中国科学院高能物理研究所
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Superconducting Magnet Group, IHEP

Fabrication of the new coils and assembly of LPF3-U

Superconducting Magnet Group, Accelerator Division
Institute of High Energy Physics, Chinese Academy of Sciences (IHEP, CAS)

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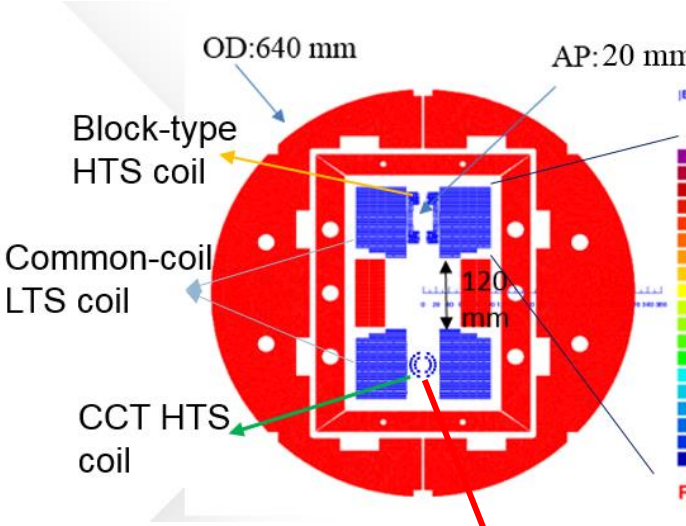
Outline

- A brief review of the fabrication of LPF3 magnet
- Design of LPF3-U magnet
- Recent progress of the new coils fabrication and assembly of LPF3-U

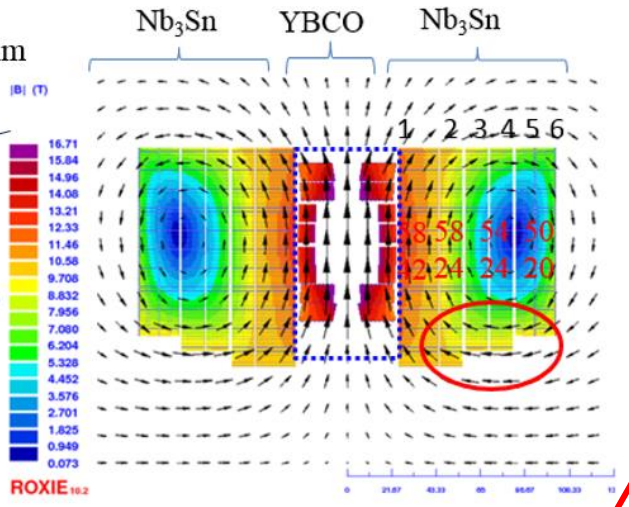
Development of LPF3 magnet

- Aiming at 16 T： 13 T (LTS) + 3 T (HTS)

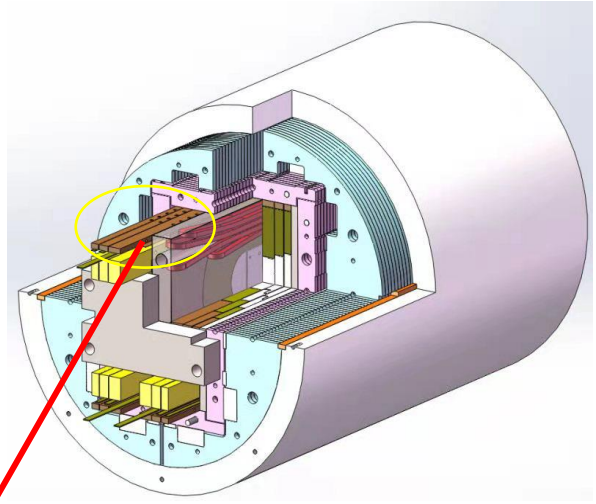
To be 16 T



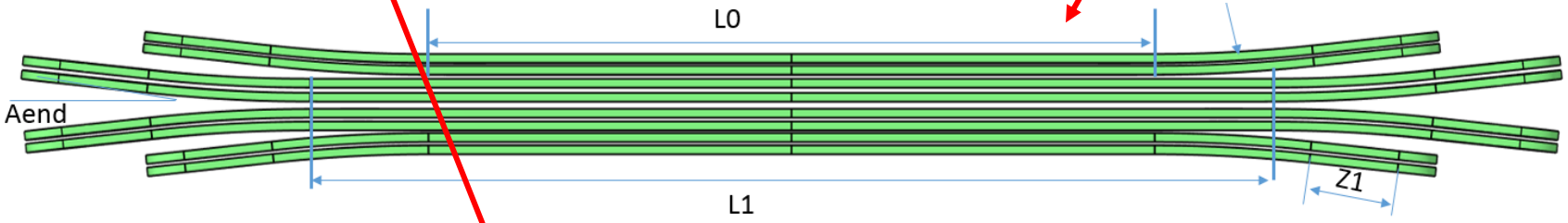
Cross-section of LPF3



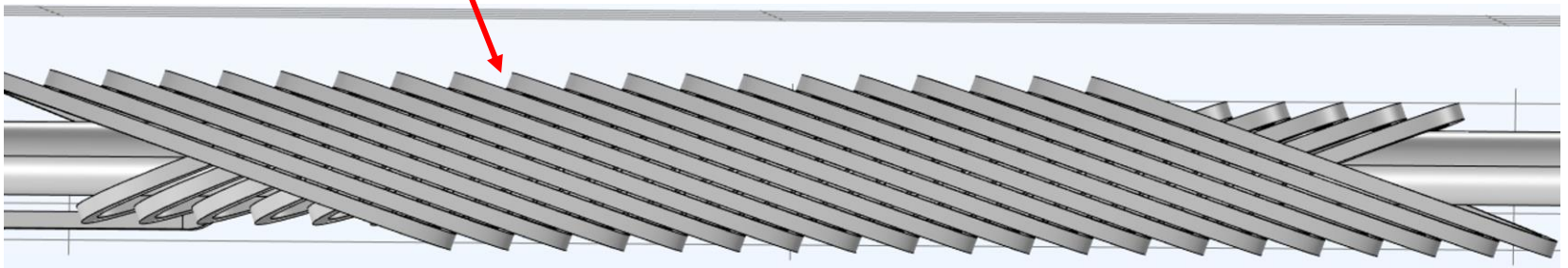
Field and flux distribution (1st and 2nd quadrant)



