

# Progress of the High Field HTS Magnet R&D for Next-generation High Energy Accelerators



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15 Jan 2026



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*Institute of High Energy Physics*  
*Chinese Academy of Sciences*

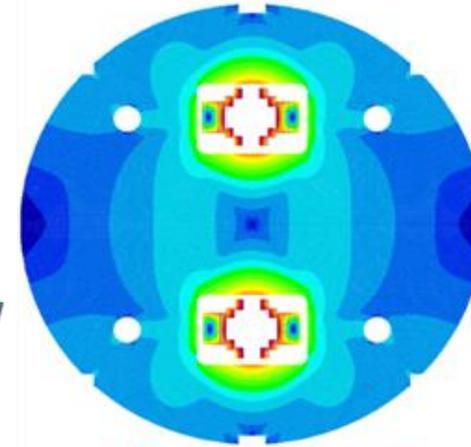
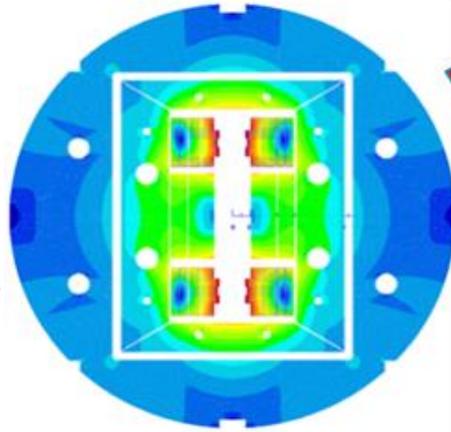
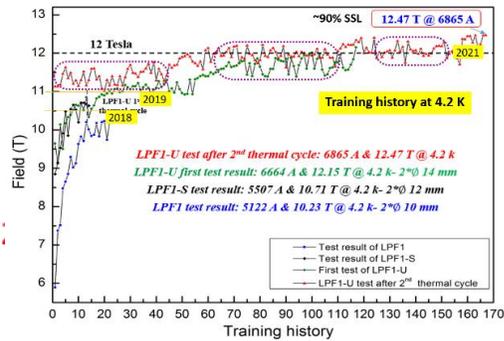
# Roadmap of the High Field Magnet R&D at IHEP



$$E[\text{GeV}] = 0.3 \times B[\text{T}] \times \rho[\text{m}]$$

2021-2026 15~16T @ 4.2K

2018-2021, 12.47T @ 4.2K  
NbTi + Nb<sub>3</sub>Sn



Nb<sub>3</sub>Sn+HTS or HTS  
2\*φ45 aperture  
20T @ 4.2K  
With 10<sup>-4</sup> field quality

NEXT-GENERATION  
PARTICLE ACCELERATORS

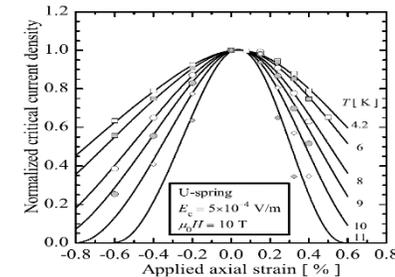
CEPC-SPPC



FCC



Challenges: Stress control,  
quench protection, field  
quality control,.....



Field (T)

20

10

2018

2030

year



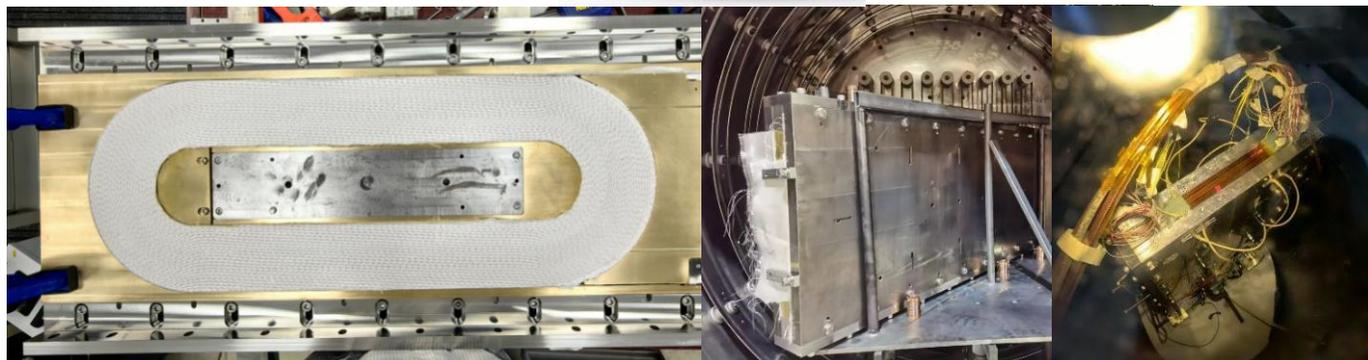
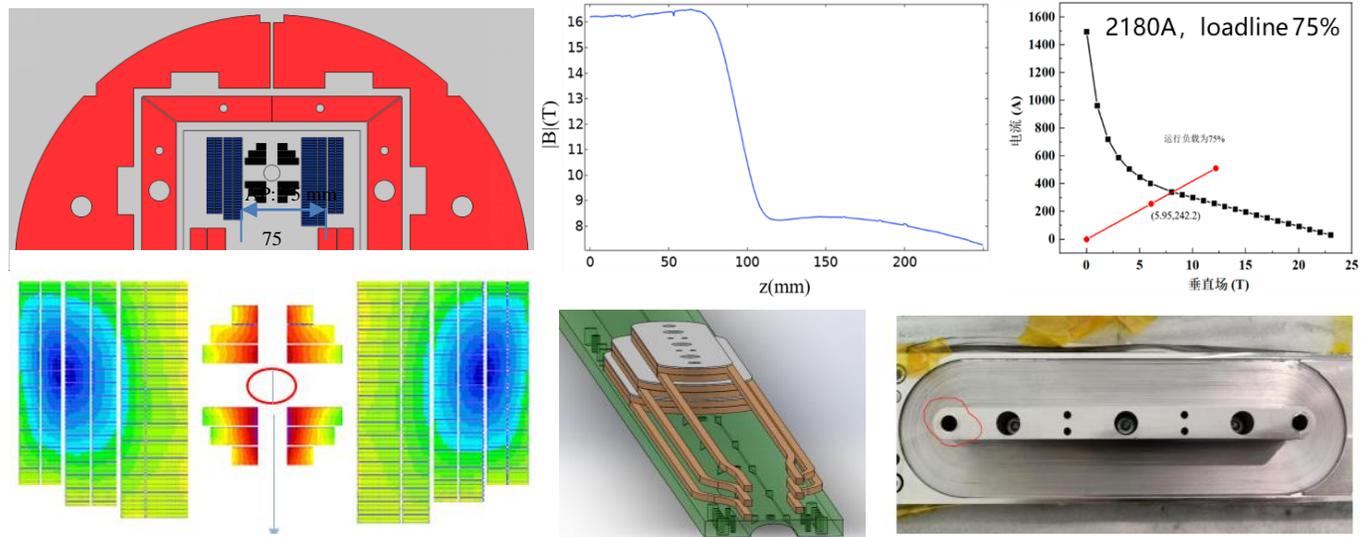
# Development of the High Field Model Dipoles



Latest design: Target field: 10 T (LTS) + 6 T (HTS) at 4.2 K

LTS: Nb<sub>3</sub>Sn common coils with shell-based structure, aperture: 2\* Ø78 mm

HTS: ReBCO racetracks, stacked tapes with MI insulation, aperture: 16\*24 mm<sup>2</sup>



HFM team @ IHEP-CAS



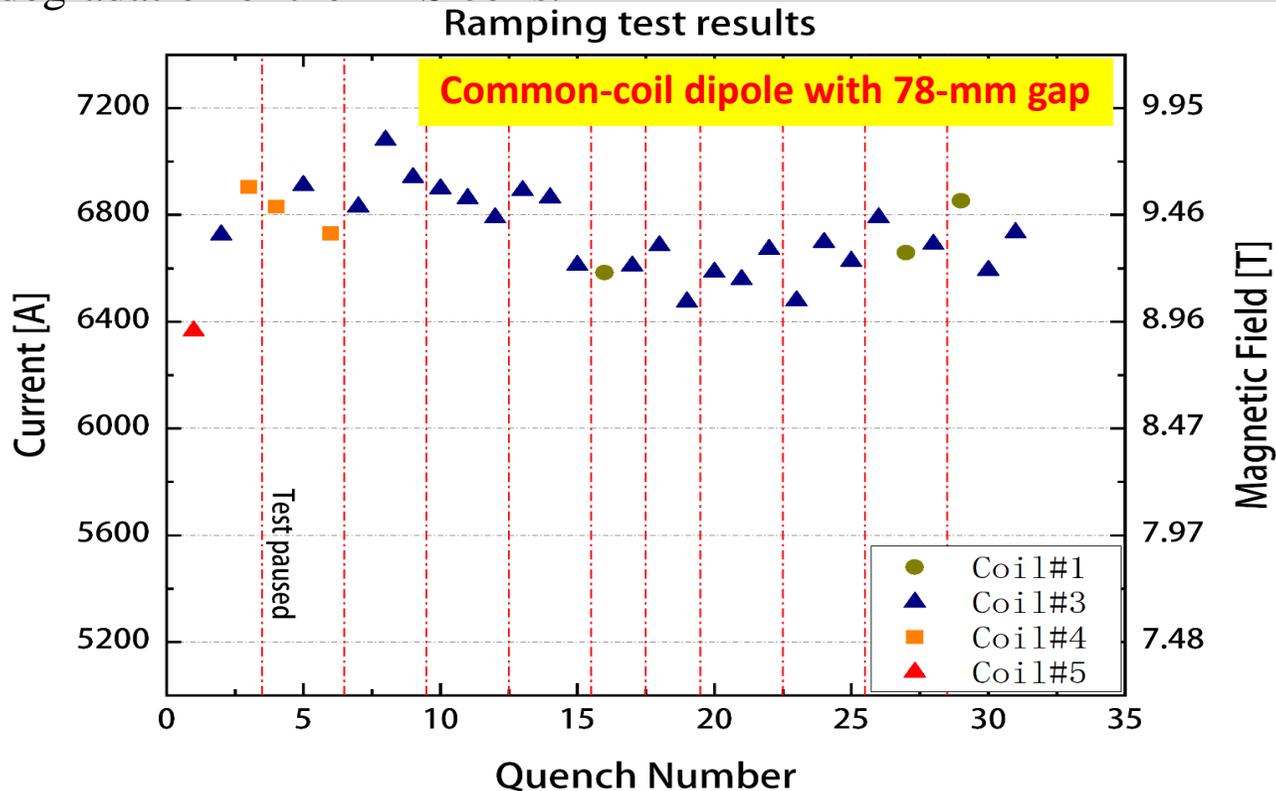
## Test of the LPF3-U magnet at 4.2 K

Nov. 2024 to Jan. 2025

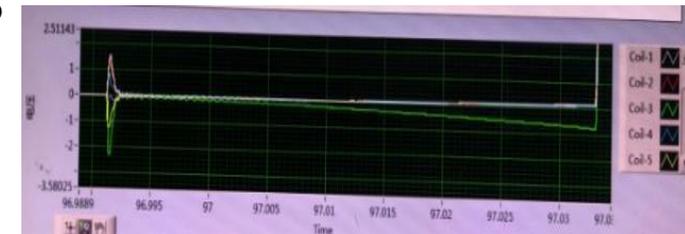


LPF3-U 磁体组装完成

**Main challenges:** The LTS coils are strongly coupled with the HTS coils in magnetic field and stress during LTS training. The HTS induced current enhance the field strength and stress of the adjacent LTS coils, and the frequent training quench of LTS cause irreversible degradation of the HTS coils.



- Nb<sub>3</sub>Sn coils reached 9.8 T, 98 % of the design value.
- Coupling between HTS & LTS caused difficulties to the training of LTS
- Most of quenches occurred in the inner Nb<sub>3</sub>Sn coils.
- LTS still have potential for performance improvement. More R&D needed on training tests.....





