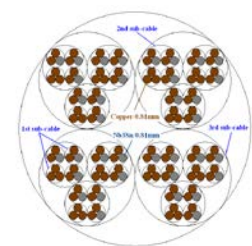
MAIN PARAMETERS OF THE CICCS

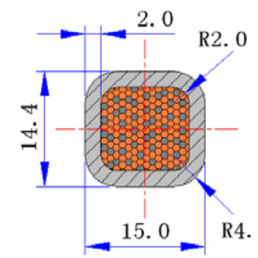
	CICC A_{I}	CICC A_{II}	CICC B	CICC C
Cable pattern	(2Sc+1Cu)x4x4x5	$\left.\begin{matrix}(2Sc+1Cu)\times 3\\(1Sc+2Cu)\times 1\end{matrix}\right\}\times 3\times 5$	(1Sc+2Cu)x3x4x5	$\left.\begin{matrix}(1Sc+2Cu)\times 3\\(3Cu)\times 1\end{matrix}\right\}\times 3\times 4$
N of superconducting strands	160	105	60	36
N of copper strands	80	75	120	108
Twist pitch (mm)	82/133/187/232	82/133/170/205	82/133/170/205	82/133/170/205
CICC dimensions(mm)	22.0x15.0	20.2 x13.4	20.2 x13.4	15.0 x14.4
Jacket material	316LN	316LN	316LN	316LN
Jacket wall thickness（mm）	2.2	2.2	2.2	2.0
Void fraction (%)	~30	~30	~30	~30