Schematic of LPF3



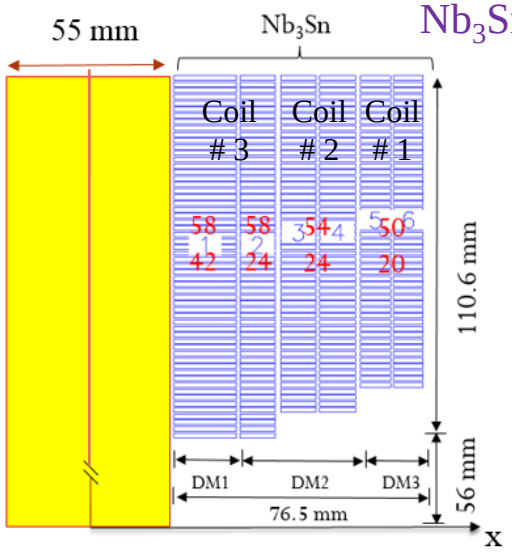
ReBCO Block-type insert coil



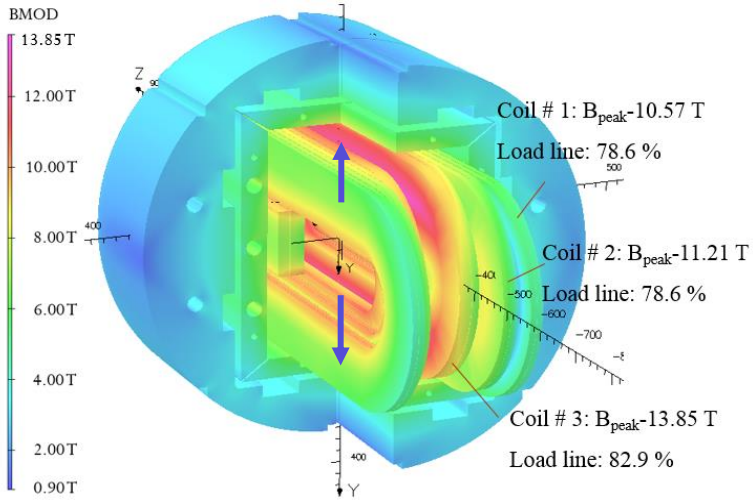
ReBCO CCT insert coil

Main parameters of LPF3

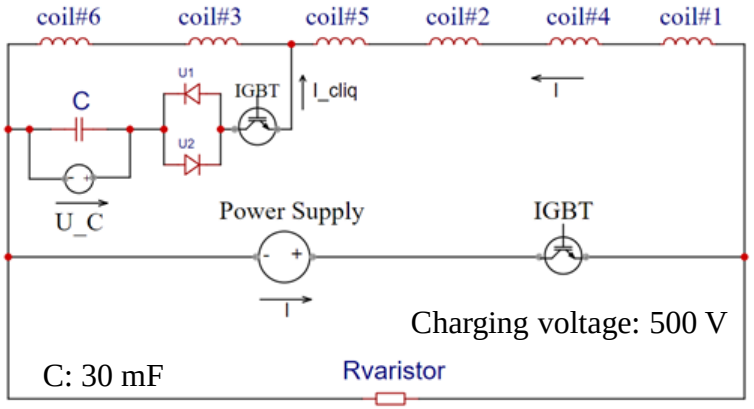
Nb_3Sn: 8300 A, main field:13 T @ 4.2 K & two 55 mm apertures



First quadrant coil layout



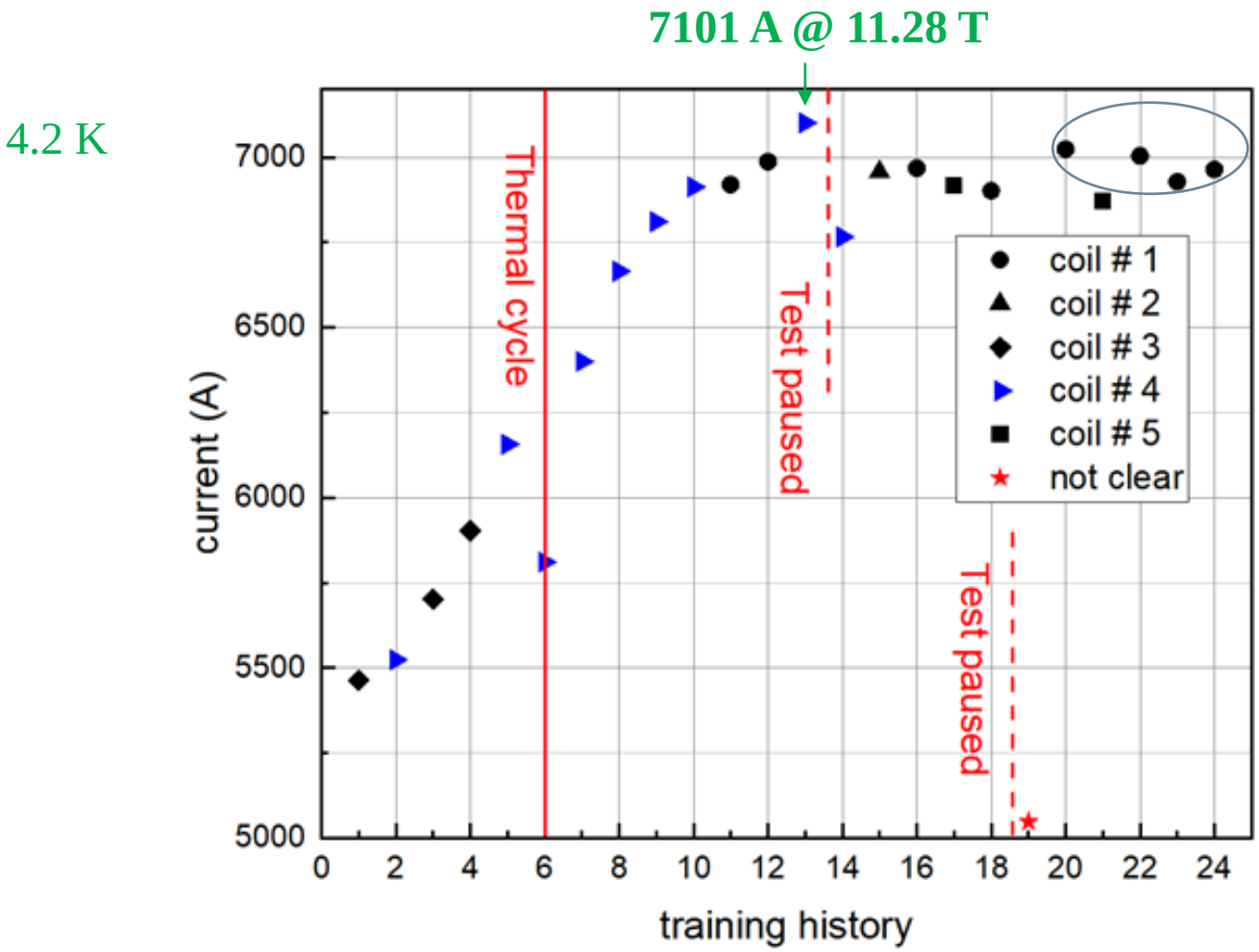
Field distribution in the magnet (3D)



- CLIQ + varistor； 2.2 MJ @ 13 T
- Hotspot temperature is 224 K at main field.