# Development of the High Field Model Dipoles



## Test of the LPF3-U magnet at 4.2 K

Nov. 2024 to Jan. 2025

The HTS coils reached a maximum excitation current of 2.5 kA (115 % of the design current) in 9 T background field, but generally degraded along with the training of LTS coils, and provided a magnetic field significantly below the design value with long delay.

HTS Stand-alone test @77 K

HTS Test after assembly @77 K

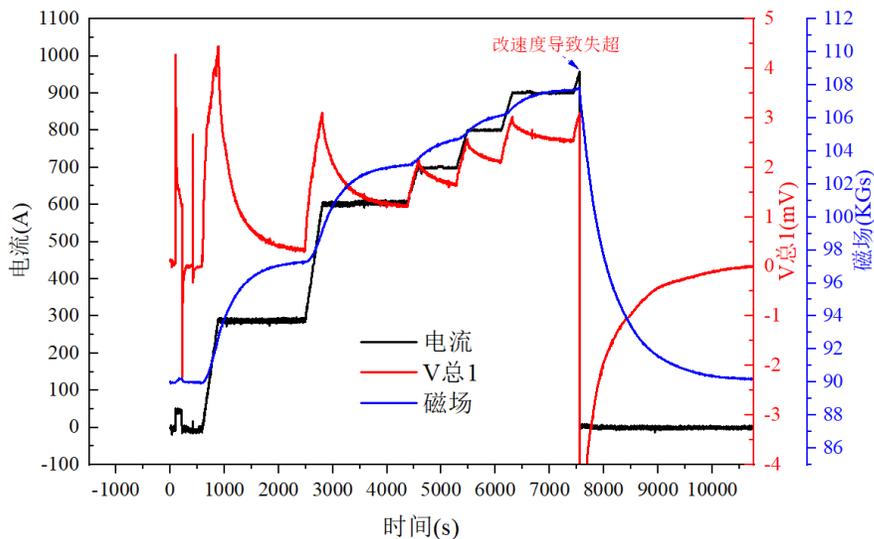
Training of LTS coils

1<sup>st</sup> HTS test with 9 T BG field

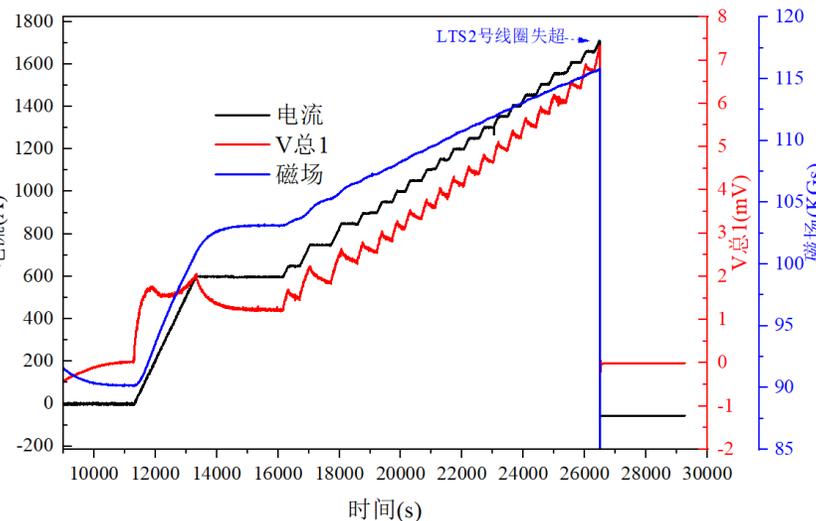
2<sup>nd</sup> HTS test with 9 T field

LTS training

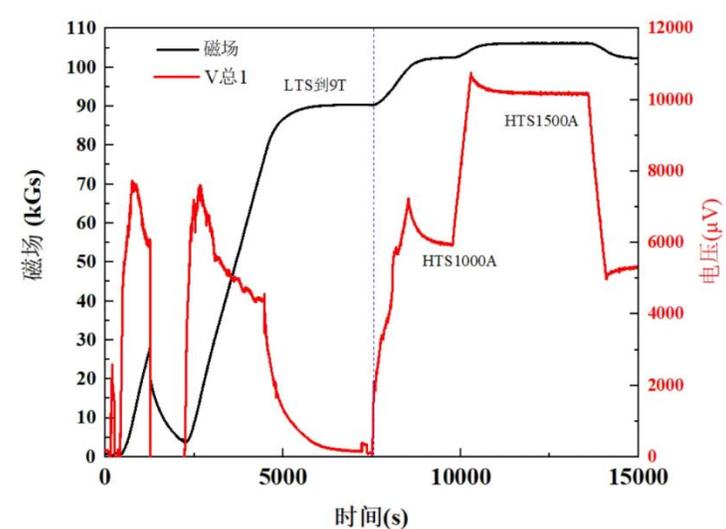
3<sup>rd</sup> HTS test with 9 T field



1<sup>st</sup> HTS test with 9 T BG field



2<sup>nd</sup> HTS test with 9 T BG field

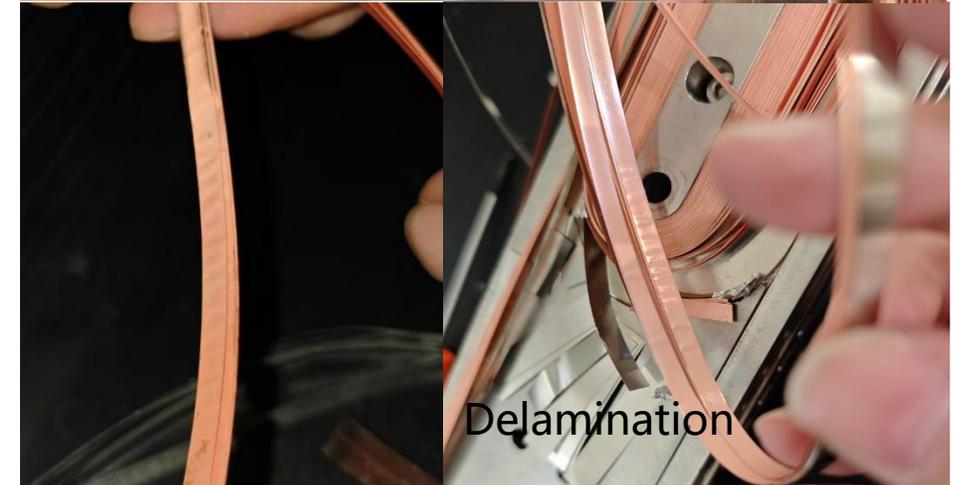
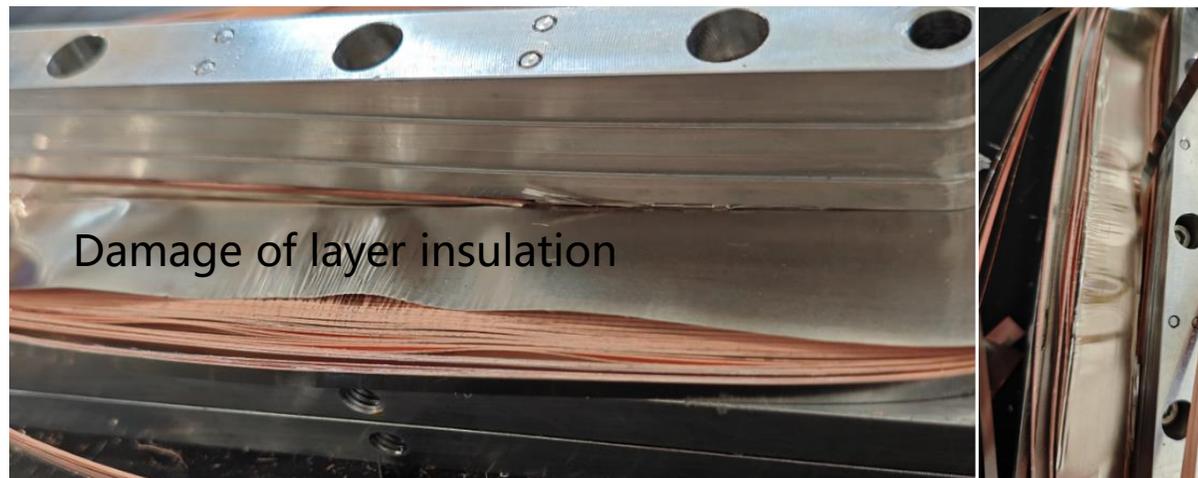
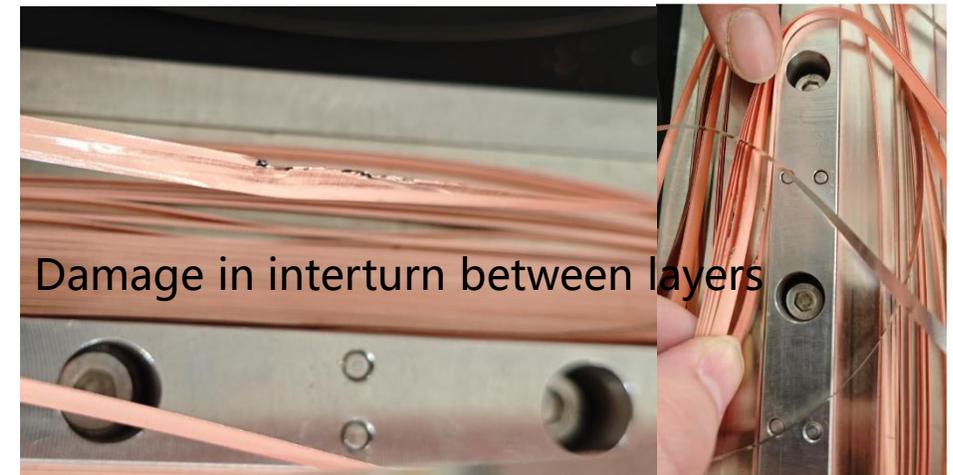


3<sup>rd</sup> HTS test with 9 T BG field



## Disassembly of the magnet and HTS coils in Jan 2025

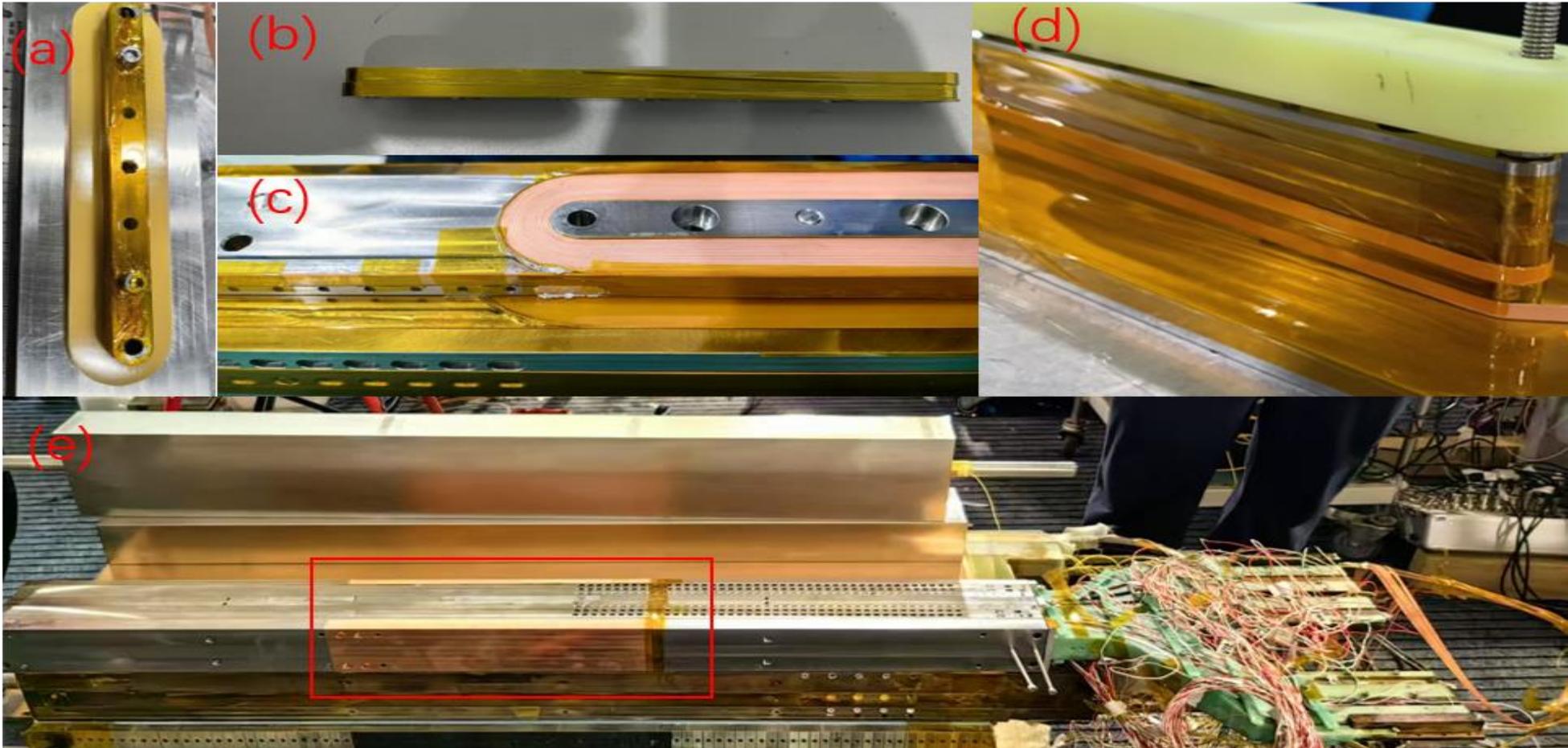
After disassembly, Serious damage of the outer HTS coils observed: conductor delamination, damage of layer insulation..., caused by strong coupling (between LTS and HTS) induced electromagnetic forces during the training of LTS