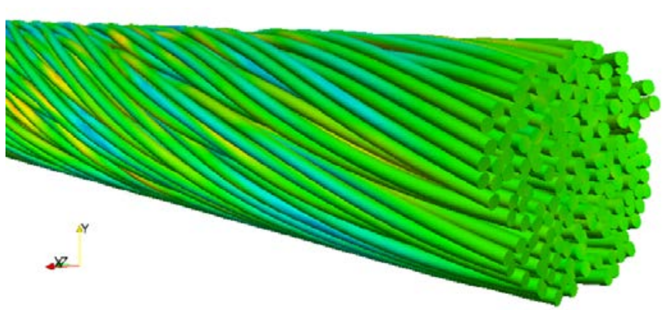


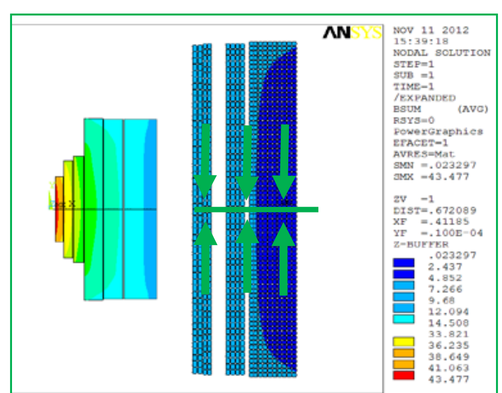


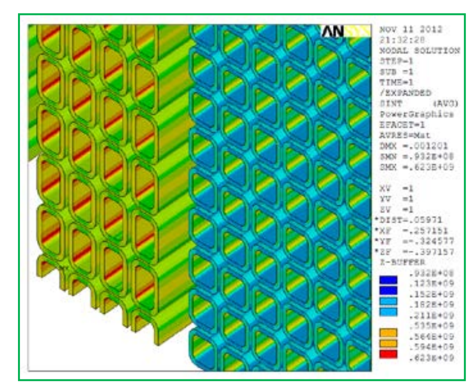






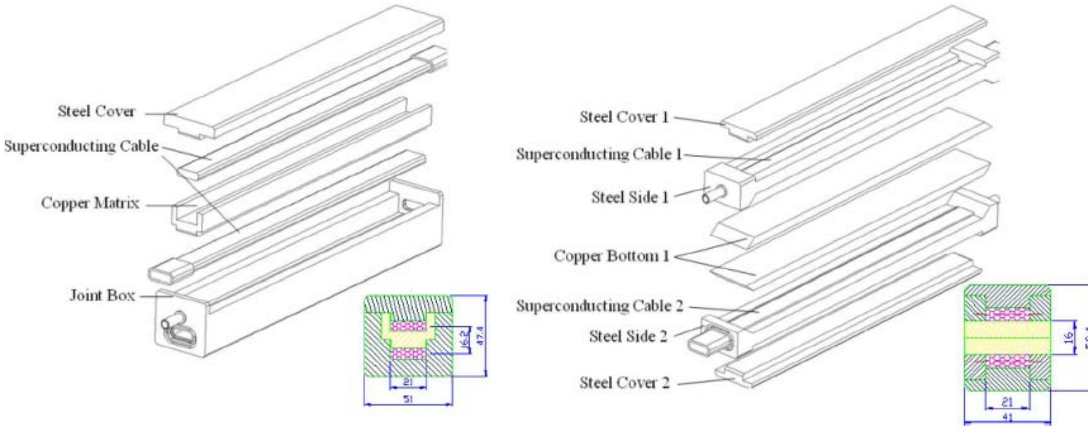




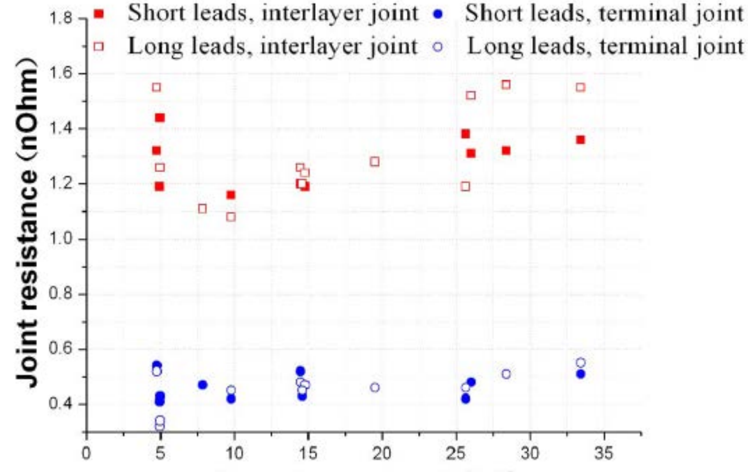


• **CICC Fabrication for the Outsert**

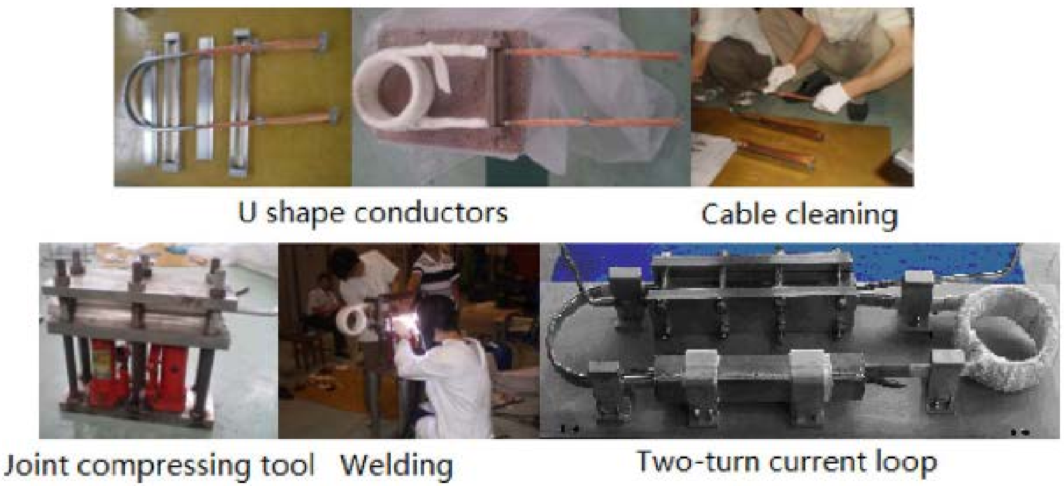
• Joint Design for the Outsert



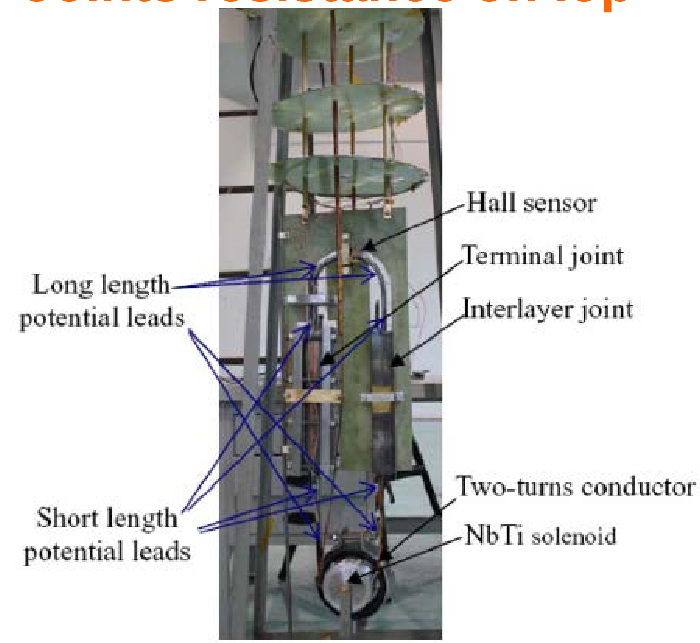
Schematic design of joints



Joints resistance on Iop

