IEEE/CSC & ESAS SUPERCONDUCTIVITY NEWS FORUM (global edition), October 2016.
This invited oral presentation 1LOr2A-02 was given at ASC 2016. Submitted to *IEEE Trans. Appl. Supercond.* for possible publication.

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ASC2016, Sep. 4-9, 2016, Denver, CO, USA

1st Performance Test of the 25 T Cryogen-free Superconducting Magnet

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IMR

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Collaborators

HFLSM, IMR, Tohoku Univ.	H. Oguro and K. Watanabe, Y. Tsuchiya
Toshiba (Magnet system)	H. Miyazaki, M. Takahashi, Y. Tosaka, K. Tasaki, S. Hanai, S. Ioka
Fujikura (Gd123 tapes)	S. Fujita, M. Daibo, H. Iijima
Furukawa (LTS cables)	M. Sugimoto, H. Tsubouchi
NIMS(R&D)	G. Nishijima, S. Matsumoto, S. Nimori, H. Kumakura, T. Shimizu
LNCMI-CNRS (R&D)	Y. Miyoshi, X. Chaud, F. Debray

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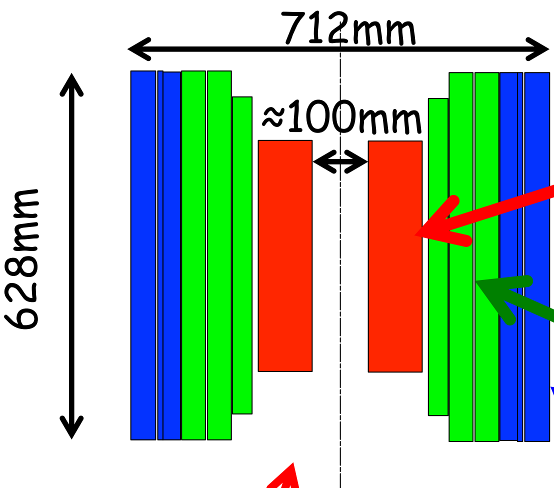
25T Cryogen-free Superconducting Magnet (25T-CSM)



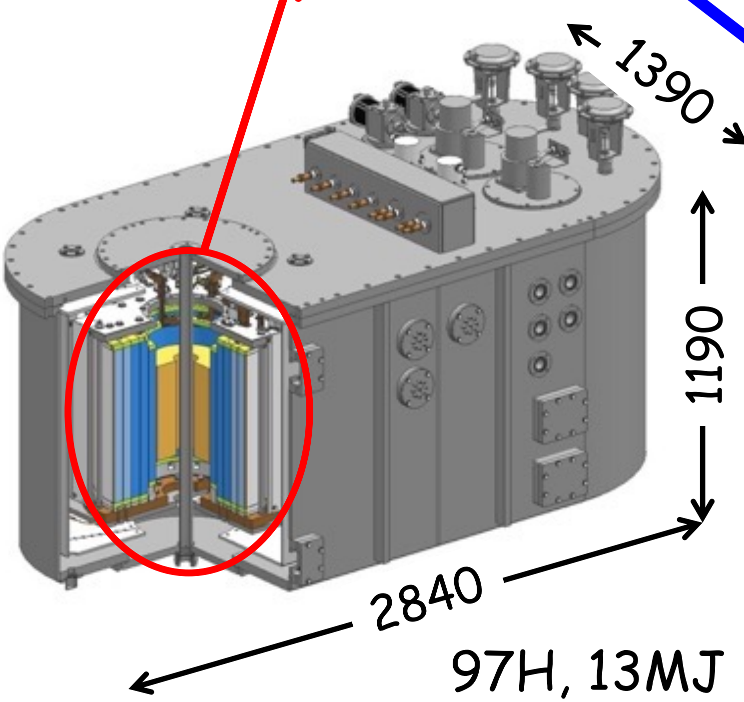
56 GdBCO single pancakes (11.5T@144A, 407MPa) /
38 Bi2223 double pancakes (11.5T@203A, 323MPa)

SEI type H-Nx

4LPo1D-01

3 CuNb/Nb_3Sn Rutherford solenoid (14T@854A, 251MPa)

3 NbTi Rutherford solenoid



97H, 13MJ

Cooling system 3LPo2B-04

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)

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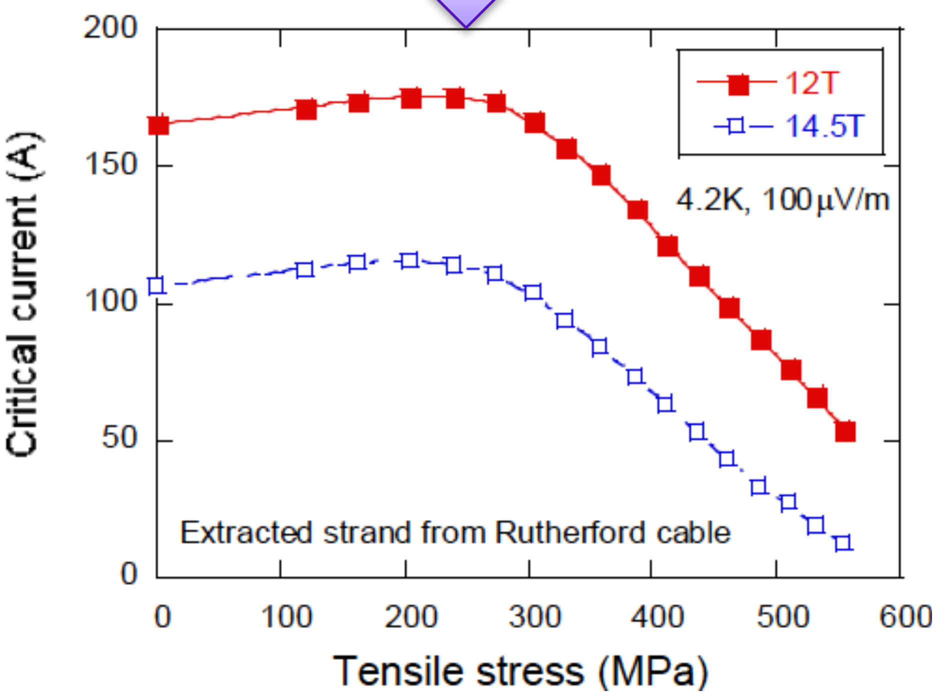
Design of a 25T-CSM (Final)

		Gd123	Nb3Sn	Nb3Sn	Nb3Sn	NbTi	NbTi	NbTi	Bi2223
Current	A	144	854						203
Inner radius	mm	52	149.5	185.3	228.6	271.7	301.6	312.9	48.0
Outer radius	mm	131.42	182.4	226.4	270.1	301.6	311.9	356.3	138.9
Height	mm	336	542.0	630.3	680.4	629.5	629.5	629.5	389.1
Space current density	A/mm^2	129.8	67.6	67.4	66.7	68.9	84.7	86.7	110
No of turns/layer	-	56	80	93	93	95	107	107	76(38DP)
No of layer	-	435	18	22	22	16	6	26	257 (ave.)
Total No of turns	-	24360	1438	2043	2043	1518	641	2779	19532
Bmax	T	25.6	13.8	11.3	8.4	6.8	6.2	5.9	25.6
Br	T	4.66	4.65	5.58	5.71	5.71	5.71	5.52	4.14
B0	T	11.5	2.43	2.91	2.73	1.91	0.78	3.25	11.50
Width of conductor	mm	5.00	6.45	6.45	6.45	6.30	5.57	5.57	4.5
Thickness of conductor	mm	0.13	1.53	1.53	1.53	1.50	1.31	1.31	0.31
Thickness of layer insulation	mm	0.055	0.075	0.075	0.075	0.075	0.075	0.075	0.07
Jcon	A/mm^2	129.8	106.2	106.2	106.2	106.2	138.6	138.6	150.4
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	-32
Hoop Stress BJR	MPa	407	-	-	-	-	-	-	-
Hoop stress Wilson	MPa	–	252	244	202	138	113	52	323

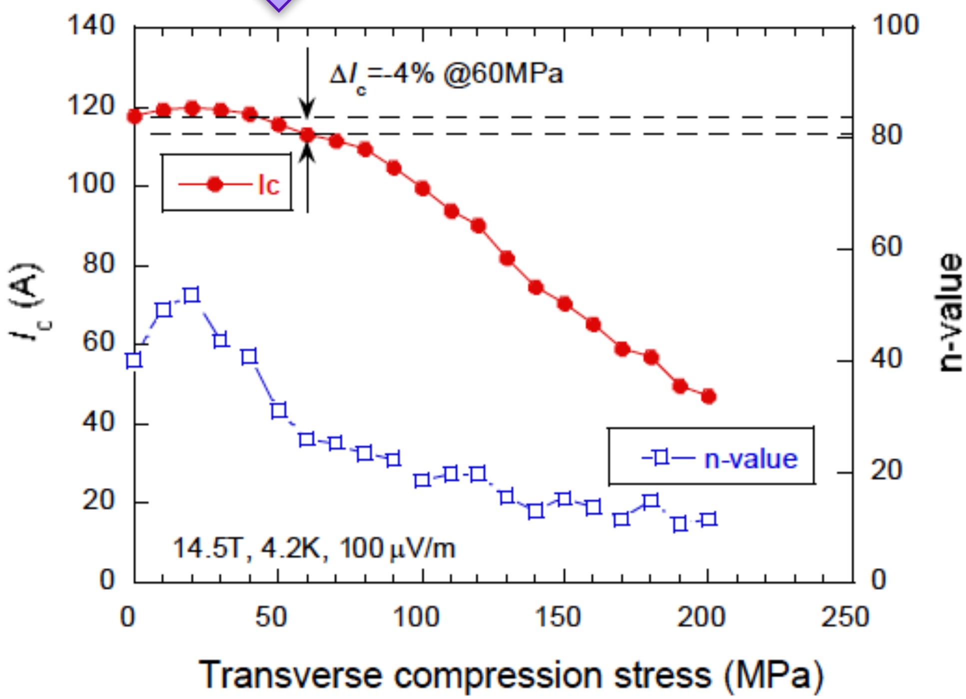
Mechanical design of the LTS coils - strand in Rutherford cable-

CuNb/Nb_3Sn Rutherford cable

Axial stress
252 MPa



Transverse stress
50 MPa



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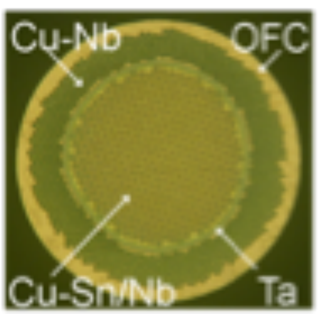
Design of LTS coils

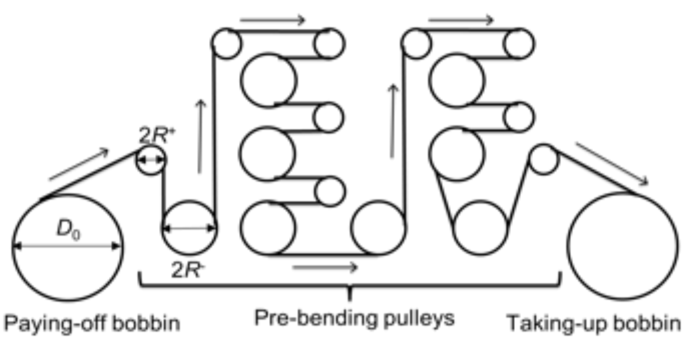
CuNb/Nb_3Sn Rutherford cable solenoids (R&W)

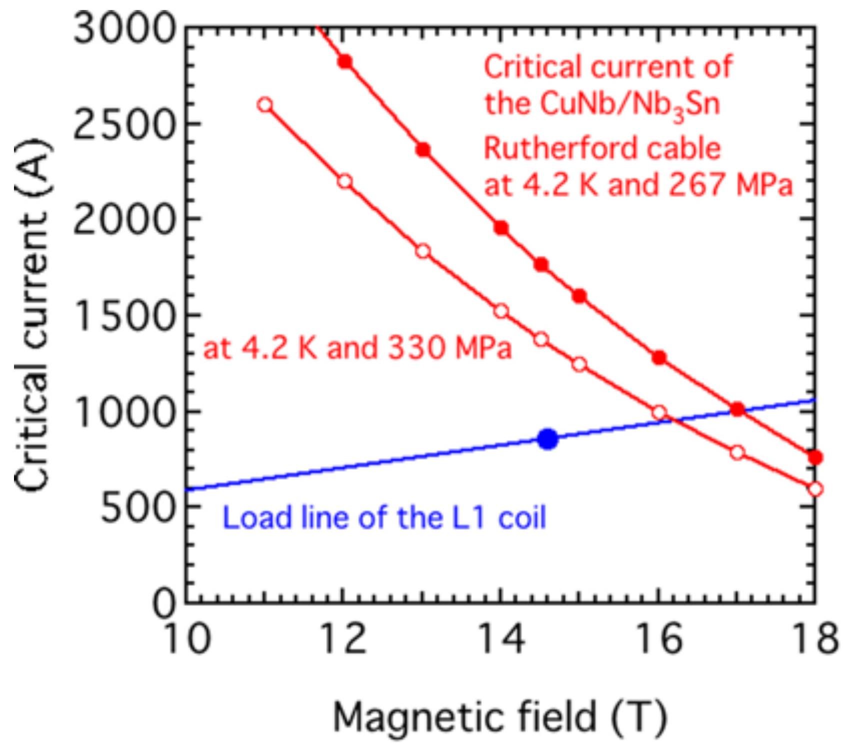
Table 1. Specification of NbTi and Nb_3Sn strands.