## Refabrication of the new HTS coils in Spring 2025

- To reduce time delay of field, the layer insulation in the coil was replaced from stainless steel to G10
- To reduce the impact of LTS quench to HTS, high-purity copper and HTS tapes were deployed around the HTS coil





# Development of the High Field Model Dipoles

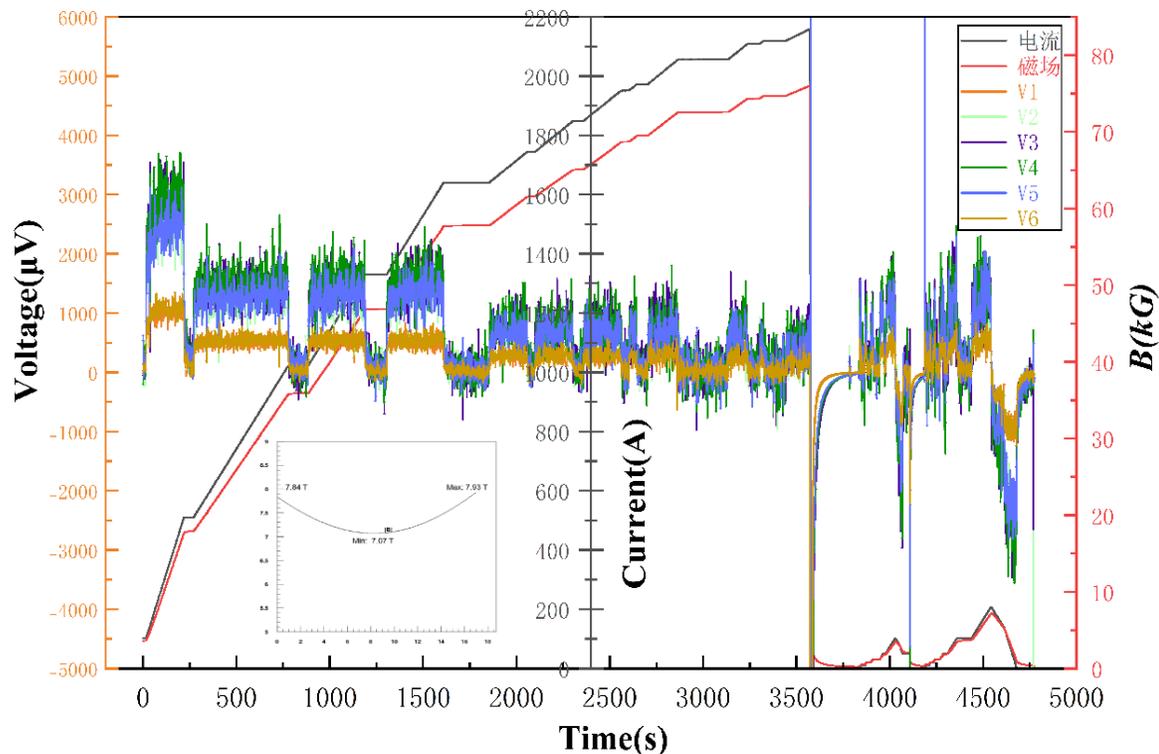


## Refabrication and test of the new HTS coils in Summer 2025

HTS stand alone: 2159 A, 7.6 T in the aperture@ 4.2 K

Maximum field on the coil (calculated): ~10 T

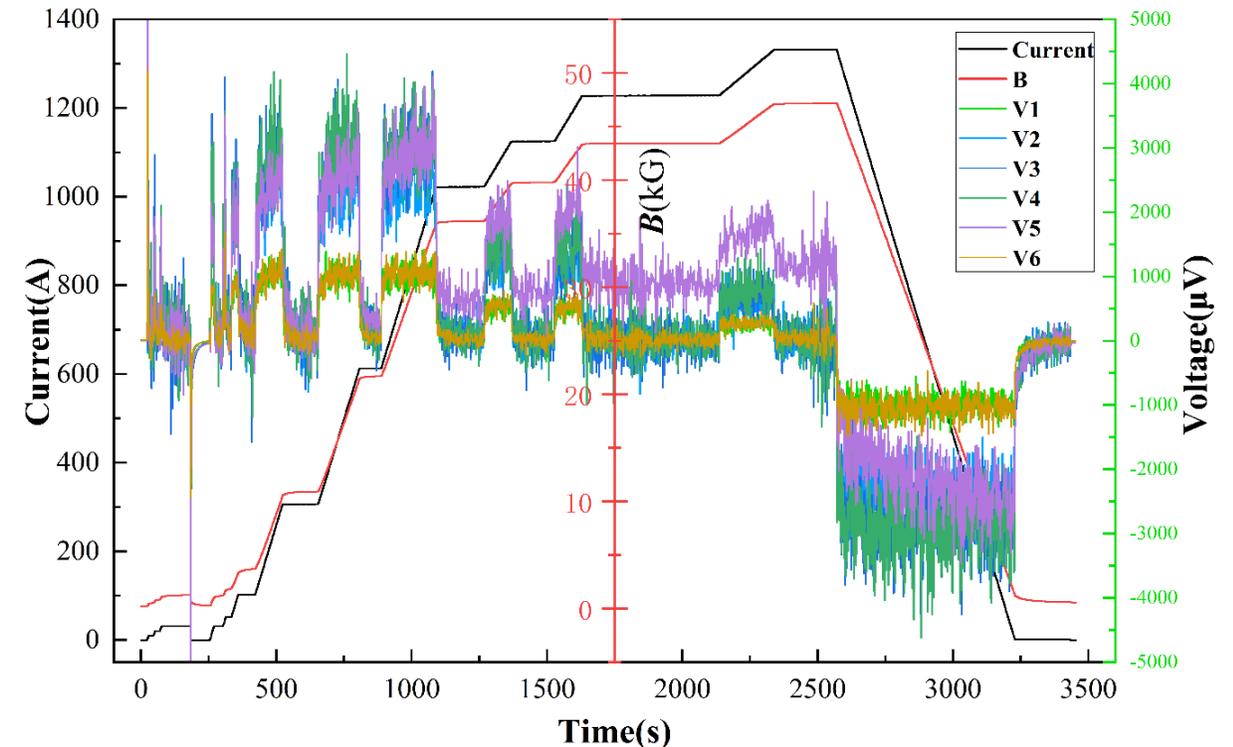
Performance limited by a power failure: current discharged in 1 s



Power failure at 2159 A damaged 1 of 6 HTS coils

Resistive voltage appeared in #5 coil from ~800 A;

bypassing #5 coil for the following tests



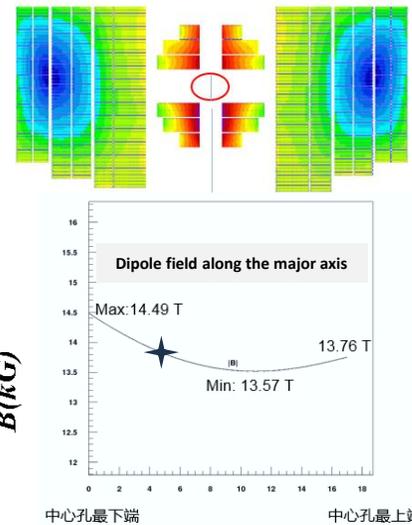
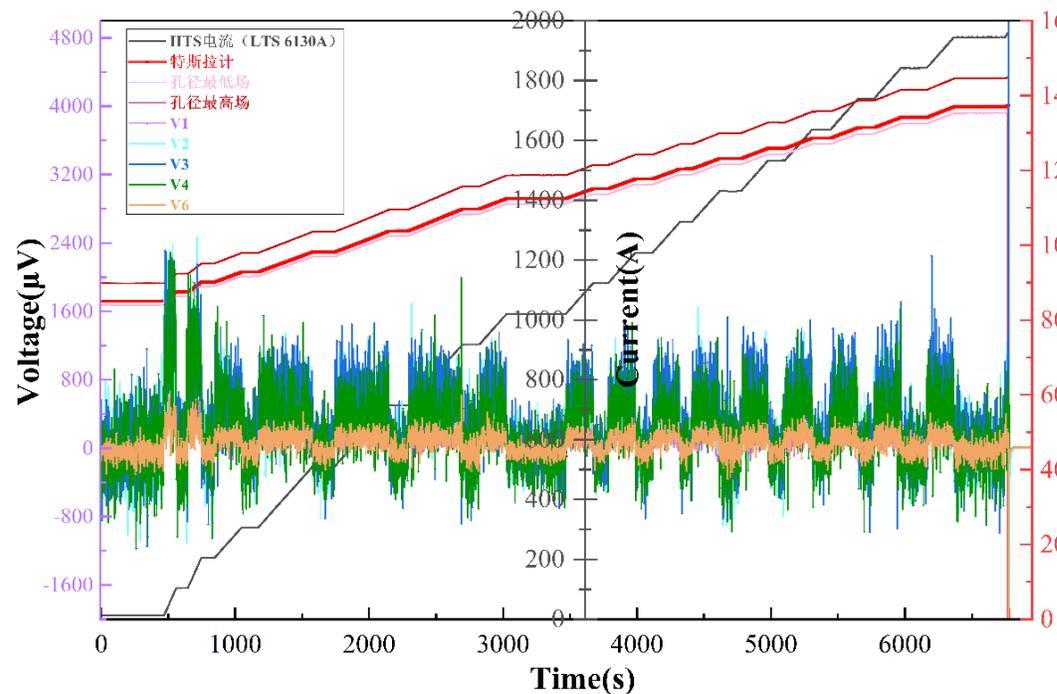


## Refabrication and test of the new HTS coils in Summer 2025

2<sup>nd</sup> powering with LTS: #3 HTS coil quench at 1959A, and after 0.4156s, the LTS quench detection system triggered. The current decay time of HTS is 1.3 s, and LTS is 0.7718 s;