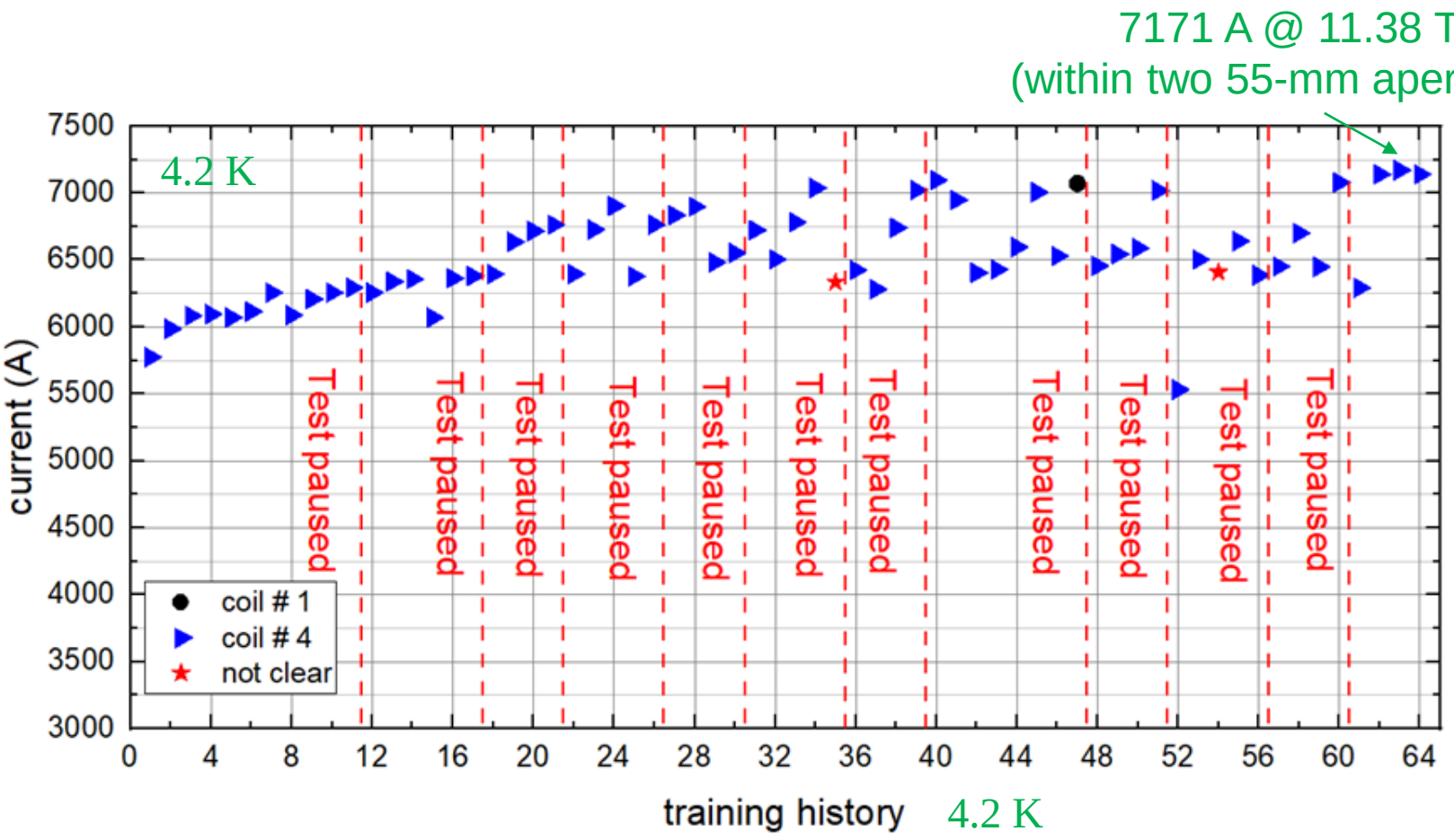
First run test results of LPF3-LTS

- The 1st preliminary test carried out in the week Sep 3-8 2023. The six Nb_3Sn coils were firstly ramped
- The performance test of LPF3 was continued after the thermal cycle. A maximum field of 11.28 T has been reached within two apertures.



Test results of LPF3-LTS after reassembly

- **The vast majority of quench events occurred in coil 4#. Reassembly of the magnet with sufficient preload effectively reduced quench events in coil 1#.**
- **Despite experiencing many quenches, the overall performance of the magnet is still on an upward trend.**



Training history of Nb_3Sn coils after reassembly

Lessons learned from LPF3

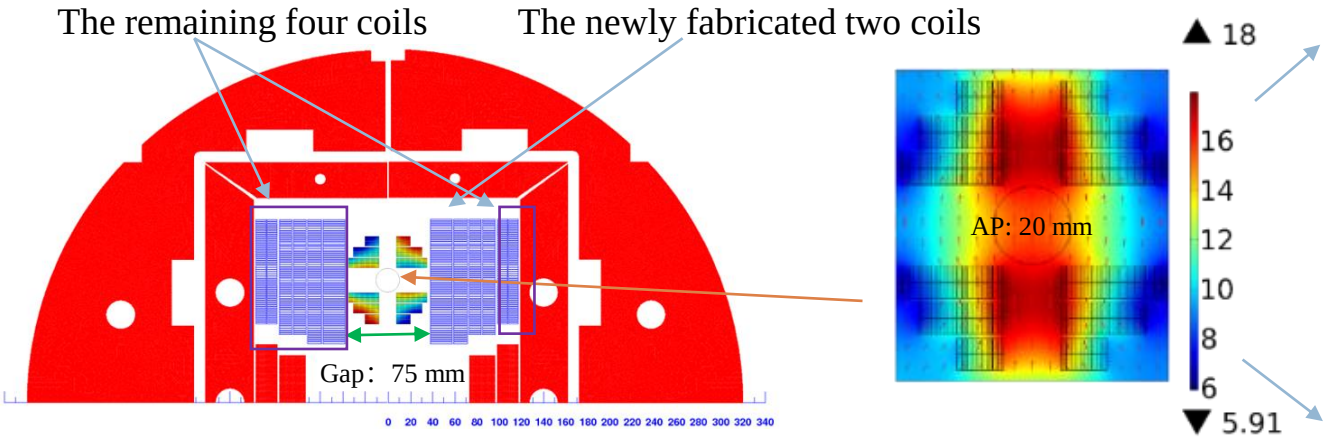
- In order to achieve the goal of 16 T earlier, the team engaged in long hours of high-intensity work. **But are often more haste, less speed**. Fatigue at work can easily lead to mistakes.
- During the 65th training test, the test personnel forgot to activate the quench detection system, causing the quench protection system to fail to work, resulting in the burning out of the two coils of the magnet after a quench
- **Dump proof-** The upgrade of the testing system, including the interlock of the power supply and quench detection & protection system, is currently in progress to ensure effective protection of the magnet in the next steps.

Quench detection system

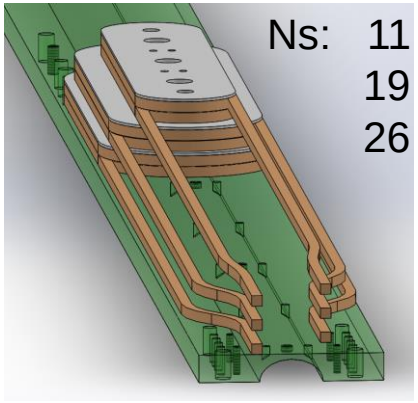
Coil 4$^{\#}$ and 5$^{\#}$ were burned out

Design of LPF3-U

- **A design combining a 10-tesla magnetic field generated by the six Nb_3Sn coils with a 6-tesla field produced by the newly fabricated racetrack HTS insert coils has been proposed.**