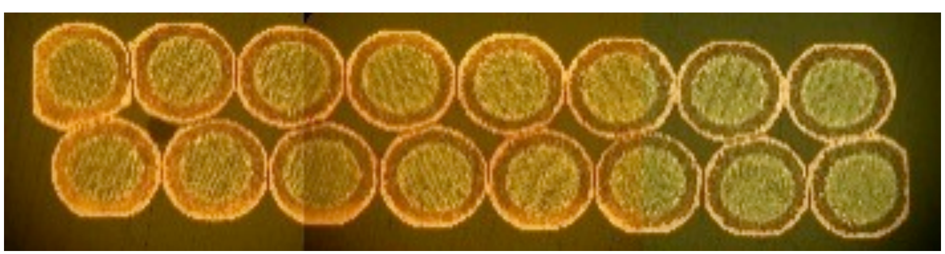
Strand	NbTi-a	NbTi-b	CuNb/Nb_3Sn
Strand diameter (mm)	0.80	0.70	0.8
Cu/CuNb/superconductor	1.9/-/1	1.9/-/1	20/35/45
Filament diameter (μm)	17.9	15.6	3.3
Number of filaments	690	690	6973
Barrier material	—	—	Ta

Load factor ≈ 90% @4.2K



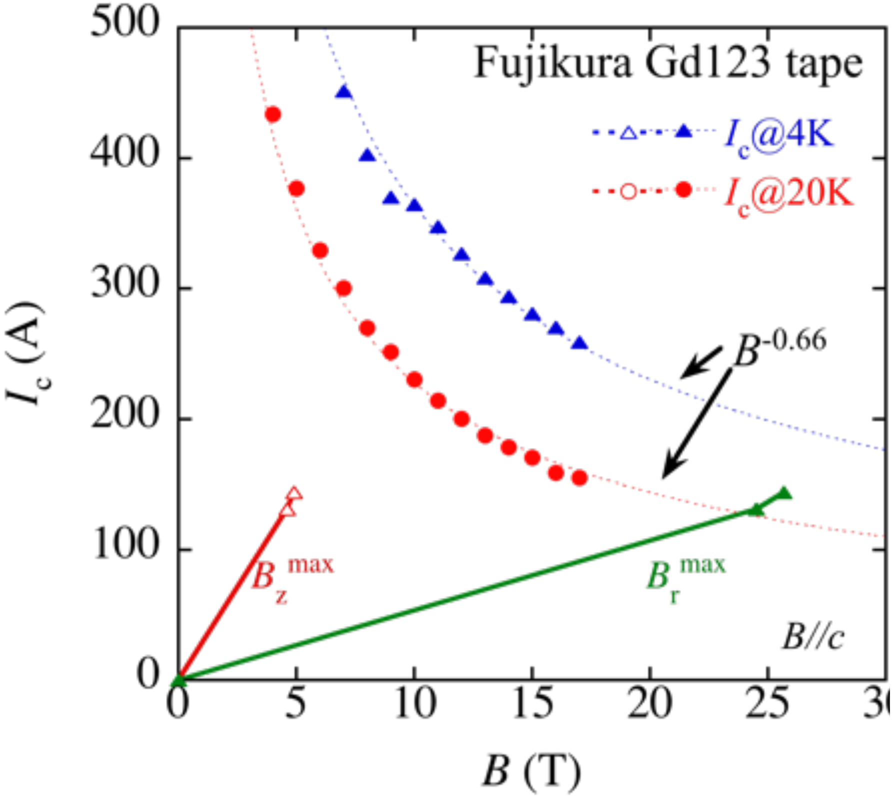


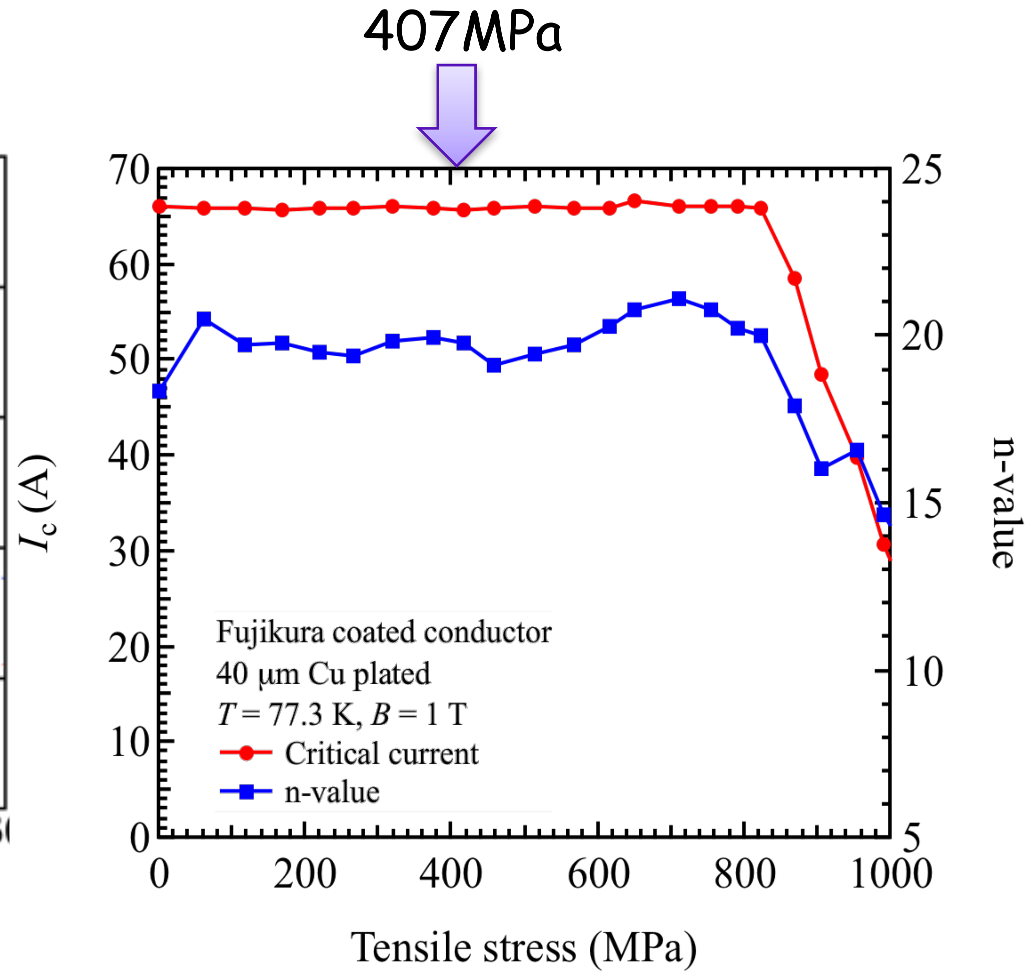




Oguro, SUST 29 (2016) 084004.
Sugimoto, IEEE TAS **25** (2015) 6000605.

Load line and stress of Gd123





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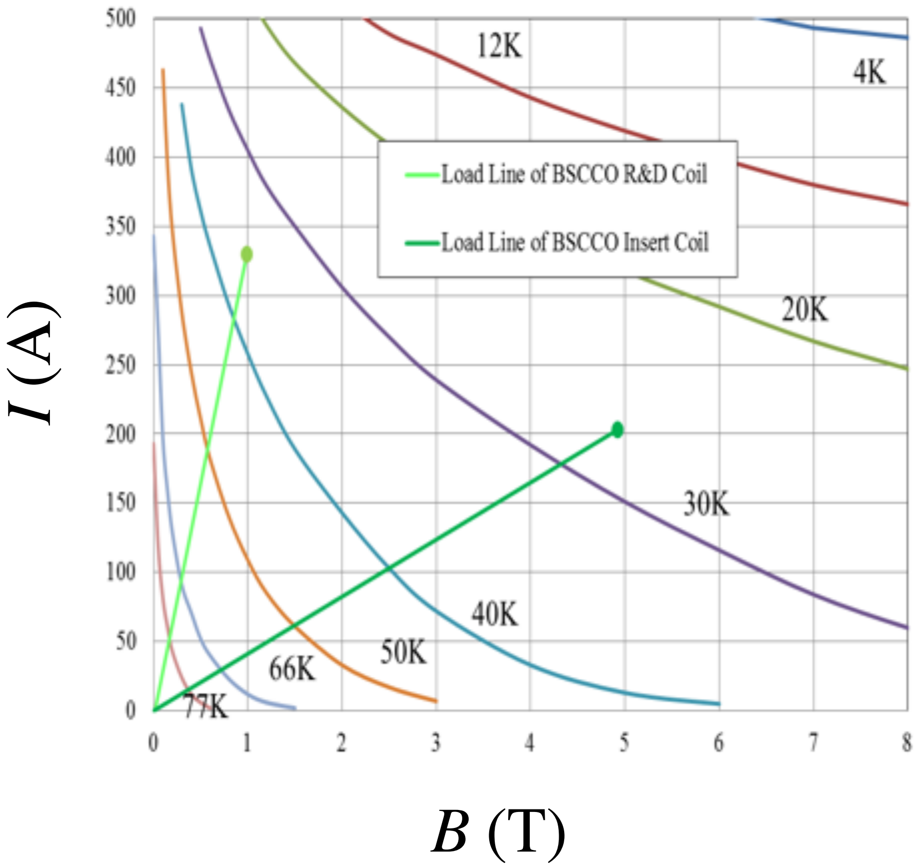
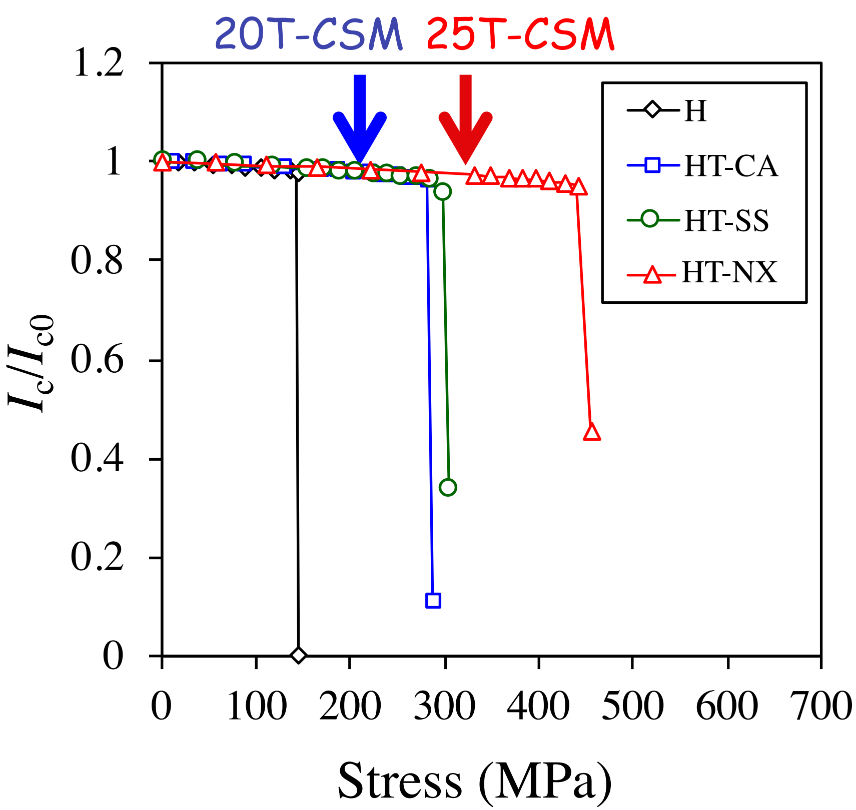
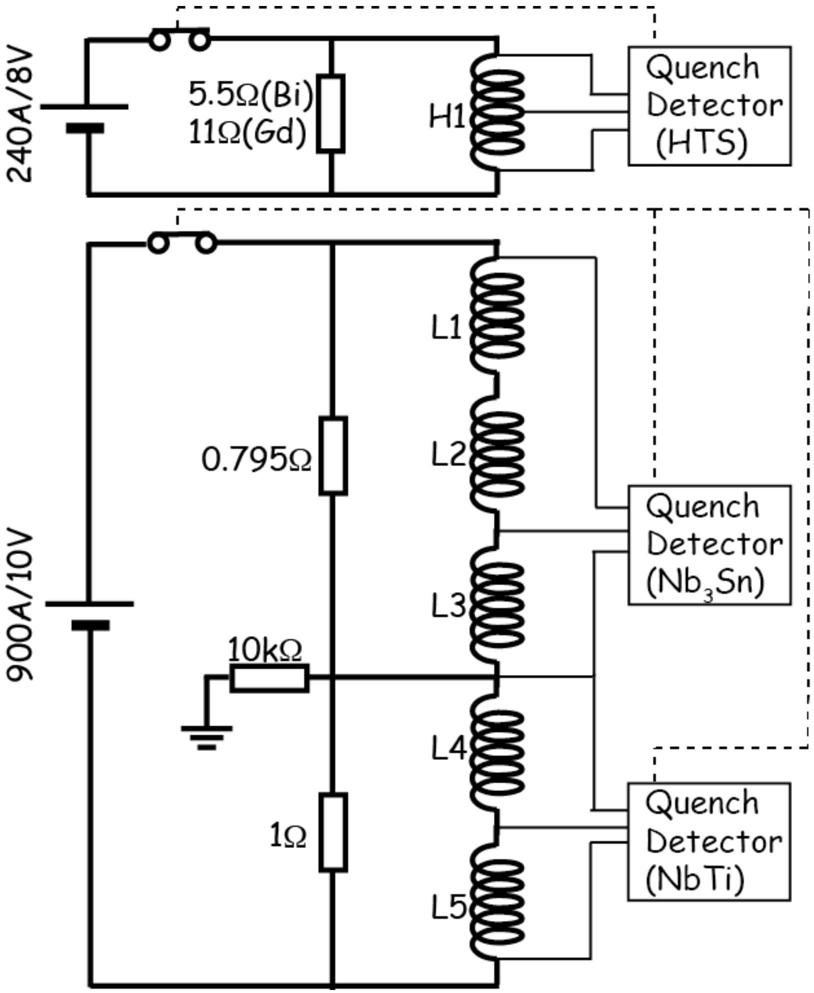
Load lines and stress limit -Bi2223 tapes-



