



中国科学院上海高等研究院
SHANGHAI ADVANCED RESEARCH INSTITUTE, CHINESE ACADEMY OF SCIENCES



5th International Workshop on Cooling Systems for
HTS Applications

Preliminary Electromagnetic Design of a 15 T HTS Racetrack Superconducting Magnet

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Date: Oct 27, 2026

□ Overview of Institute and Research Group

Shanghai Synchrotron Radiation Facility (SSRF)
432 m, 3.5 GeV, user operation started from 2009

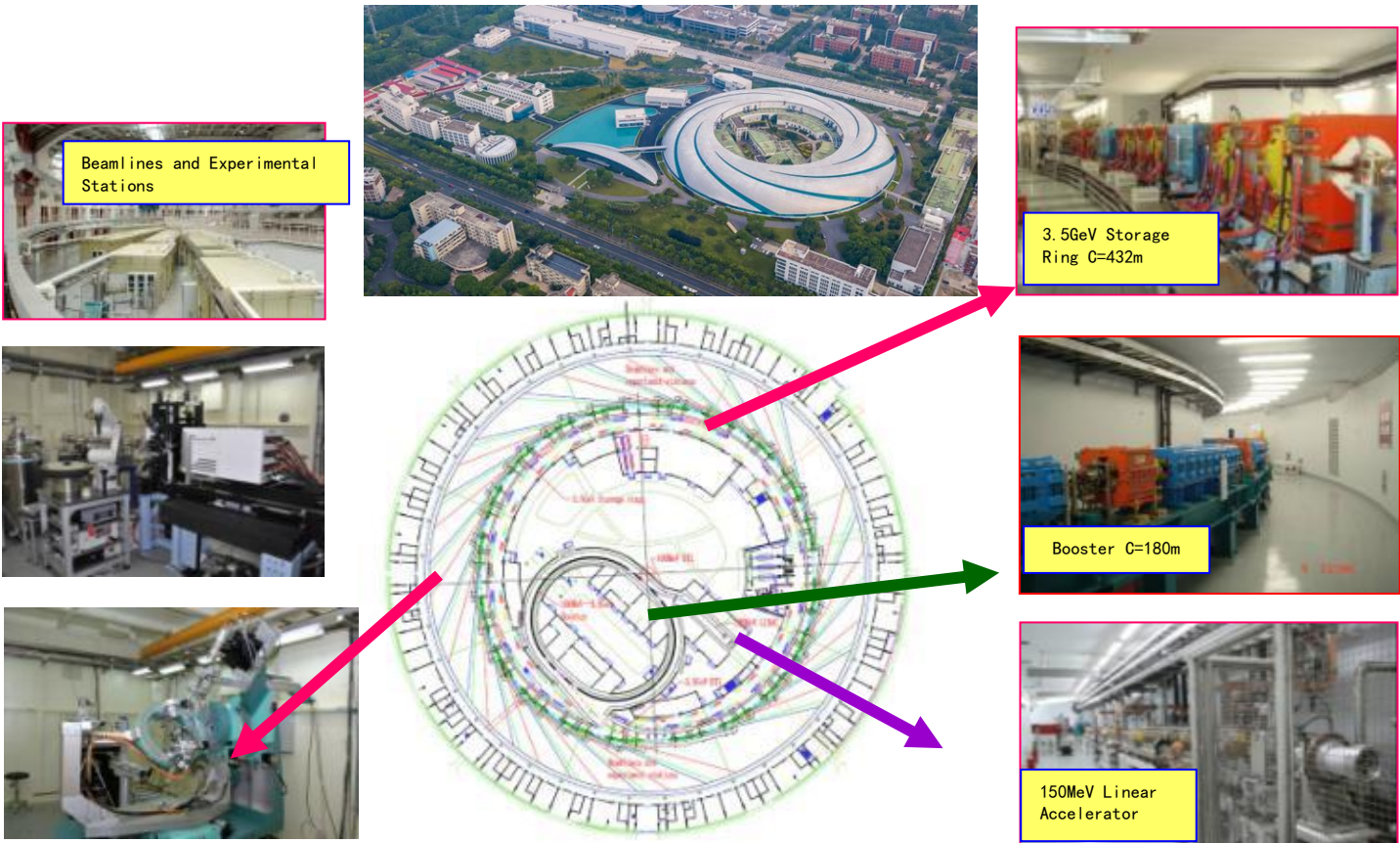
Shanghai Hard X-ray FEL facility (SHINE)
3.1 km, 8 GeV, under construction

Shanghai Soft X-ray FEL facility (SXFEL)
532 m, 1.5 GeV, user operation started from 2023



Overview of Institute and Research Group

SSRF is a 3.5 GeV third generation light source, opened to users in May 2009, now it has 38 beamlines and 55 end-stations in operation for user experiments.