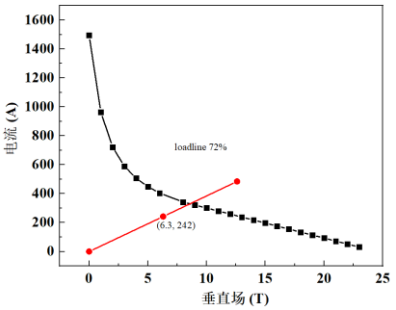


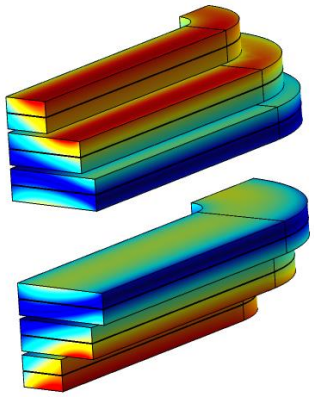
Wound in parallel in seven layers

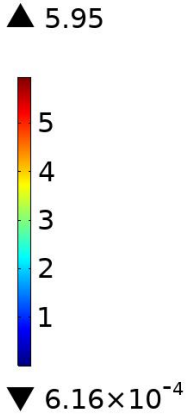


Six layers ReBCO + one layer SSL

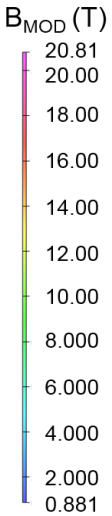
LPF3-U: 10 (LTS) + 6 (HTS) T magnet design

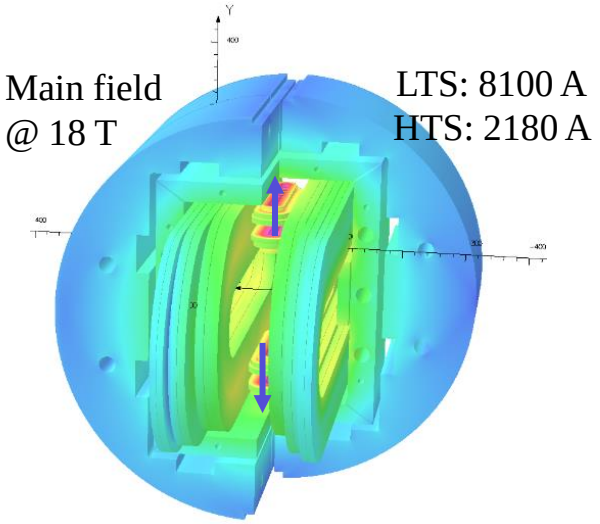






HTS load line ratio: 72 %

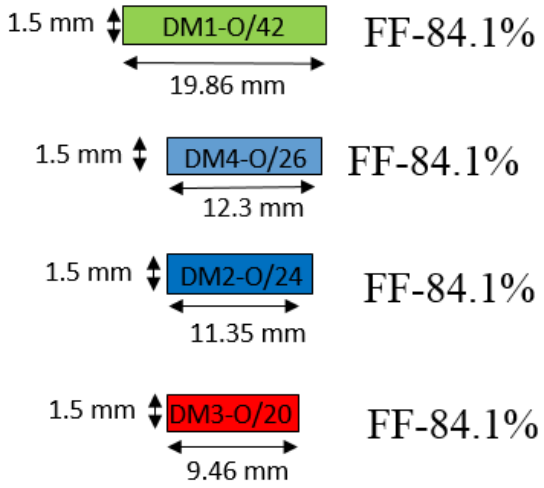




LTS load line ratio: 85 %

Fabrication of the two new Nb_3Sn coils - Rutherford cable

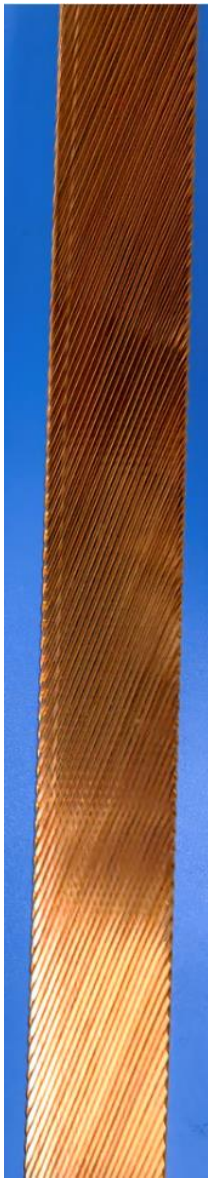
- **With OST strand:**
  - **0.85 mm**
  - **Non- Cu: ~ 45%**
  - **RRR: ~ 300**
  - **Ic @ 12 T: ~ 650 A**
  - **Ic @ 15 T: ~ 370 A**



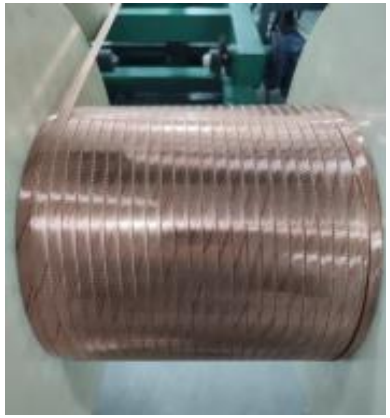
Main parameters of the strands and Rutherford cables

Cabling machine

24-strands



42-strands

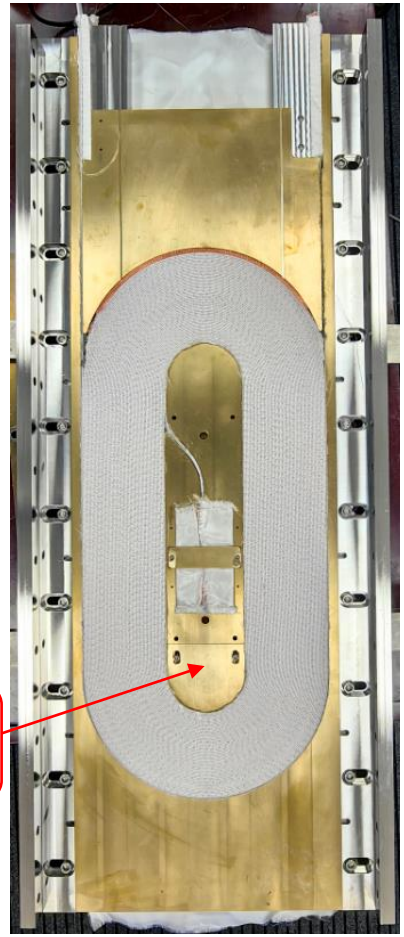


- **20-strands & 24 strands Rutherford cables- More than 200-m long**
- **26-strands & 42 strands Rutherford cables- More than 100-m long**