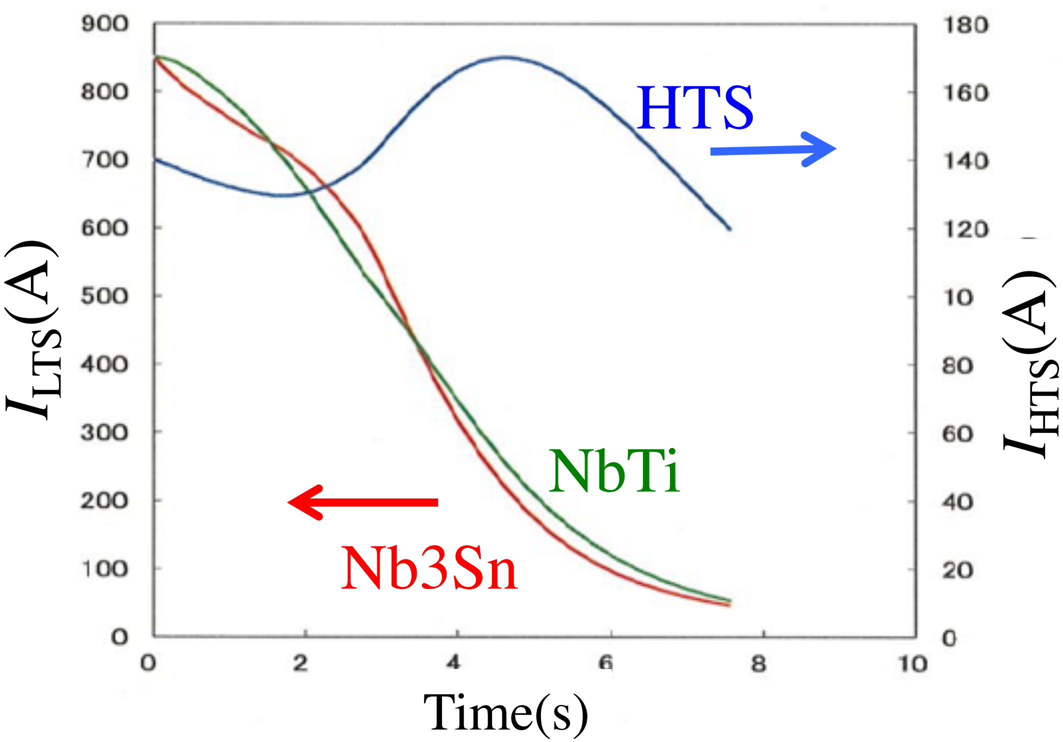


Quench protection

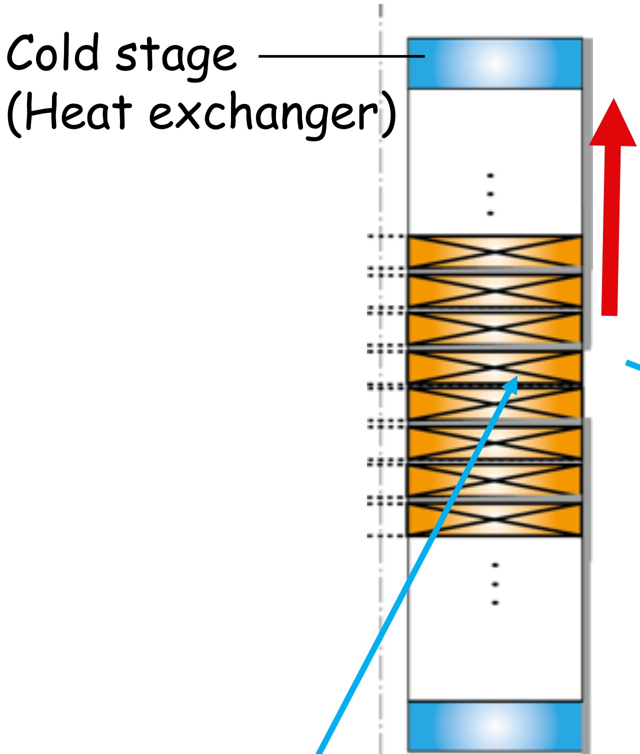


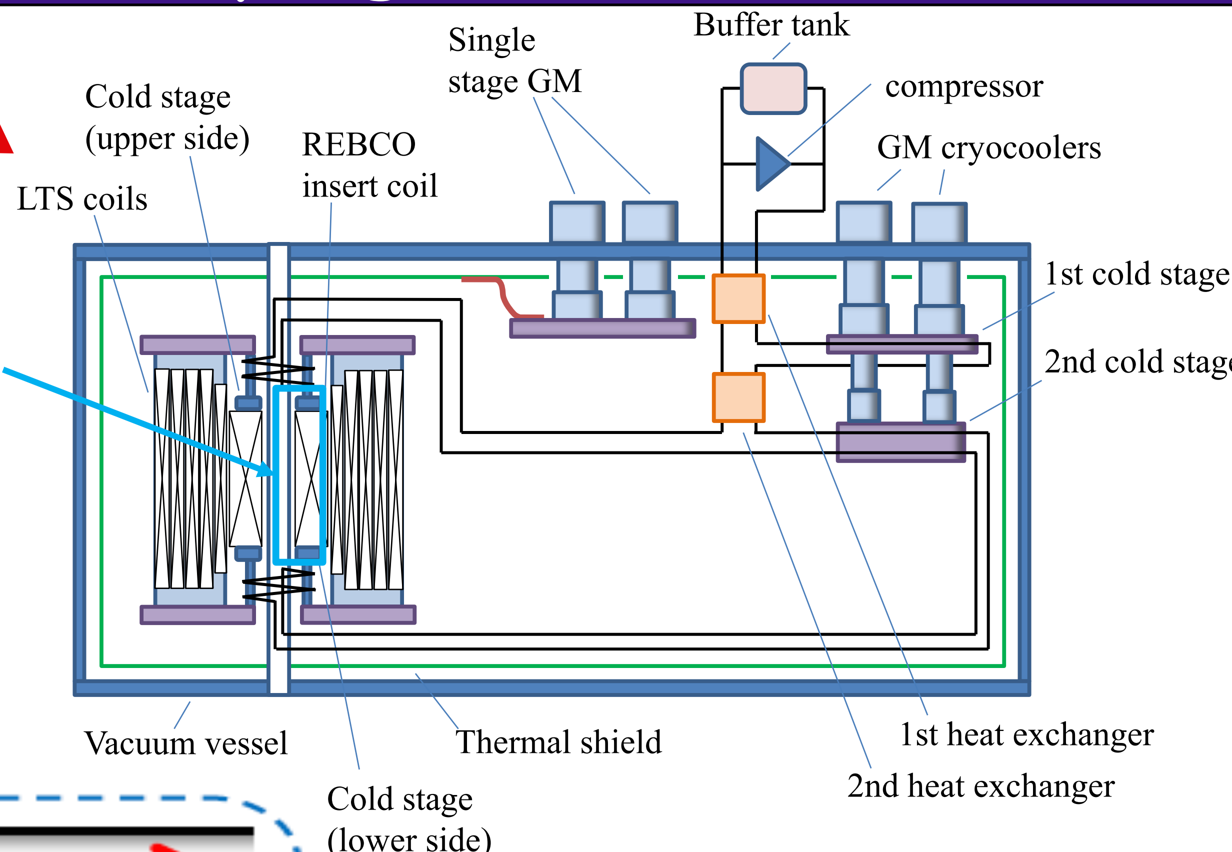
I_c(Gd123) > 200 A @20K

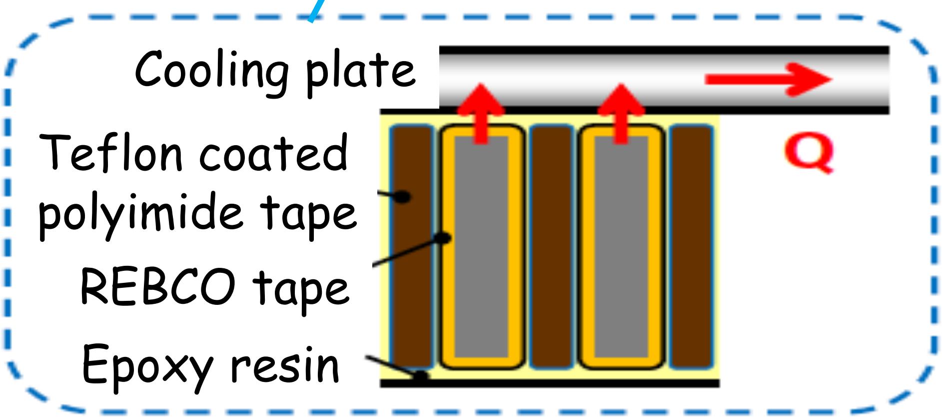
Induced I would not become larger than Ic @20 K.



Cooling and impregnation of HTS







Cooling system
-> Takahashi 3LPo2B-04

All turns are separated but the edge part is connected to the cooling plate.