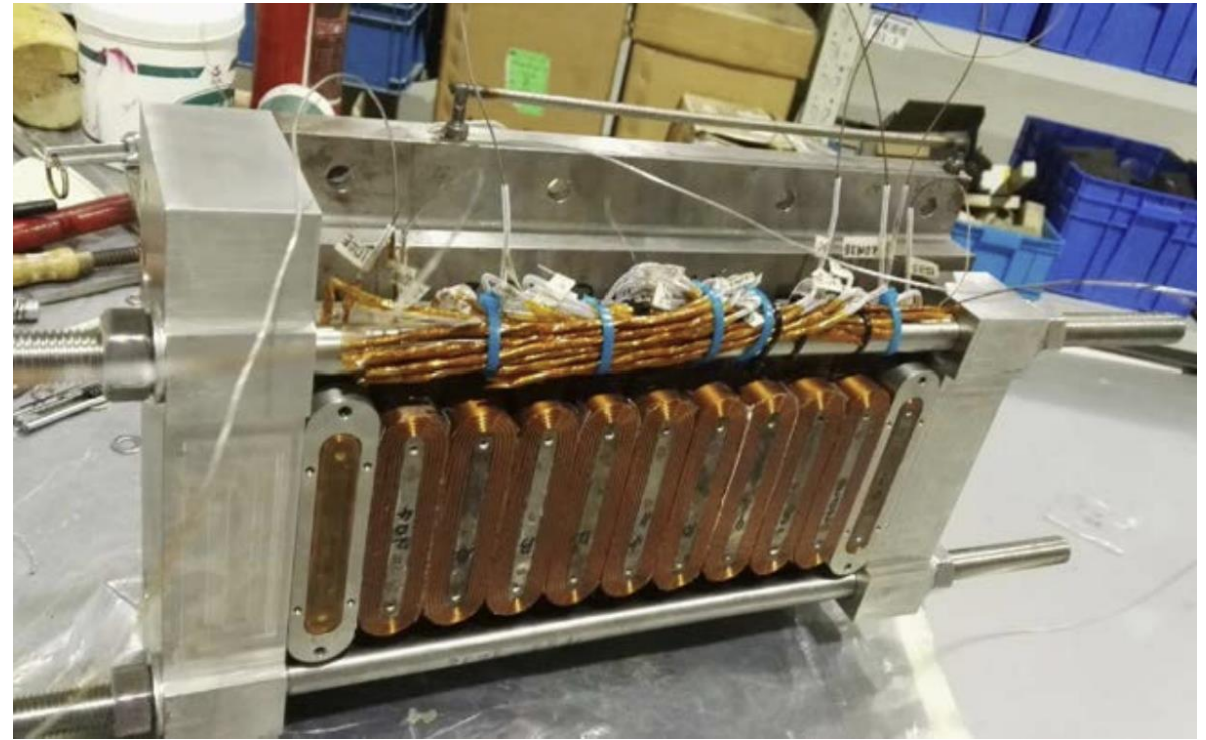
SSRF operation Parameter	
Storage Ring Energy	3.5 GeV
Circumference	432m
Natural Emittance	4.2 nm-rad
Multi-bunch Single-bunch	200-300 mA 20 mA
Coupling	0.3 ~ 0.7%
RF Voltage	4-5 MV
Beam Lifetime	10 ~ 20 hrs
Linac Energy	150 MeV
Booster Output Energy	3.5 GeV
Injection interval	10 min (top-up)

□ Overview of Institute and Research Group

- The superconducting wiggler at SSRF is a home-developed high-field insertion device with a peak field of 4.2 T. It serves as the photon source for the BL12SW hard X-ray beamline