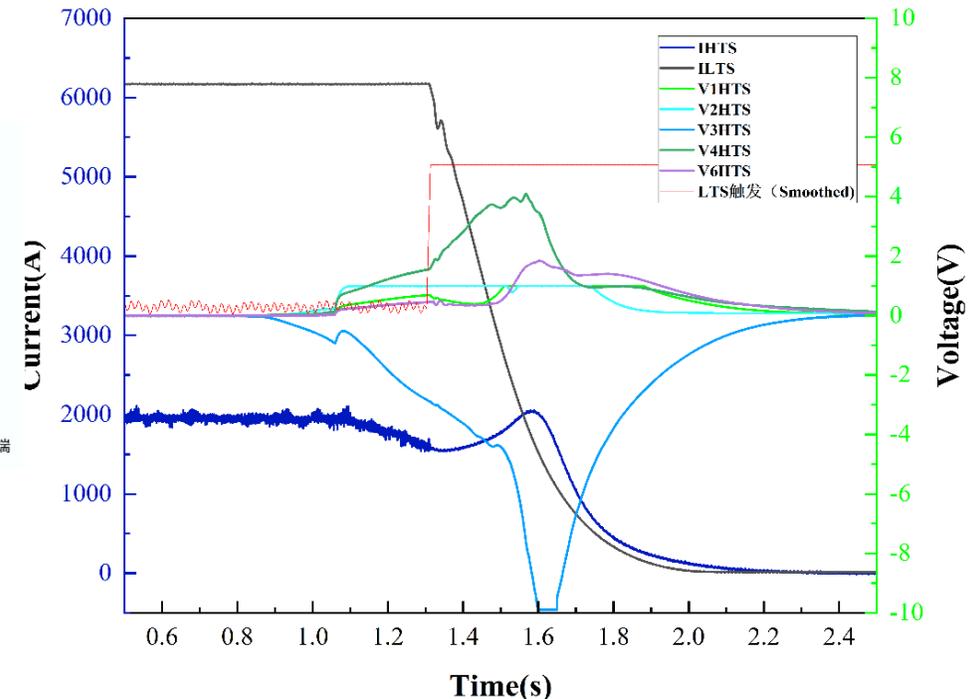
### 2<sup>nd</sup> HTS powering with Nb<sub>3</sub>Sn at 4.2K

Quench at HTS 1959 A & LTS 6130 A (bypassing #5 HTS coil)



Field map within the aperture. The highest field in the HTS coil ~16.2T (calculated)

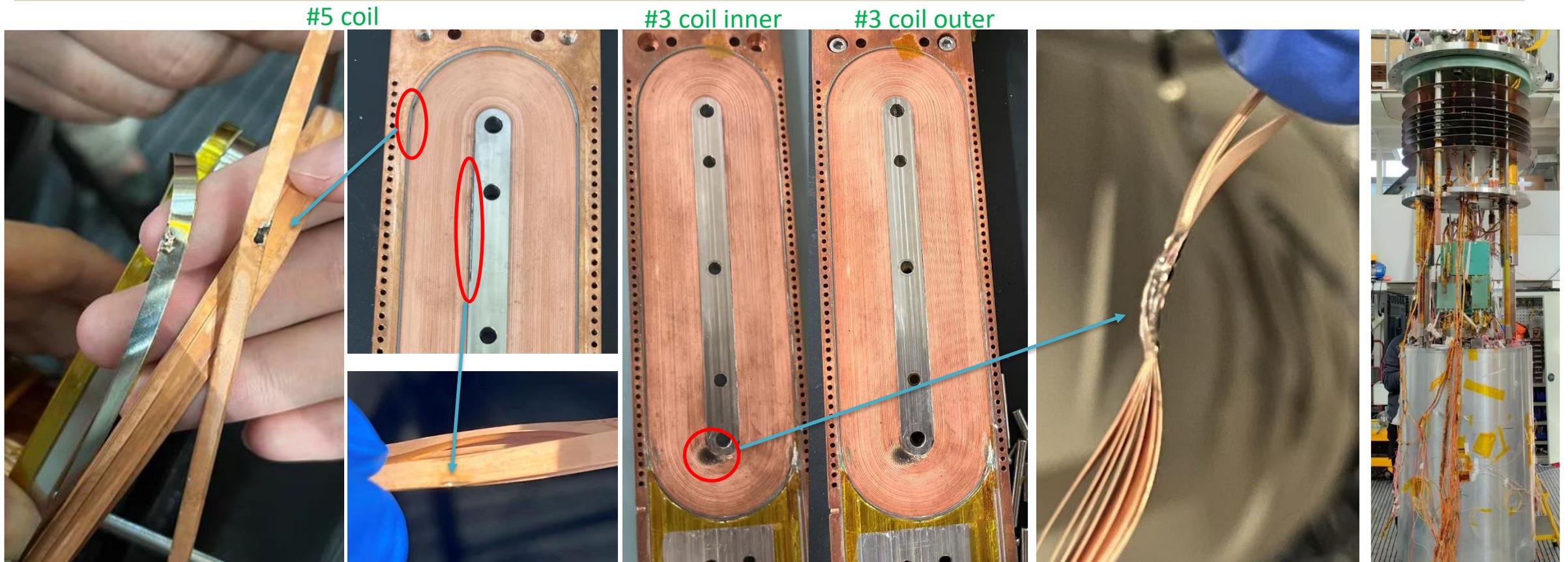
### Voltage and current variations during the quench





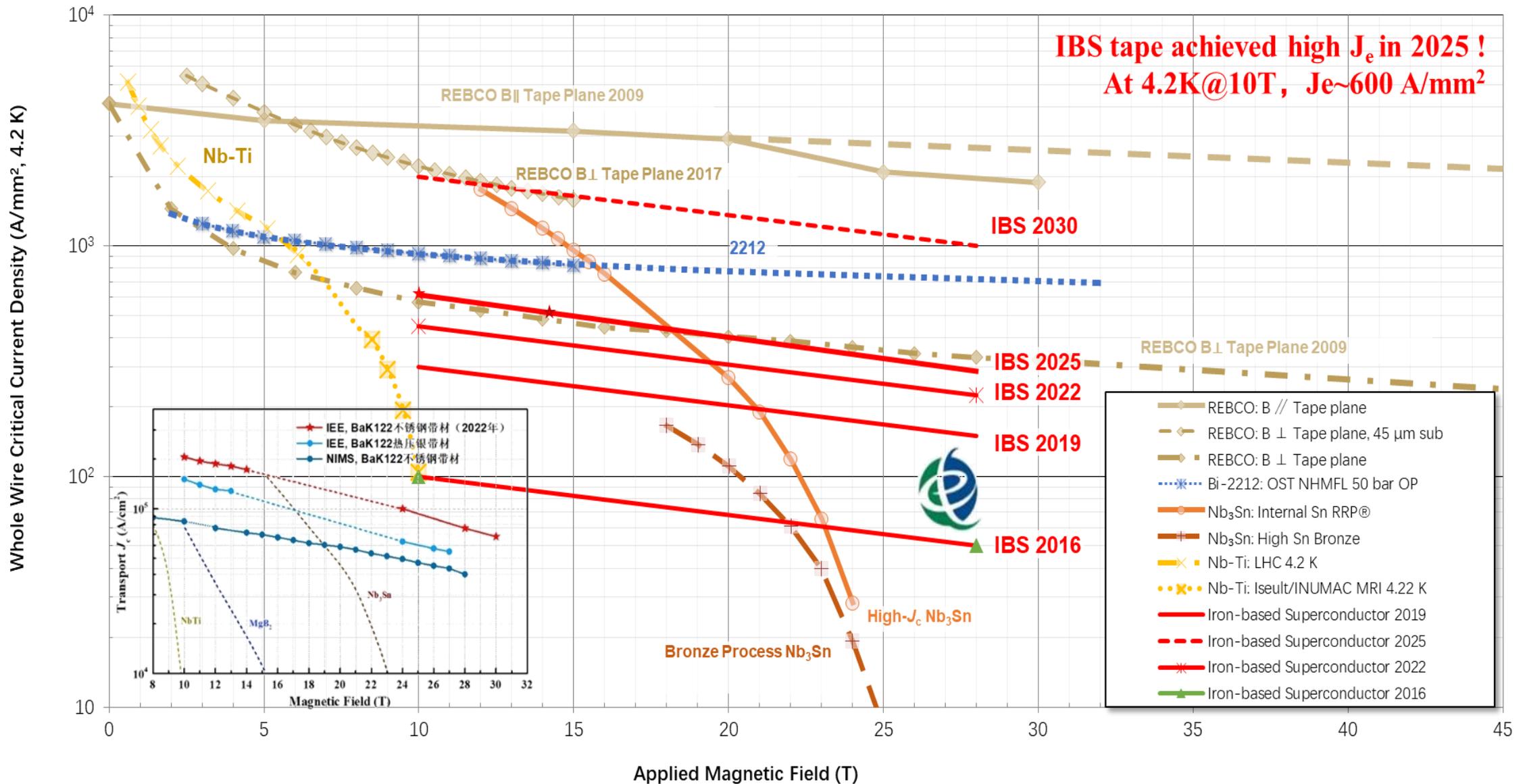
## Refabrication and test of the new HTS coils in Summer 2025

- Power failure damaged coil (#5 coil) during the stand-alone test: conductor partially burned at the coil end
- Quench at 14 T damaged coil (#3 coil) during powering with Nb<sub>3</sub>Sn coils: conductor burned at the bending section
- **New ReBCO coils have been fabricated and assembled in the magnet, test will be done in Jan 2026**



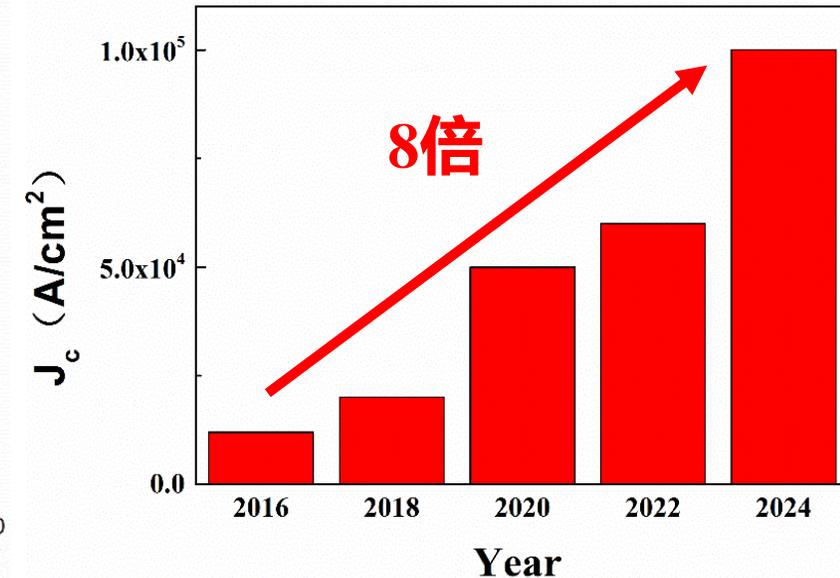
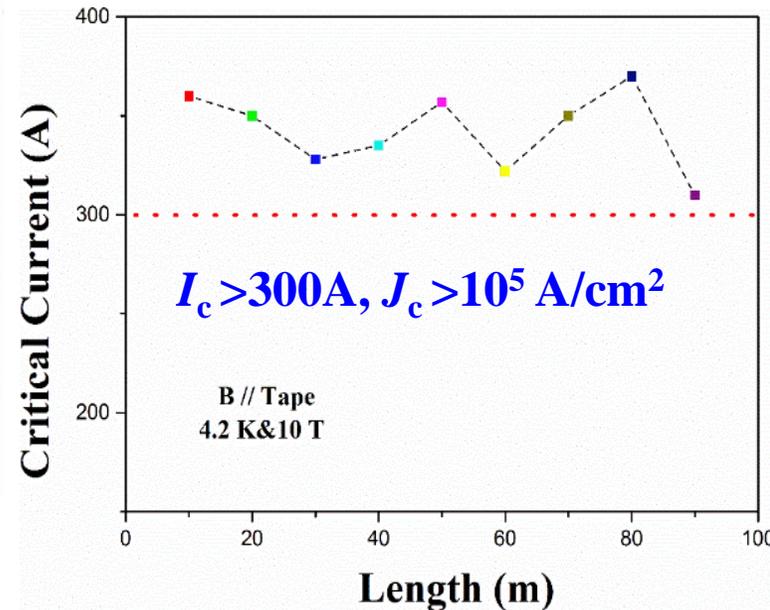
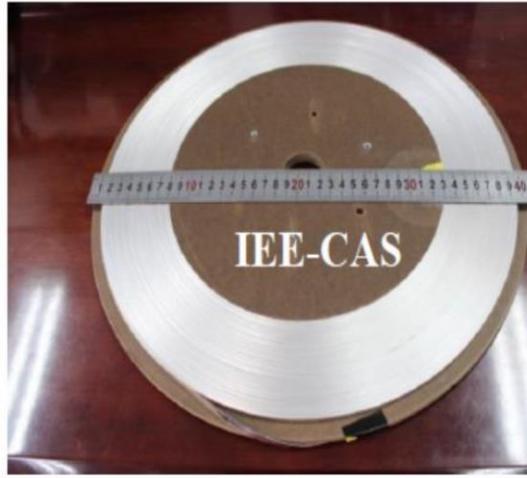
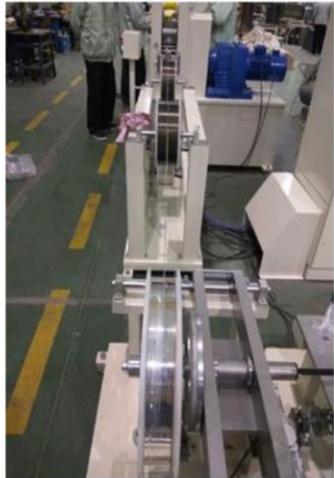


