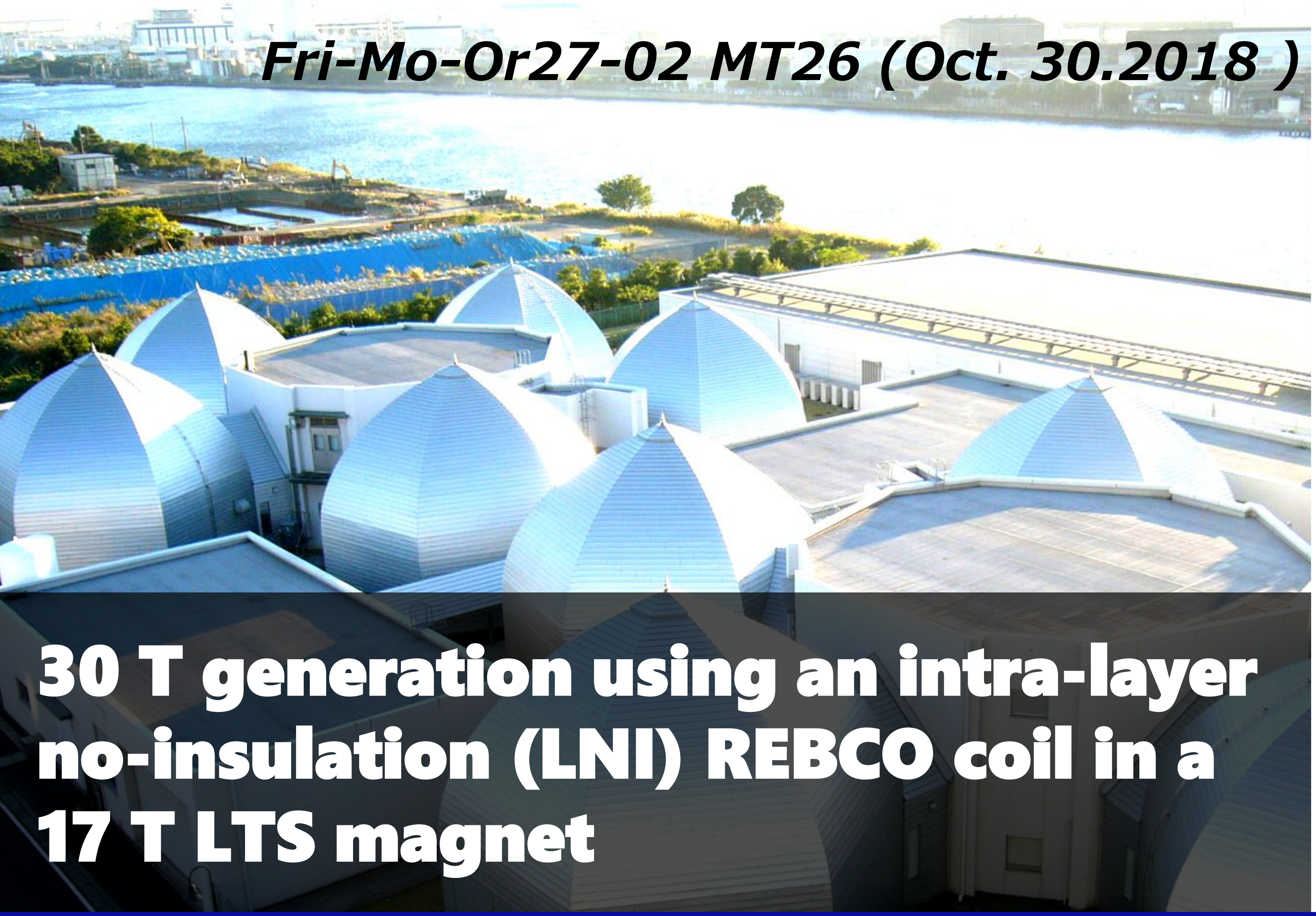
Fri-Mo-Or27-02 MT26 (Oct. 30.2018)



30 T generation using an intra-layer no-insulation (LNI) REBCO coil in a 17 T LTS magnet

MT 26 International Conference on Magnet Technology
Vancouver, Canada | 2019

CHIBA UNIVERSITY
RIKEN
NIMS
JASTEC SUPERCONDUCTOR

Part of the present work was supported by the JST Mirai-Program Grant Number JPMJMI17A2 and Grant-in-Aid for JSPS Fellows Grant Number 19J11812

Y. Suetomi[1,2], T. Yoshida[2,3], S. Takahashi[2,3], T. Takao[3], G. Nishijima[4], H. Kitaguchi[4], Y. Miyoshi[5], M. Hamada[5], K. Saito[5], P. Renzhong[2], Y. Yanagisawa[2], H. Maeda[2,6]

[1] Chiba University, [2] RIKEN, [3] Sophia University, [4] NIMS, [5] JASTEC, [6] JST