NbTi wiggler in SSRF



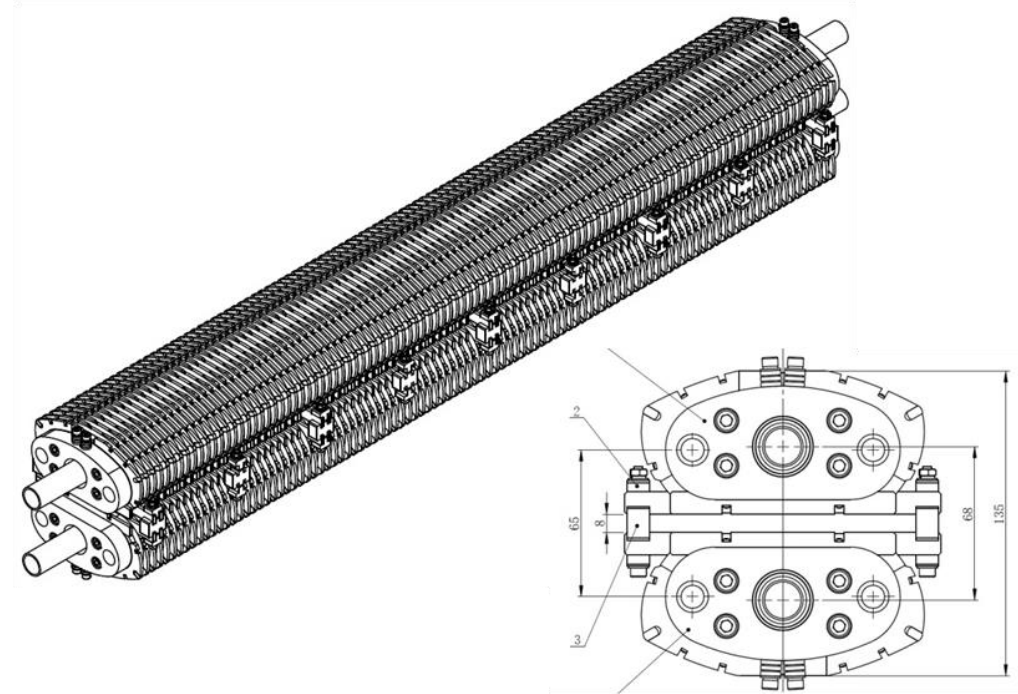
The model coil of NbTi wiggler

□ Overview of Institute and Research Group

- As China's first SCU with storage-ring beam commissioning, the SSRF superconducting undulator prototype has a 16 mm period, 9.5 mm gap and 50 periods, with 0.67 T design peak field and 0.57 T measured field.



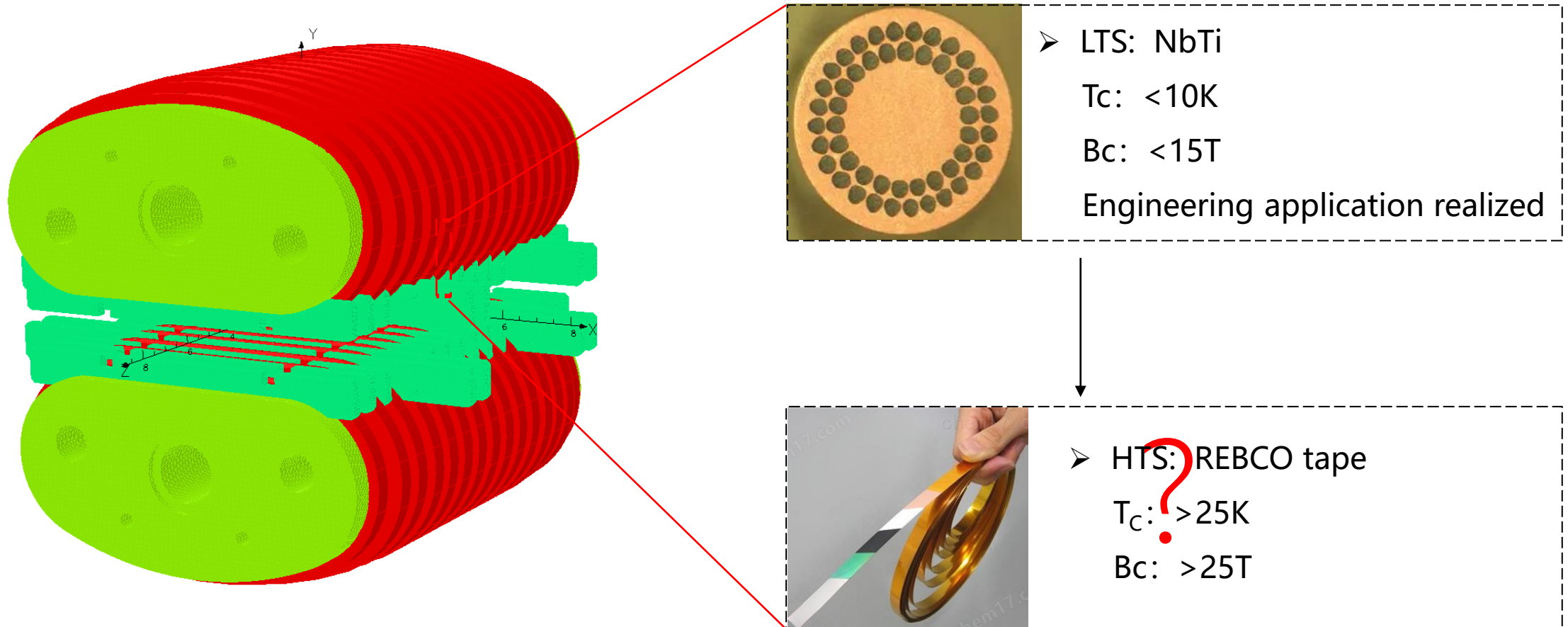
HTS wiggler in SSRF



The model coil of undupator

□ Overview of Institute and Research Group

- So far, SSRF has limited experience in HTS magnet applications. We aim to build up relevant technical capabilities starting from the design of a 15 T HTS racetrack coil.