# IBS Technology: Status and Outlook



## Powder-In-Tube 122 tapes: Long length

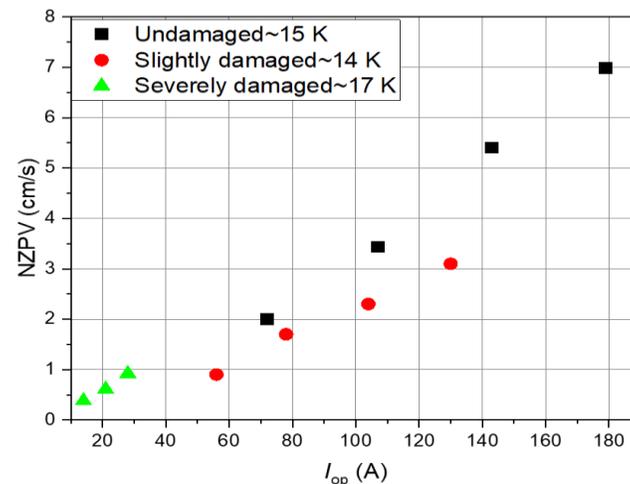
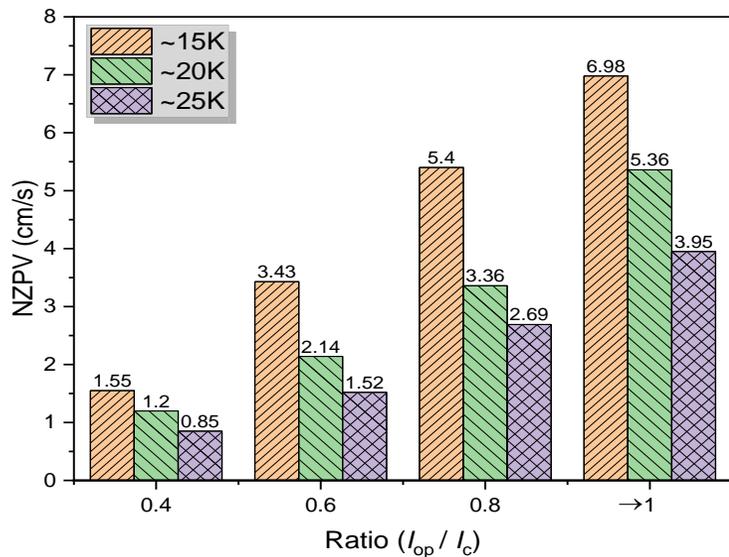
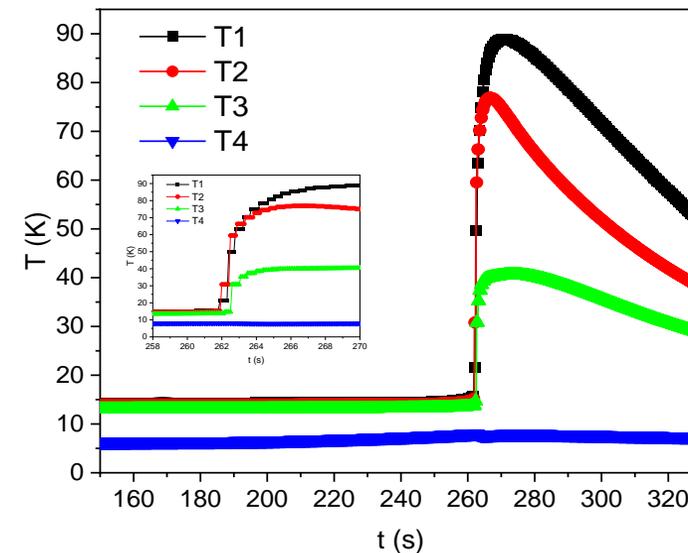
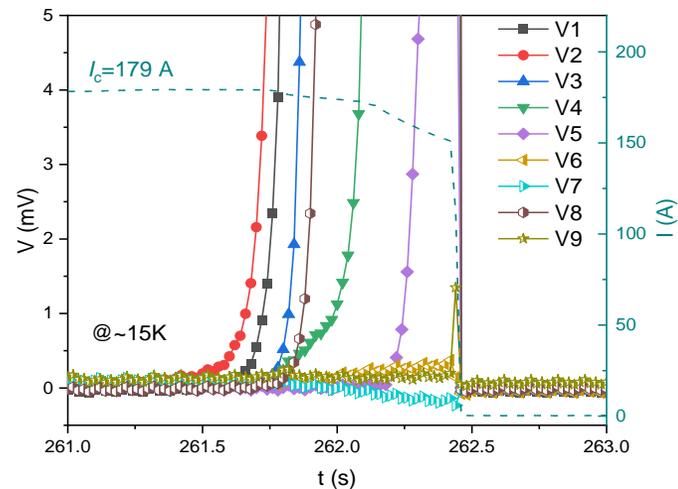
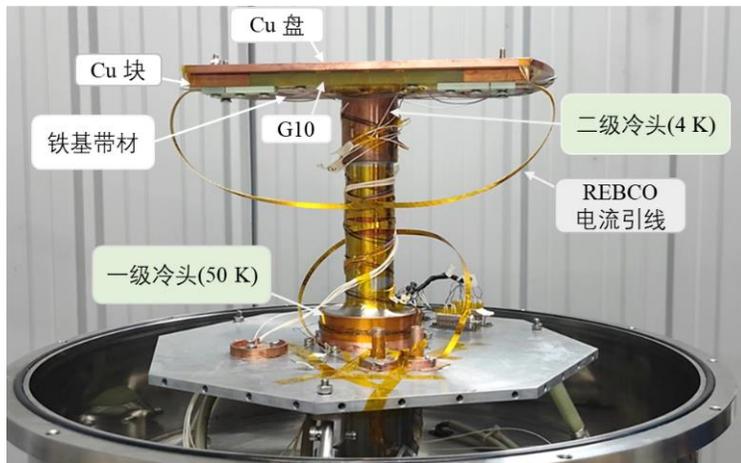
**100m long, 7-core Ba122 tapes** are fabricated by rolling process, and the  $J_c$  is continuously improving.



**In 2024, the  $J_c$  of long wires has been increased to  $10^5$  A/cm<sup>2</sup> @ 4.2 K, 10 T by optimizing fabrication process**



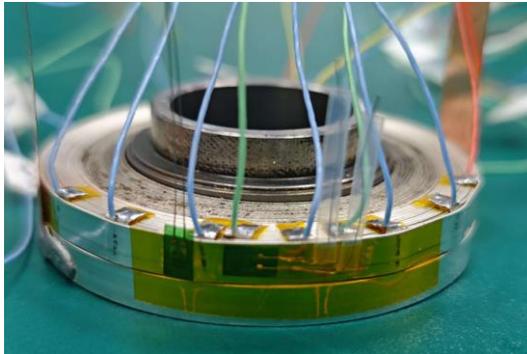
## Quench propagation study of the IBS tapes and coils



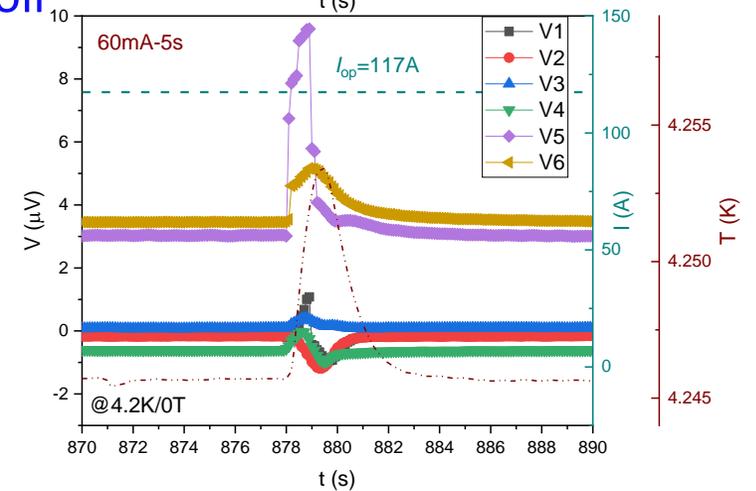
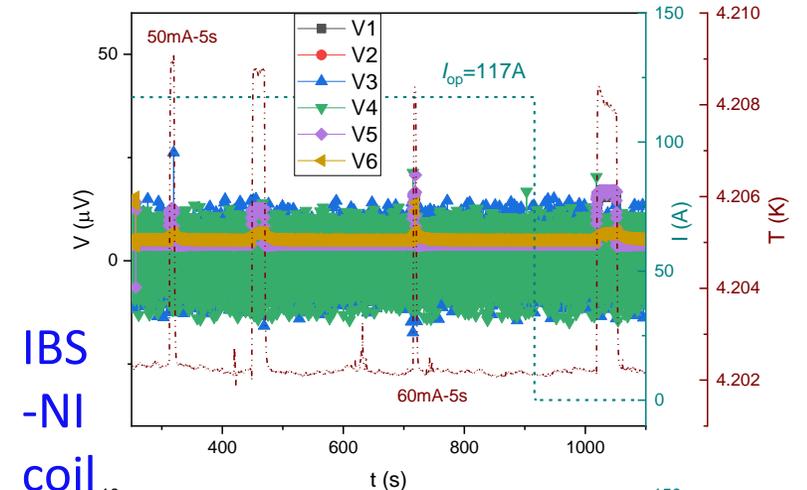
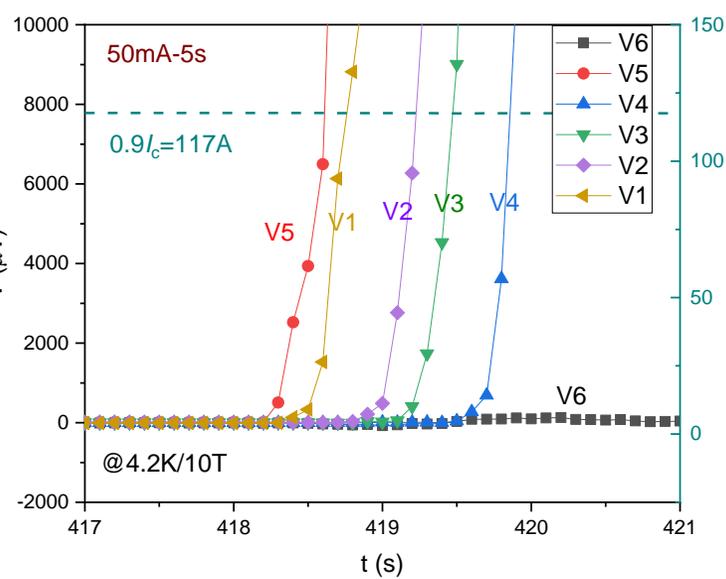
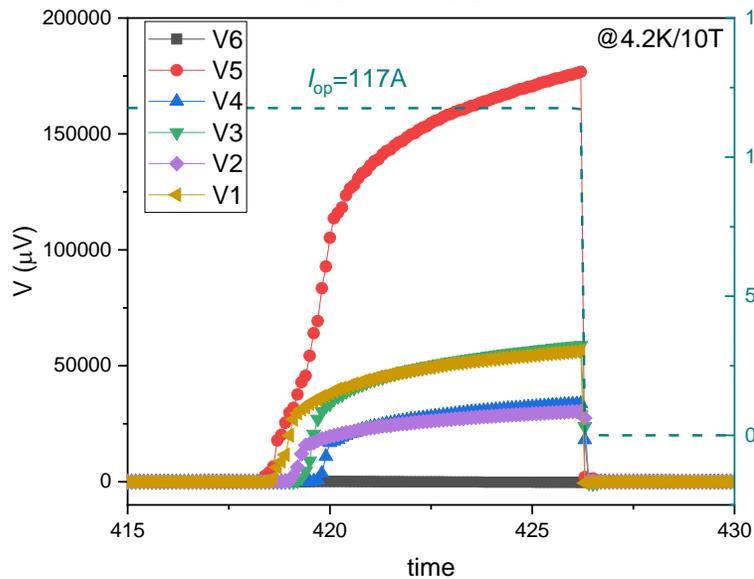
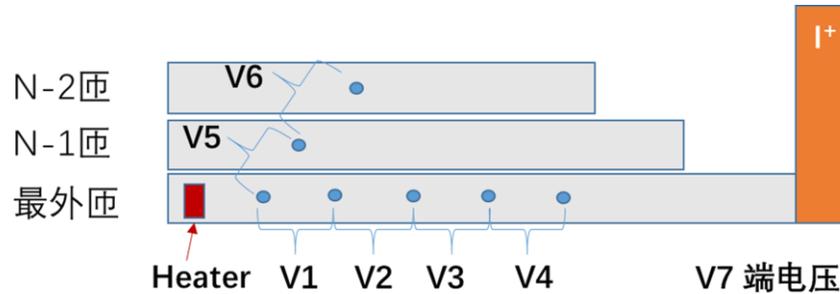
In 15~17K, when the transmission current of iron-based superconductor is 14-179A, the corresponding NZPV value is 0.4–7cm/s



