25.1T generation in 25T cryogen-free superconducting magnet (25T-CSM) with a modified Bi2223 insert

Satoshi Awaji[1], Arnaud Badel[1#], Kohki Takahashi[1], Tatsunori Okada[1], Satoshi Hanai[2], Hiroshi Miyazaki[2*], Shigeru Ioka[2]

1 High Field Laboratory for Superconducting Materials, Institute for Materials Research, Tohoku University

2 Toshiba Energy System & Solutions Corporation

Present address: #G2ELab-CNRS, *Kyushu Univ.

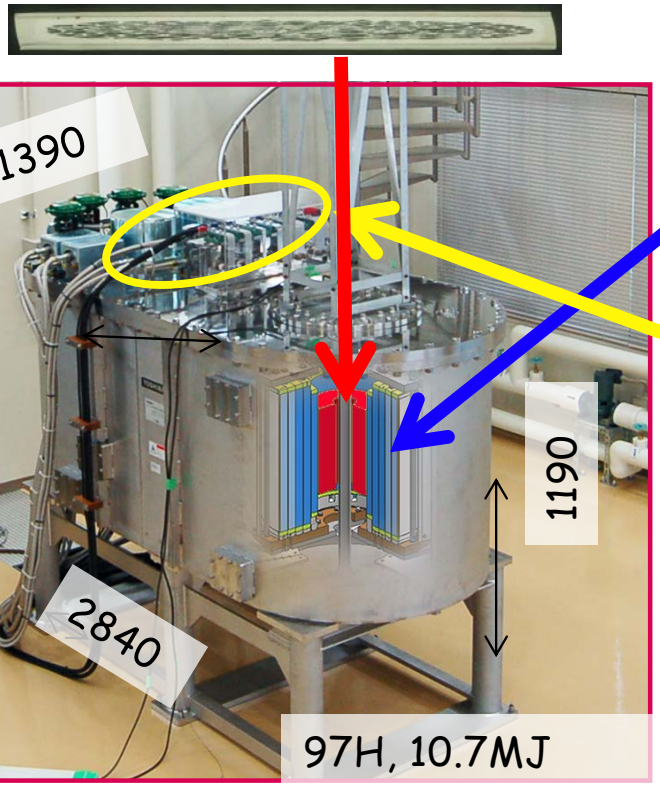
25T Cryogen-free Superconducting Magnet (25T-CSM)

Magnets (HTS-Bi2223): 10.6T@188A

38 Ni-alloy/Bi2223 double pancakes

ϕ96mm x ϕ280 mm x h390 mm

Max. hoop stress 323 MPa

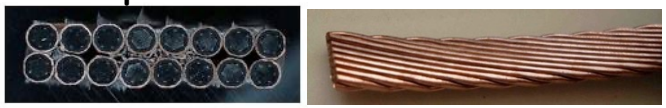


Magnets (LTS): 14T@854A

3 CuNb/Nb3Sn Rutherford solenoids

ϕ300 mm x ϕ539 mm x h628 mm

Max. hoop stress 251MPa



3 NbTi Rutherford solenoids

ϕ545 mm x ϕ712 mm x h628 mm

Max. hoop stress 138 MPa

Cooling system

Conduction cooling using He circulation

Shield: 2 x 1 stg GM cryocooler

HTS: 2 x 4K-GM cryocooler

(3W@4.2K, 10W@8K)

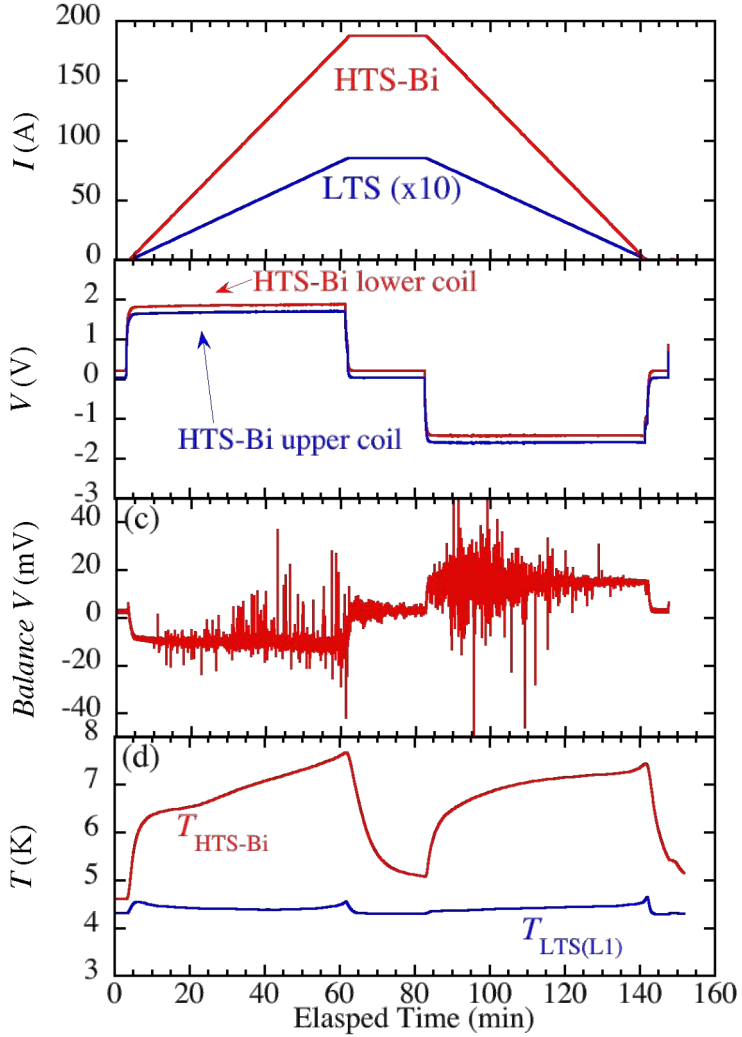
LTS: 2 x GM/JT cryocooler (8.6W@4.3K)