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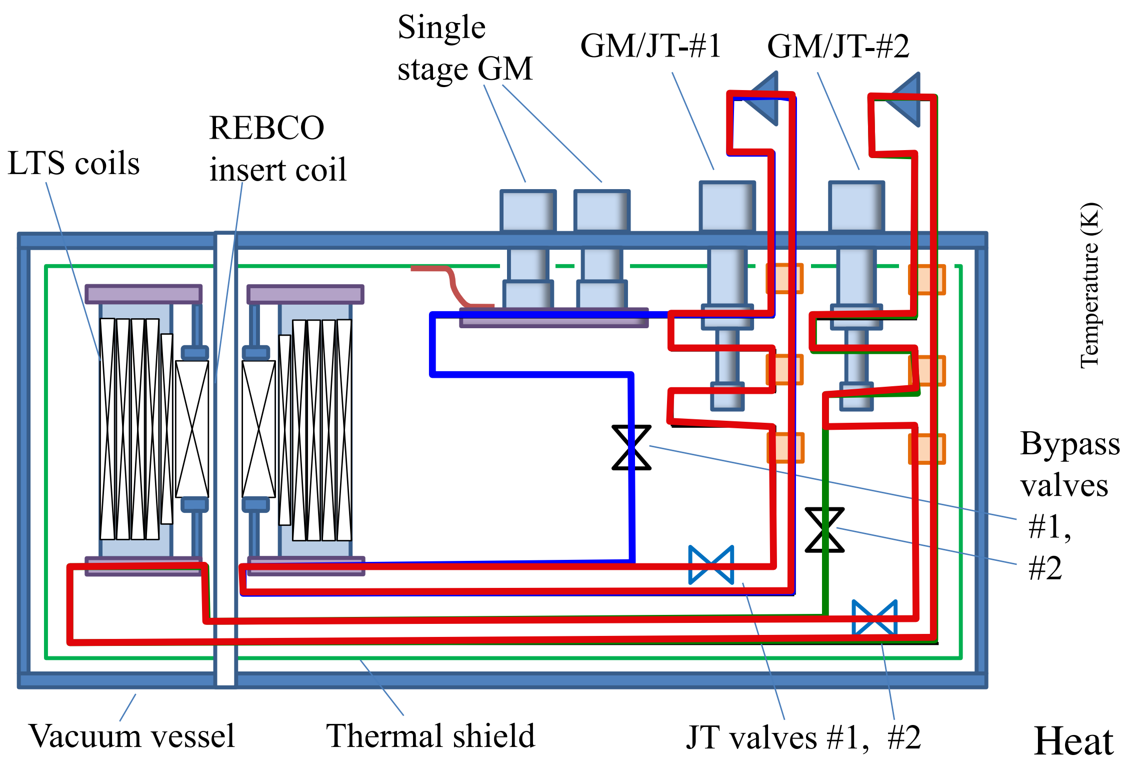
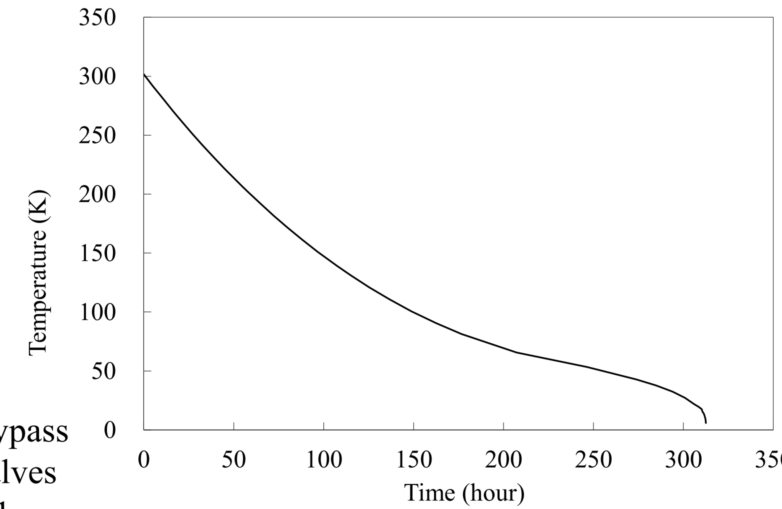
Cooling the LTS coil in the 25T-CSM





Heat load to the GM/JT cryocoolers at 4 K

	Heat load
AC-loss of the LTS coils	2.63 W
Joule loss of the junctions	0.869 W
Heat invasion from the support	0.189 W
Heat invasion from the support of the REBCO coil	0.037 W
Thermal radiation	0.151 W
Heat load from the cold stage of the power lead	1.70 W
Total	5.58 W

Cooling modes

mode 1 (300–50 K)
mode 2 (50–20 K)
mode 3 (20–4 K)

Cooling system -> 3LPo2B-04

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LTS coil
stand-alone test

HFLSM
Sendai

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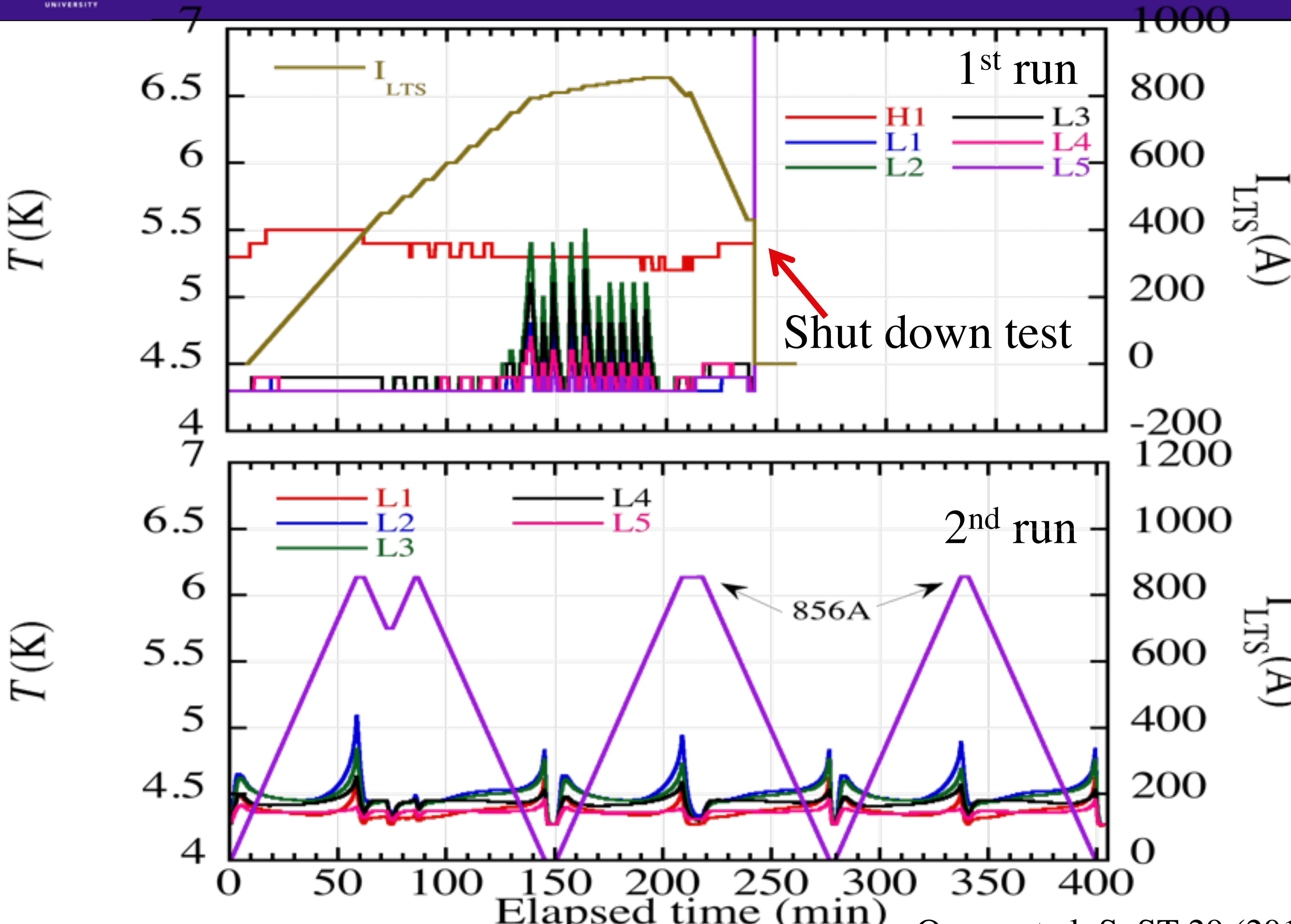
TEST results of LTS coil



Oguro et al, SuST 29 (2016) 084004

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Gd123 insert coil

HFLSM Sendai

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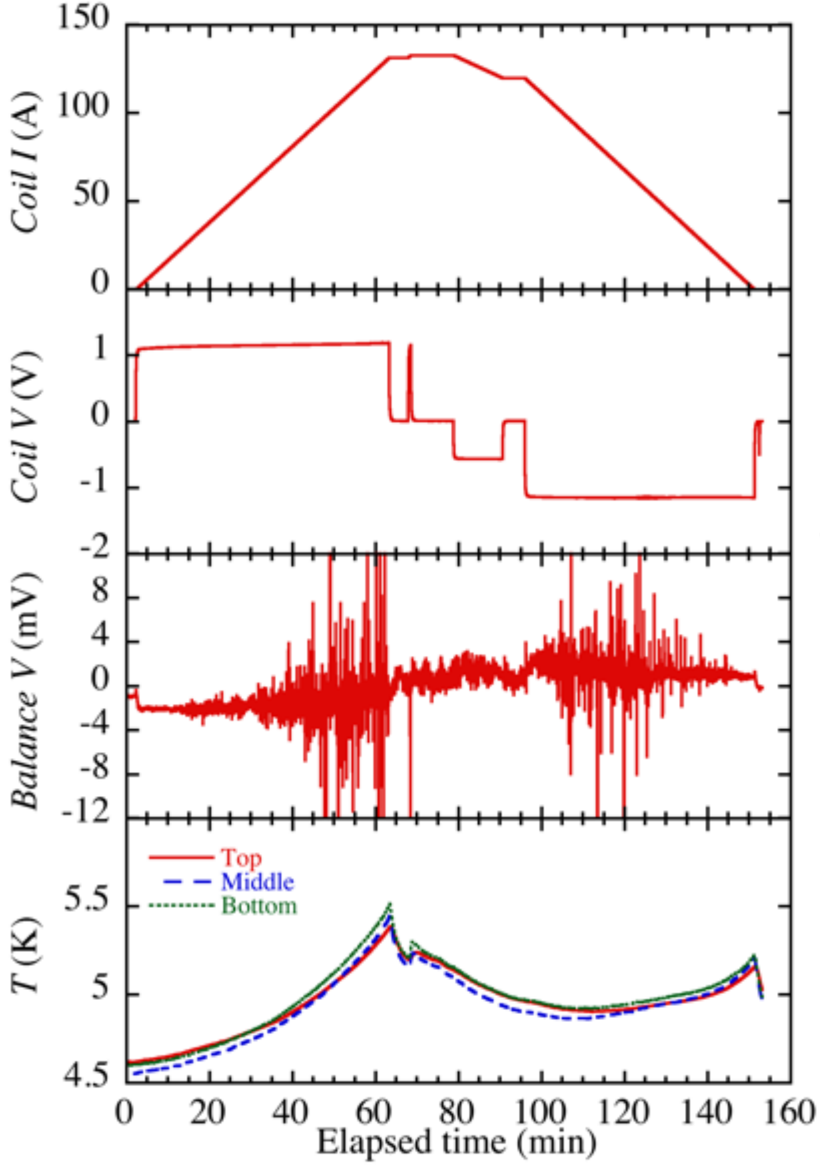
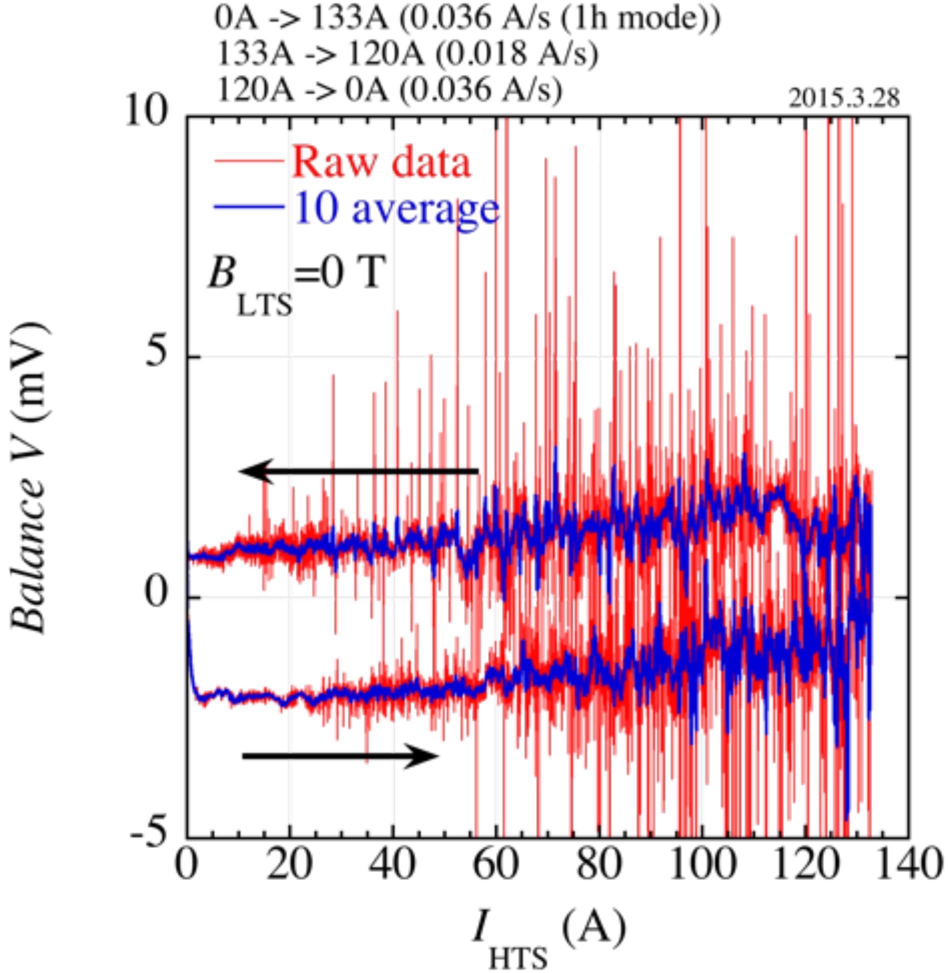
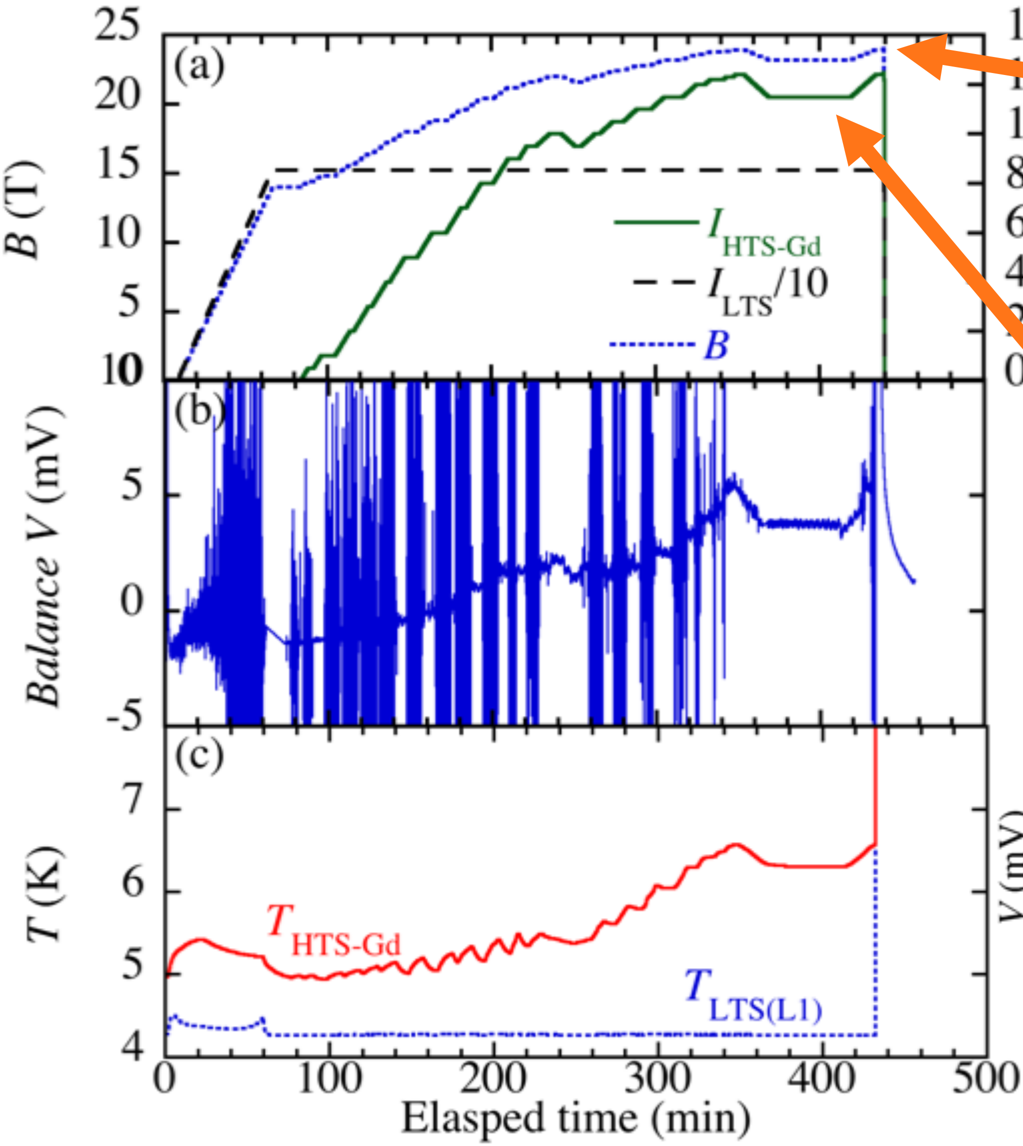
Gd123 insert stand-alone test