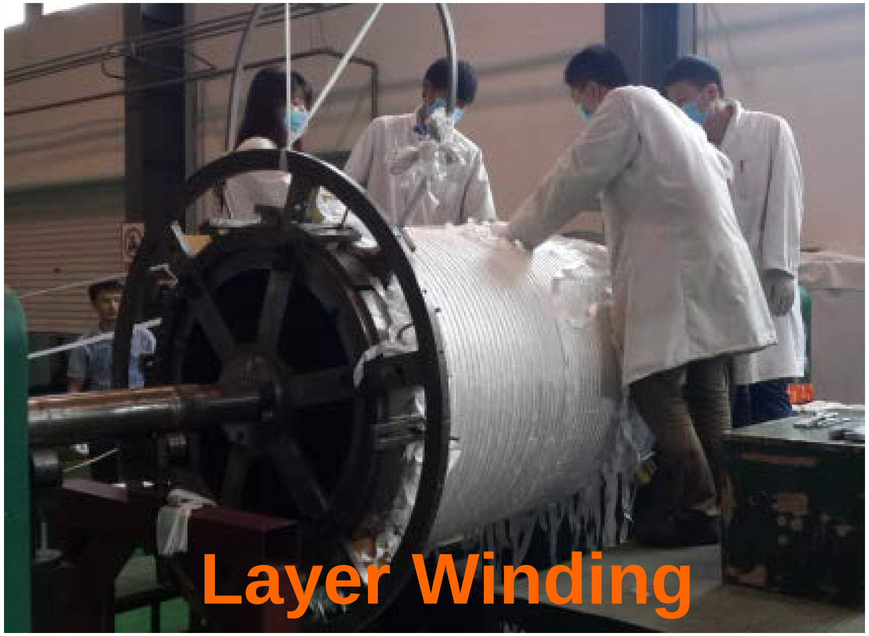


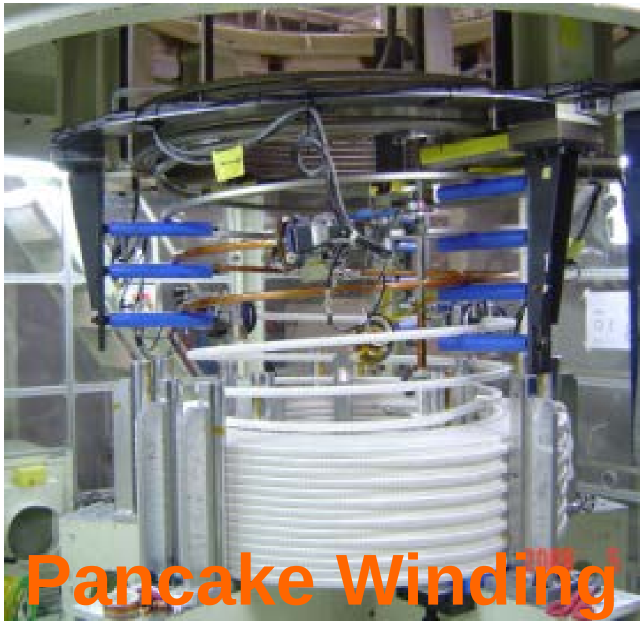
R & D of joints

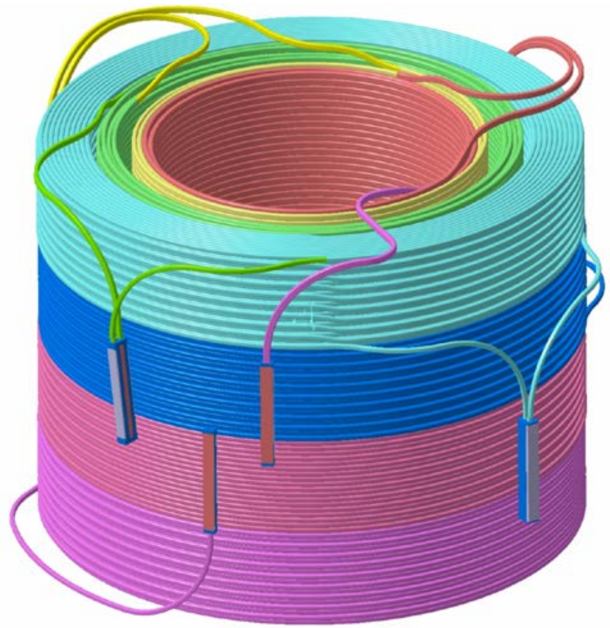


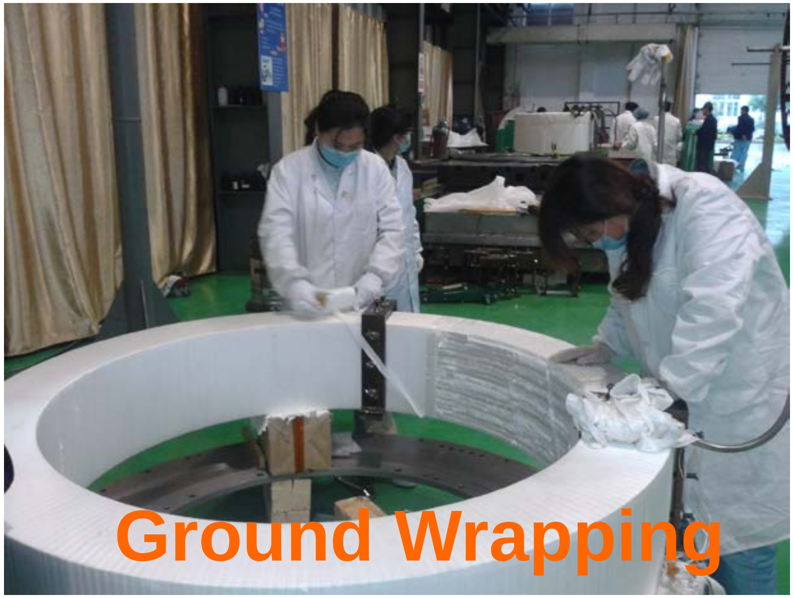
Joints resistance test system

- **Winding Process for the Outsert**





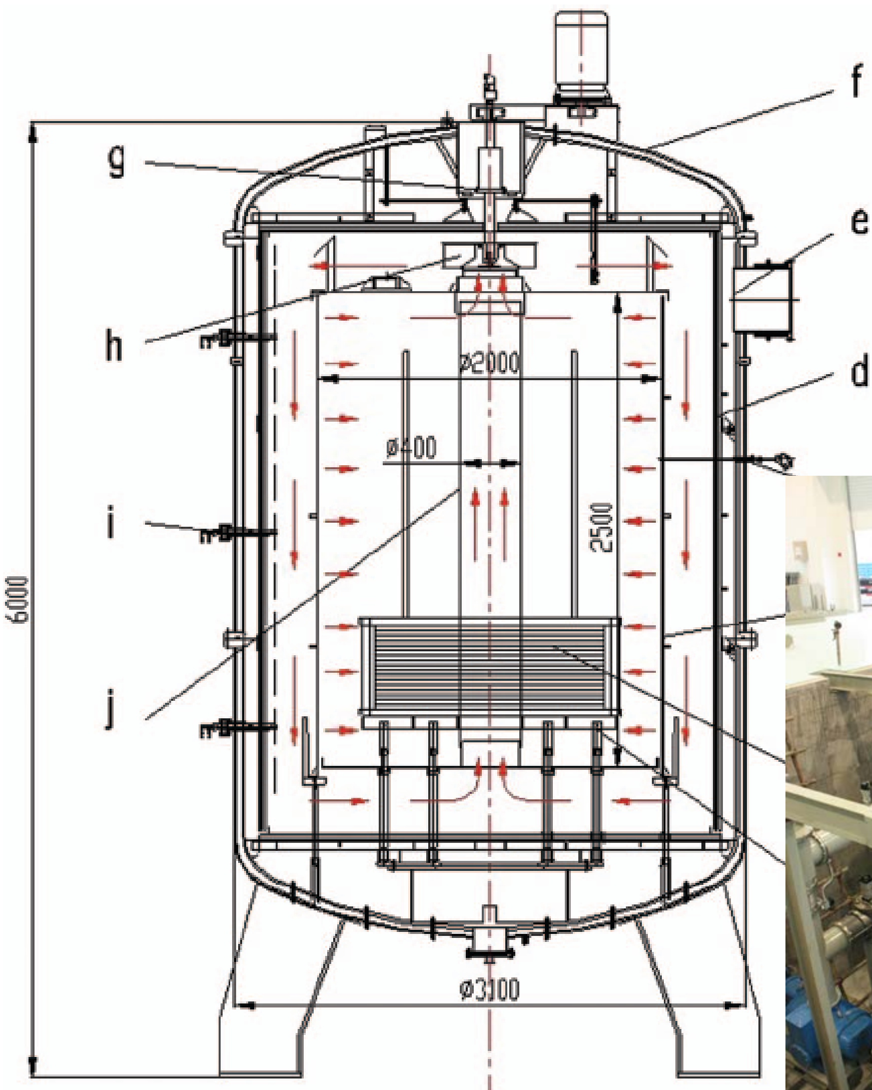




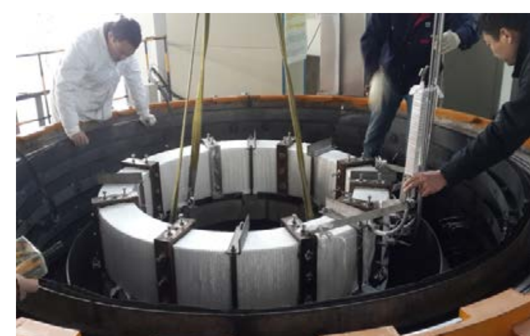
• Heat Treatment for the Outsert

TABLE I. Specifications of the heat treatment furnace.