## Quench propagation study of the IBS tapes and coils

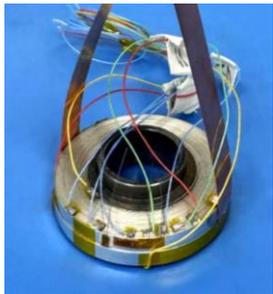
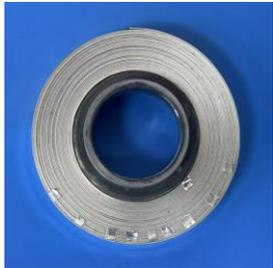


IBS-MI coil





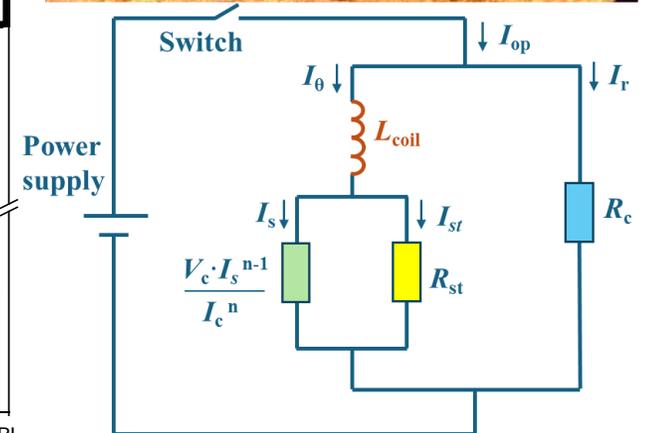
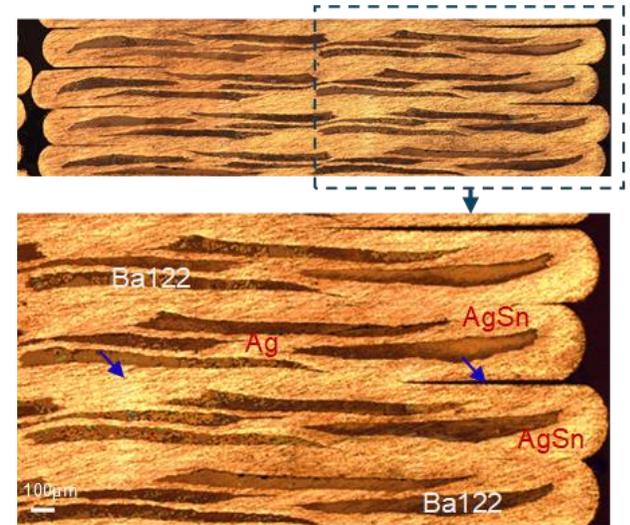
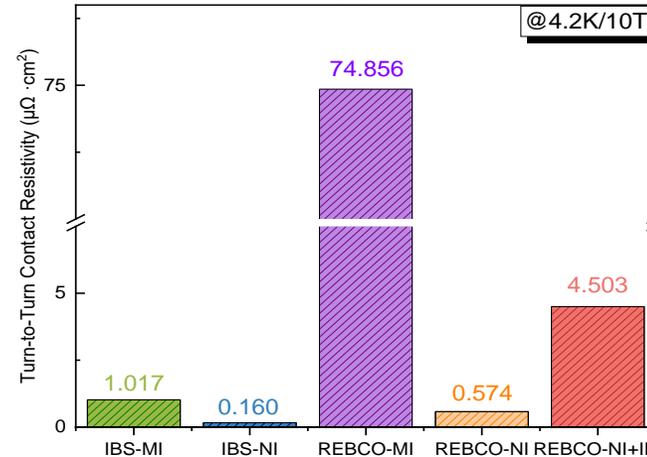
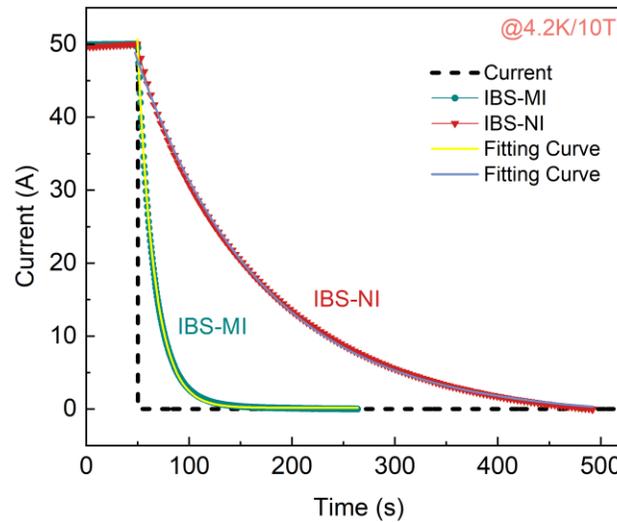
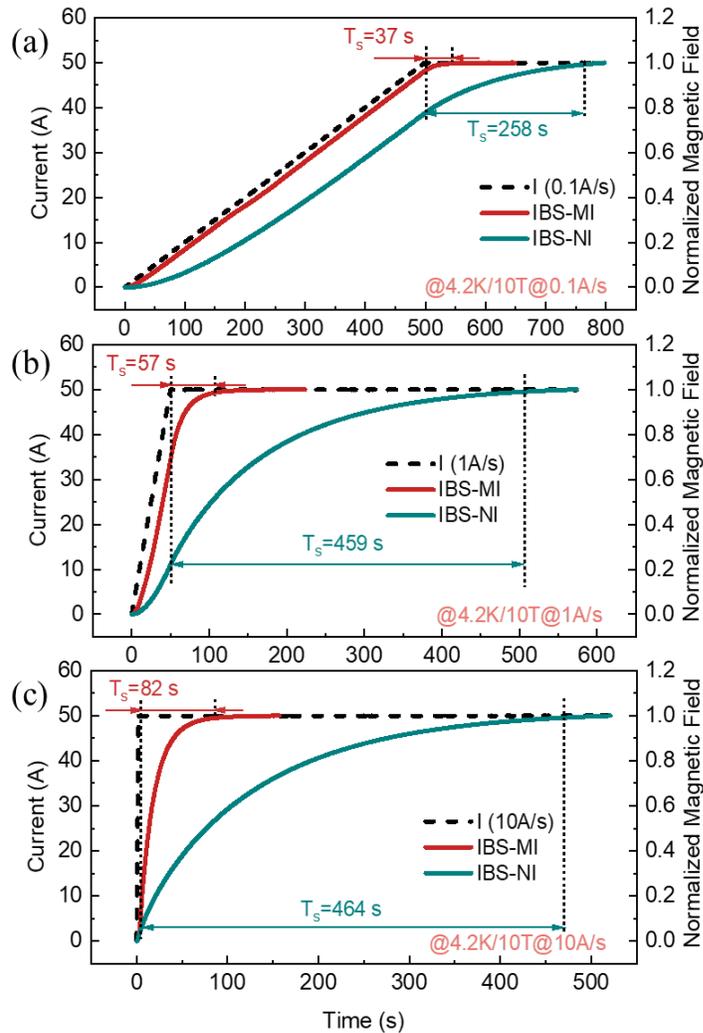
## Performance comparison with different fabrication methods



IBS coil



REBCO coil





## IBS Solenoid Coil tested at 32-35 T background field

2024 Supercond. Sci. Technol. 37 015001

IOP Publishing

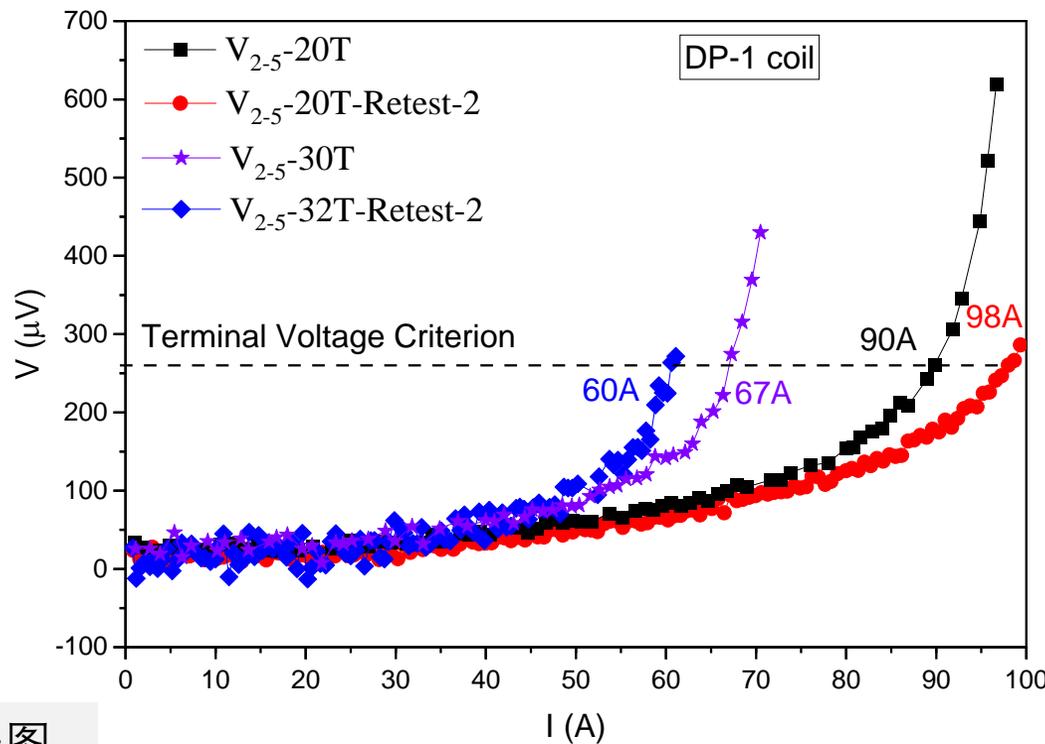
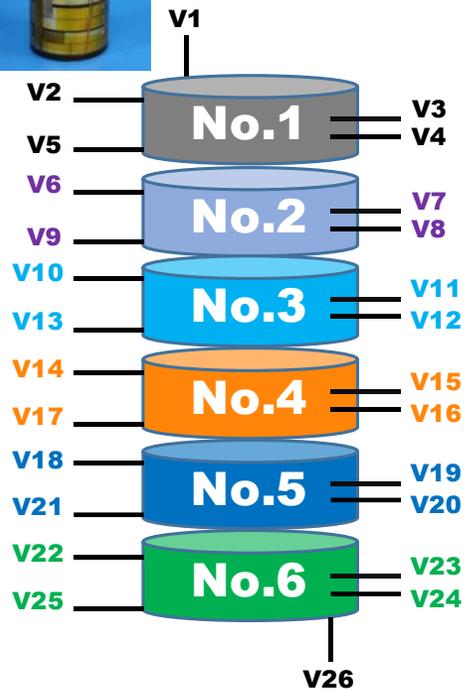
Supercond. Sci. Technol. 37 (2024) 015001 (12pp)