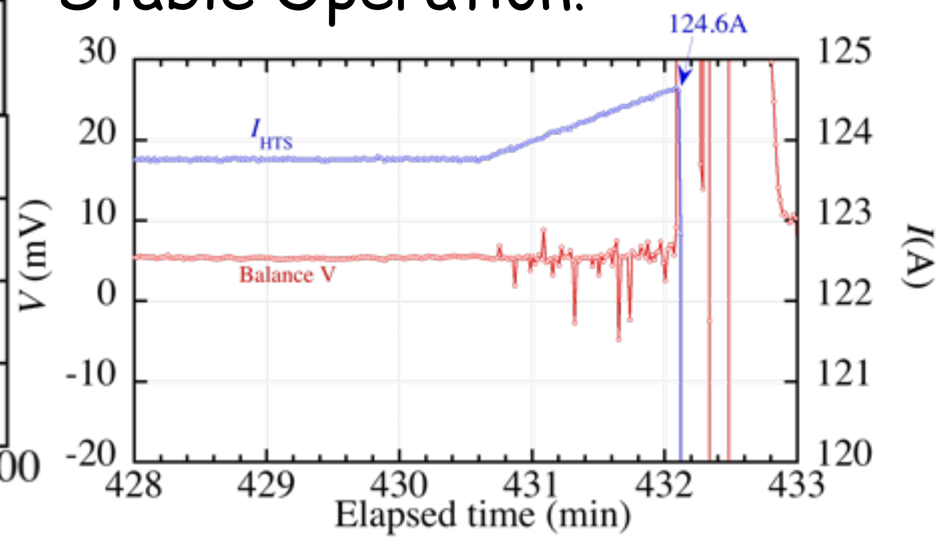
S. Awaji et al., SuST 29 (2016) 05510

25 T-CSM combination test



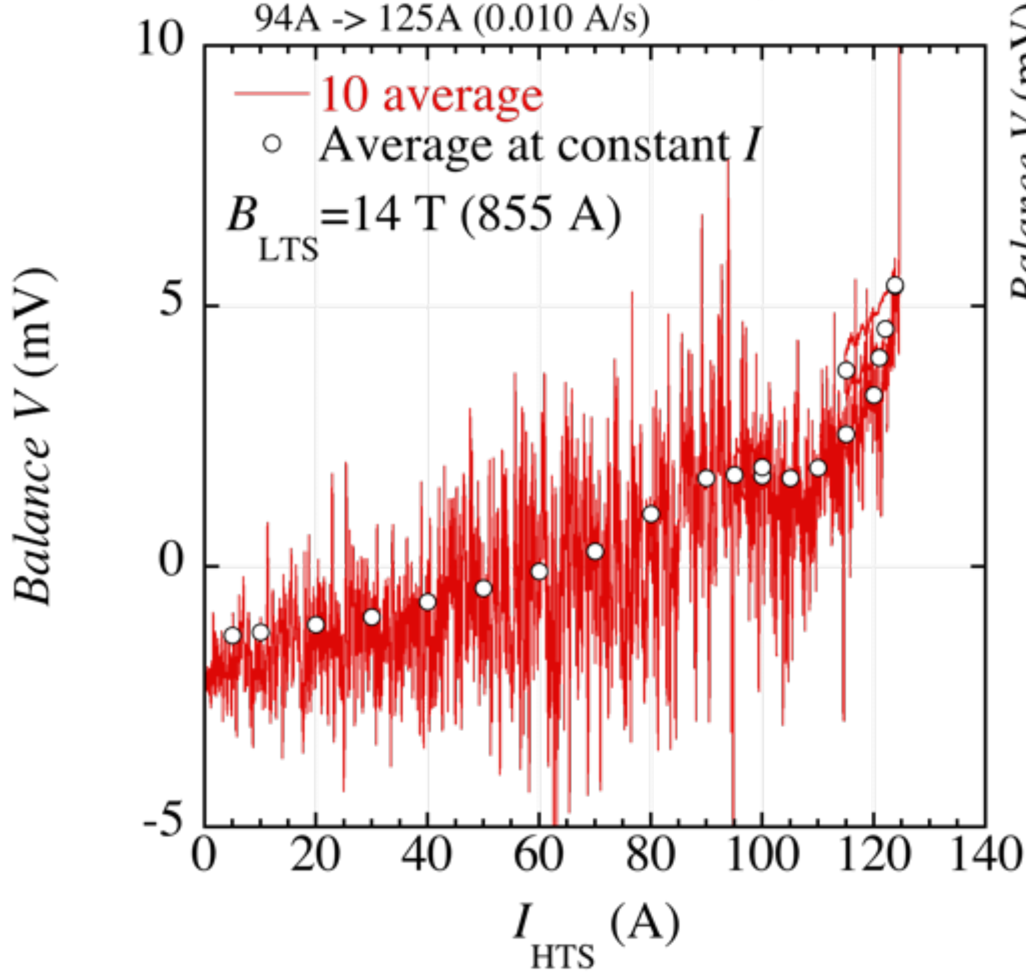
B_{cal} = 24.01 T (124.6A)
(B_{meas} = 23.61 T)
Quench point

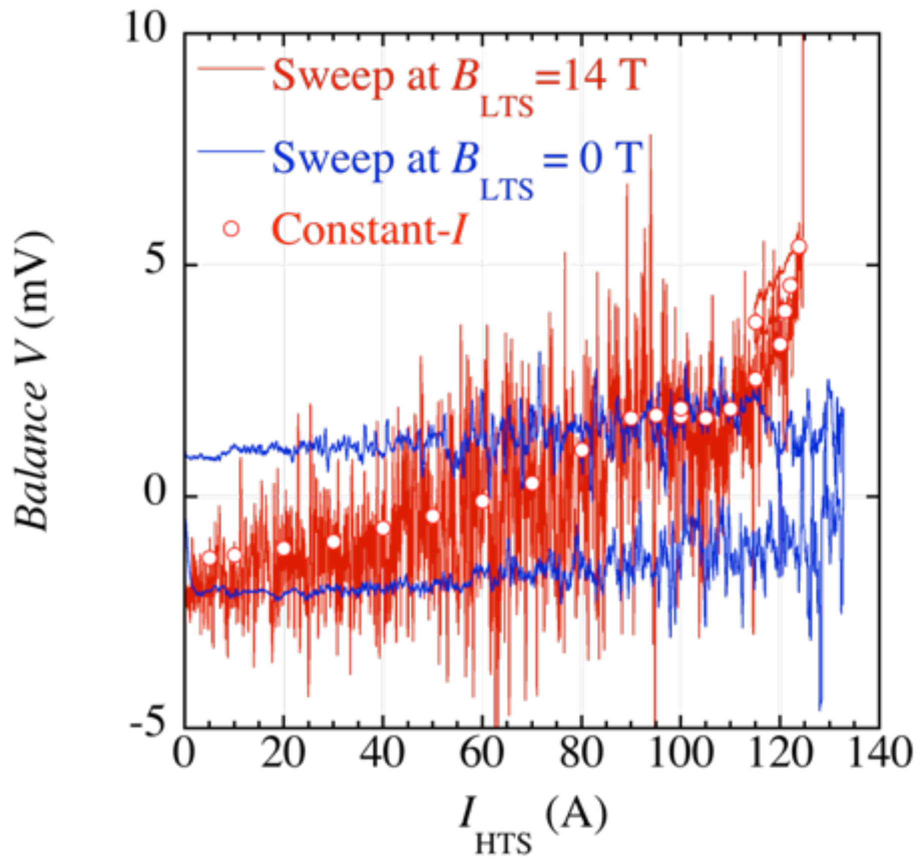
B_{cal} = 23.94 T (110A)
(B_{meas} = 23.55 T)
Stable Operation!