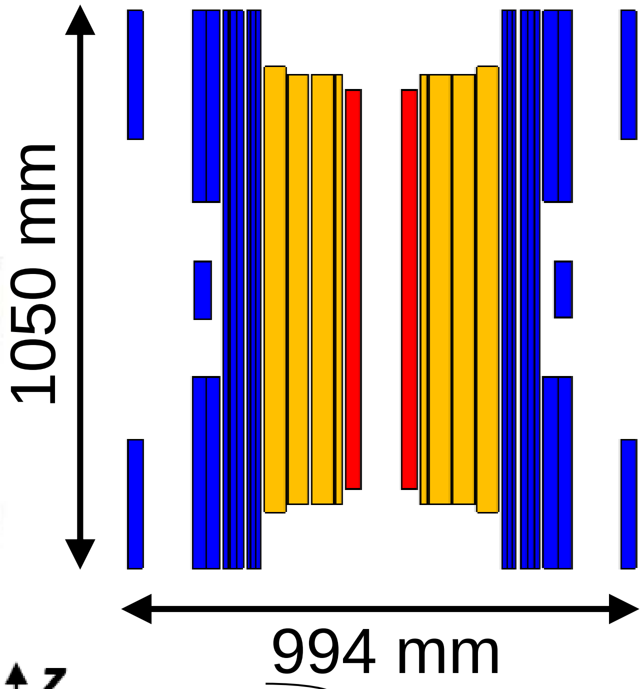
Contents

1. Background : Towards 1.3 GHz NMR

2. 30 T generation
   by LTS/Bi-2223/LNI-REBCO coils

3. LNI-REBCO coil quench at 31 T

Our target : Persistent mode 1.3 GHz NMR magnet



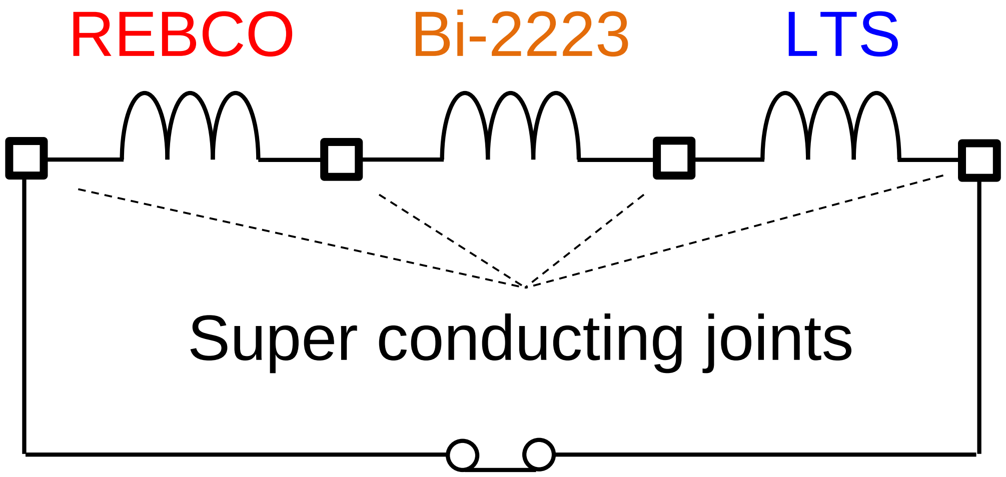
- REBCO
- Bi-2223
- LTS: NbTi + Nb_3Sn

z
r

Layer-wound coil

Primitive designs by Hamada, JASTEC

H. Maeda., IEEE TAS, 29, 5 (2019)



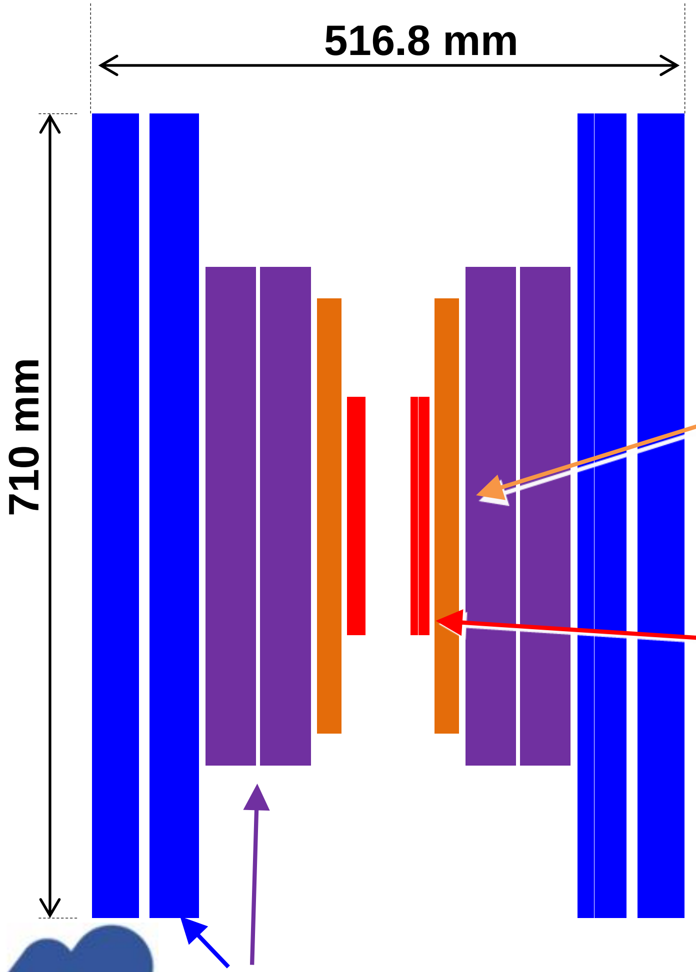
Requirements

- **30.5 T** generation by LTS / Bi-2223 / REBCO **layer-wound** coils.

etc.

Previous achievement :

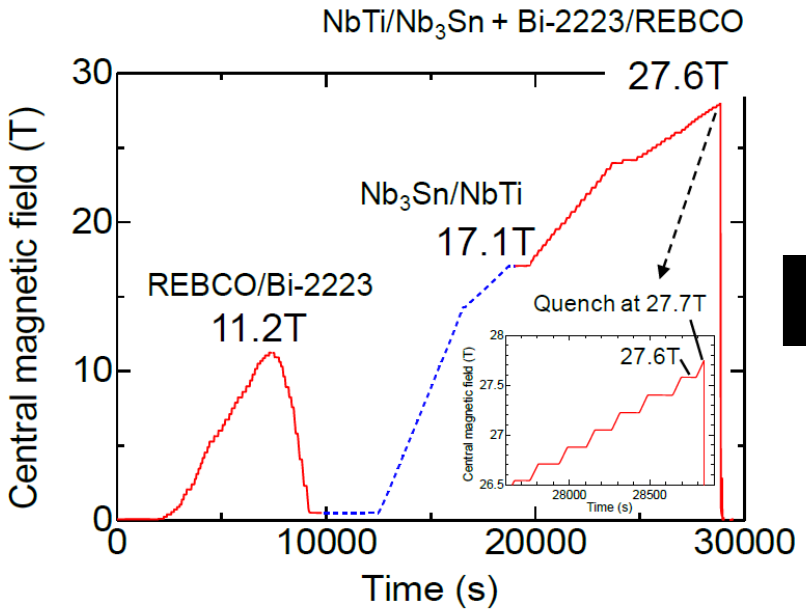
27.6 T generation by LTS / Bi-2223 / REBCO layer-wound coils



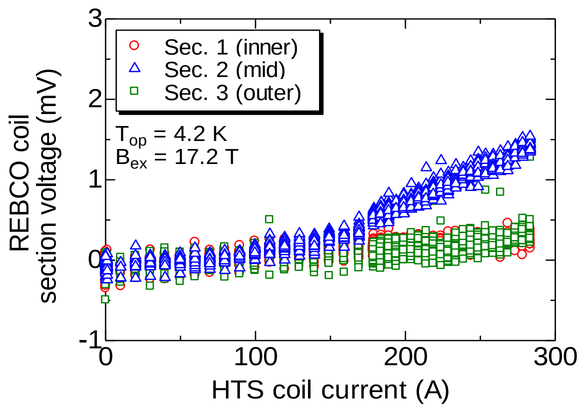
Bi-2223 (Insulated)

REBCO (Insulated)

Nb_3Sn – NbTi (17 T)



Burnout on the REBCO coil

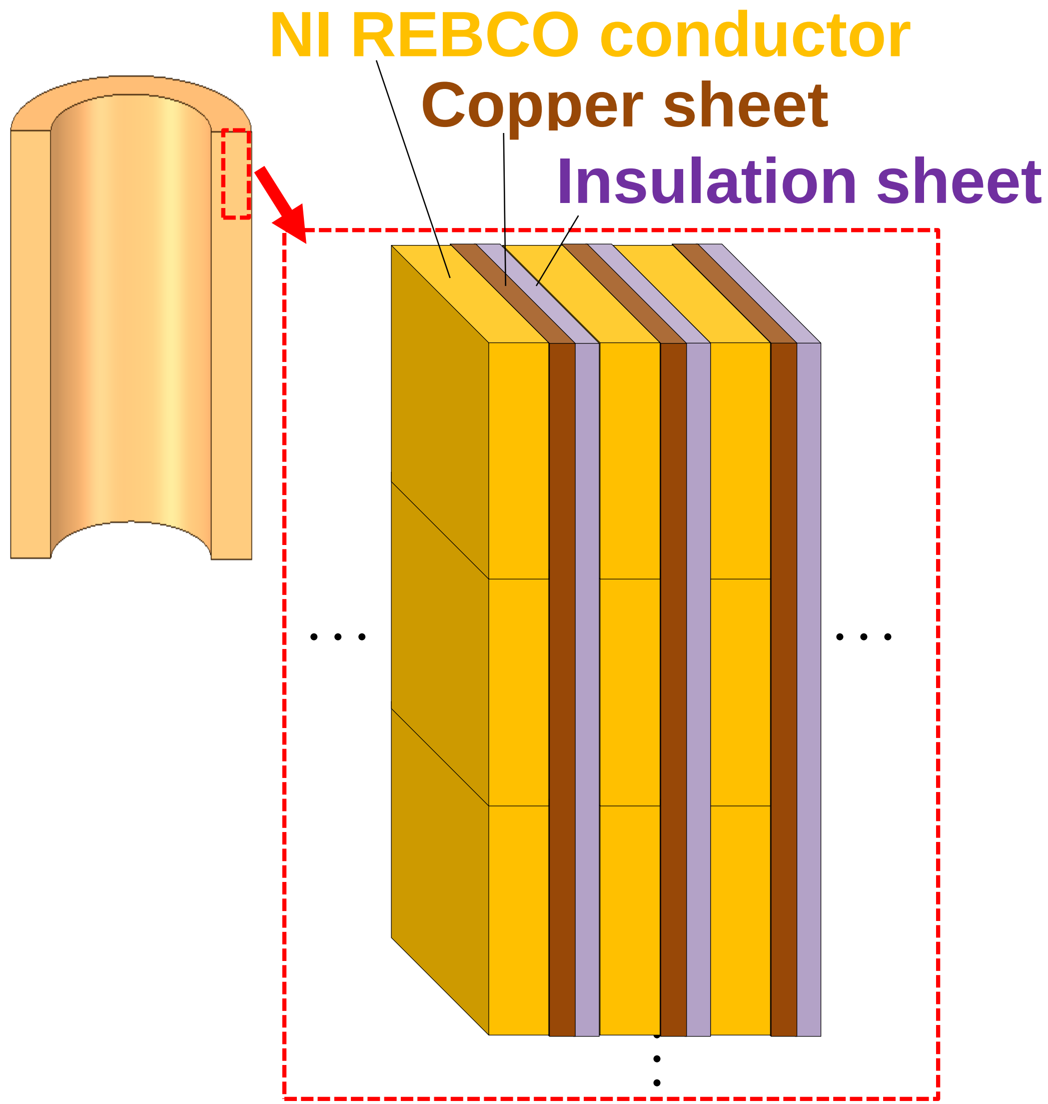


Degradation in the middle section of the REBCO coil

Y Yanagisawa et al., IEEE/CSC & ESAS SUPERCONDUCTIVITY NEWS FORUM (Global Edition), 21(6), 3599–3603., (2016)