1. Requirements of the 15 T HTS coil

Main parameter for 15 T HTS coil

Central Field	>10 T
B _{max} of coil	<20 T
Arc Radius	5 mm
Max. Stress	<600 MPa
Cooling Method	LHe bath cooling
Operation temperature	4.2K-20 K
-	VPI
-	Stycast 2850+CAT 24LV
I _{op} /I _c	≤50%

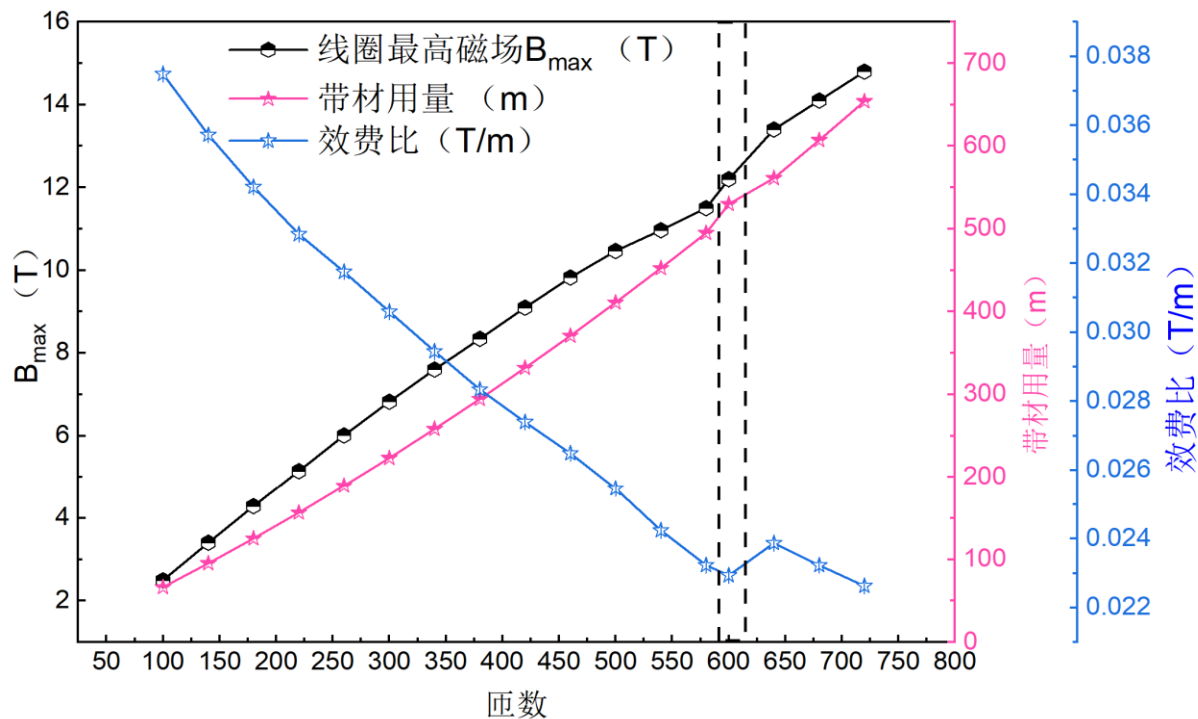
Parameters of Thin-substrate HTS Tapes of SST	
width (mm)	4
thickness (μm)	50
I _c (77 K, 自场)	200 A
I _c (4.2 K, 15 T)	200*2.29 A
Bending radius (mm)	5

应用领域	强电应用	超导带宽度	等级	I _c (77K, s.f.)
	 超导电力	3mm	常规	85-120A
			高性能	120-145A
			超高性能	145-165A
		4mm	常规	110-160A
			高性能	160-200A
			超高性能	200-250A
		12mm	常规	360-500A
			高性能	500-600A
			超高性能	600-800A
	基带厚度/材料	30 μm 哈氏合金		