Awaji *et al.*, SuST. **30** (2017) 065001

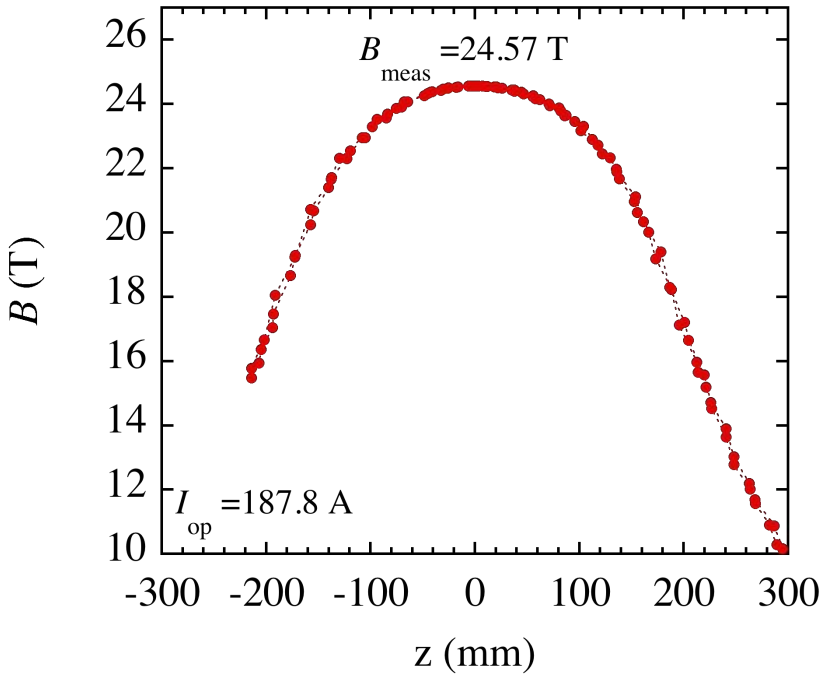
Design of a 25T-CSM

		Bi2223	Nb3Sn	Nb3Sn	Nb3Sn	NbTi	NbTi	NbTi
Current	A	203	854					
Inner radius	mm	48.0	149.5	185.3	228.6	271.7	301.6	312.9
Outer radius	mm	138.9	182.4	226.4	270.1	301.6	311.9	356.3
Height	mm	389.1	542.0	630.3	680.4	629.5	629.5	629.5
Space current density	A/mm^2	110	67.6	67.4	66.7	68.9	84.7	86.7
No of turns/layer	-	76(38DP)	80	93	93	95	107	107
No of layer	-	257 (ave.)	18	22	22	16	6	26
Total No of turns	-	19532	1438	2043	2043	1518	641	2779
Bmax	T	25.6	13.8	11.3	8.4	6.8	6.2	5.9
Br	T	4.14	4.65	5.58	5.71	5.71	5.71	5.52
B0	T	11.50	2.43	2.91	2.73	1.91	0.78	3.25
Width of conductor	mm	4.5	6.45	6.45	6.45	6.30	5.57	5.57
Thickness of conductor	mm	0.31	1.53	1.53	1.53	1.50	1.31	1.31
Thickness of layer insulation	mm	0.07	0.075	0.075	0.075	0.075	0.075	0.075
Jcon	A/mm^2	150.4	106.2	106.2	106.2	106.2	138.6	138.6
Tcs	K		6.69	8.37	9.94	5.98	6.20	6.39
Averaged compressive stress	MPa	-32	-38	-50	-48	-47	-55	-92
Hoop Stress BJR	MPa	-	-	-	-	-	-	-
Hoop stress Wilson	MPa	323	252	244	202	138	113	52