25 T-CSM combination test (Gd) - IV properties -

0A -> 95A (0.018 A/s (2h mode))
94A -> 125A (0.010 A/s)





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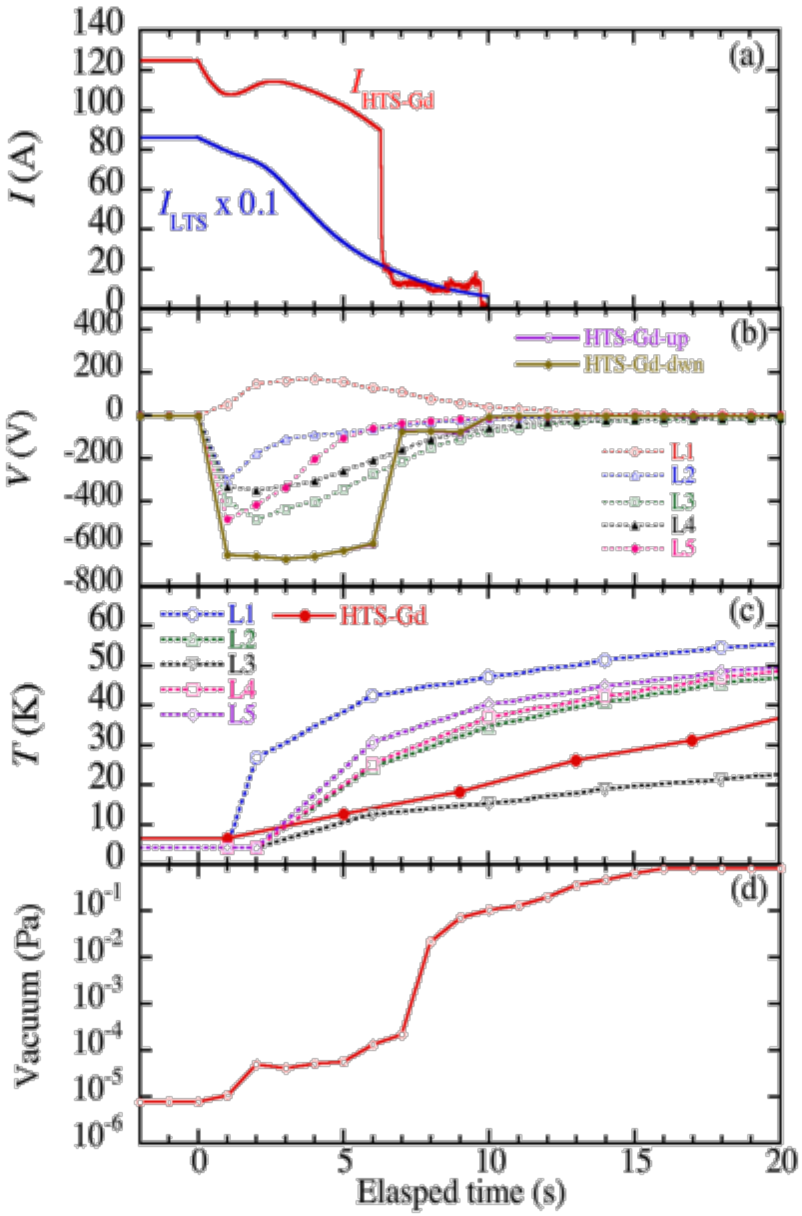
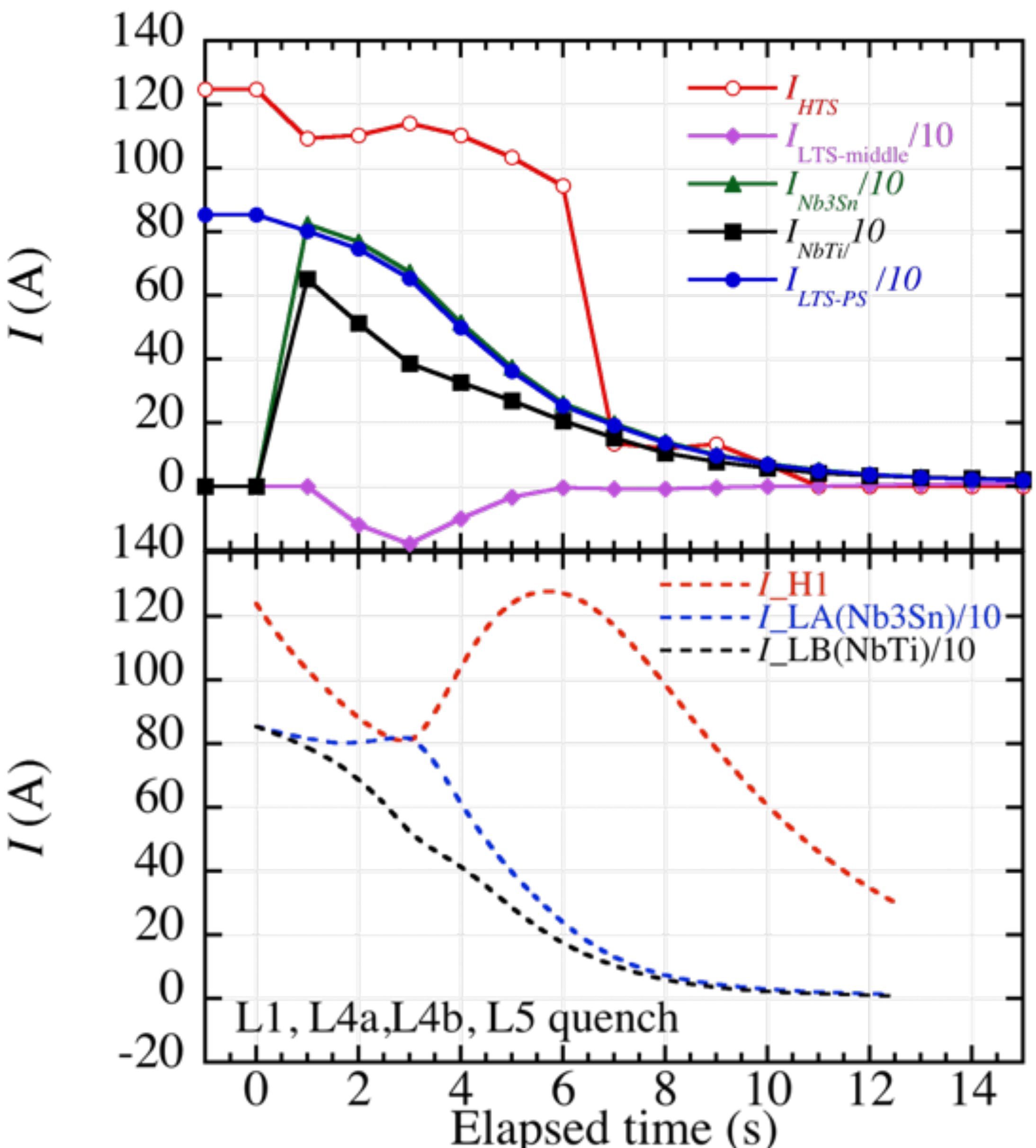
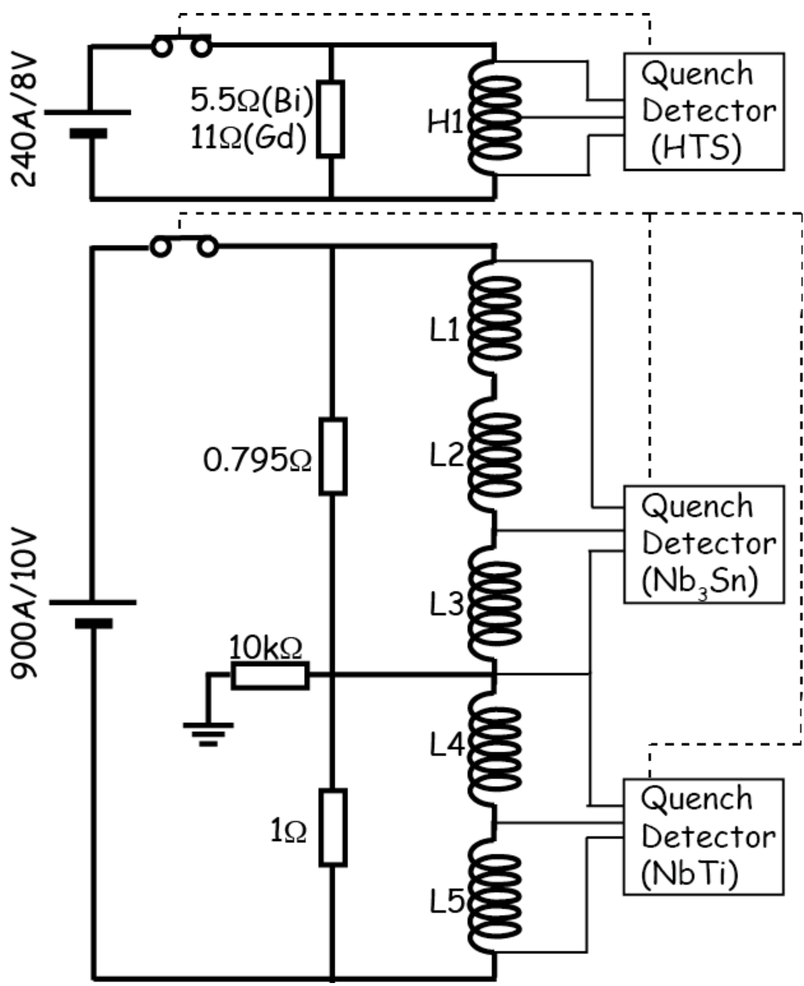
V, T, Vacuum profiles after quench



- Quench was detected due to the thermal runaway of HTS coil.
- 650 V x 2 at HTS coil was generated after the quench.
- Drop of I_{HTS} at 6 s past after the quench protection mode.
- Vacuum was deteriorated rapidly at the same time.
- The quench protection seems to work well al least for 6 s after the quench?

Comparison to quench simulation





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Bi2223 insert coil

HFLSM Sendai

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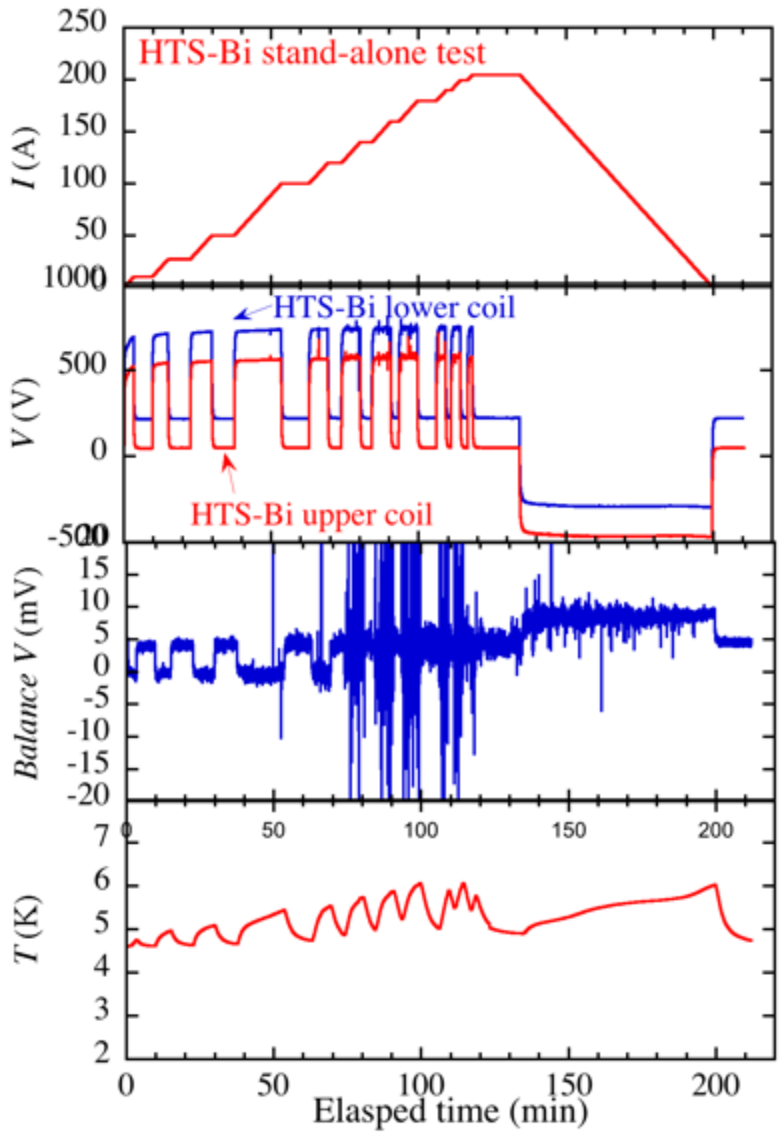
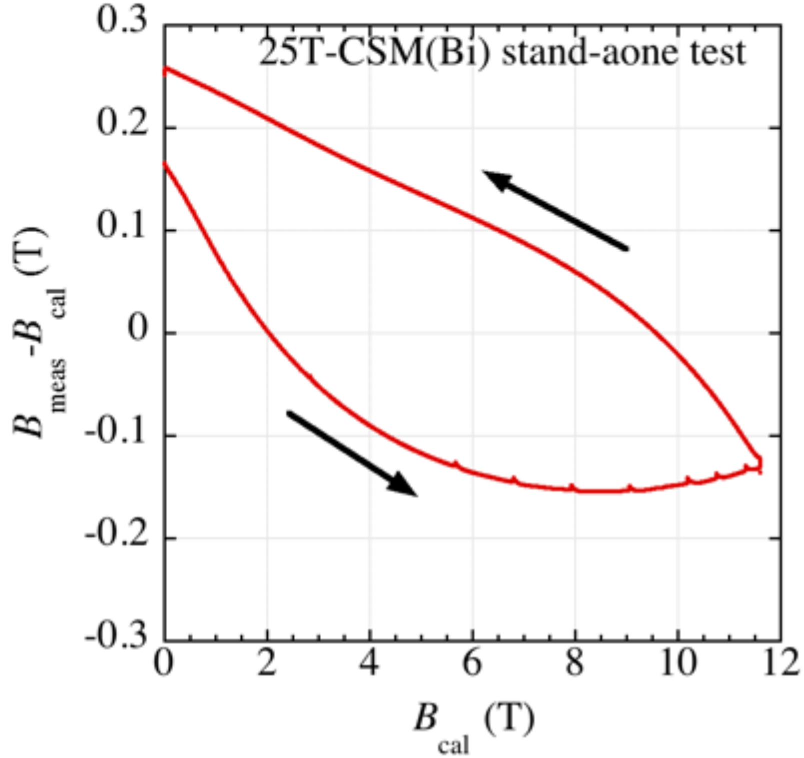
Bi2223 insert stand-alone test