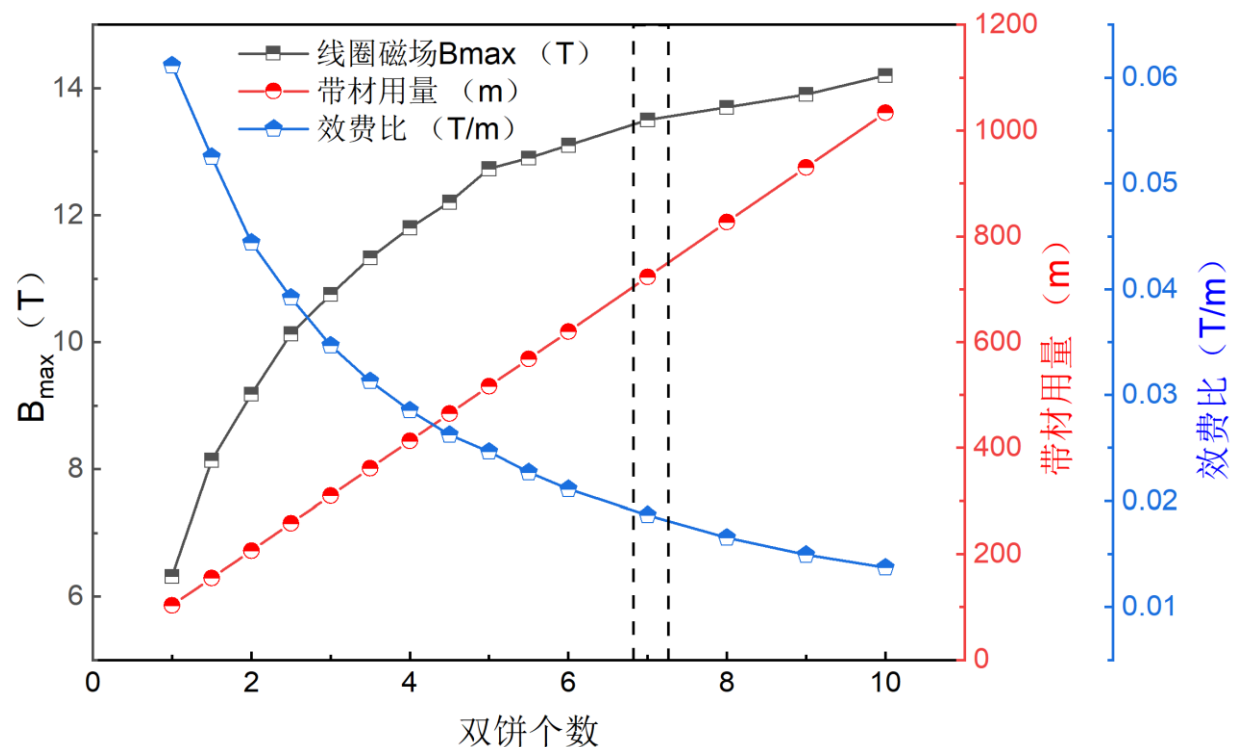
2. EM Optimization of the 15 T Racetrack Coil



- Turn optimization reveals saturated field and cost-efficiency at 600 turns (5 DBs, 1 mm gap, 50 mm straight length, 4 mm arc radius, 200 A operating current).



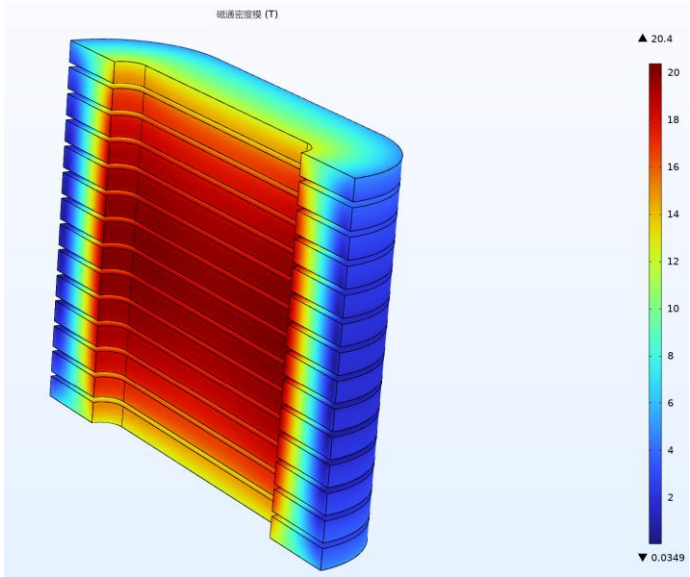
- Double-pancake optimization shows saturated field and cost-efficiency at 7 pancakes (600 turns, 1 mm inter-pancake gap, 50 mm straight length, 4 mm arc radius, 200 A operating current).



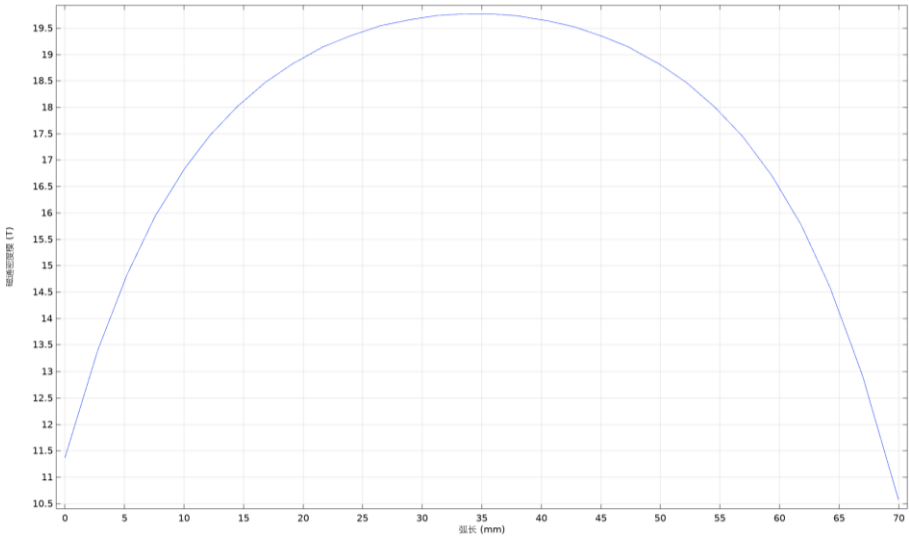
Conclusion: **7 double pancakes with 600 turns each DP** minimize HTS tape consumption.