Coil winding

Coil winding machine

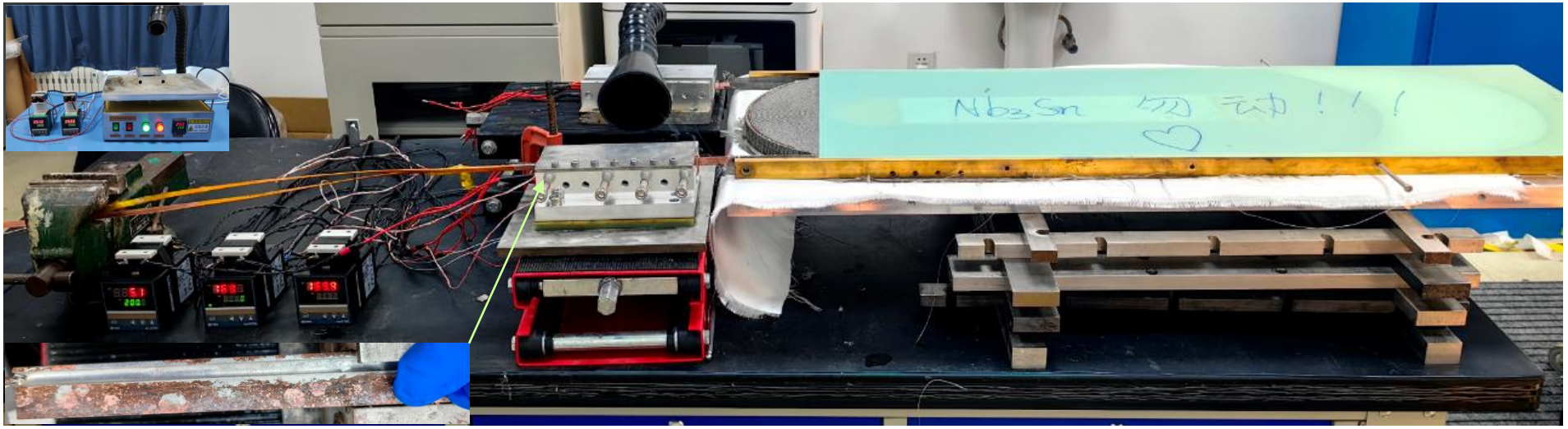
Heat treatment furnace



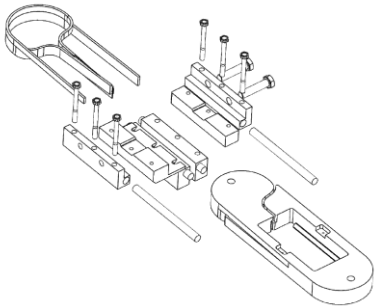
New coil 4# after winding

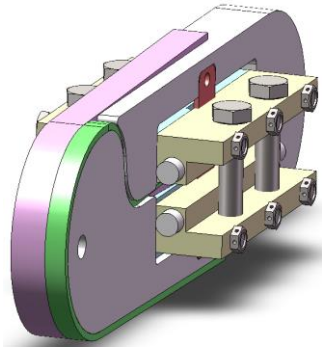
- The horse-shoes and end-shoes (used as the coil container) were produced with aluminum-bronze due to its similar coefficient of thermal expansion (CTE) with Nb_3Sn cables
- The central posts were designed and manufactured in two parts. After the coil winding, the bolts were loosened, and part 2 could move freely to accommodate the cables' expansion and shrinkage during heat treatment, with the consideration of minimizing the damage to the cables.

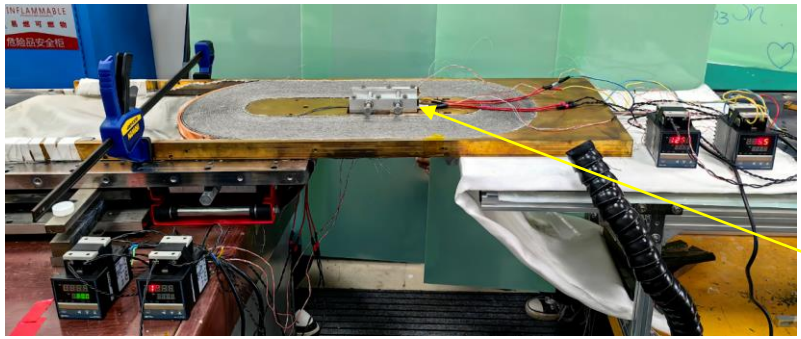
NbTi & Nb_3Sn joints soldering

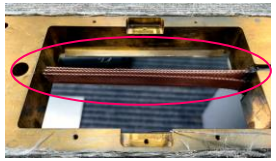


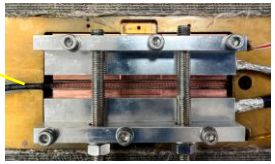
NbTi & Nb_3Sn joints soldering system







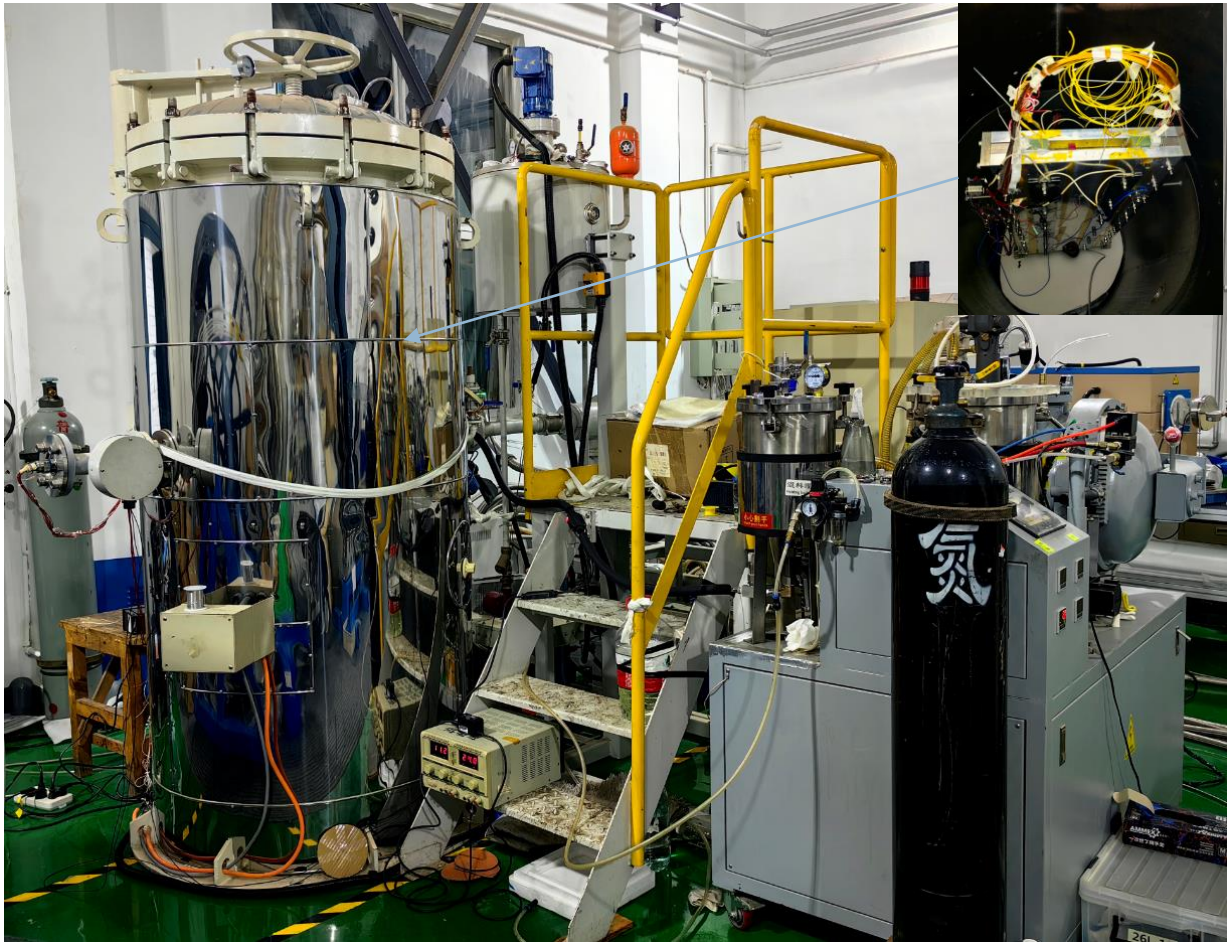




Inner joints soldering system

- Double pancake with graded coil configuration; 2-in-1 structure to improve the efficiency