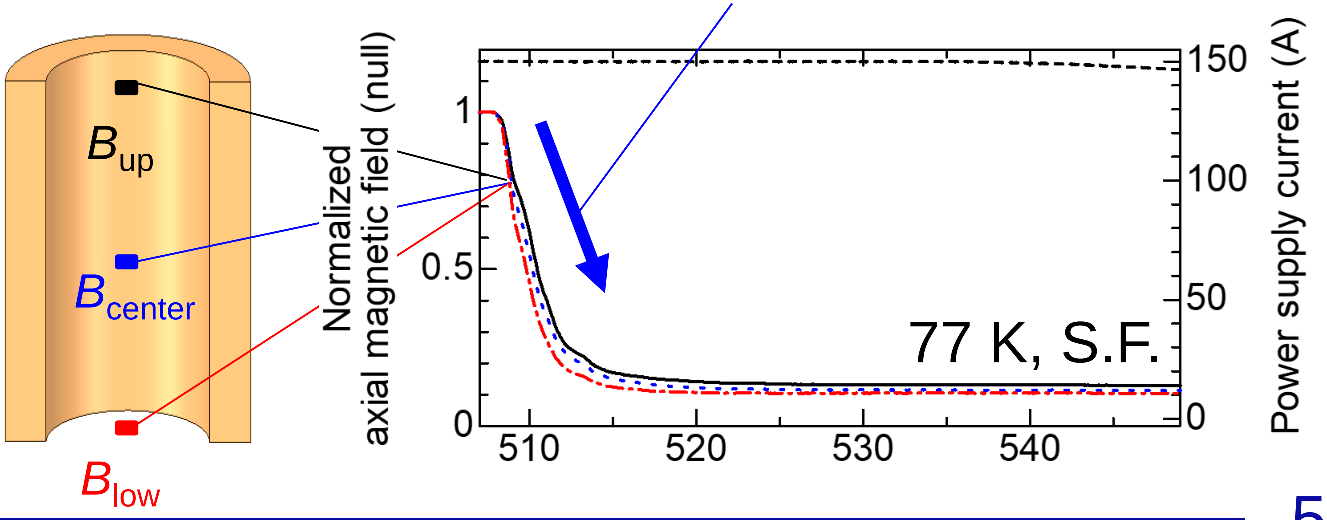
Possible protection method for a REBCO layer-wound coil : "intra-Layer No-Insulation (LNI)" method

Y Suetomi et al., SuST, 32, 045003 (2019)



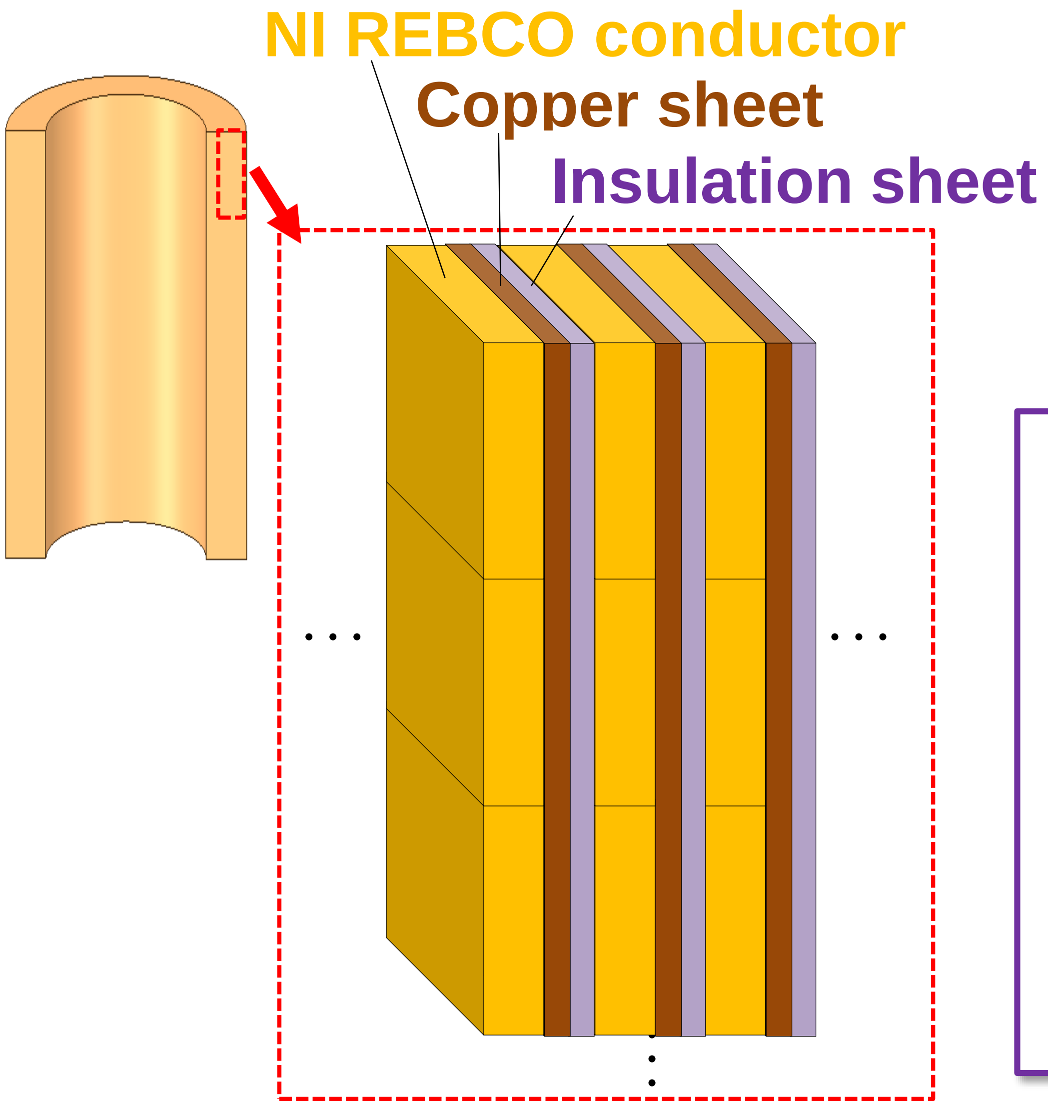
- **Short field delay**
- **Self-protection**

Homogeneous field decay in the axial direction during quench.



Possible protection method for a REBCO layer-wound coil : "intra-Layer No-Insulation (LNI)" method

Y Suetomi et al., SuST, 32, 045003 (2019)



- **Short field delay**
- **Self-protection**

The effectiveness of the LNI coil under the following conditions has not been revealed.

- **Practical number of layers (~100 layers)**
- **Under high-fields (>20 T)**

B_{low}

Objectives of this work

To demonstrate…

- Generation of >30 T by LTS / Bi-2223 / REBCO layer-wound coils.
- Protection for a REBCO layer-wound coil against a quench under high-fields by an LNI method.

Contents

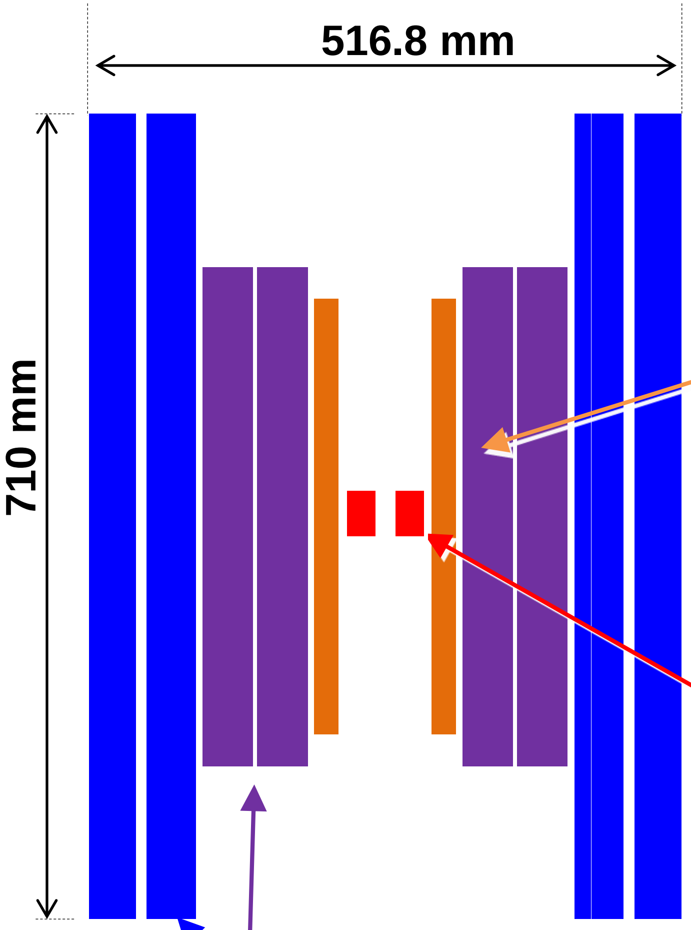
1. Background : Towards 1.3 GHz NMR

2. 30 T generation
   by LTS/Bi-2223/LNI-REBCO coils

3. LNI-REBCO coil quench at 31 T

Configuration of 30 T model test coil

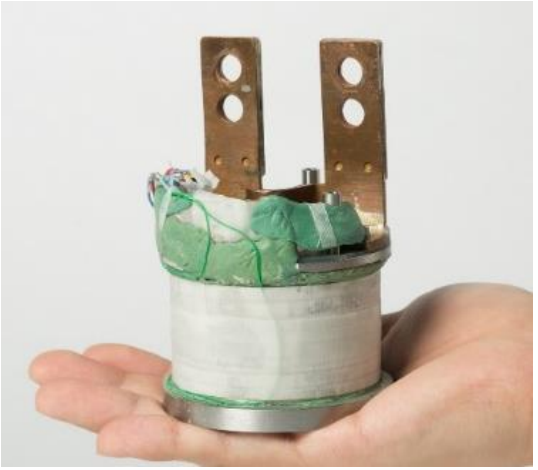
30 T generation test coils

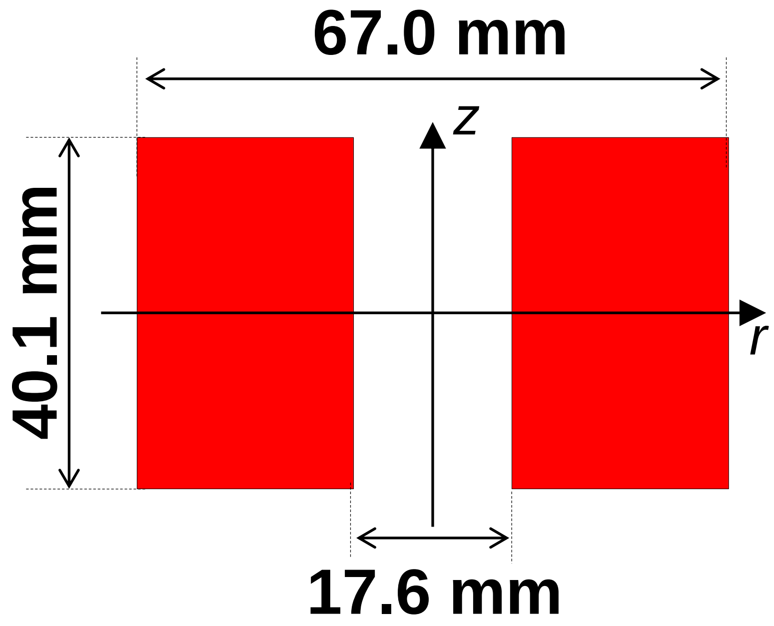


Bi-2223 (Insulated)