2. EM Optimization of the 15 T Racetrack Coil

Straight-section length	50 mm
Arc radius	5 mm
Number of DPs	7
Turns	600×7
I_{op}	300 A
I_c	326 A
Length of HTS tape	120*7
B_{max}	20.4
B_{center}	19.7
Hoop stress	220 MPa
Radial stress	50 MPa



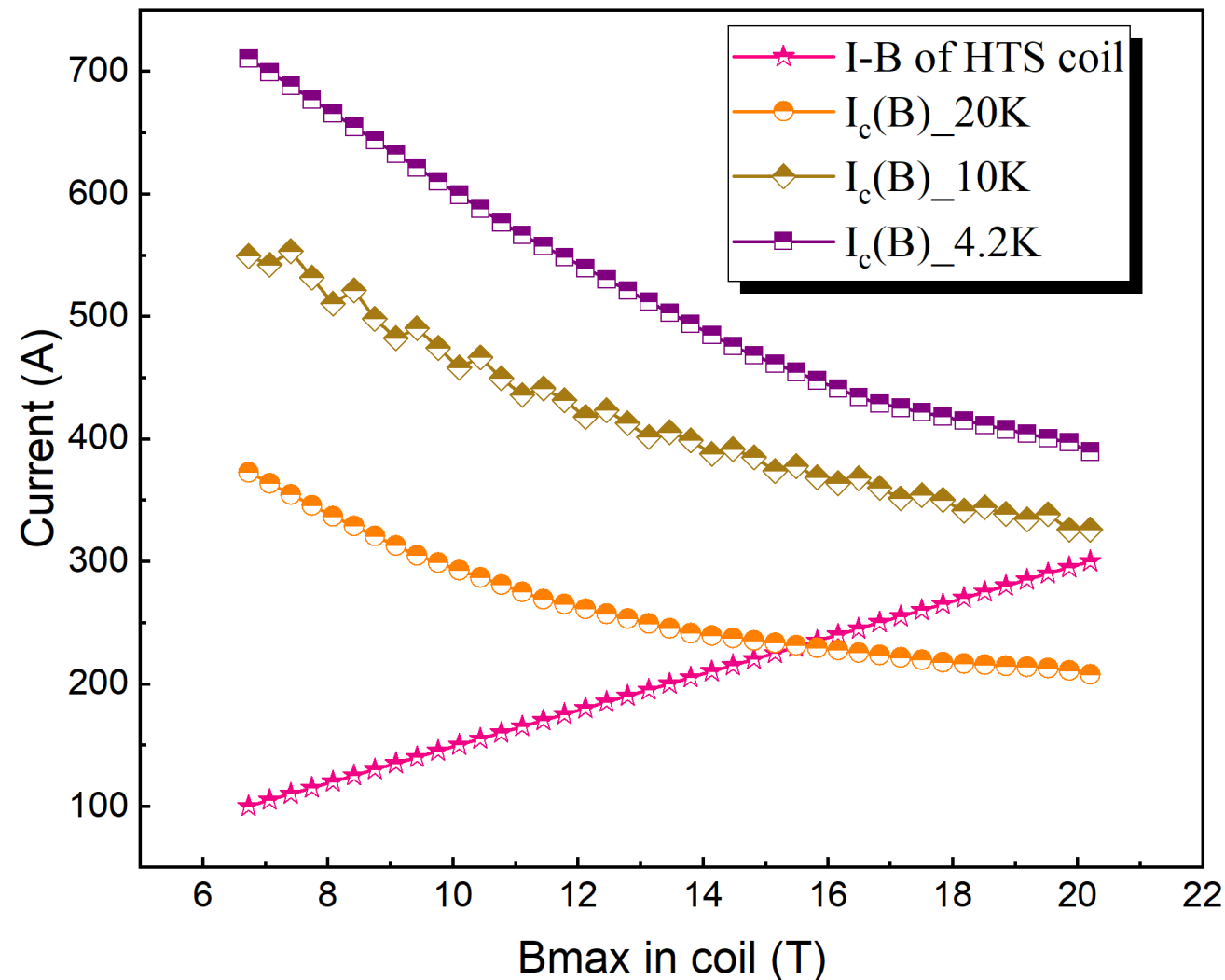
EM results for HTS coil (Bmax=20.4 T)