Coil VPI

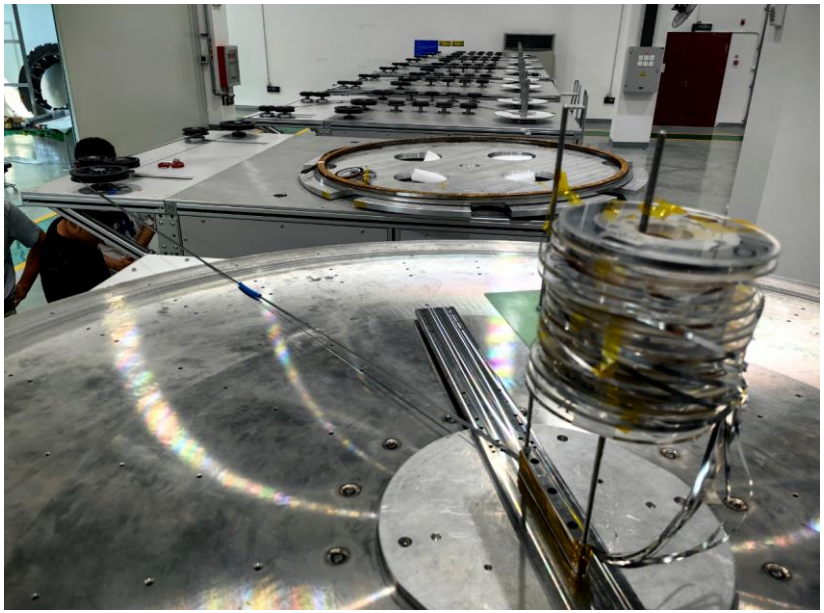


VPI system

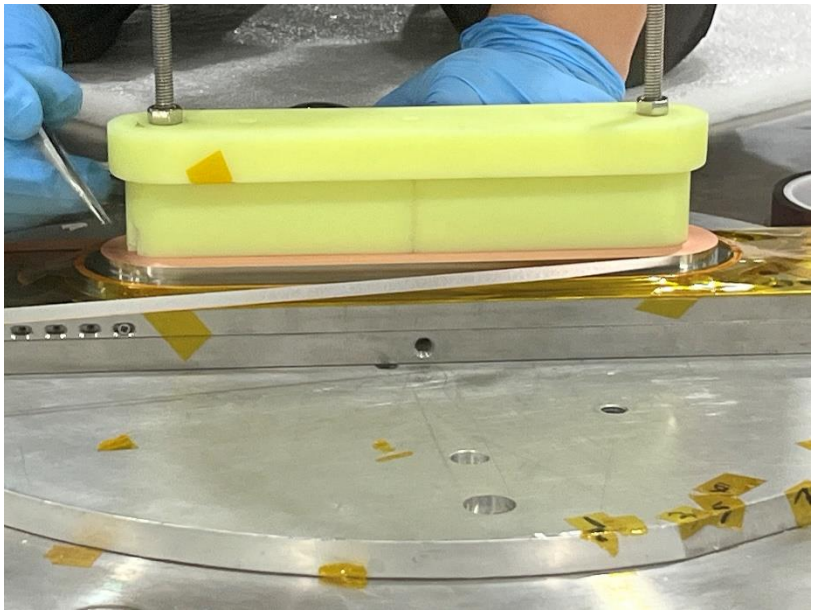
Coils after VPI

- Fiber optical sensors based on Fiber Bragg Grating (FBG) has been confirmed in LPF series magnets. They have also been used in LPF3-U magnets, implemented in all the six coils and mounted on the surface of the shell to monitor the stress variation during all three loading steps
- After instrumentation, the coils were dipped with CTD-101K using our self-developed VPI system, which has been updated with a much bigger impregnation tank with the function of providing 0.5 MPa positive pressure.