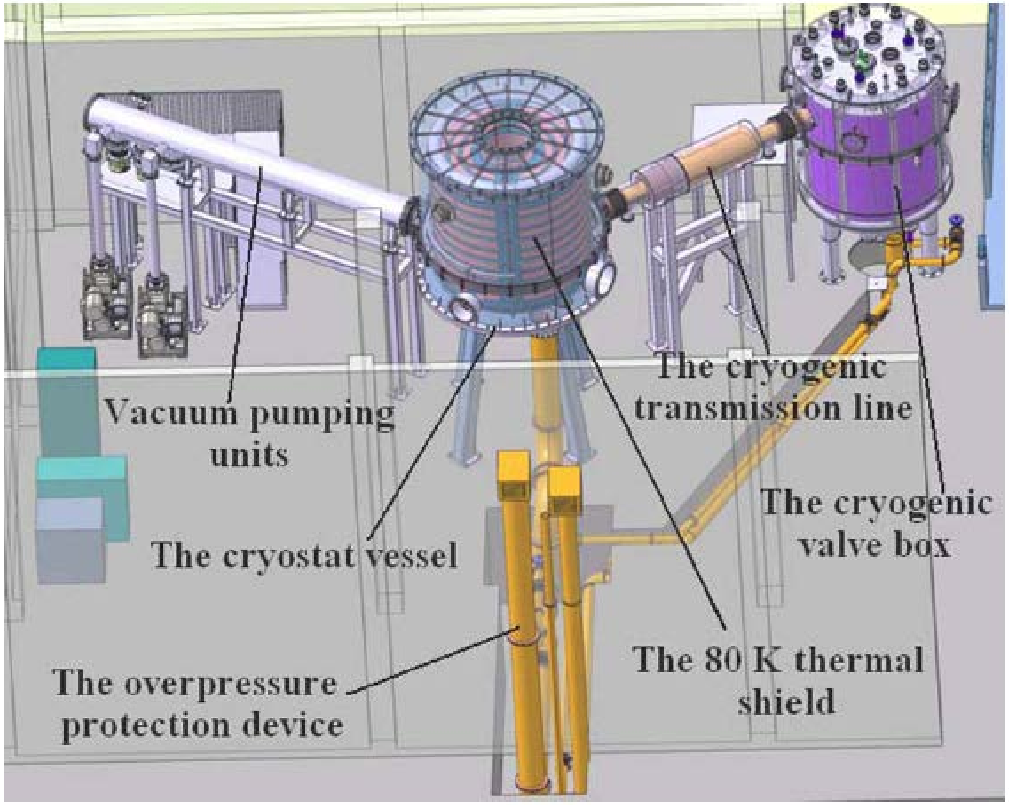
Items	Value
The max. temperature	900 °C
Temperature uniformity	≤ ± 5 °C (200 °C– 650 °C)
Max. size of the oven	Ø2000 mm × 2500 mm
Temperature ramping rate	5 °C – 30 °C /hr
Precision of controlling temperature	≤ ± 1 °C
The ultimate vacuum	∼5 × 10^{-7} torr
The achievable working vacuum	1 × 10^{-6} torr
The leak rate	<1 × 10^{-6} mbar/s
The continuous working time	>200 hr