Nb_3Sn – NbTi (17 T)

LNI-REBCO coil #2

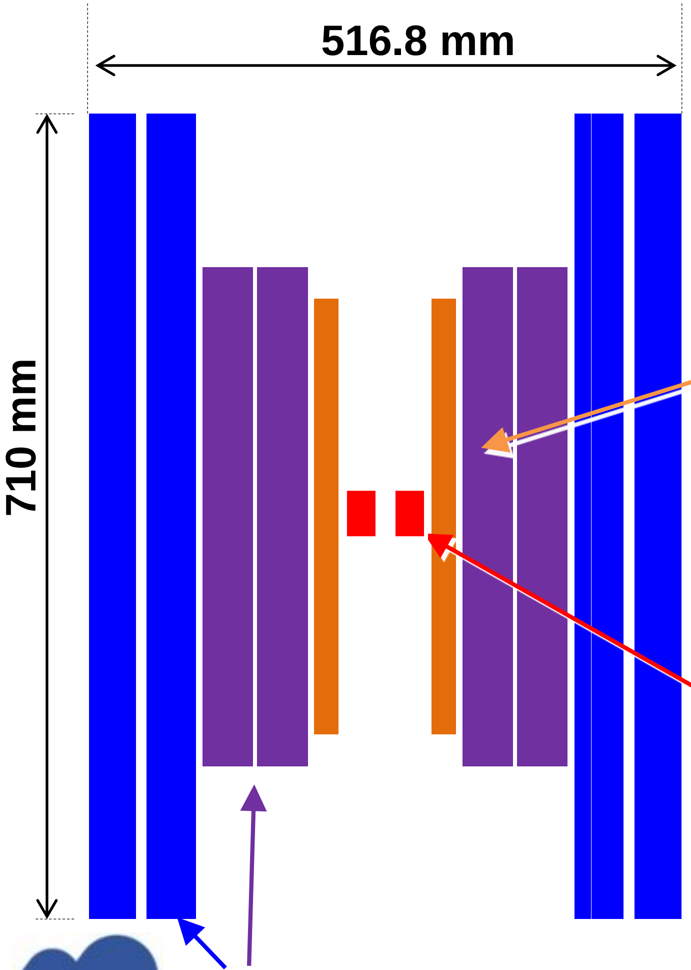




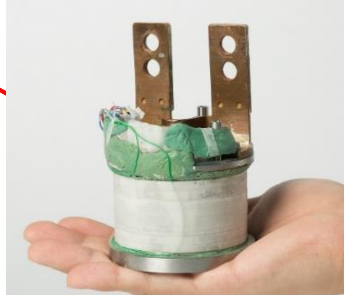
- 1604 turn
  (~9 turns/layer × 180 layers)
- τ (4.2 K, S.F.) = 0.21 s

Configuration of 30 T model test coil

30 T model test coil



Bi-2223 (Insulated)



LNI-REBCO #2

Nb_3Sn – NbTi (17 T)

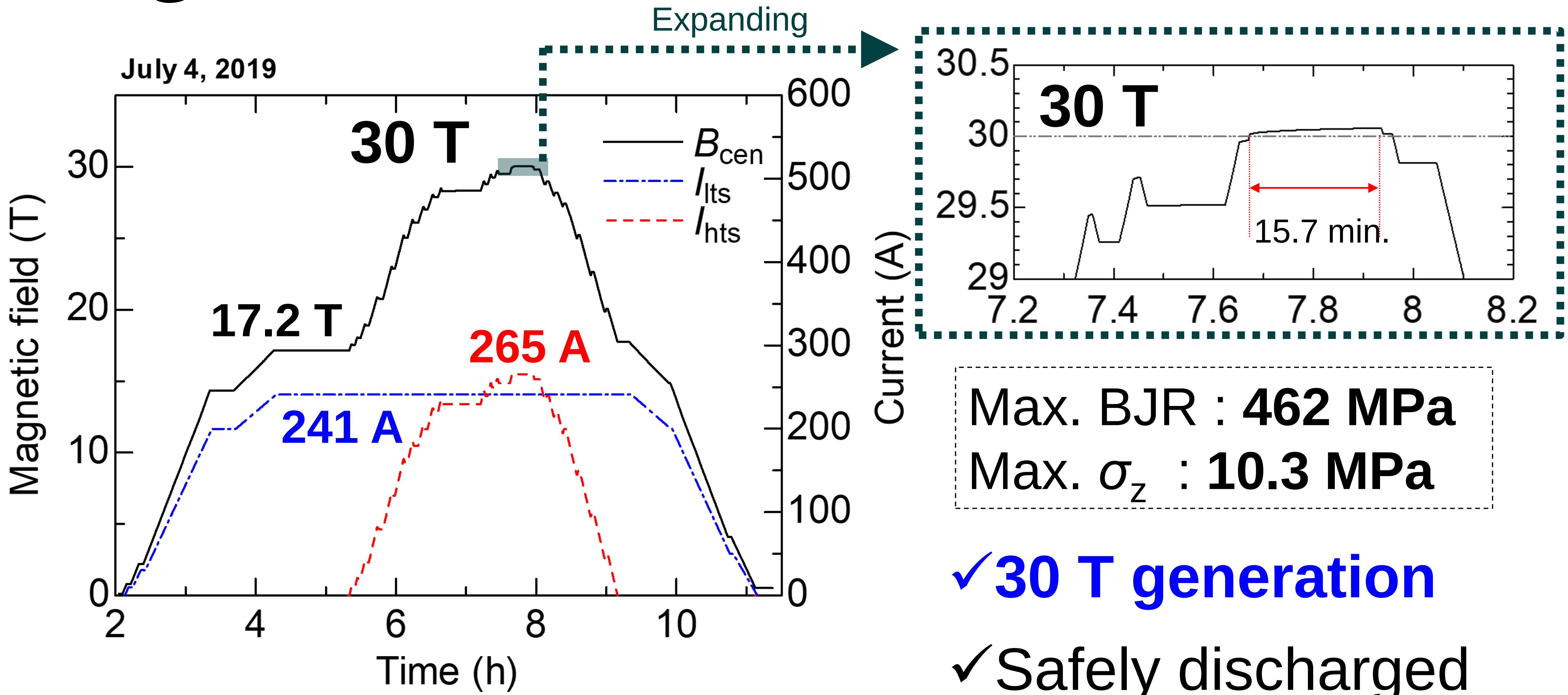
Parameters	REBCO coil	Bi-2223 coil
Conductor Type	SuperPower Inc. SCS4050	SEI, Ltd. HT-NX
Winding	LNI	Layer-wound
Inter-layer material	Cu+PET sheet (26 μm)	-
Impregnation	Paraffin wax	Paraffin wax
Over-band material / Over-band thickness	Ni-alloy tape / 2.1 mm	Brass round wire / 0.9 mm
Coil I.D. / O.D. (mm)	17.6 / 66.95	81.1 / 125
Coil height (mm)	40.1	384
Number of turns	1604 (~9 ×180)	4640 (~80×58)
Number of joints	0	3
Iop (A)	265	
Iop / Ic	0.56	0.51
Magnetic field (T)	9.3	4.0
Self-inductance (mH)	47.7	450