On-axis Magnetic Field Distribution

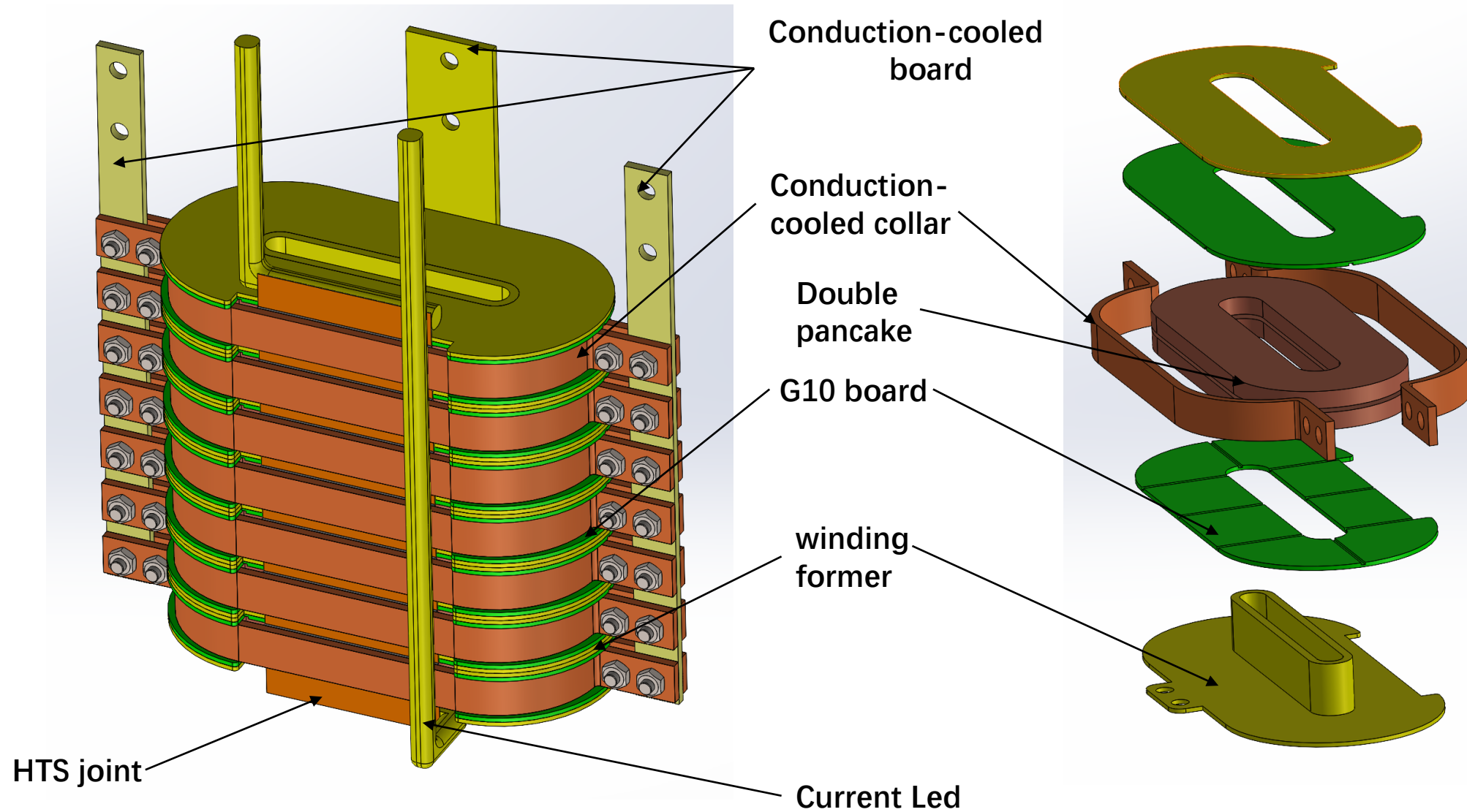
2. EM Optimization of the 15 T Racetrack Coil

- The previous current and magnetic field were near the coil’ s performance limit. Based on simulation results, we adjusted it to a central field of **~15 T at 235 A**.