B_{cal} = 11.60T
B_{meas} = 11.48T
I_{op} = 204.8A



-> Hanai et al, 4LPo1D-01

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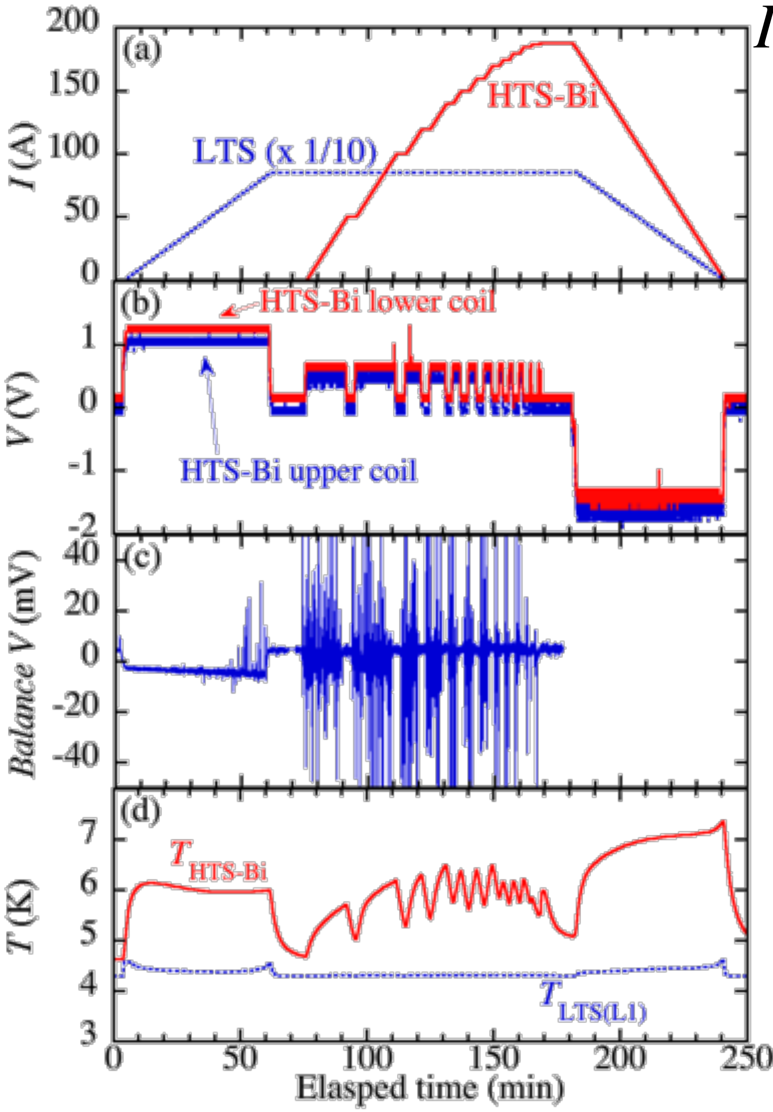
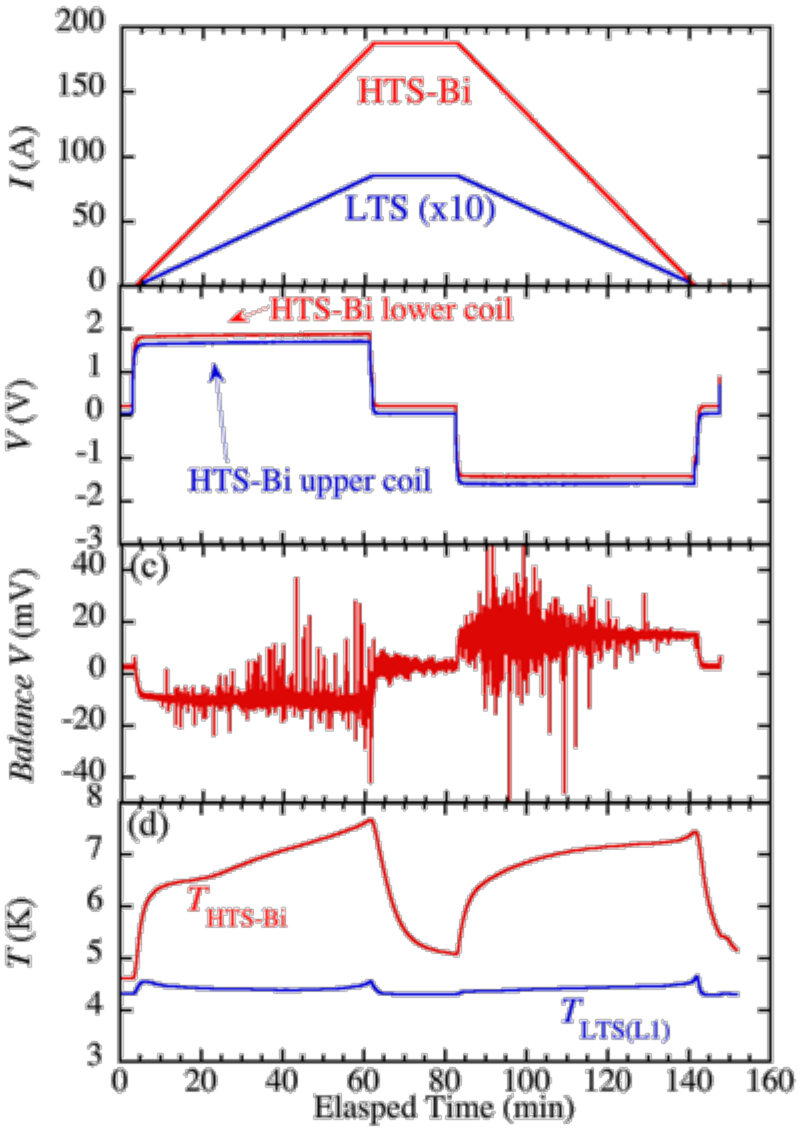
25T-CSM-Bi combination test