13 T

Center magnetic field : 13 T + 17 T = 30 T

Results

30 T generation

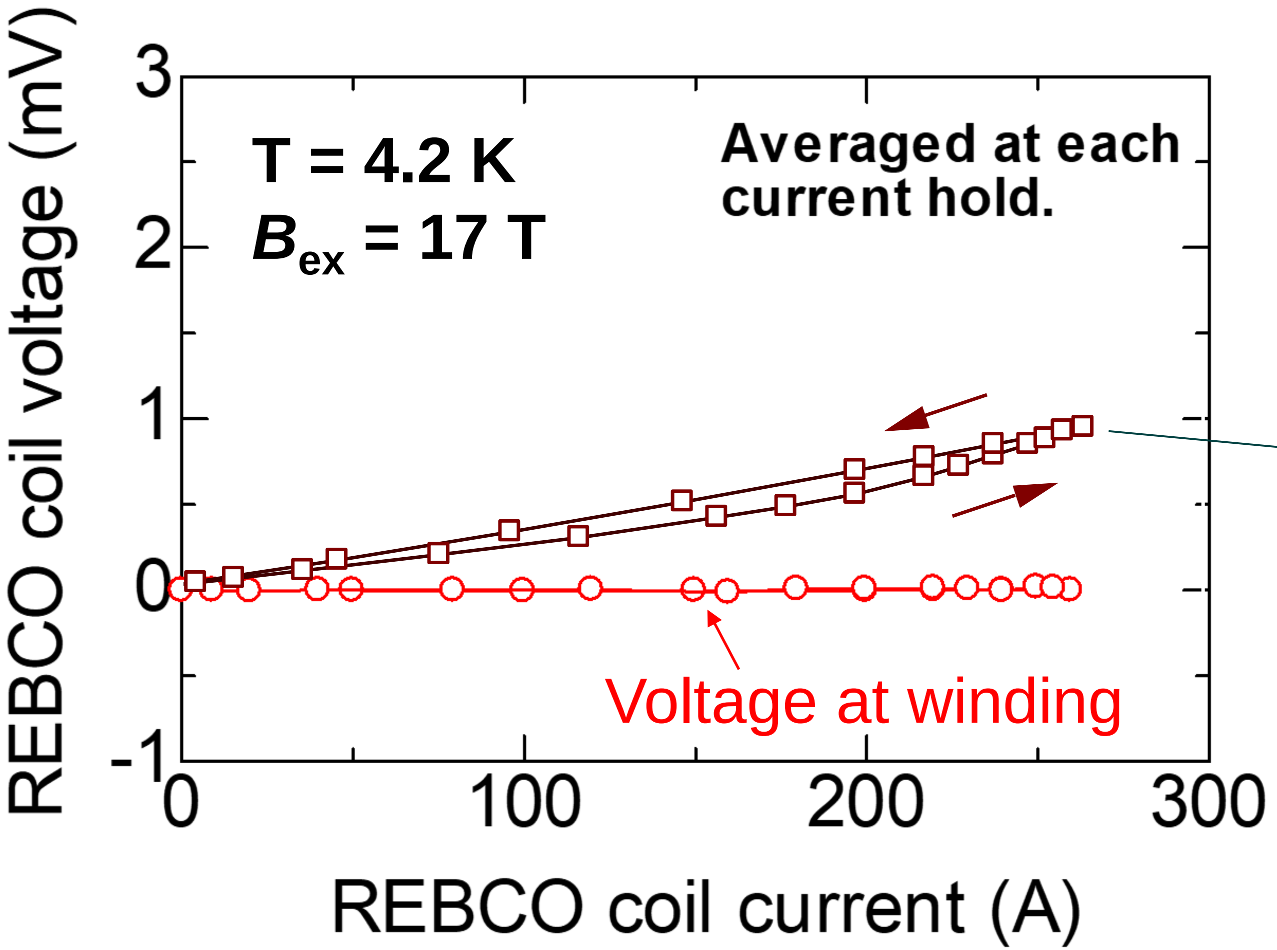


Max. BJR : **462 MPa**
Max. σ_z : **10.3 MPa**

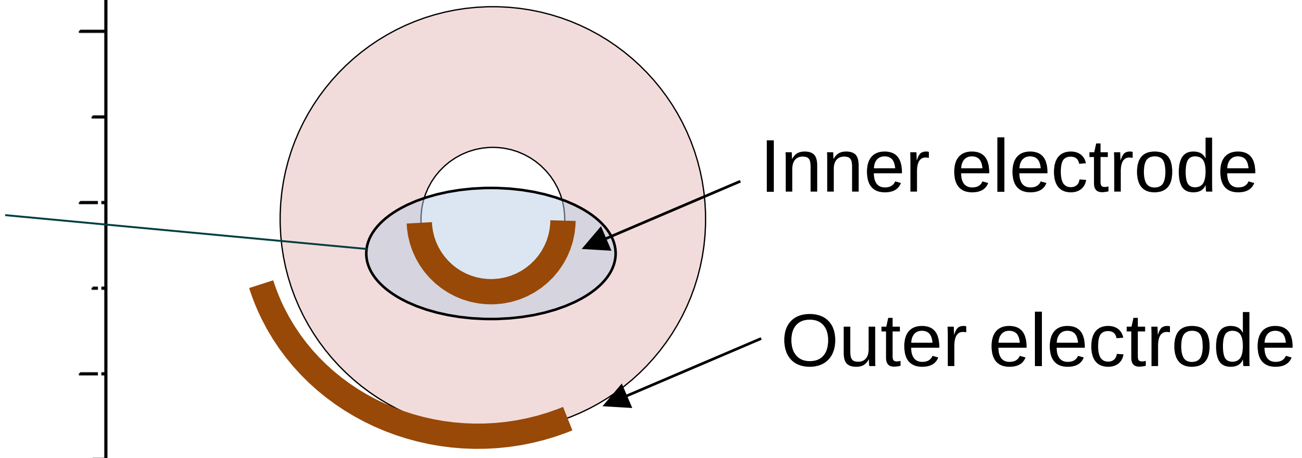
✓**30 T generation**

✓Safely discharged

30 T generation : Coil voltage



✓No normal voltage

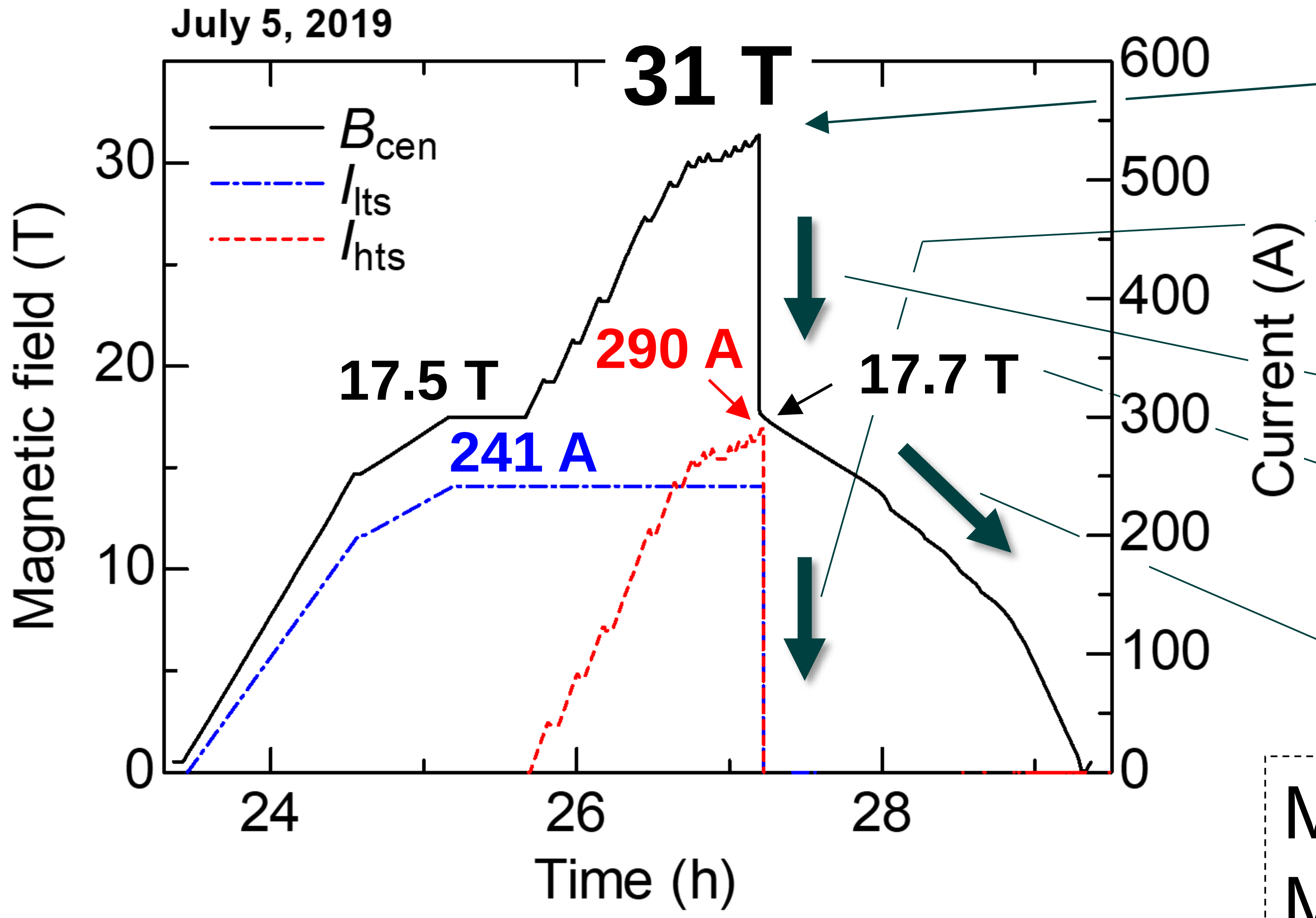


- The junction resistance at the inner electrode slightly increased due to electromagnetic forces.