HTS coil fabrication

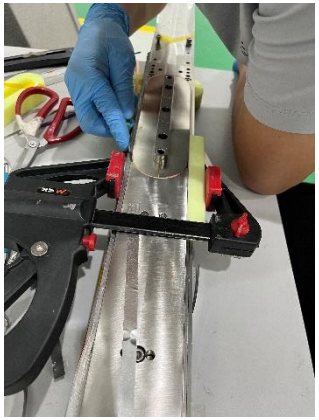


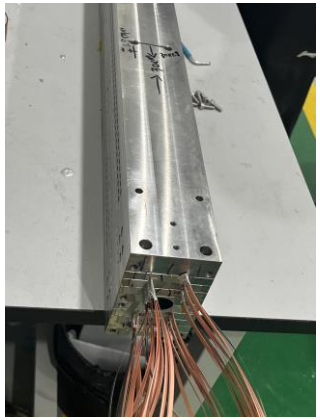
HTS coil winding machine



Coil winding process

Picture of one double pancake coil



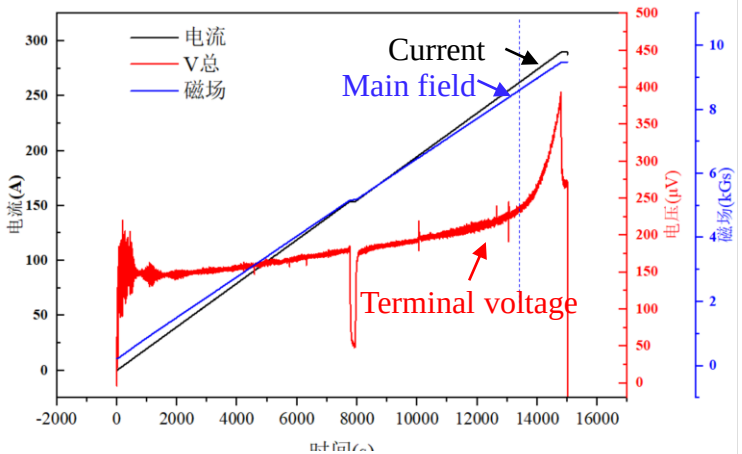


Assembly of the six pancake coils

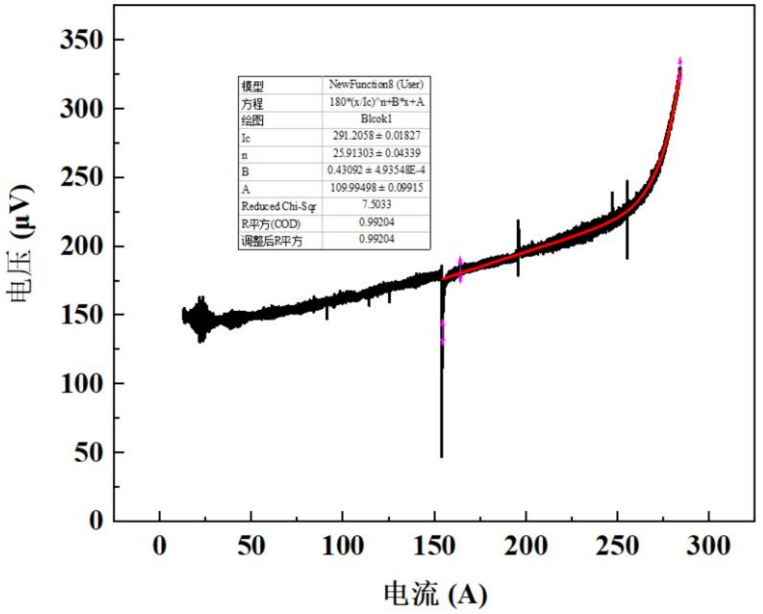
Coils connection

HTS coil stand-alone test at 77 K

HTS insert coil after assembly



Main field:
0.93 T @ 77 K



Ic: 291 A

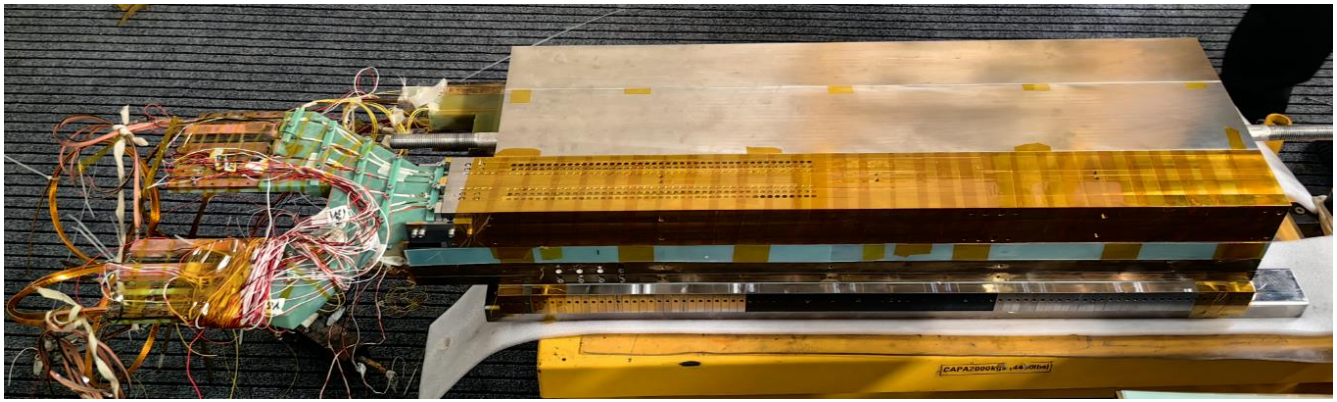
(Criteria: 0.1 uv/ cm)

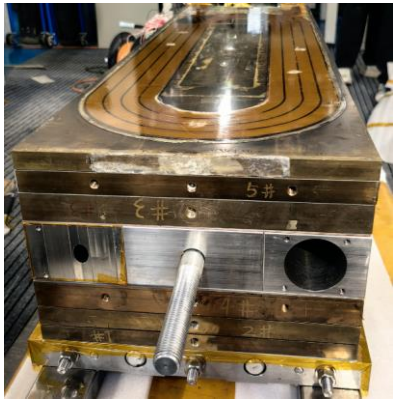
N value: 26

Test results

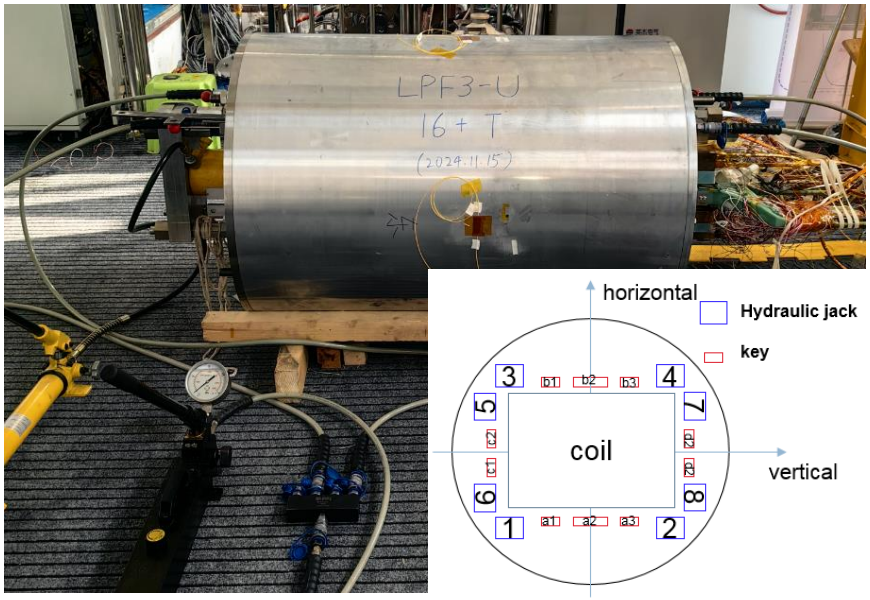
- The coil demonstrated favorable performance during the liquid nitrogen test @77 K. Subsequently, it will be inserted into the magnet LPF3-U for further evaluation under liquid helium conditions.