24.6T achievement

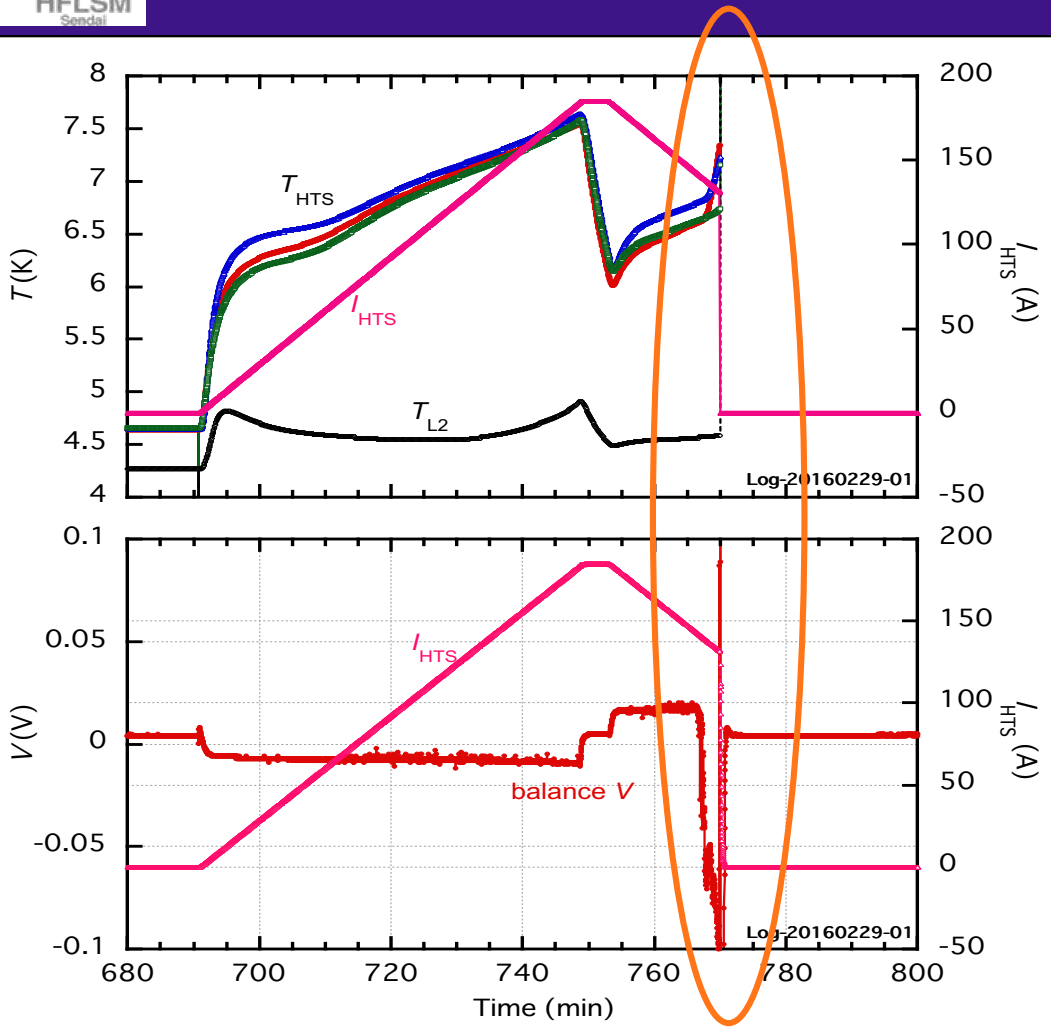


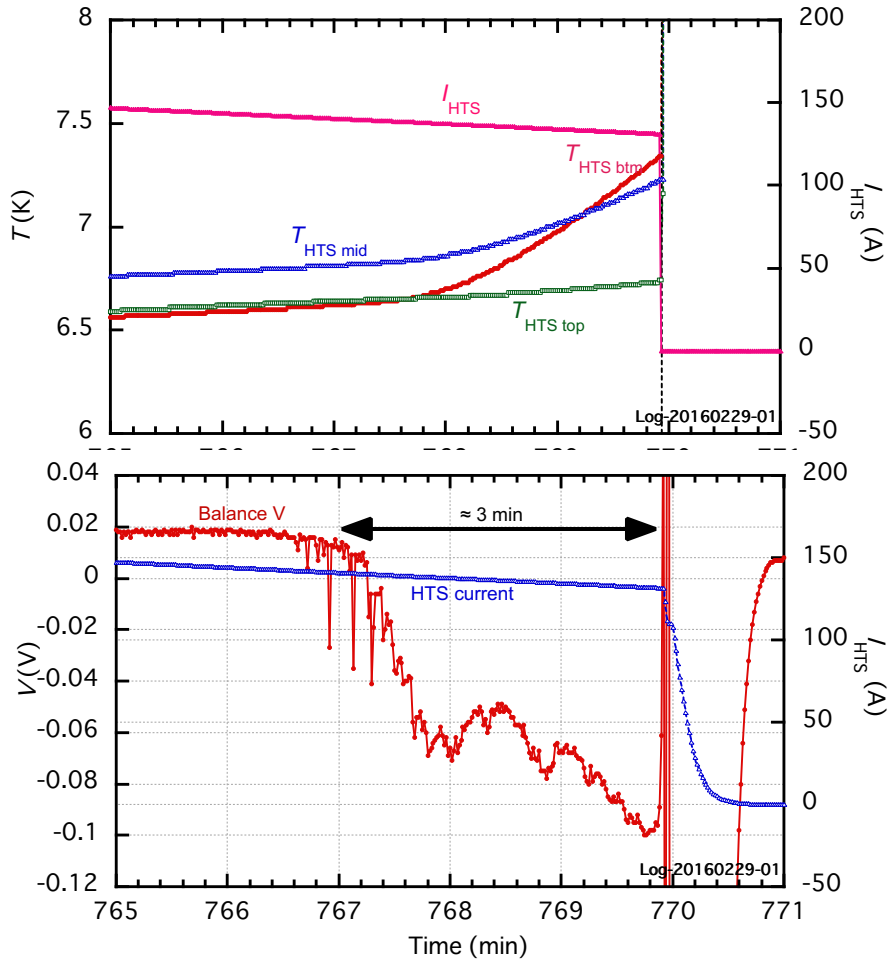
24.6 T @I_{HTS}=187.8A I_{LTS}=854A



Operation as a user magnet since 2016.

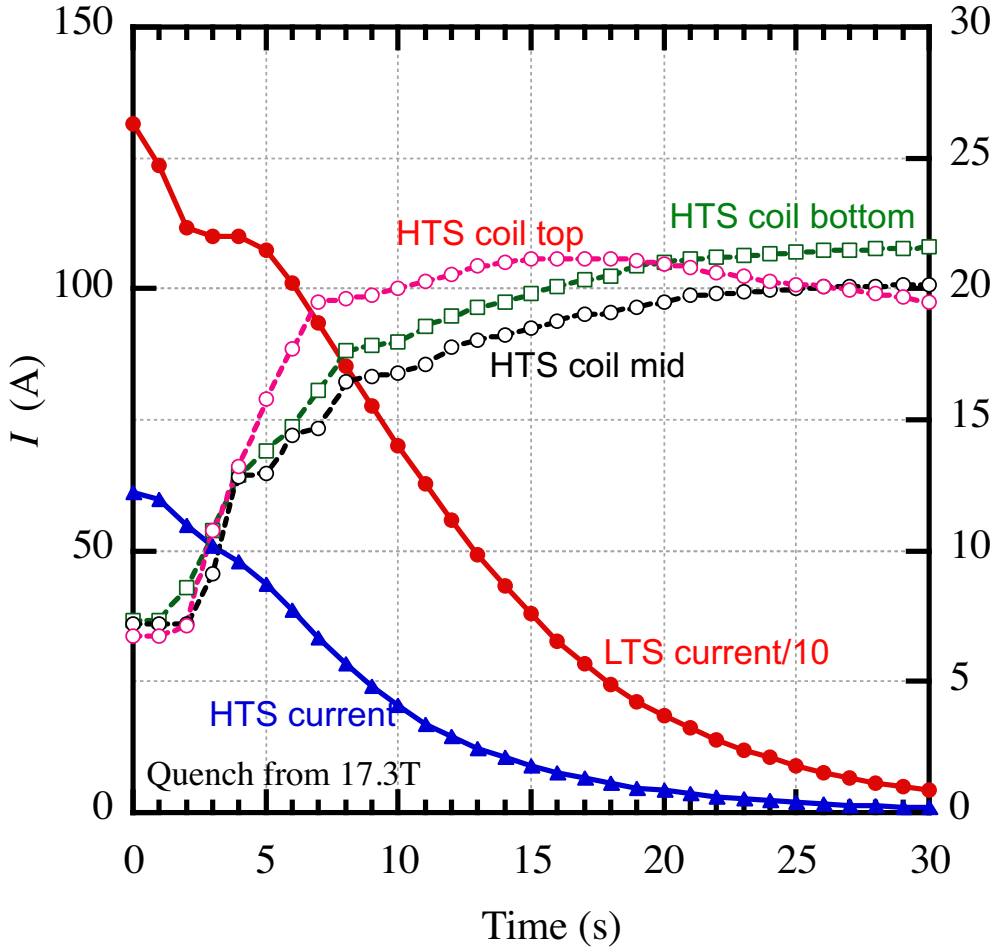
Quench at 17.3T in 2016

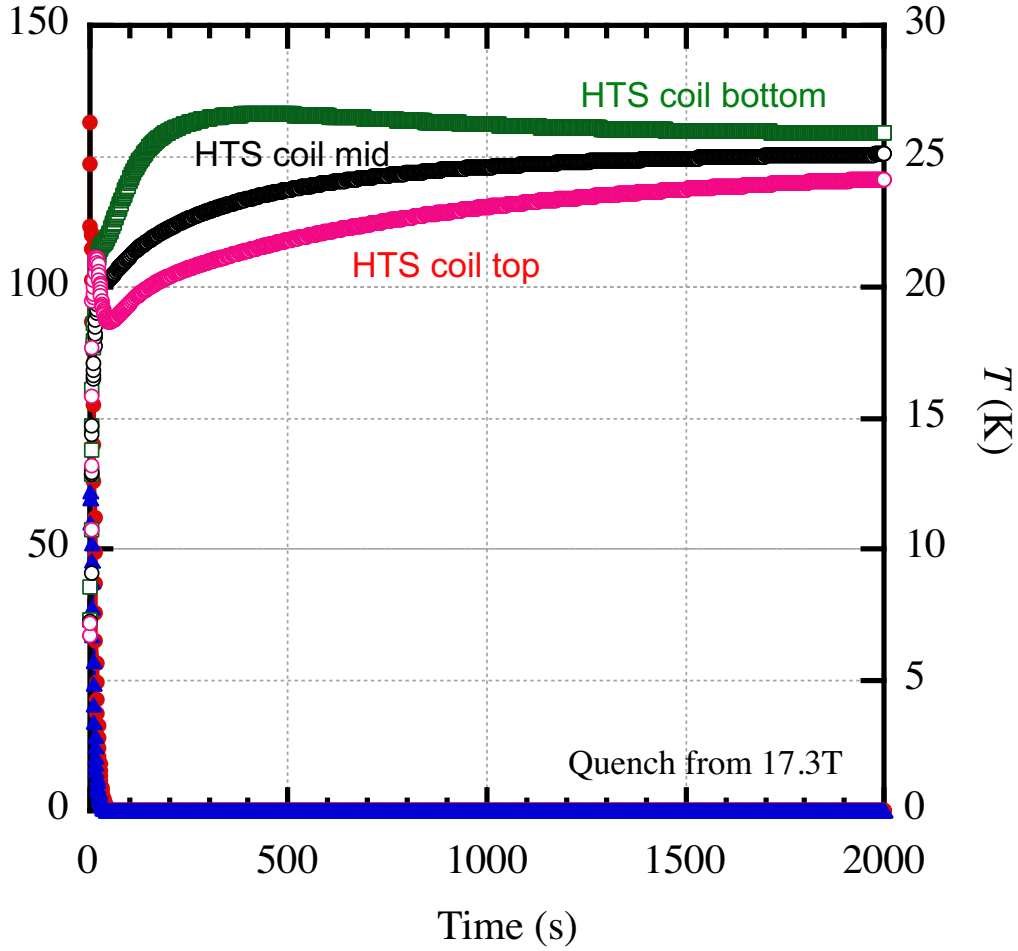




Local heating and thermal runaway?