Contents

1. Background : Towards 1.3 GHz NMR
2. 30 T generation
   by LTS/Bi-2223/LNI-REBCO coils
3. LNI-REBCO coil quench at 31 T

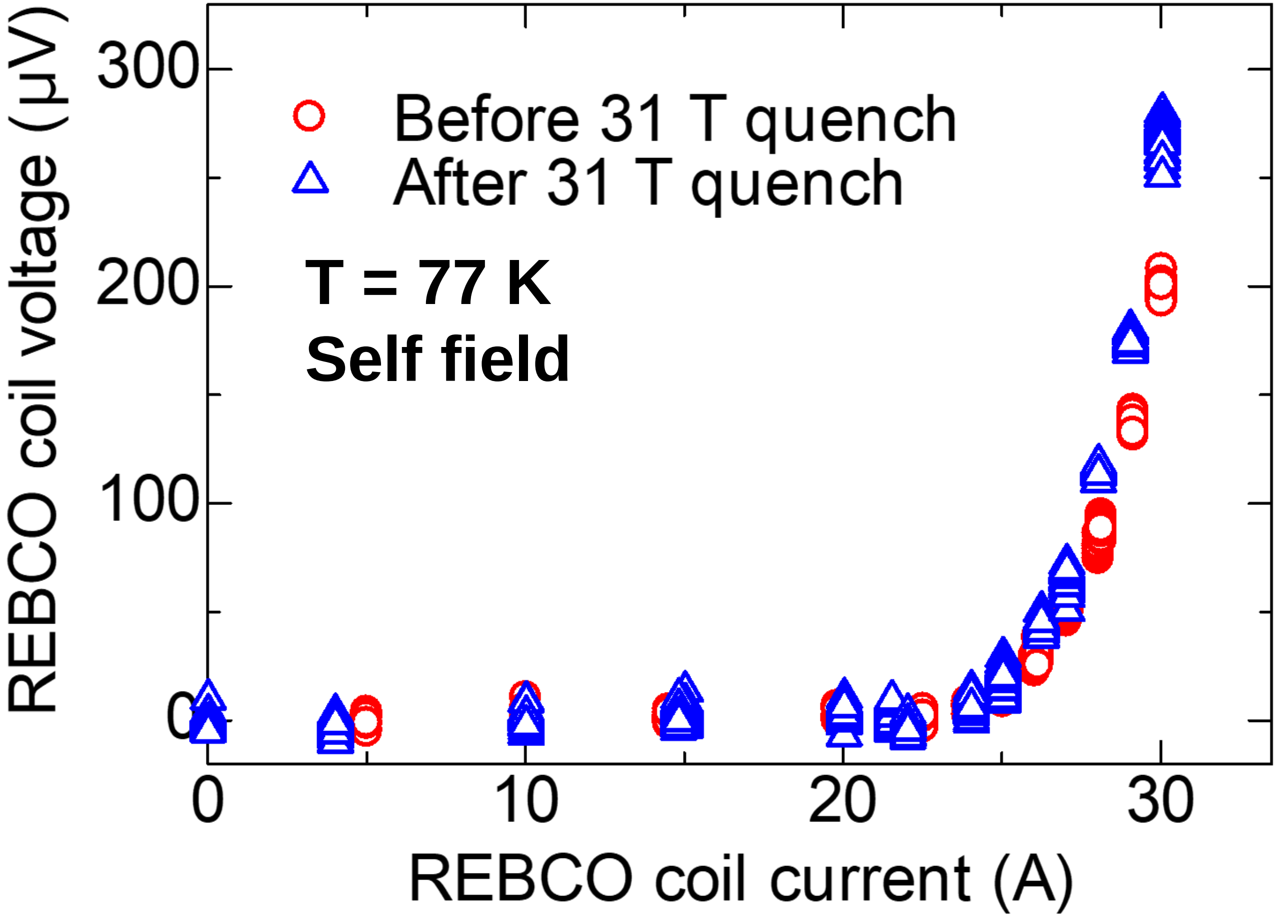
31 T generation ➡ REBCO coil Quench



1. Quench occurred in the LNI-REBCO coil
2. Power supplies were shut down
3. HTS fields vanished
4. No quench in the LTS coil
5. Diode discharge

Max. BJR : **513 MPa**
Max. σ_z : **12.9 MPa**

Confirmation of the coil characteristic change



✓**No degradation**

Degradations due to unbalanced electromagnetic forces as seen in the case of NI DP coils didn't occur.

✓**LNI-REBCO coil was protected from very high-field quench.**

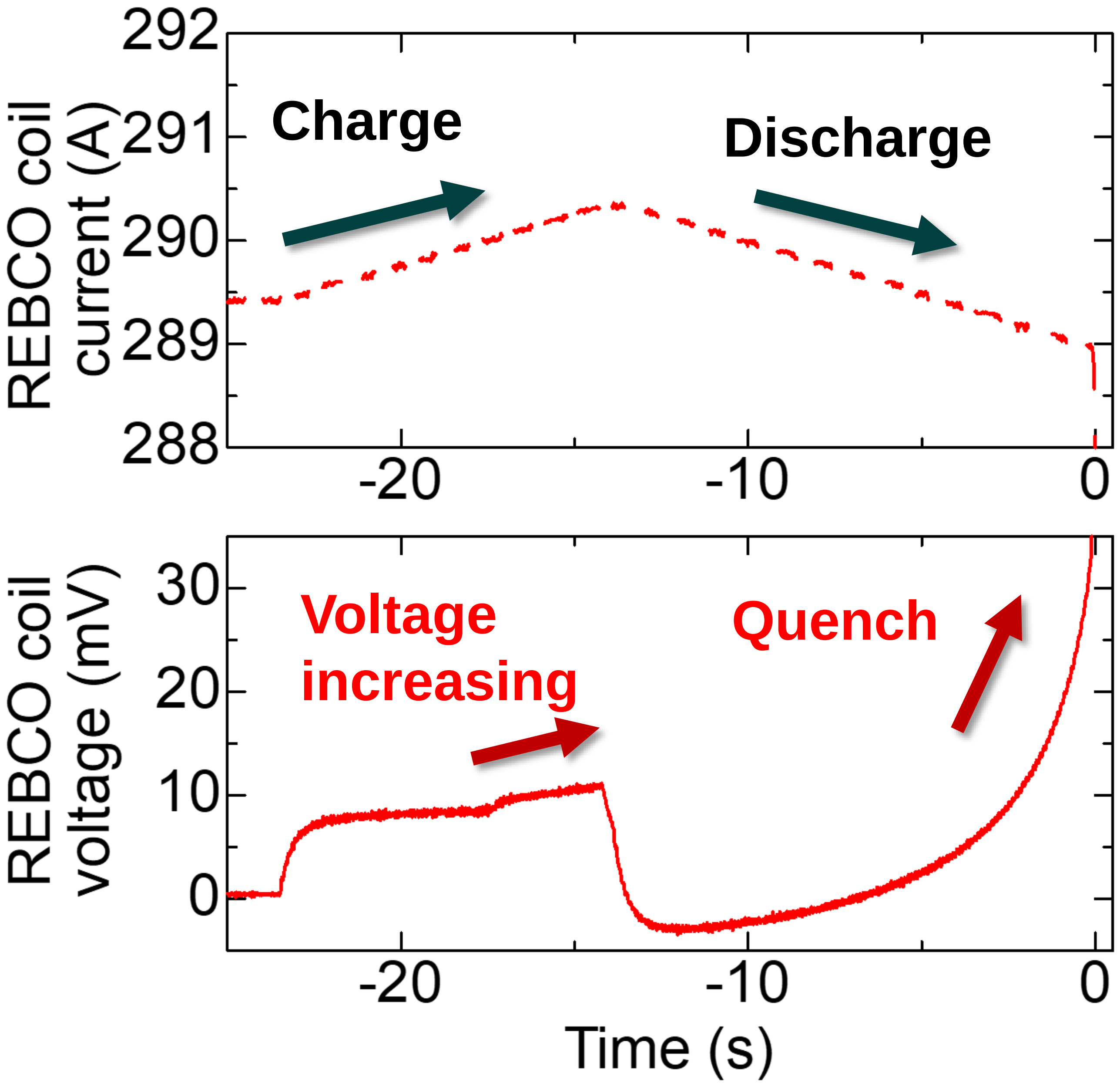
Short summary

✓31 T was generated by using the LTS / Bi-2223 / REBCO layer-wound coils without any degradation.