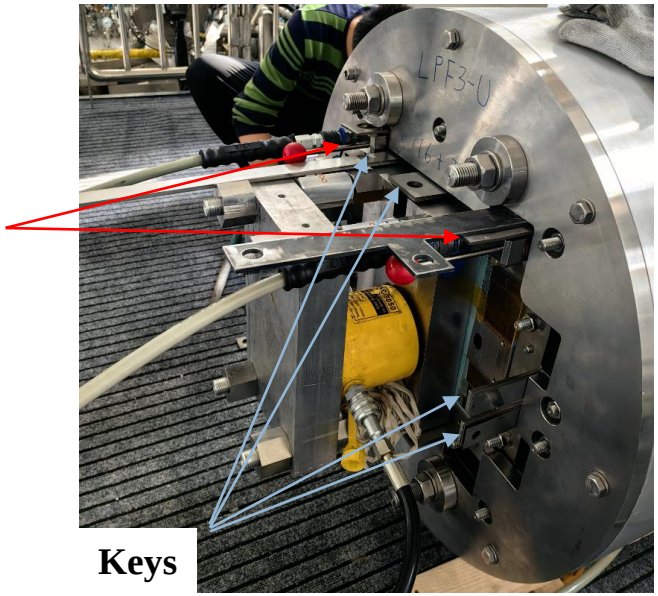
Assembly of LPF3-U





Coil assembly





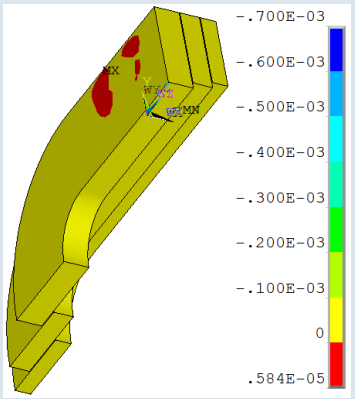
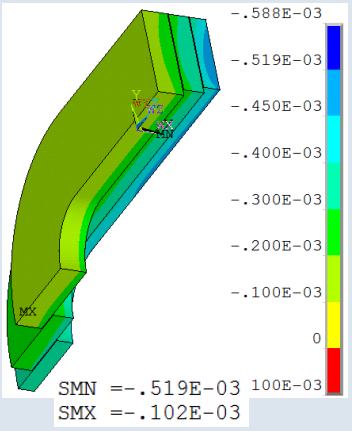
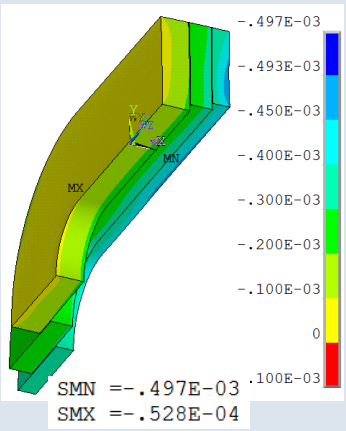
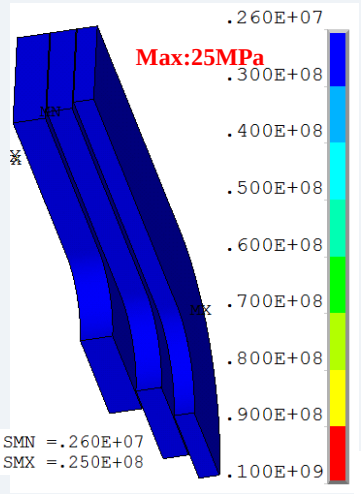
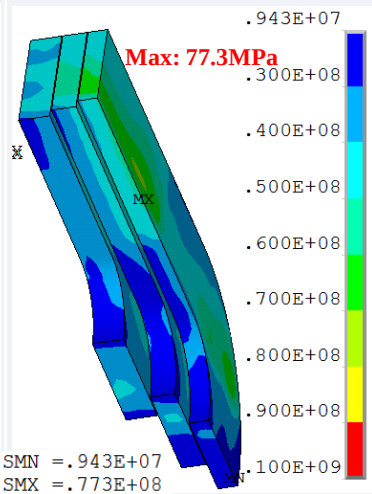
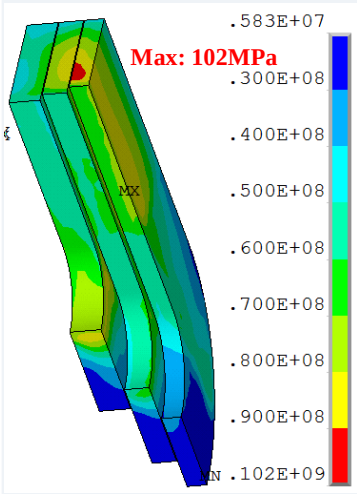
Pre-loading system

Hydraulic pistons

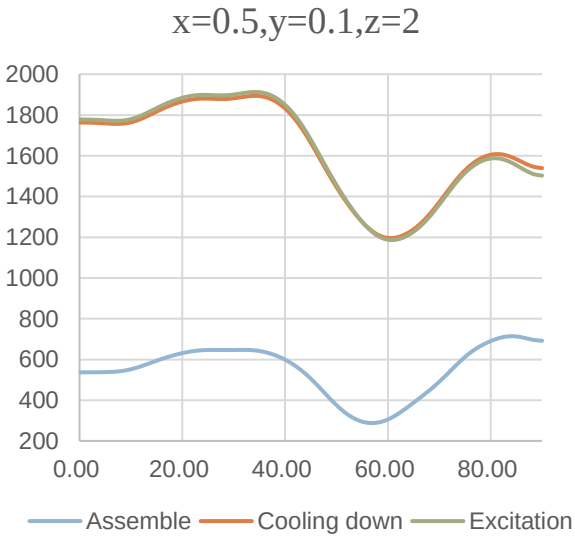
Magnet assembly

- The support structure for LPF3-U has adopted a shell-based design, with an improved "Bladder & Key" technology. Dedicated hydraulic pistons were investigated and utilized to replace the traditional bladders.

Assembly of LPF3-U

0.5/0.1/2	assemble	Cooling down	excitation
X-displacement			
Von-stress			

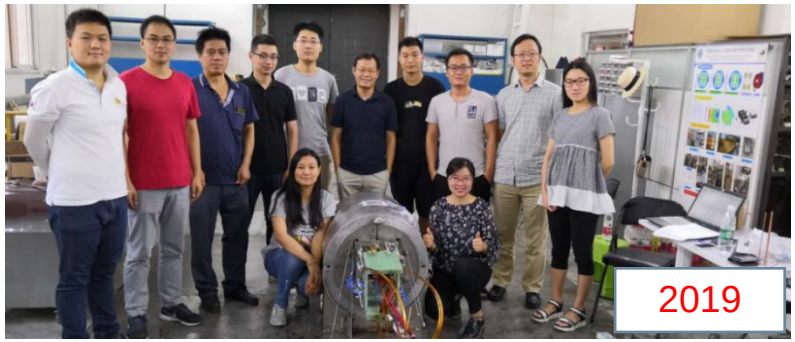
Mechanical analysis of LPF3-U

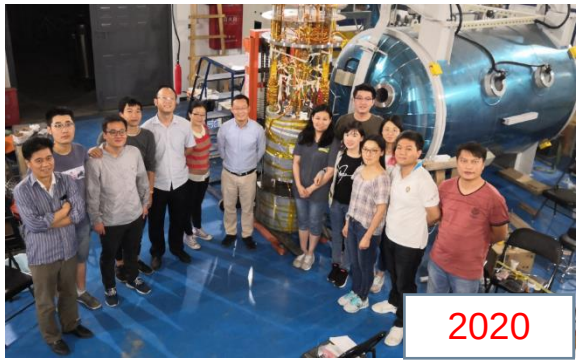


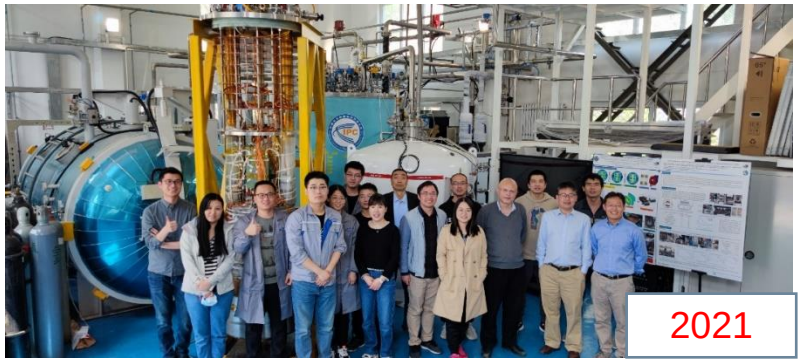
	Horizontal（0°）	Vertical（90°）
Assembly	540με	692με
Cooling down	1765με	1540με
Excitation	1778με	1503με

Strain distribution in the shell

- Fiber optical sensors were utilized to guide the pre-stress implementation during LPF3-U magnet assembly.
- Peak stress is around 100 MPa during the three loading steps from assembly to energization of the magnet to 16 T.
- Performance tests would be carried out next week, and we anticipate favorable outcomes.







10.23 T	→	10.71 T	→	12.47 T	→	To be beyond 16 T
Year:2018		2019		2020-2021		2022-2024

Welcome to visit Qingjin's lab!

中国科学院高能物理研究所
Institute of High Energy Physics, CAS

中科院高能所超导磁体组
Superconducting Magnet Group, IHEP

Thanks !