Scheme of the furnace

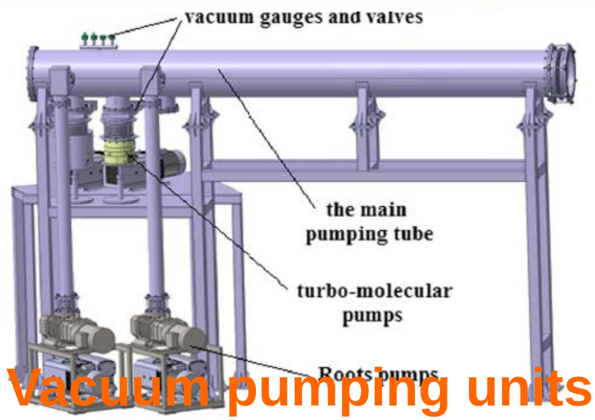


• Cryostat components for the Outsert

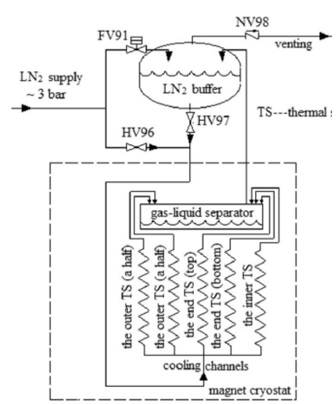


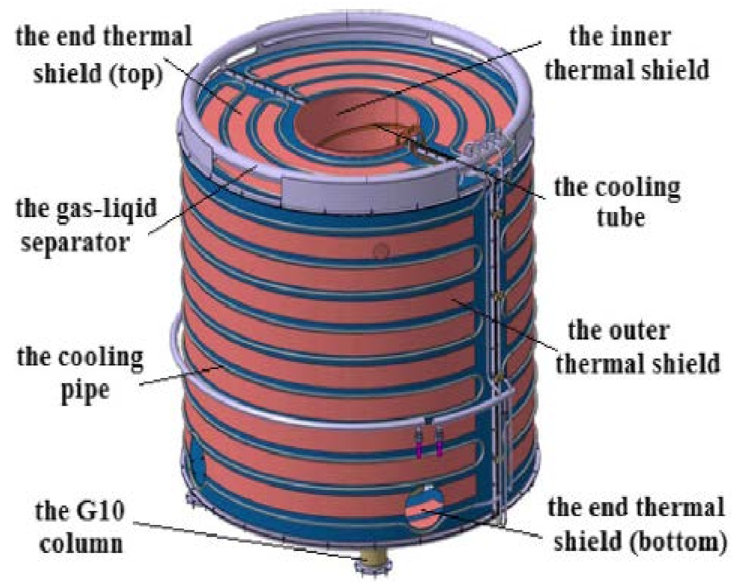
CRYOSTAT VESSEL PARAMETERS

Cryostat vessel outside diameter, mm	2890
Cryostat vessel inside diameter, mm	800
Total height of the cryostat vessel, m	6.0
Vertical height of the support leg, m	2.93
Main cylindrical section thickness, mm	15
Design base pressure, Pa	5×10^{-4}
Material of construction	304L
Required leak rate of completed cryostat vessel, Pa• m^3/s	1×10^{-6}
Interior surface area , m^2	45
Interior free volume, m^3	16
Total mass of the cryostat vessel, ton	15



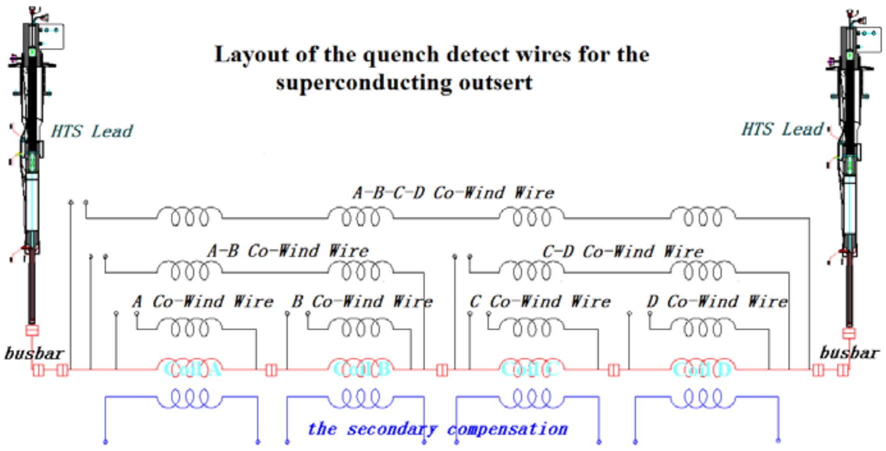
Vacuum pumping units





80 K thermal shield

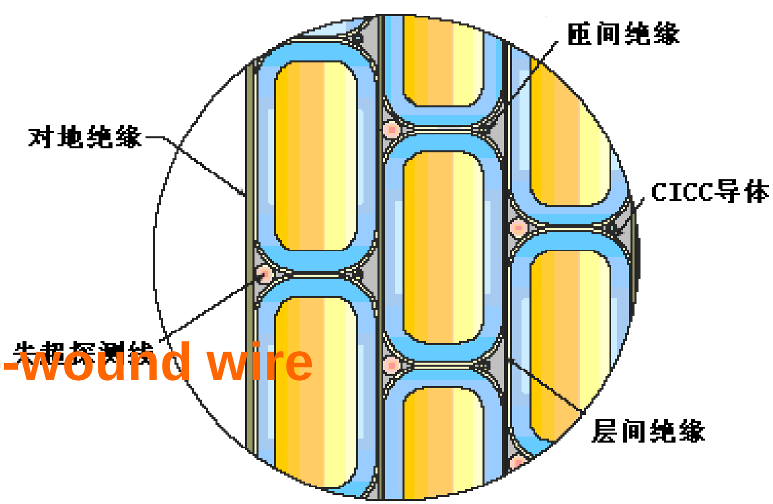
• Quench Detection and Protection for the Outsert



Layout of quench detection circuit

Main parameters of quench detection:

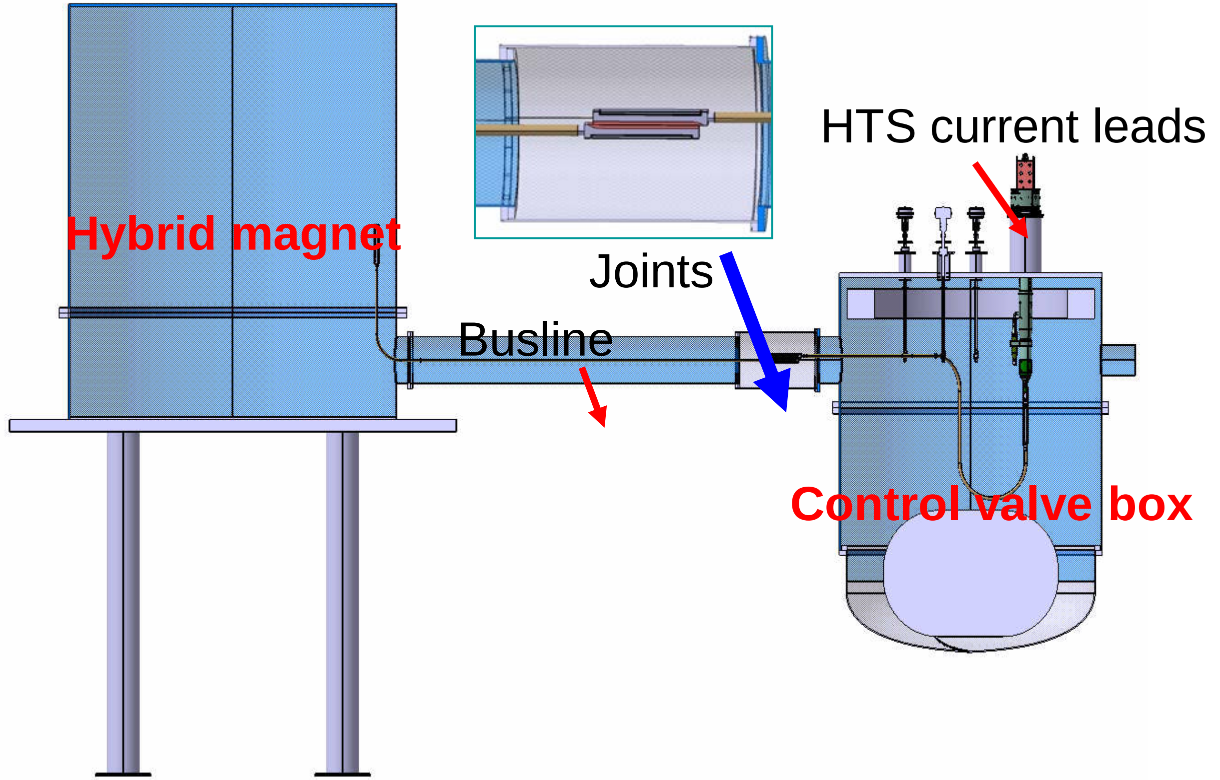
- Operating current, Iop (kA) 13.41
- Inductance, L(H) 1.02975
- Stored energy, E(MJ) 92.589
- Dump resistance, R_D (Ω) 0.272
- Discharge time constant, τ_d (s) 3.788
- Voltage threshold (mV) 40~50
- Delay time, t_d (s) < 0.7
- Switch action time, t_s (s) < 0.1
- Max. terminal voltage (kV) < 4
- Hot spot temperature (K) <150