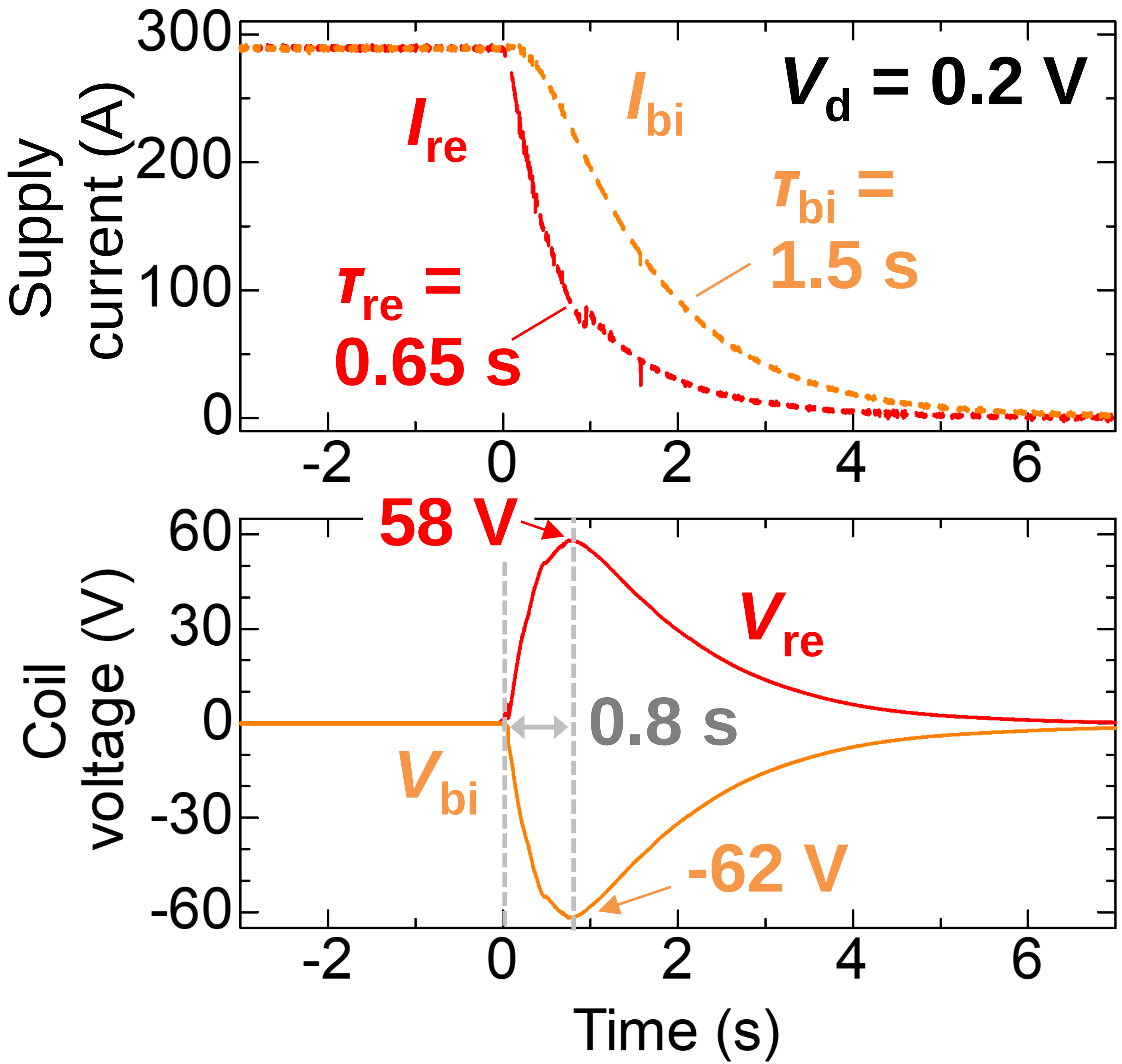
(The highest field ever achieved by a ***LAYER-WOUND*** *superconducting coil)*

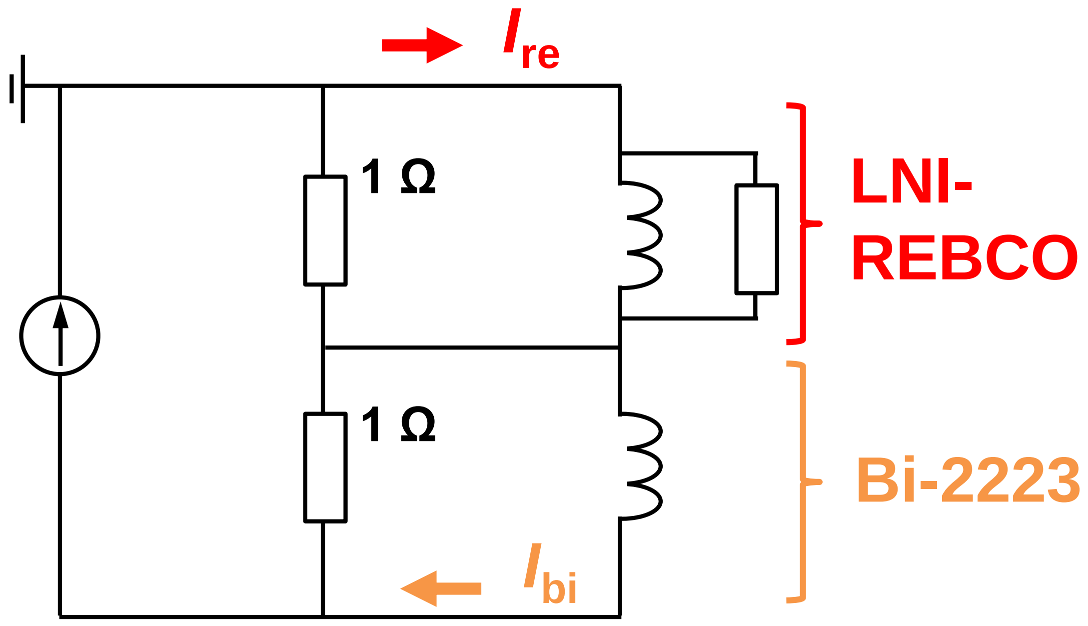
Behavior of the self-protection

Initiation of the quench

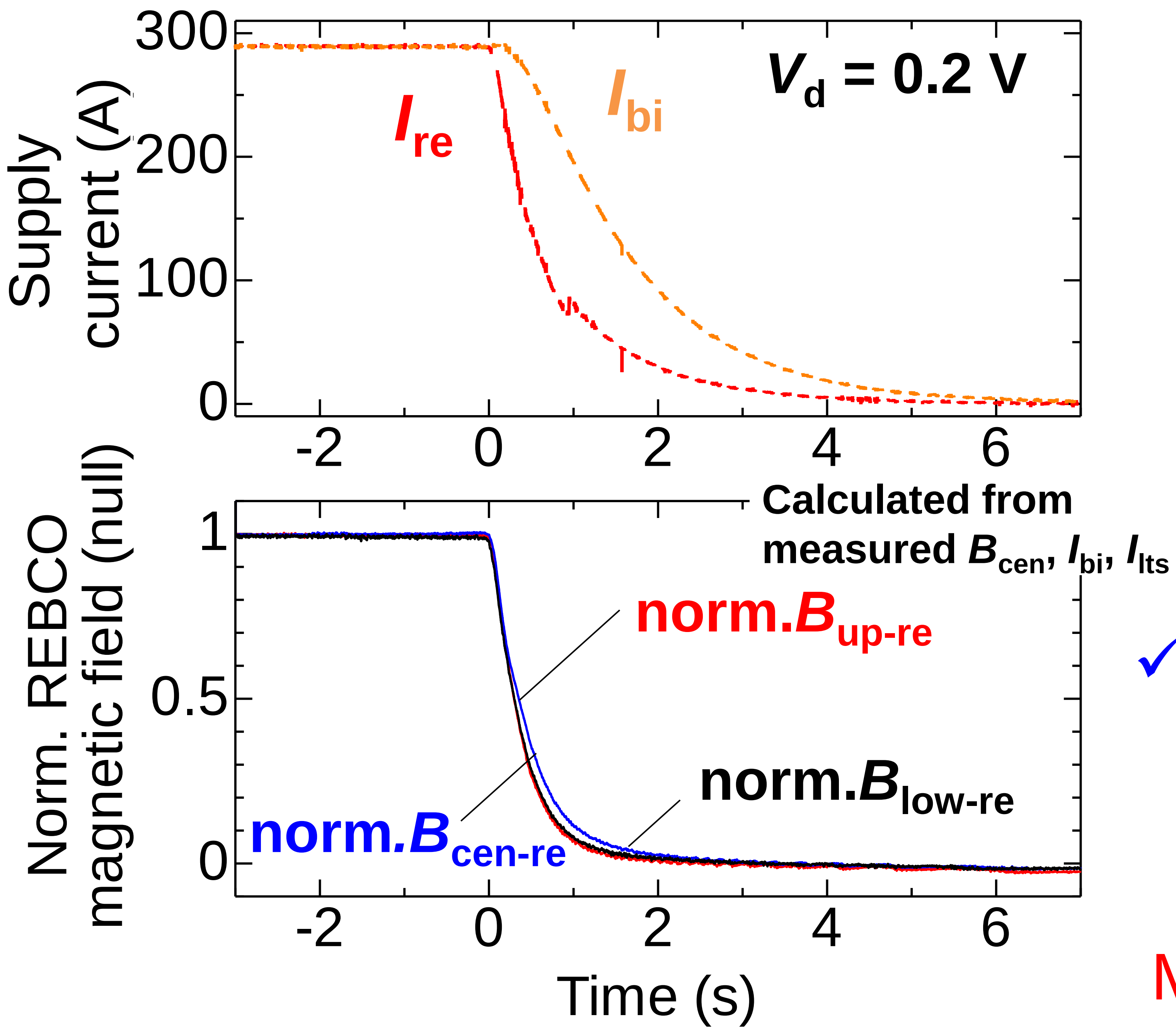


During the quench

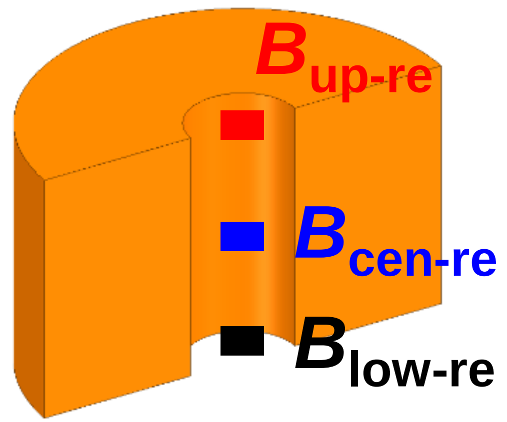




- ✓ The DC power supply was shut down with **0.2 V** of V_d.
- ✓ The Bi-2223 coil did not quench.