Superconductor Science and Technology

<https://doi.org/10.1088/1361-6668/ad0b95>

### Development of metal-insulated iron-based superconducting coils and charging tests under high magnetic fields up to 32 T

Chunyan Li<sup>1</sup>, Jin Zhou<sup>1</sup>, Yanchang Zhu<sup>2</sup>, Cong Liu<sup>2</sup>, Rui Kang<sup>1</sup>, Yingzhe Wang<sup>1</sup>, Chengtao Wang<sup>1</sup>, Ze Feng<sup>1</sup>, Juan Wang<sup>1</sup>, Xianping Zhang<sup>1</sup>, Dongliang Wang<sup>2</sup>, Donghui Jiang<sup>1</sup>, Chuanying Xi<sup>3</sup>, Xinxing Qian<sup>3</sup>, Fang Liu<sup>1</sup>, Yanwei Ma<sup>2,4</sup> and Qingjin Xu<sup>1,4</sup>



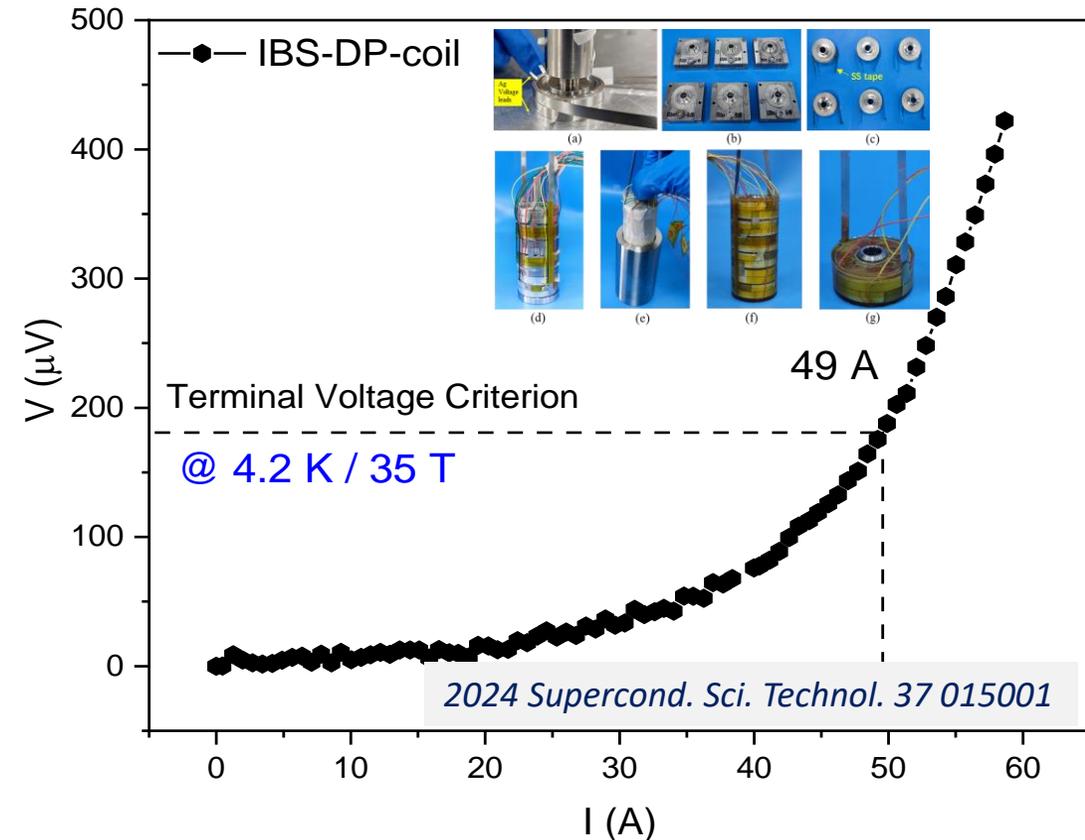
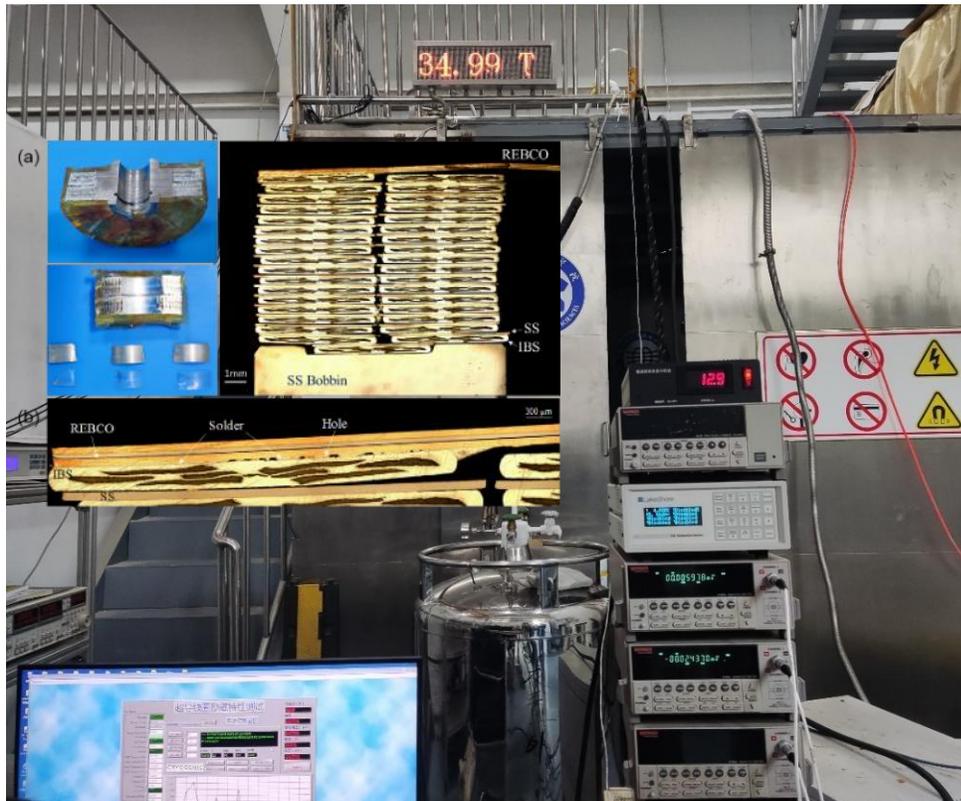
DP-6串联线圈电压引线图

Fabricated a series-connected IBS coil consisting of six DP coils and tested at 32T background field



## IBS Solenoid Coil tested at 32-35 T background field

$I_c$  of  $\Phi 34\text{mm}$ -17 turns-DPC reached **49 A at 4.2 K and 35 T**



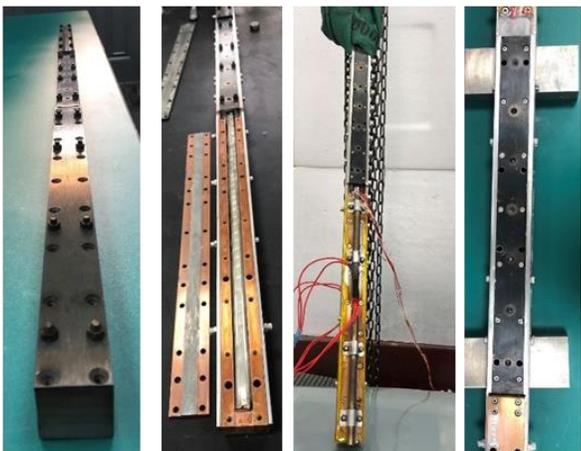
Fabricated a series-connected IBS coil consisting of six DP coils and tested at 35T background field



## Development of the first 7-kA class IBS transposed cable



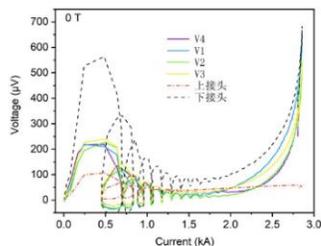
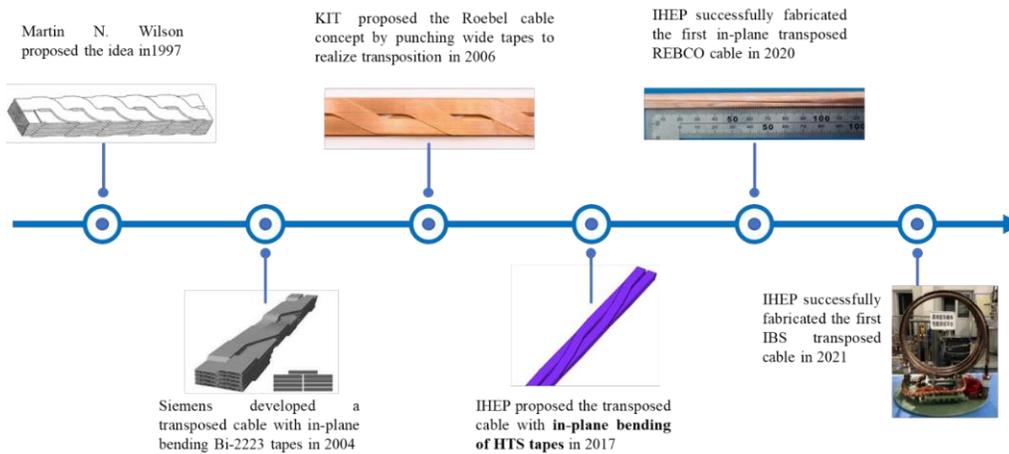
测试电缆热处理