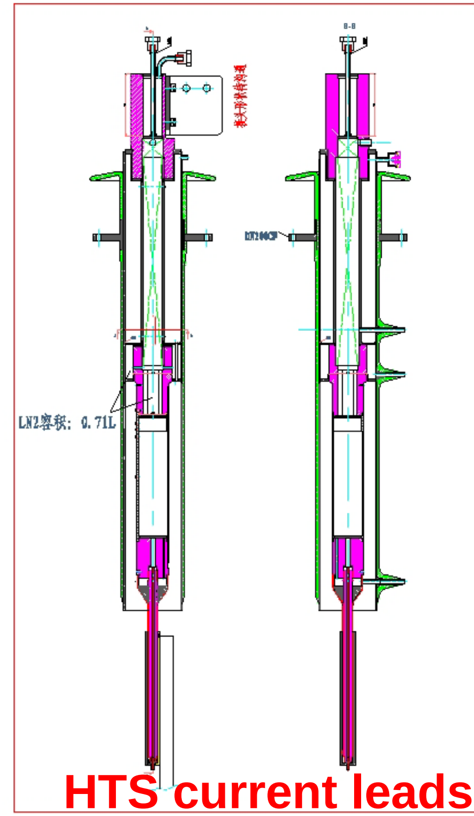
Scheme of conductor cross-section

Four pieces of co-wound wire were installed on the four outer corners of the CICC, the co-wound can compensate the inductive signals, and be used for quench signal detection.

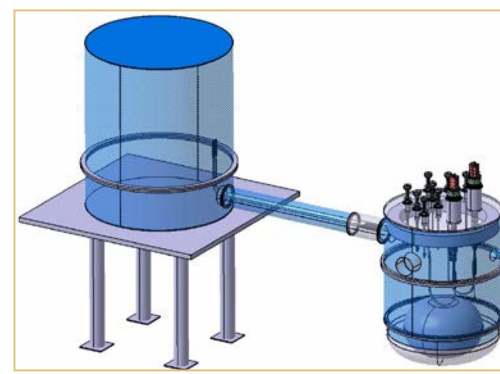
• HTS Current leads for the Outsert



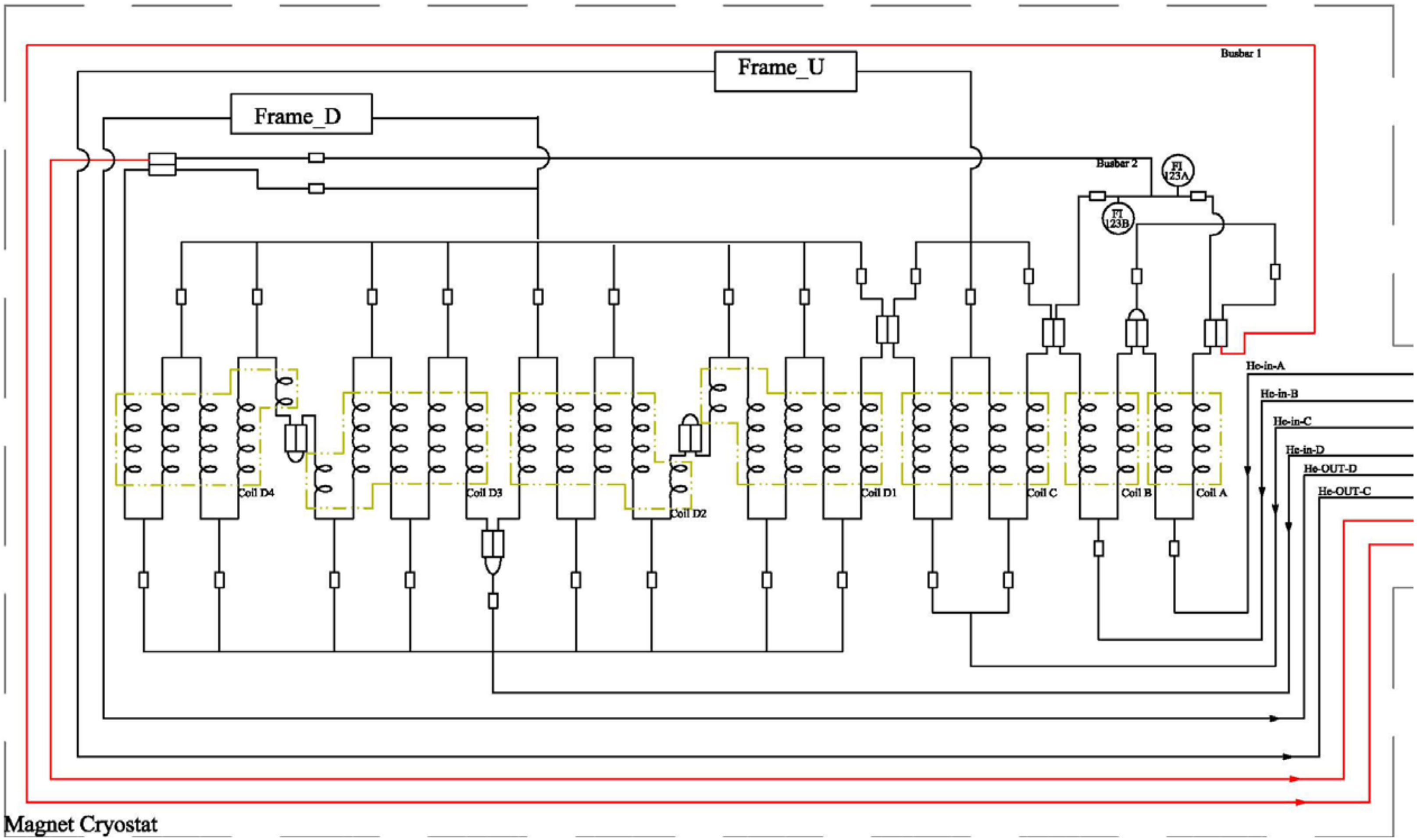
The diagram of HTS current leads and busline