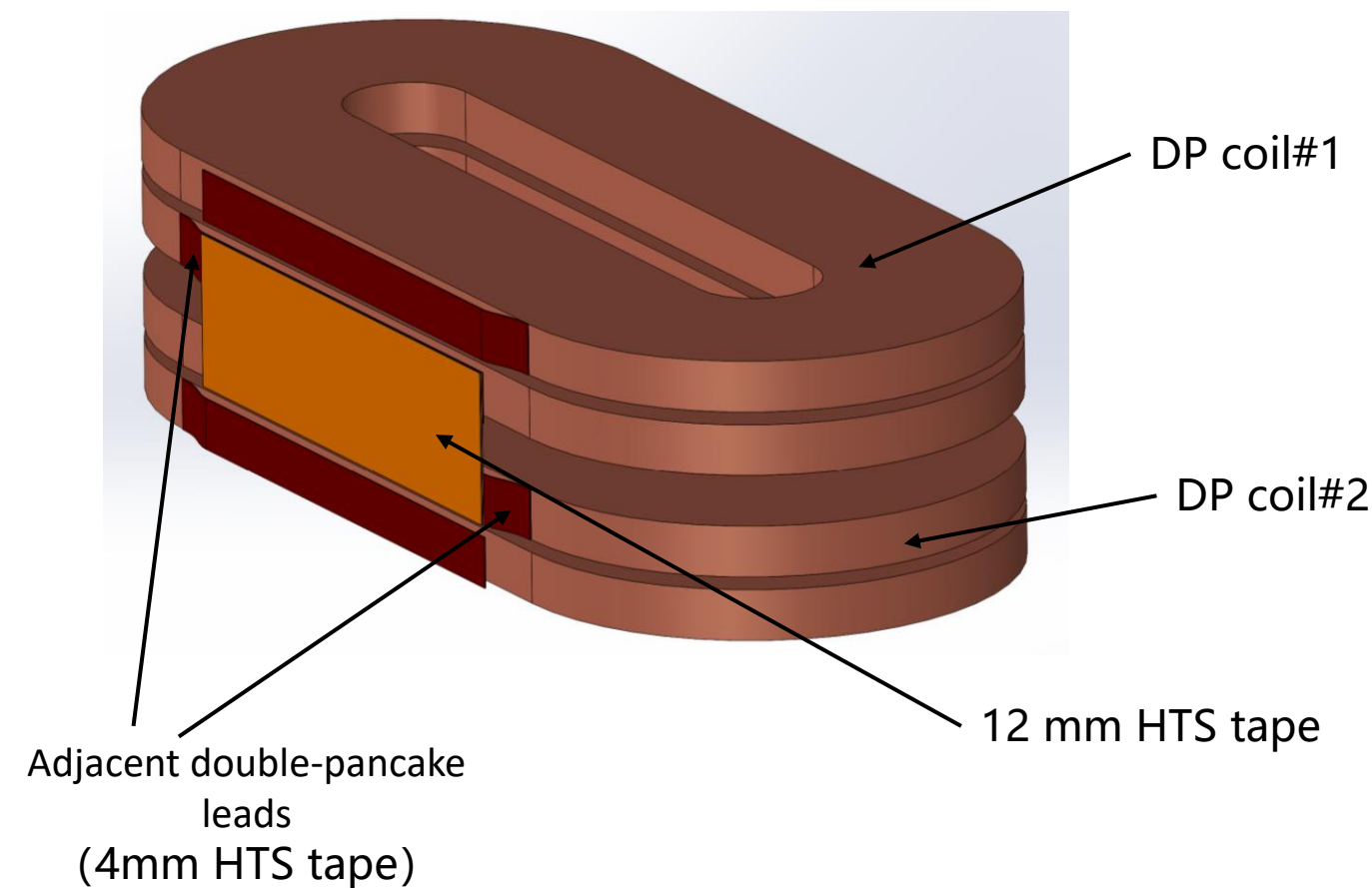
Straight-section length	50 mm
Arc radius	5 mm
Number of DPs	7
Turns	600×7
I_{op}	235 A
T_{op}	4.2 K
I_c	478 A
B_{max}	15.7
B_{center}	15.1

3. Structural Design of the 15 T Racetrack Coil



3. Structural Design of the 15 T Racetrack Coil

- Bridge-joint structure: adjacent double pancakes bridged by 12 mm-wide tape, Sn63Pb37 solder, melting point 183 °C



典型成分的软钎焊料合金

合金类型	熔点(°C)	电阻率 μΩ·m	热导率 W/M.K	热膨胀系数 10 ⁻⁶ /°C	抗拉强度 Mpa
Sn-In51-Bi32.5	60	0.522		22	33.4
In-Bi33.7	72	0.422			26
Sn-In26-Bi57	79				37
Sn-In29.7-Bi54	81				
In-Bi67	109				
Sn-In52	118	0.147	34	20	12
Sn-Bi58	138	0.383	19	15	55.16
In97-Ag3	143	0.075	73	22	5.5
In90-Sn10	143-151				9.7
In100	157	0.072	86	29	1.88
Sn-Ag2.8-In20	175-187	0.176	54	28	46.8
Sn-Bi17-Cu0.5	180-209	0.155	44.5	19	37.5
Sn-Ag3.5-Bi0.5-InX	194-206	0.138	52	26	48
Sn-Ag3.1-InX	204-205	0.131	56	27	51
Sn-Ag3.0-Cu0.5	217-218	0.132	58	21	50
Sn-Ag3.8-Cu0.7	217-220	0.132	57	22	48
Sn-Ag4.0-Cu0.5	217-220	0.132	62		51.5
Sn-Ag0.3-Cu0.7	217-221	0.133	60	20	40
Sn-Ag1.0-Cu0.5	215-227	0.133	60		43
Sn-Ag3.5	221	0.108	33	30	39
Sn-Cu0.7	227	0.133	64	26	34.5
Sn100	232	0.111	73	24	13.1
Sn-Sb5	245-250	0.145	28	31	40.7
Sn-Sb10	245-266	0.149	42	27	44
Sn-Au80	280	0.224	57	16	276
Ge-Au88	356	0.151	44	13.4	185
Zn-Al-CuX	382	0.124	76	27	226
Sn-Pb37	183	0.146	51	25	52
Sn-Pb36-Ag2	179	0.145	42	27	44
Sn-Ag2.5-Pb92.5	287-296	0.2	26	24	29.03
Sn-Ag2.5-Pb95.5	299-304	0.23	25	24	31



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Thank you for your attention!