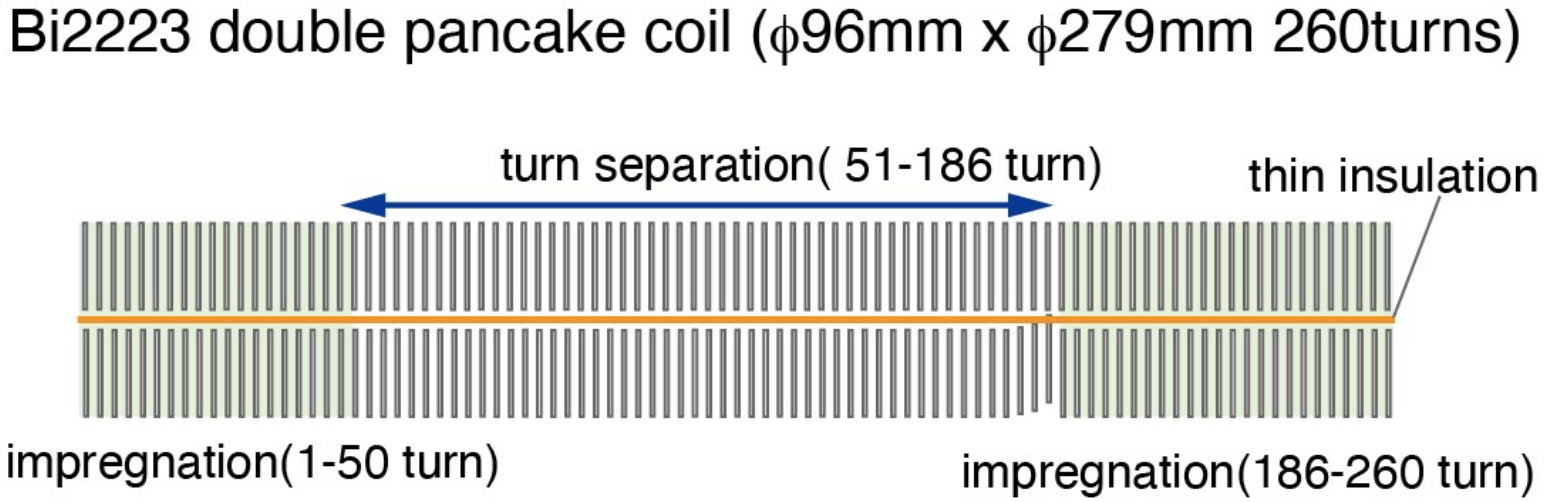
Quench behavior





Short circuit in Bi2223 DP

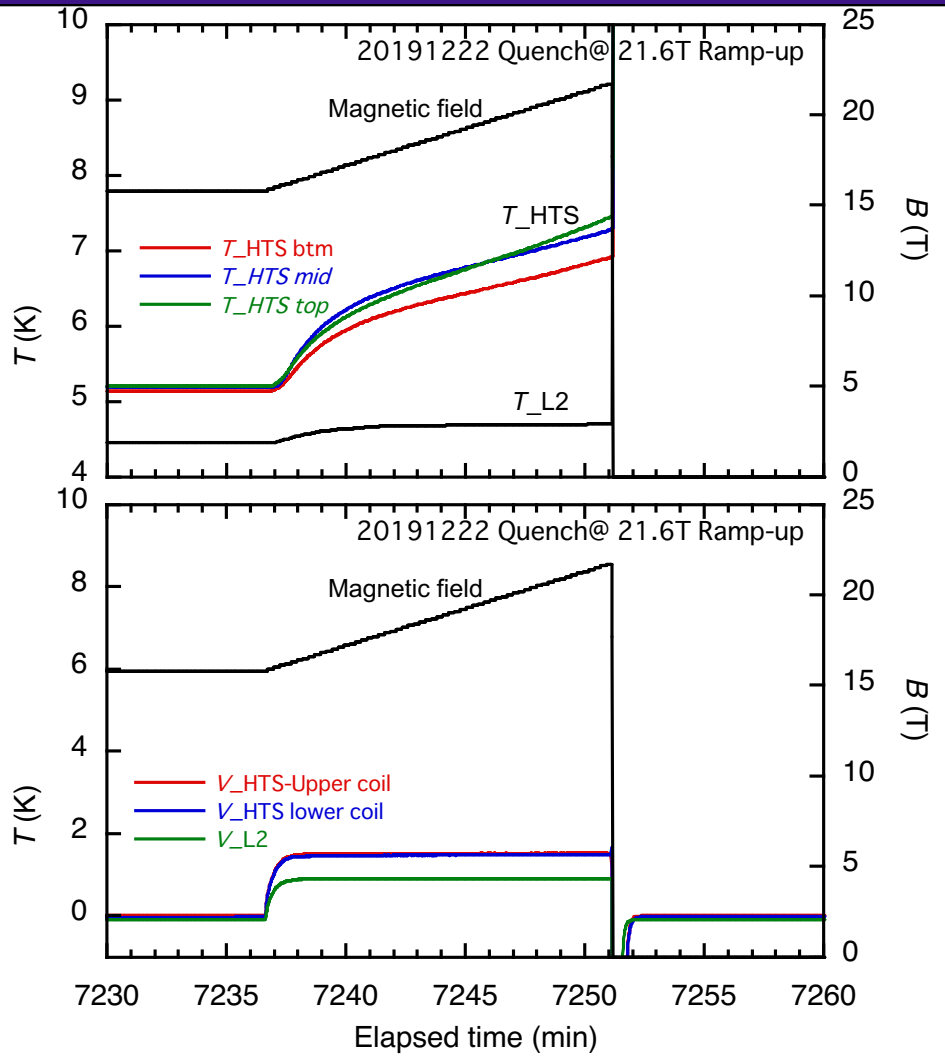
The short circuit was found in the 34th DP by the resistance measurement.
(65% reduction in resistance)