A pair of 16 kA HTS current leads were used to decrease the thermal load of cryogenic system.



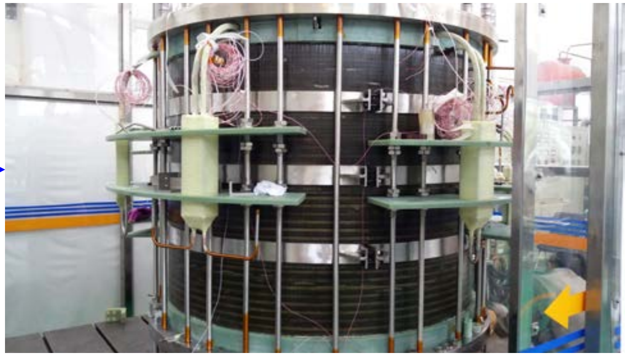
- **Cooling Scheme for the Outsert**



The outsert has 8 layers in total 72 pancakes in coil C. An independent hydraulic channel is assigned to each group of six double pancakes. A set of four valves at the inlet distributes the total mass flow of 18 g/s, and controls the mass flows through each cooling channel.

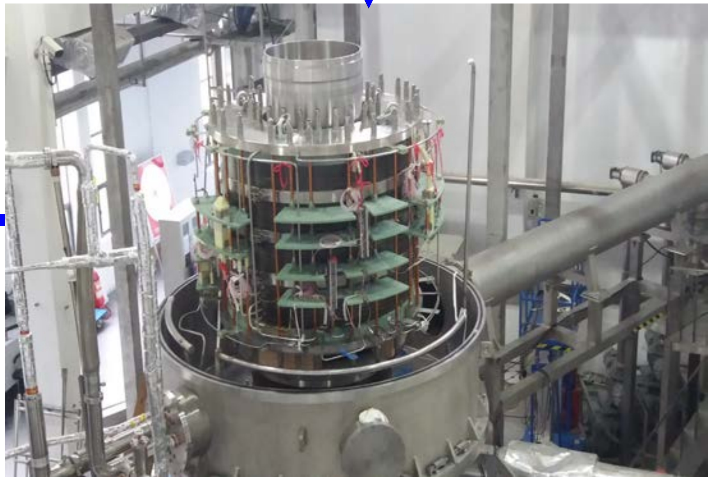
- # Final Assembling of the Outsert

Subcoil



Superconducting coils

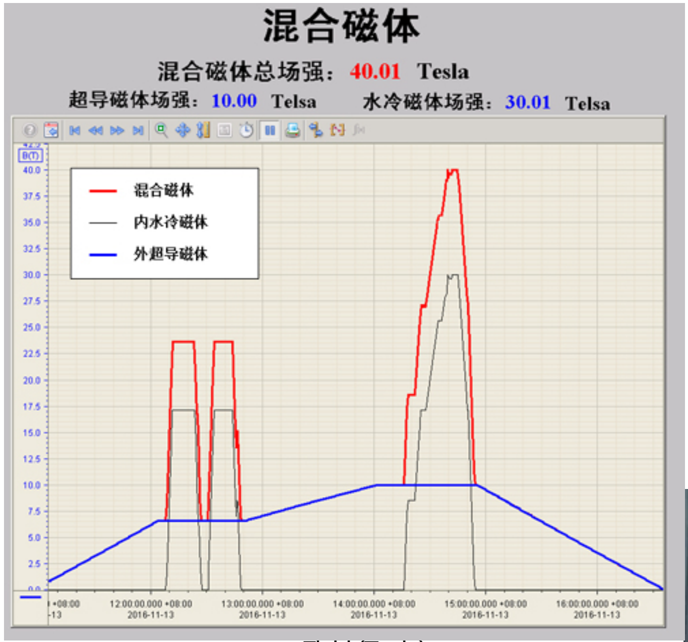
Lifting assemly



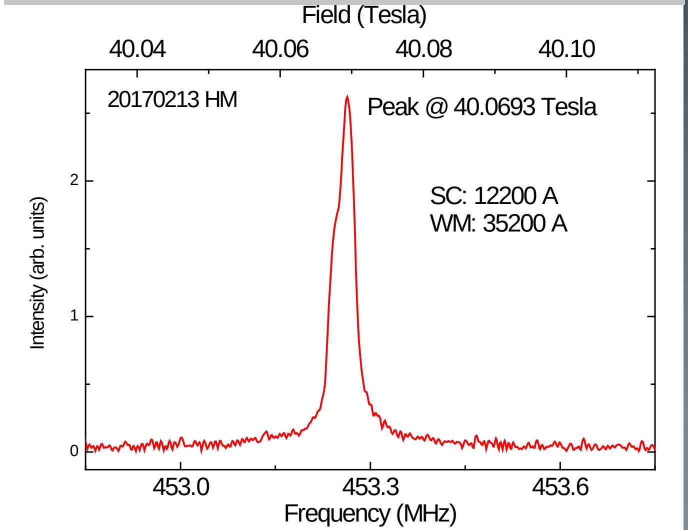
Coils installed in place

Hybrid magnet system

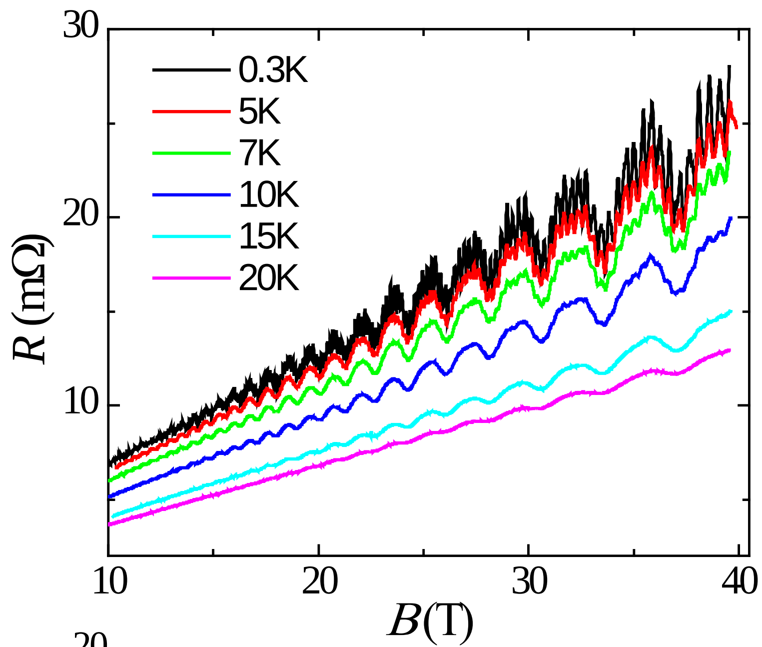
• Commissioning of the Hybrid Magnet



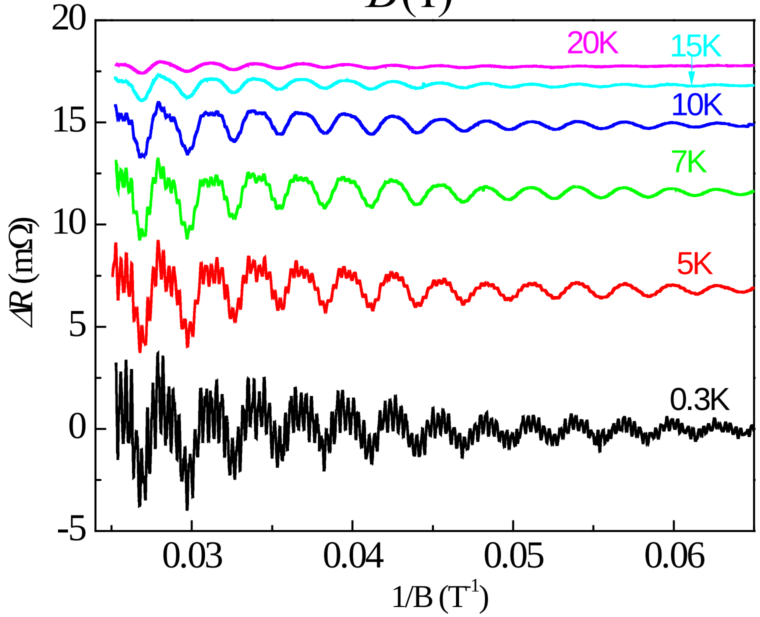