24.6 T

I_{HTS}=187.8A

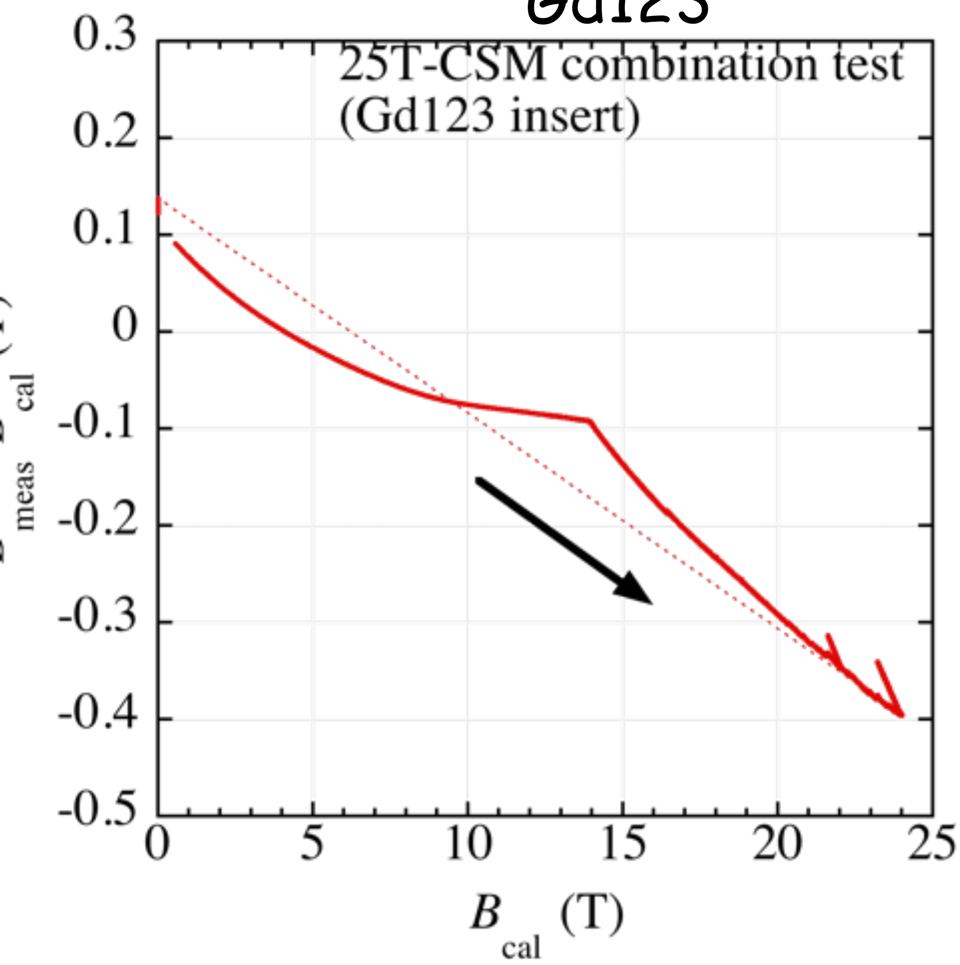
I_{LTS}=854A



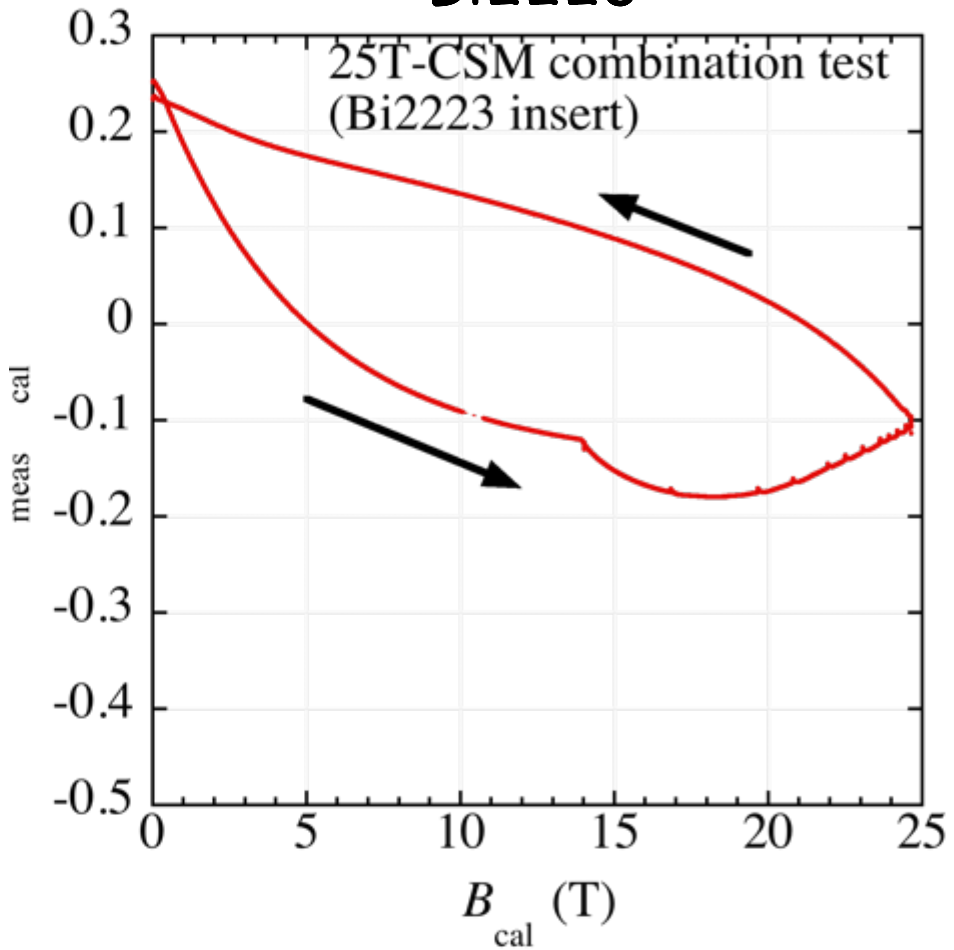


Field hysteresis

Gd123



Bi2223



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Field monitor for 25T-CSM

Field monito coil

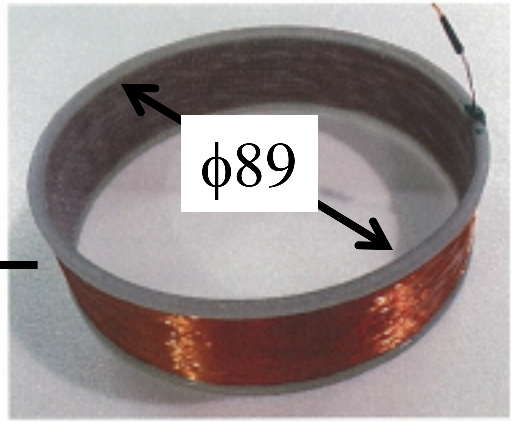
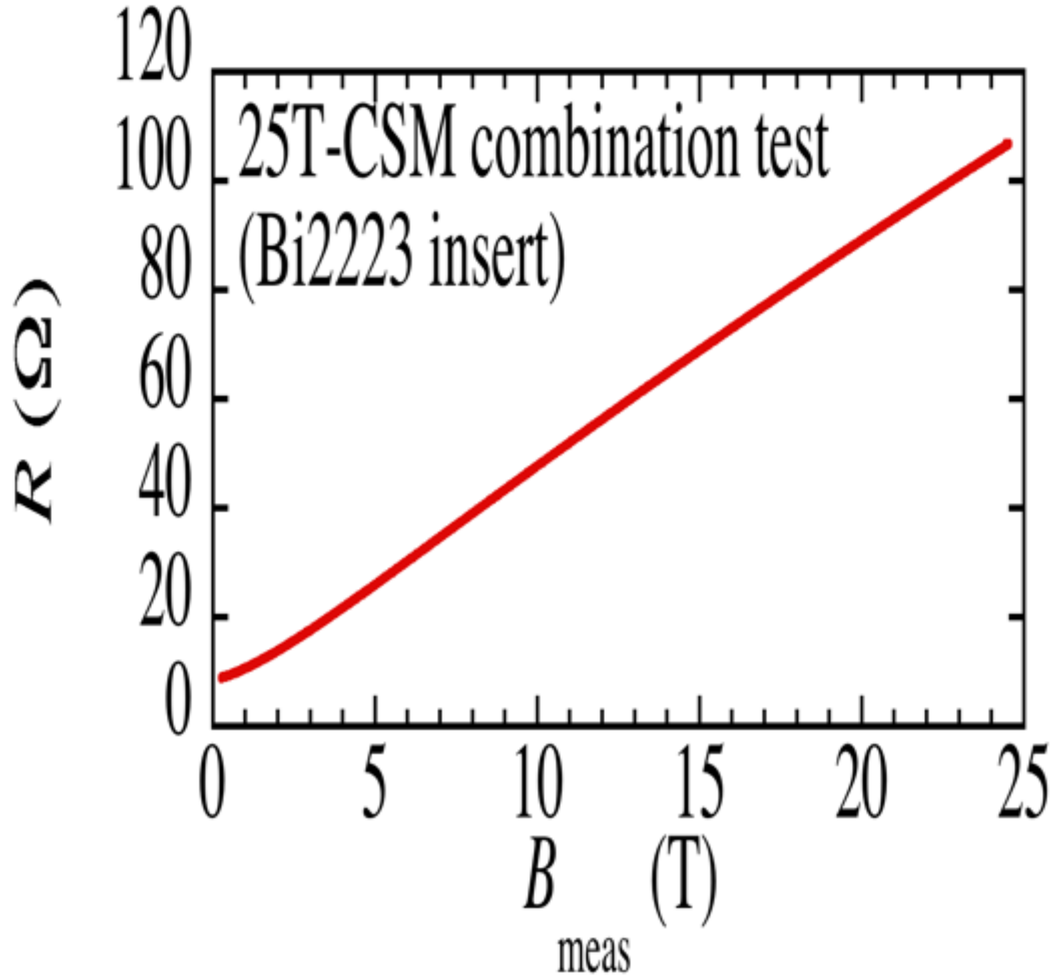
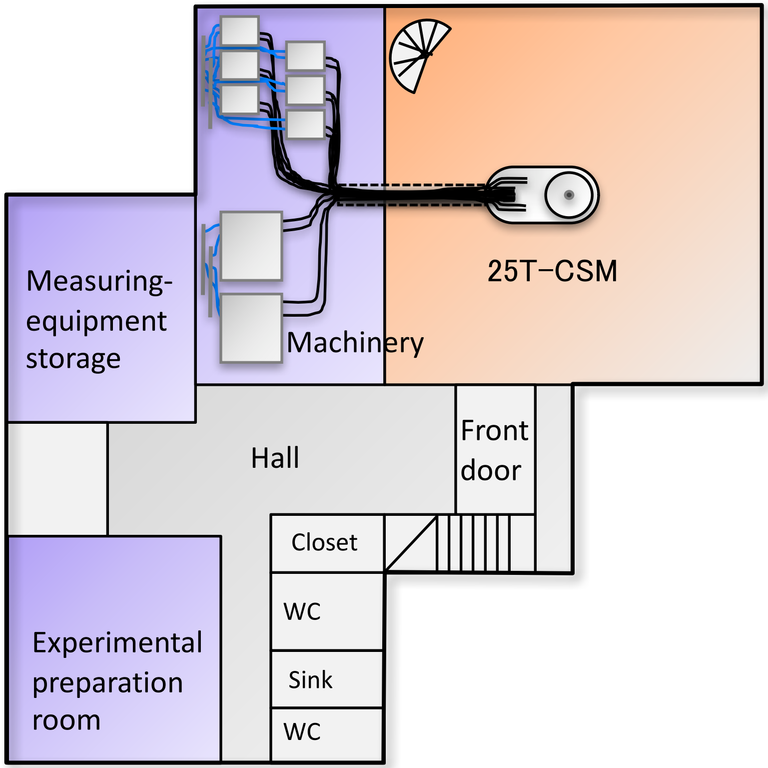


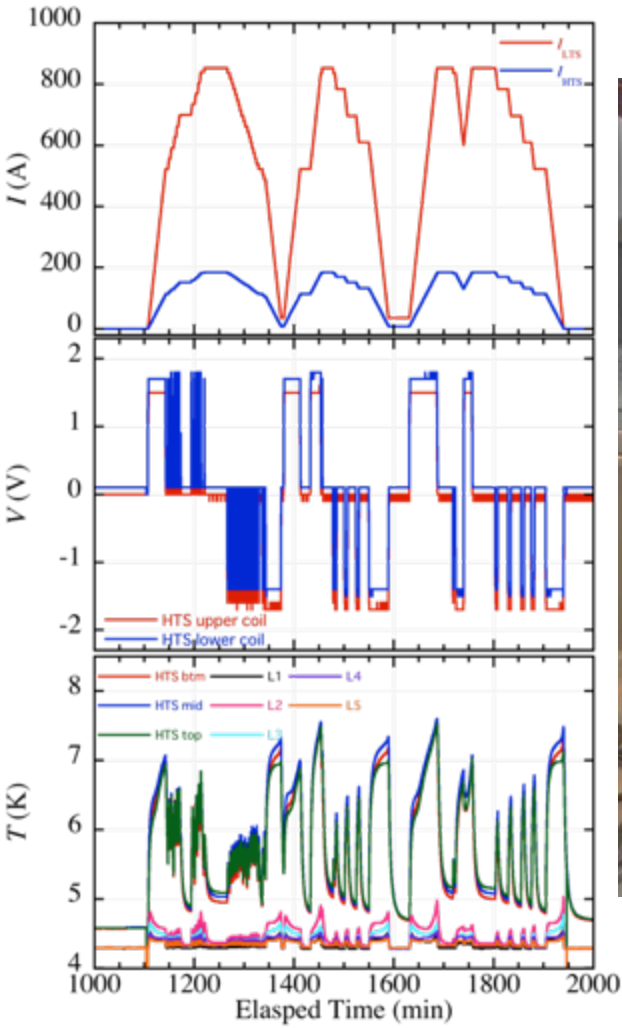
図6 磁場モニタコイル外観

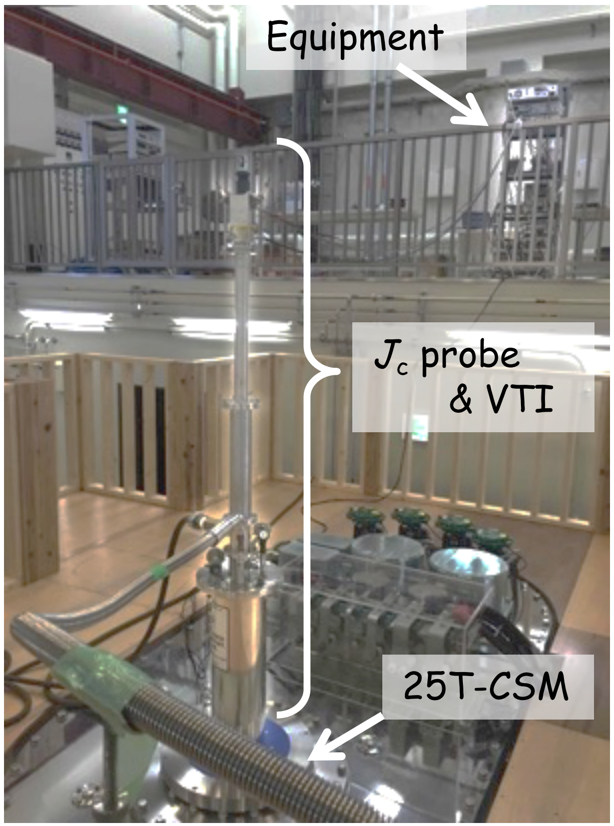


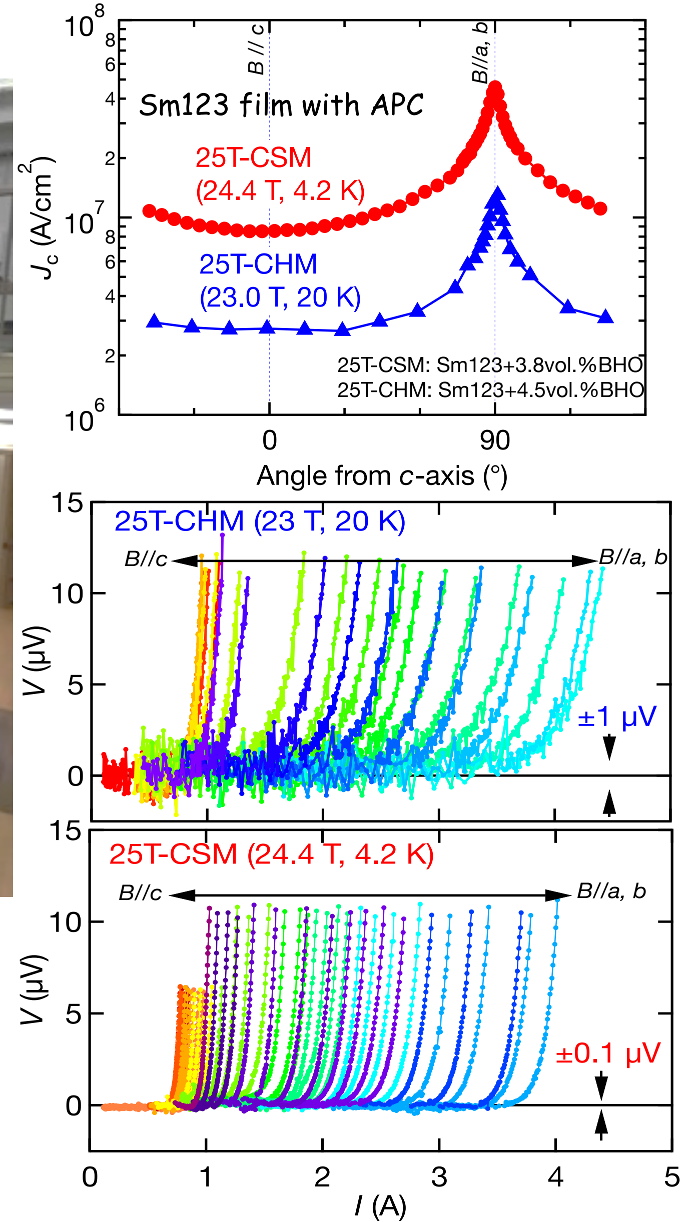
25T-CSM at HFLSM Annex building



J_c measurement using 25T-CSM







No time limit! Small noise level!

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Summary

- 25T-CSM was installed and tested at the HFLSM, IMR, Tohoku University.
  - CuNb/Nb_3Sn, NbTi Rutherford cable coils (LTS coils)
    - 1 hour ramping up to 14 T of the LTS outsert coil was confirmed without training quench.
    - High stress operation in 251 MPa was succeeded.
  - Gd123 insert coil (HTS-Gd coils)
    - 1 hour charging/discharging up to 10.5 T was confirmed by the single mode test.
    - 24.01T was generated but a thermal runaway of the HTS coil happened.
  - Bi2223 insert coil (HTS-Bi coils)
    - 1 hour charging/discharging up to 11.5 T was confirmed by the single mode test.
    - **24.6T was achieved successfully within one hour charging time by the simultaneous ramping of both HTS and LTS coils.**