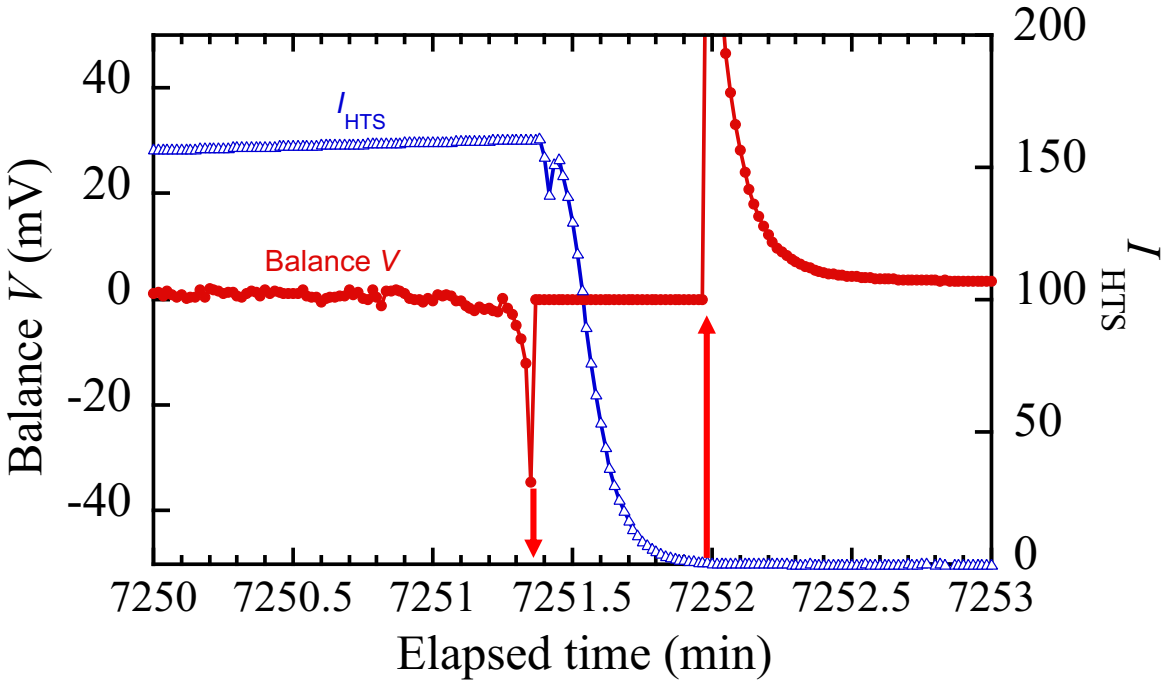


- Bi2223 tapes slipped and touched to the next pancake with breaking thin insulation sheet.
- Pores in epoxy between pancakes in DP was found.
- All turn separation, thin insulation and poor impregnation reduce the coil stiffness. (Probably origin of spiks of the coil voltages)

-> Three DPs were replaced to one new DP and spacers. (38DP ->36DP)

2nd quench in 2019

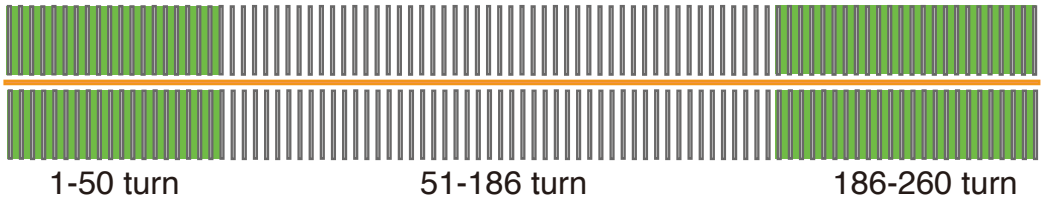




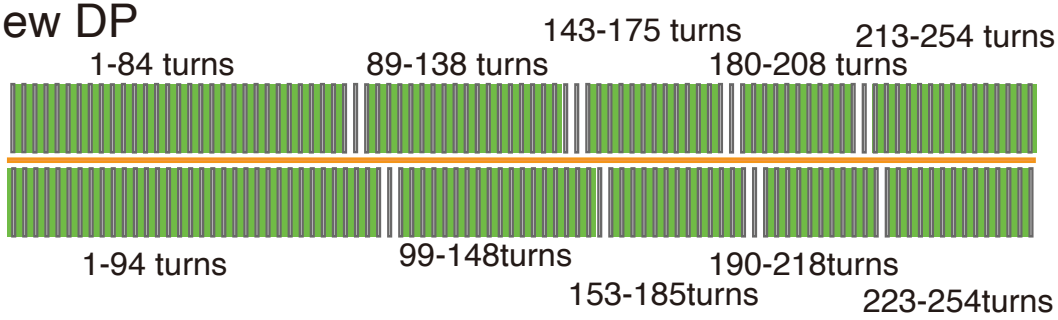
The short circuit in DP was confirmed.

Mechanical design of New Bi223 insert

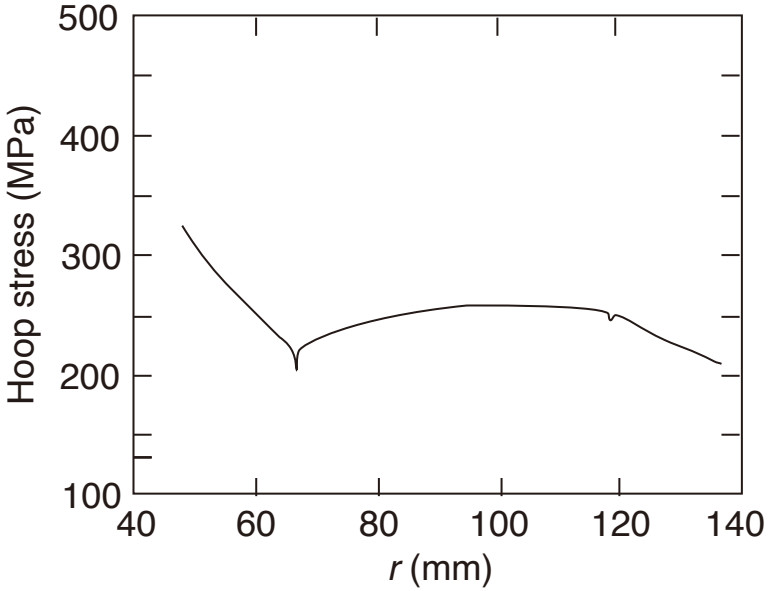
Old DP



New DP



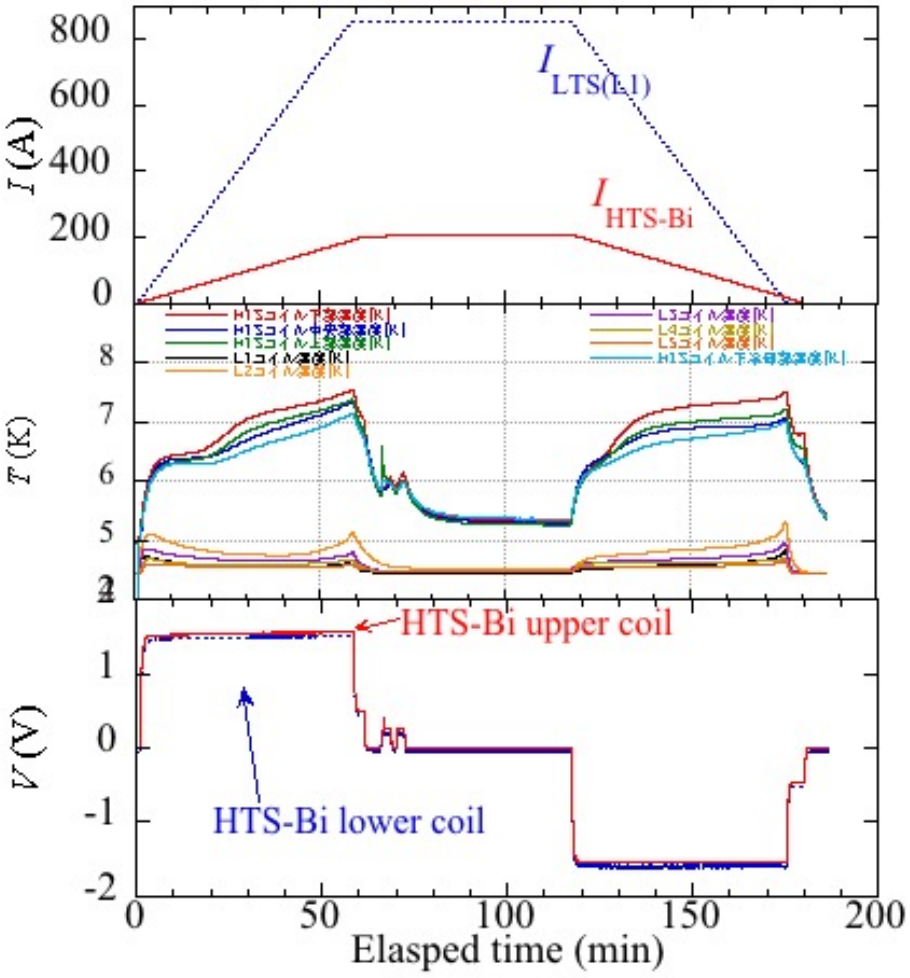
323MPa@25.5T (Old design)