The first successful performance of the hybrid magnet produced 40T on Nov. 13, 2016, since that day, a series of scientific experiments have been carried out on the hybrid magnet system.

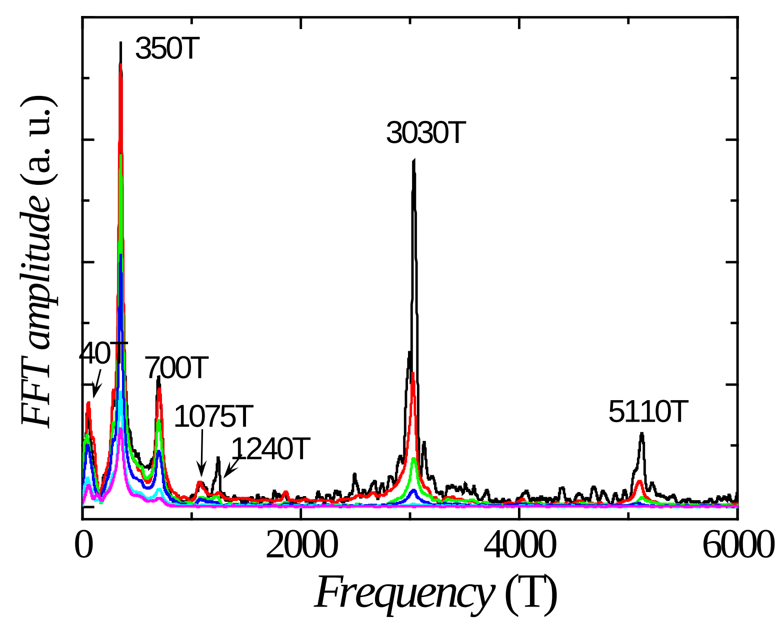


- # Research on the hybrid magnet



- **Layered trigonal $PtBi_2$ single crystal**
- **Extremely large linear magnetoresistance (LMR)**
- **Pronounced SdH oscillations**





3. Summary and Prospective

- A 10 T superconducting magnet with 800 mm large bore has been successfully developed at CHMFL.

- A 40 T hybrid magnet combined with a superconducting outsert and a resistive insert have been operated at CHMFL.

- A series of researches have been carried out on the hybrid magnet.

- The hybrid magnet has the potential to produce more than 45T central field after a maintenance of the resistive insert in the near future.

Thank you
for your attention