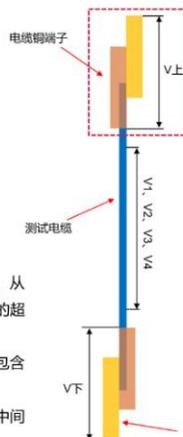
热处理后样品

接头焊接

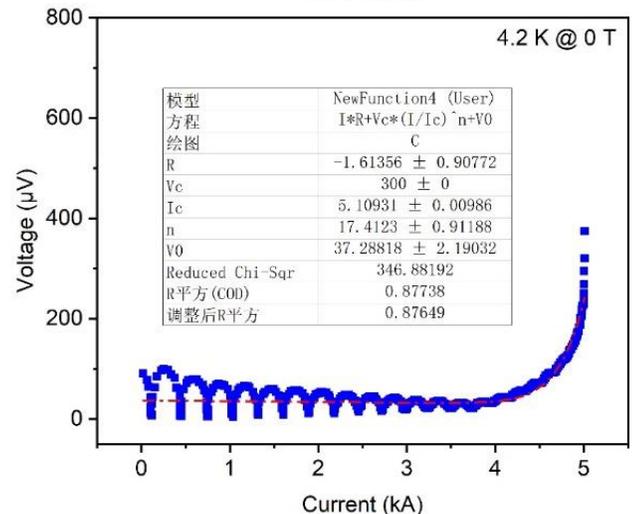
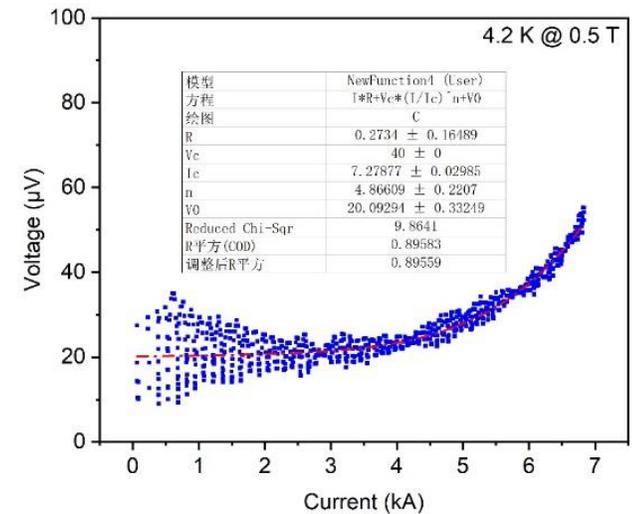
石蜡固化



- 1、上接头、V1-V4、下接头将电缆分成三部分，从V-I曲线可以确定上接头焊接质量很好，且包含的超导带性能没有损伤；
- 2、下接头的V-I曲线出现非线性的转变，说明包含在下接头中的超导带性能出现损伤；
- 3、V1-V4的转变和下接头几乎一致，是否证明中间部分的超导带也受到损伤？



- 可能出现问题的地方：
- 1、不锈钢接头替换成铜接头（操作非常小心）
  - 2、焊接头时罐锡的小孔位置容易损伤（熔的都是锡丝）
  - 3、电压引线用的比较粗，焊完后翘着，虽然用石蜡固化了，有一定的保护作用，但是石蜡的强度非常低，组装的时候，下部电压引线是折到背面安装的，有可能损伤，等样品邮寄回来确定.....
  - 4、运输.....（包装的很好）





# Development of the CCT magnets for HL-LHC



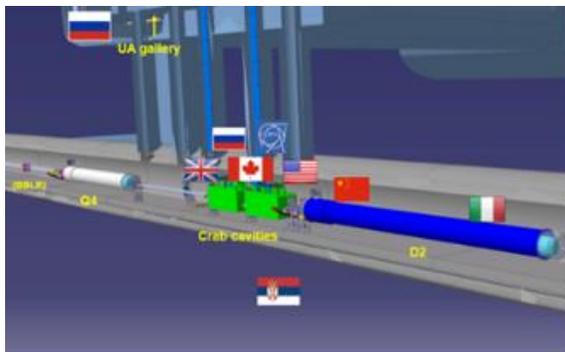
Labels in the diagram include: UA Gallery, Service cavern, Connection to LHC (UL), Service gallery (UR), SC Links, Collimators, Crab cavities, TAXN, DFM, DFX, D1, CP, Q3, Q2b, Q2a, Q1, TAXS, Q4, D2, and various national flags representing contributing countries.

HL-LHC WP3: IR magnets S. Izquierdo Bermudez D. Duarte Ramos (Deputy) August 2025		
<b>Nb<sub>3</sub>Sn magnets</b> <b>Triplet Q1-Q3</b> G. Ambrosio, S. Feher (FNAL), S. Lequembre Bermudez (CERN WPE)	<b>Nb-Ti correctors</b> <b>Orbit correctors</b> F. Toral (CIEMAT), J. Carlos Perez (CERN WPE)	<b>Nb-Ti and resistive main magnets</b> <b>Separation dipole D1</b> T. Nakamoto (KEK), J. Carlos Perez (CERN WPE)
<b>Triplet Q2</b> S. Lequembre Bermudez (CERN WPE)	<b>High order correctors</b> M. Statera (INFN LASA), J. Carlos Perez (CERN WPE)	<b>Recombination dipole D2</b> S. Fartouh (INFN Genova), A. Foussat (CERN WPE)
<b>Bunchers</b> L. Baudin (CERN WPE)	<b>D2 correctors</b> Q. Xu (IHEP), A. Foussat (CERN WPE)	<b>MQYY</b> D. Simon (CEA), A. Foussat (CERN WPE)
<b>Installation</b> S. Le Naour (CERN WPE), J. Ferradas Trullas (CERN WPE)	<b>D1-DFX Connection module</b> R. Diaz Vaz (CERN WPE)	<b>MBW and MQW</b> P. Thouret (CERN WPE)
		<b>Q4, Q10 in IR1 and IR5</b> H. Pin (CERN WPE)

Logos at the bottom: CERN, C22, IHEP, CERN, US HL-LHC ACP, INFN, and CERN.



# Development of the CCT magnets for HL-LHC



合作协议签订

首套正式磁体发往CERN  
与其他磁体集成后水平性能测试

磁体隧道安装及调试



2018

2020

2022

2024

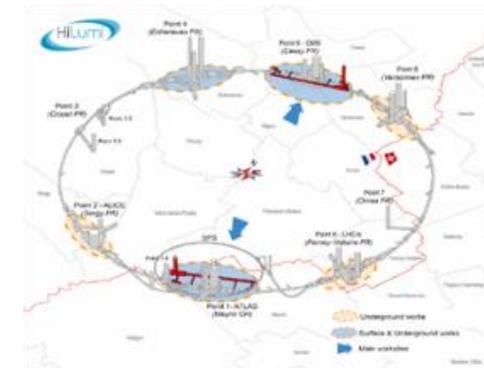
2026

2027

全尺寸样机通过测试后  
发往CERN

完成全部12套正式磁体  
参加LHC束流调控

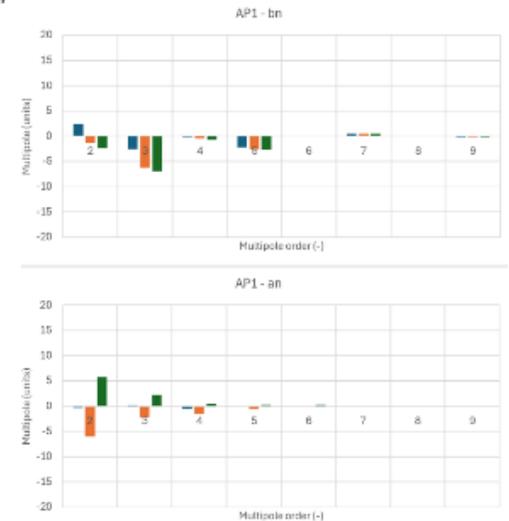
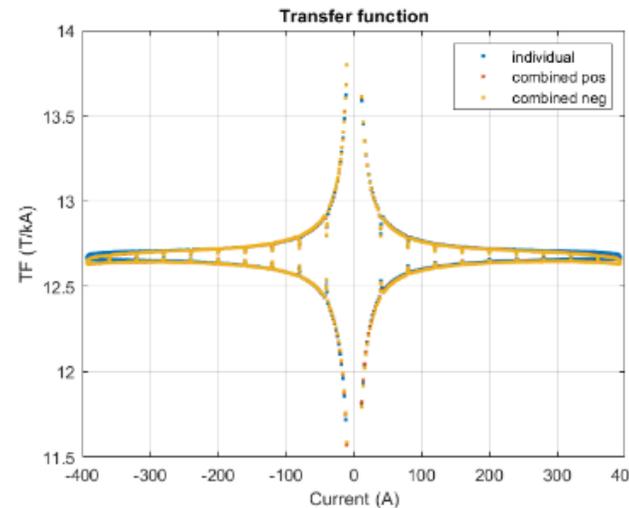
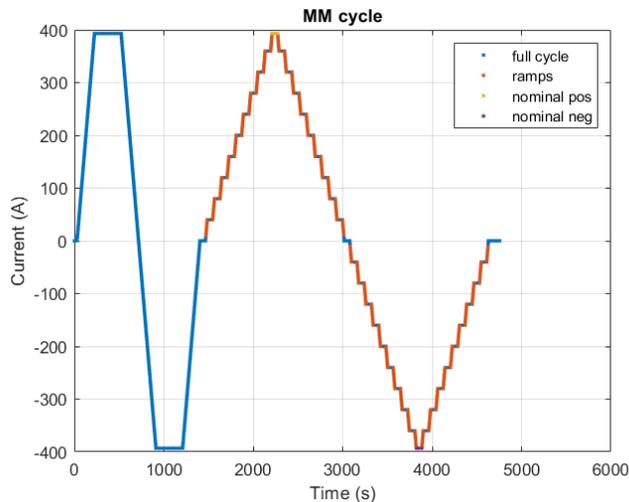
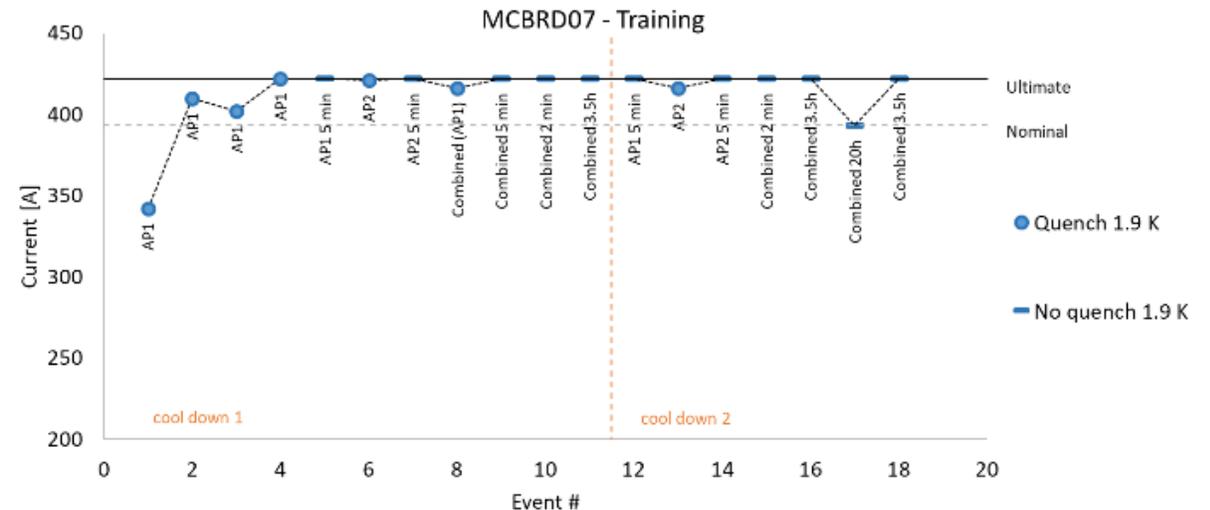
HL-LHC束流调试





- All the delivered magnets have been successfully tested at CERN.
- All the tested magnets reached the design target: field strength, field quality, operating stability...

Performance Test at CERN





# Summary



- Long-term high field HTS magnet R&D is ongoing for future high-energy accelerators at IHEP-CAS
- Hybrid model dipoles with LTS and HTS are being developed from 2021. ReBCO coils reached record-breaking dipole field at 4.2 K: beyond 7 T in the aperture and beyond 14 T with Nb<sub>3</sub>Sn coils, but quench protection issue still to be solved
- Continuously pioneer IBS related conductor and magnet R&D: Significant improvement in  $J_e$  of IBS tape in 2025, IBS coil  $I_c$  reached 49 A at 35 T. 7 kA class IBS transposed cable successfully developed
- Delivery of all HL-LHC CCT magnets expected to be completed by early 2026. Continuous collaboration with CERN on High Field HTS technology is expected for the next years

*Thanks for your attention!*