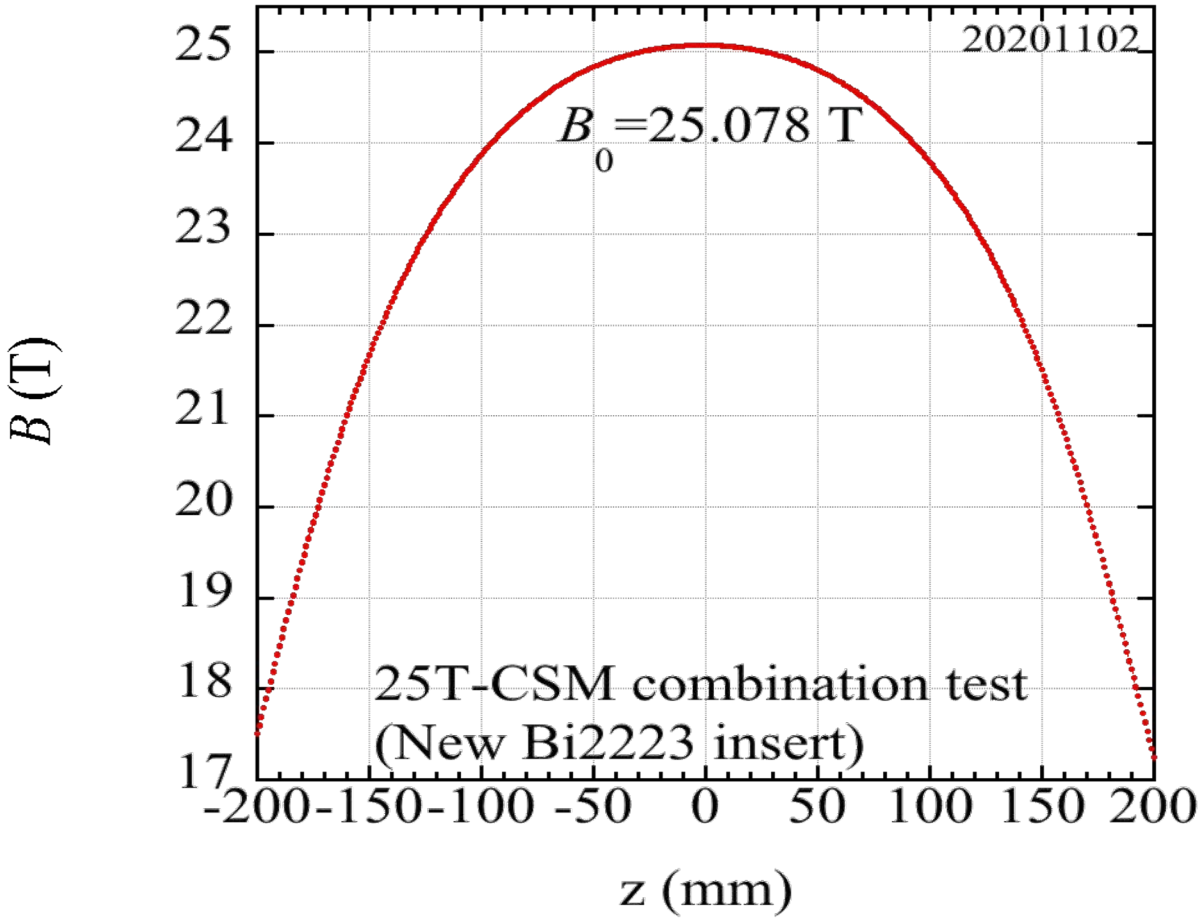


296MPa@25.5T (New design)

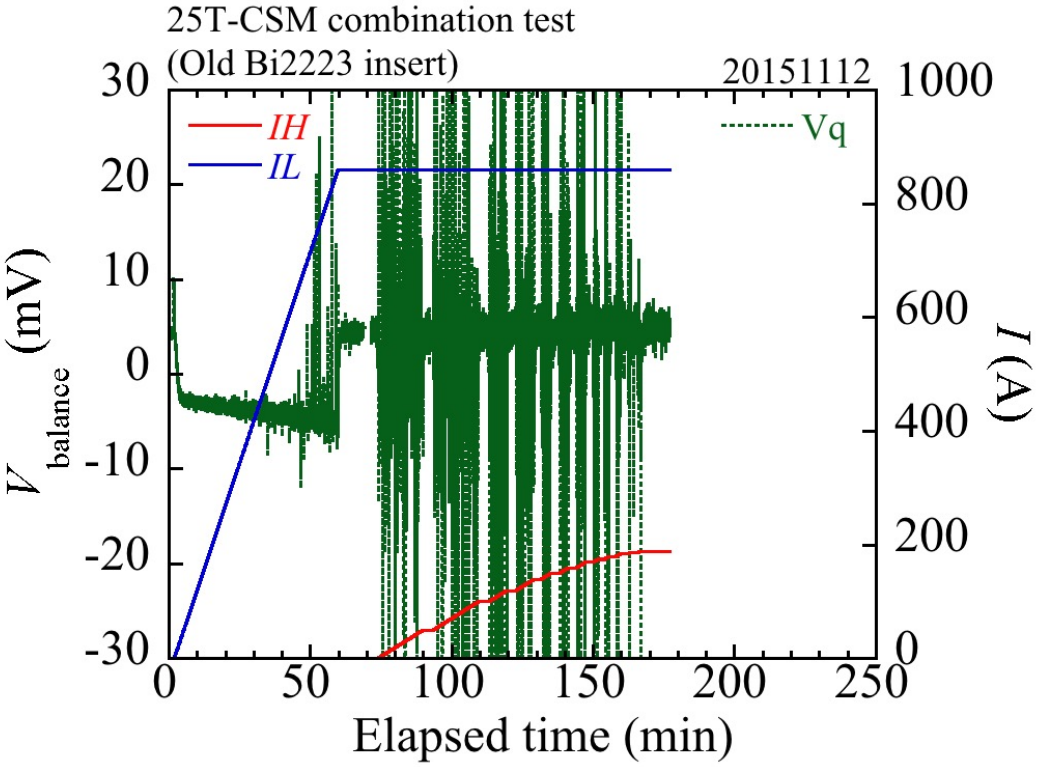
	1st Block	2nd Block	3rd Block	4th Block	5th Block
Upper PC	284 MPa	290 MPa	291 MPa	292 MPa	297 MPa
Lower PC	296 MPa	293 MPa	292 MPa	293 MPa	291 MPa

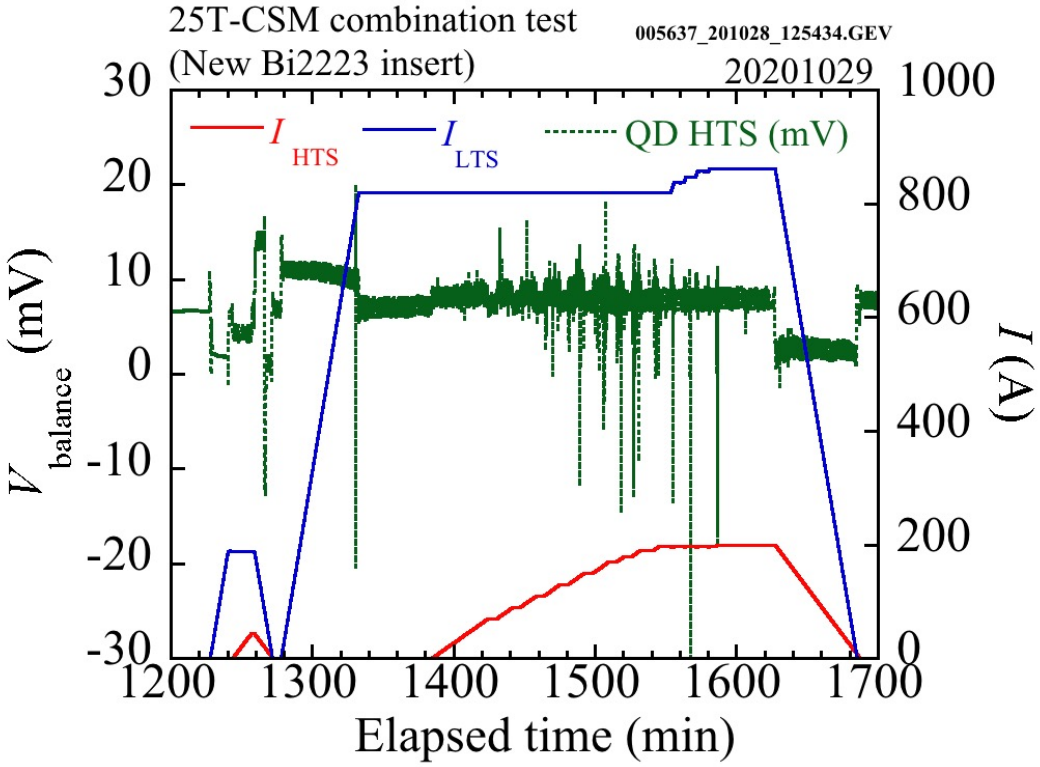
Achievement of 25.1 T



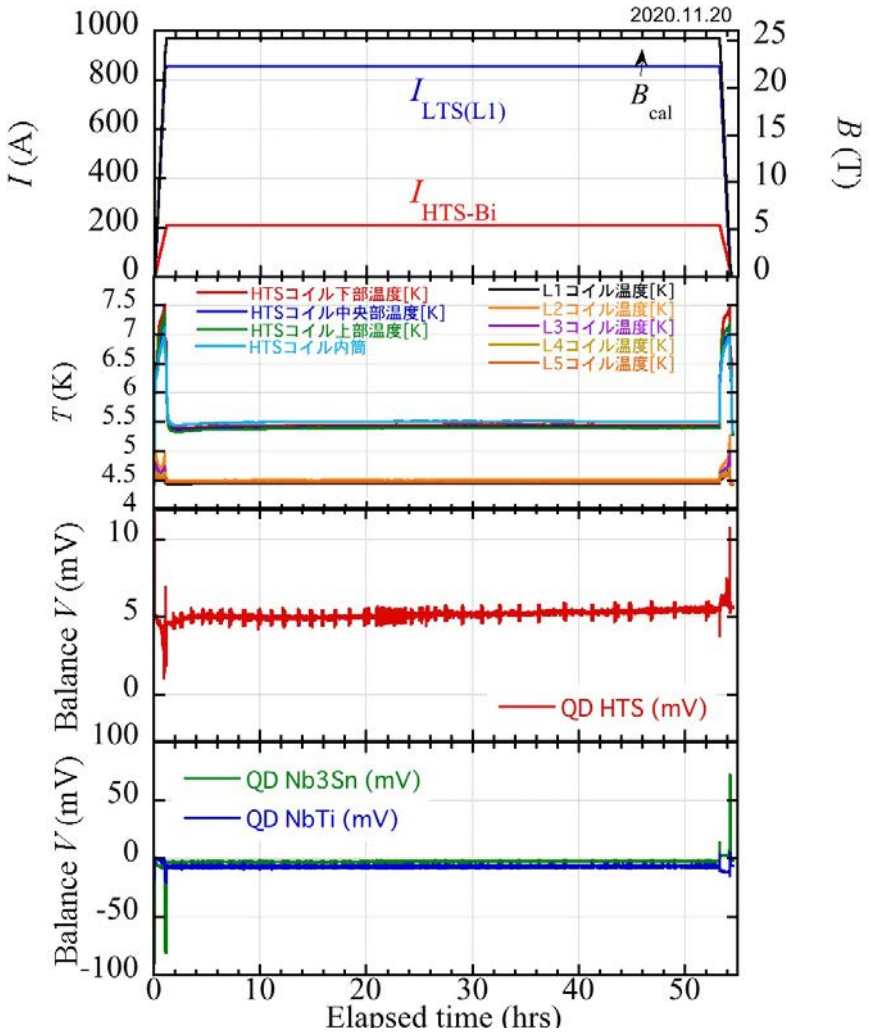


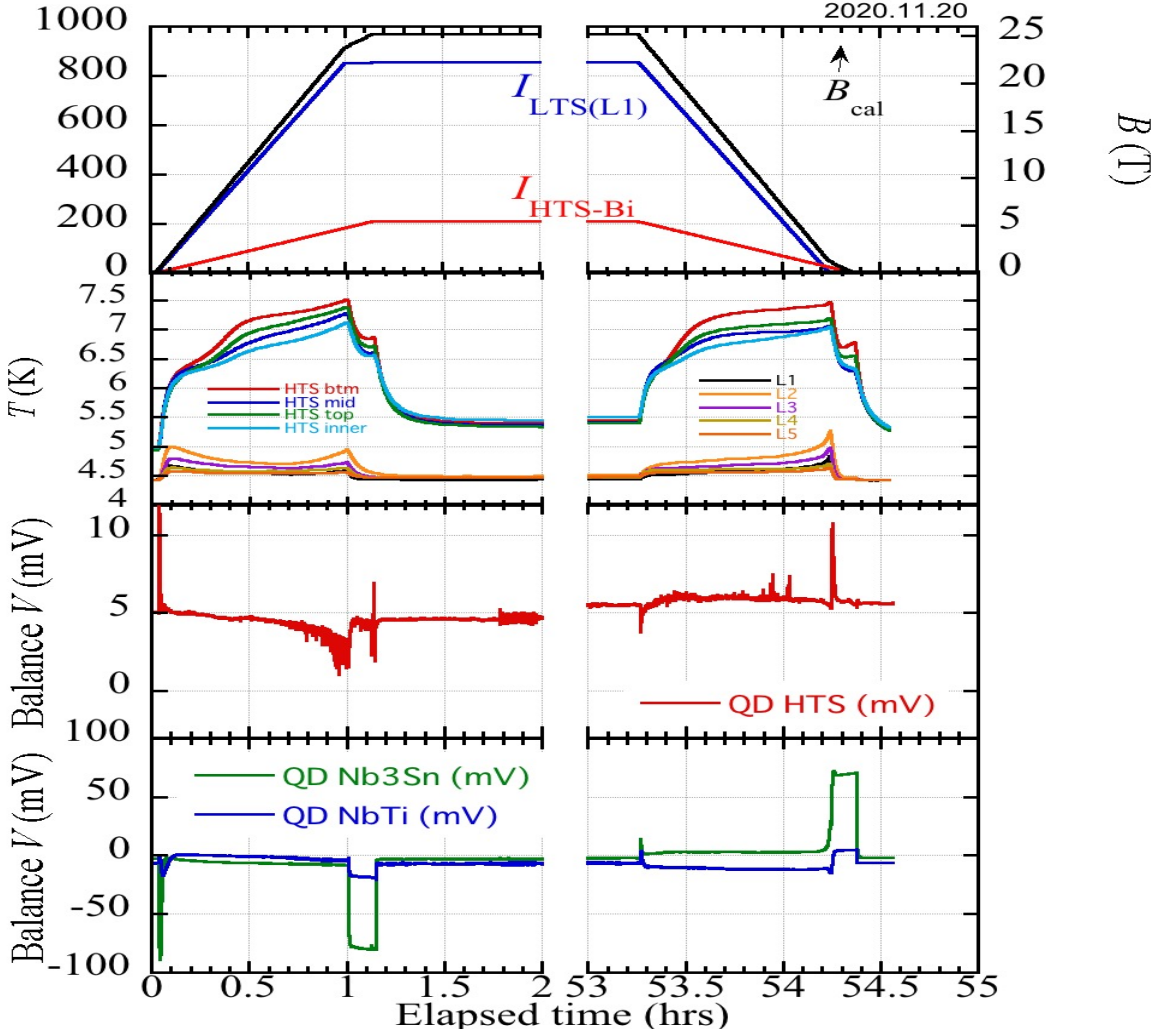
HTS Valance V of old and new Bi2223 inserts



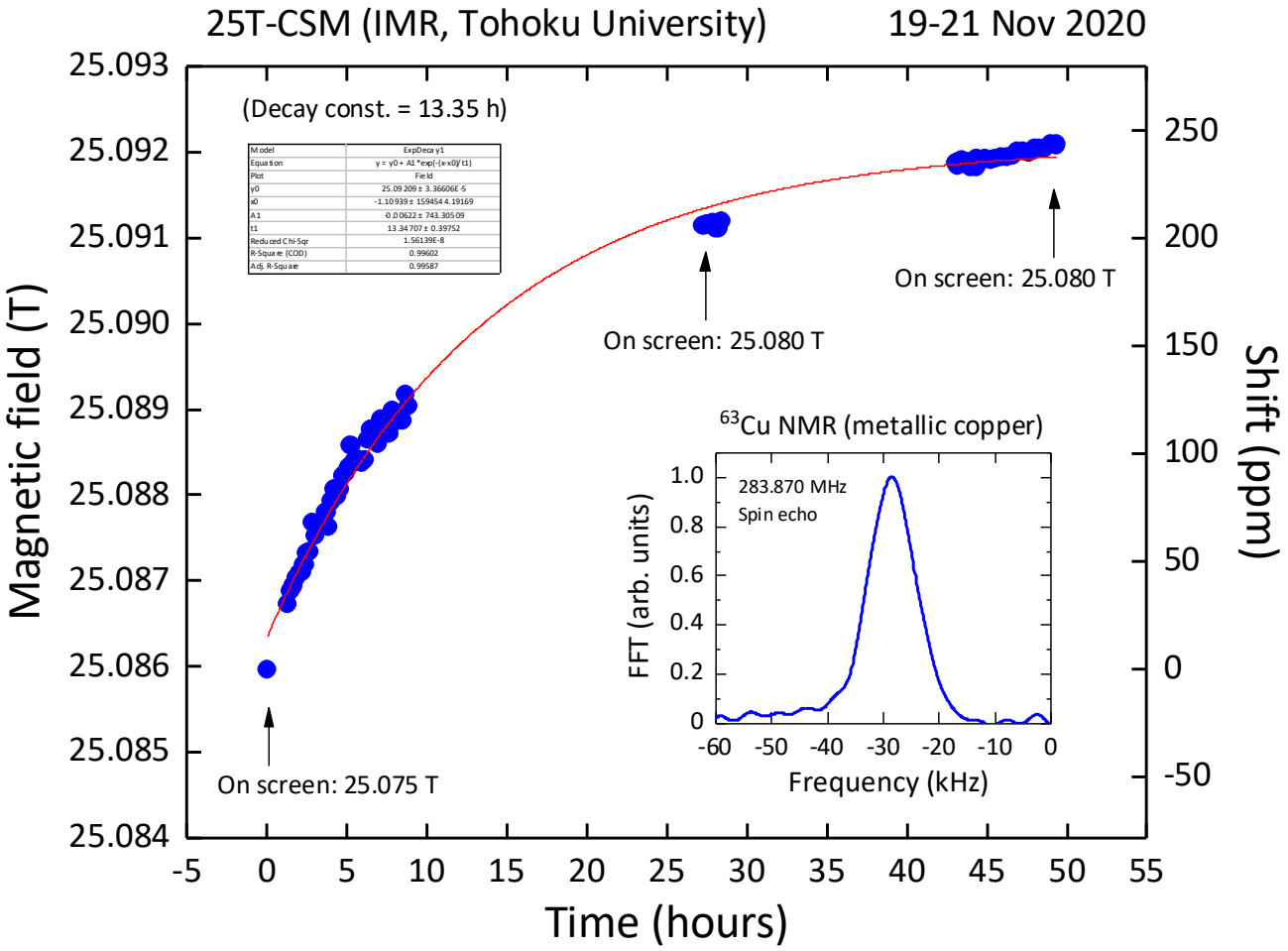


50h hold at 25.1 T





Confirmation of magnetic field by NMR



(Time origin corresponds to 4 hours after ramping the field from 0 to 25.1 T)

Courtesy of M. Hirata (IMR)

Summary

- The quench due to a short circuit between pancakes took place in 34th/38 DPs of the 25T-CSM. The axial stress induced the slip of Bi2223 widning in the all turn separation section and it touched to the next pancake with breaking the thin insulation between pancakes.
- All turn separation, thin insulation and poor impregnation reduce the coil stiffness. -> Coil stiffness should be improved.

- Mechanically separated 5 section Bi2223 insert with the same design was made. New Bi2223 insert was re-installed into the 25T-CSM. We successfully achieved 25.1 T with drastic reduction of spike voltages.

- New 25T-CSM is now open for users since January 2020.