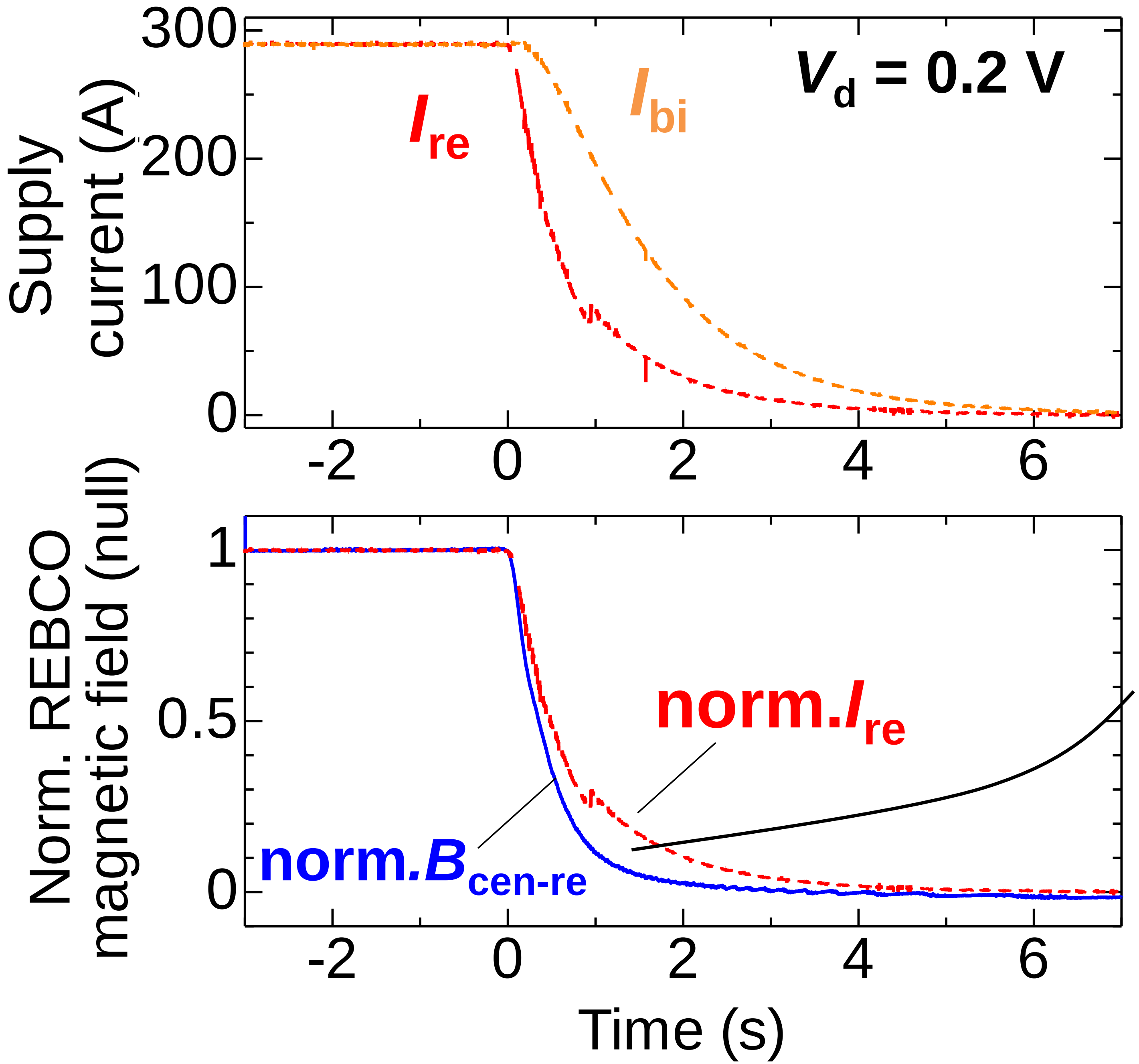
During the quench



LNI-REBCO coil #2

✓ **Magnetic fields homogeneously decayed in the axial direction.**

Major benefit of an LNI coil



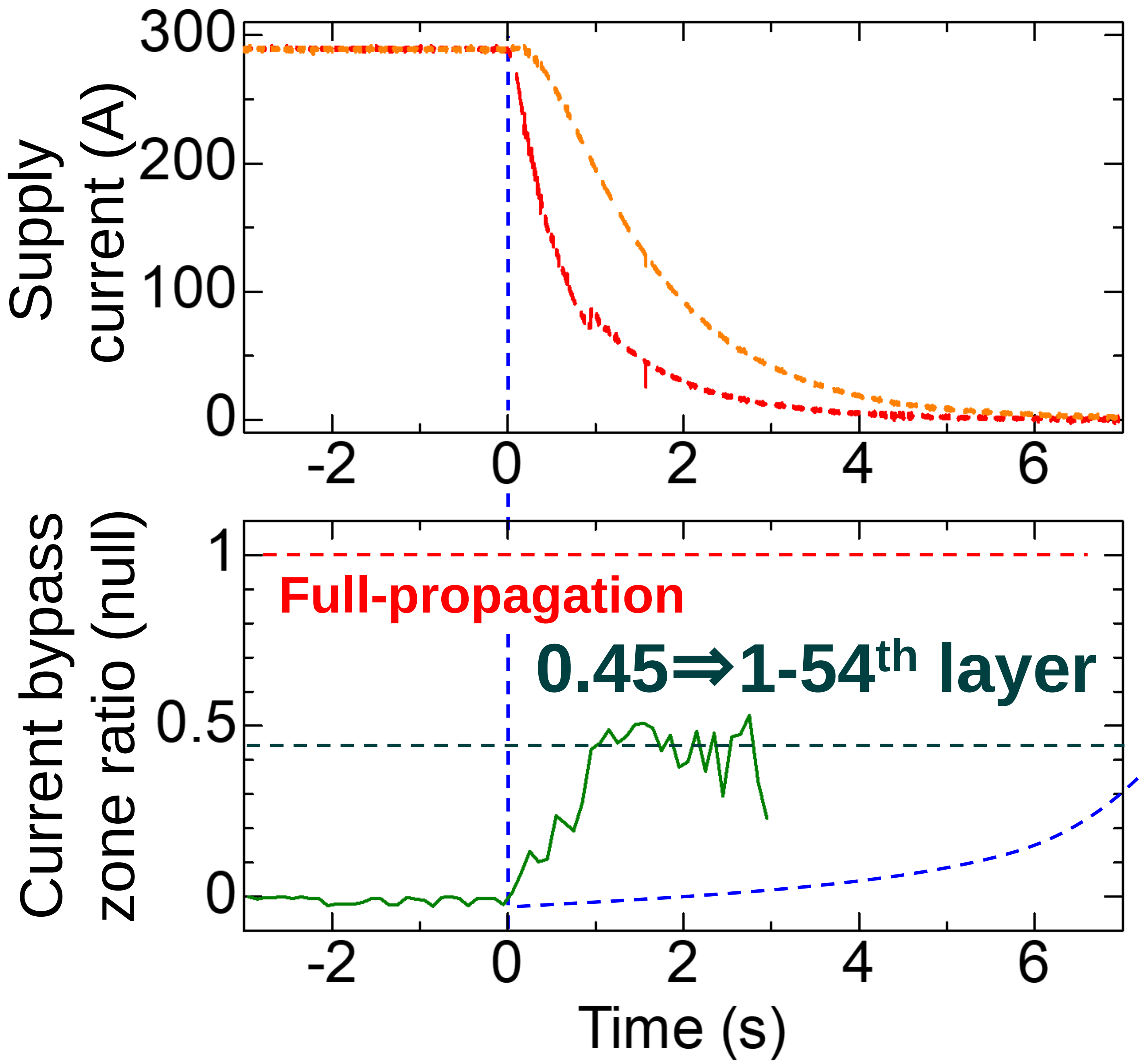
During the quench

Differences between I_{re} and B_{cen-re}

↓

Current bypass zone ratio

Propagation ratio



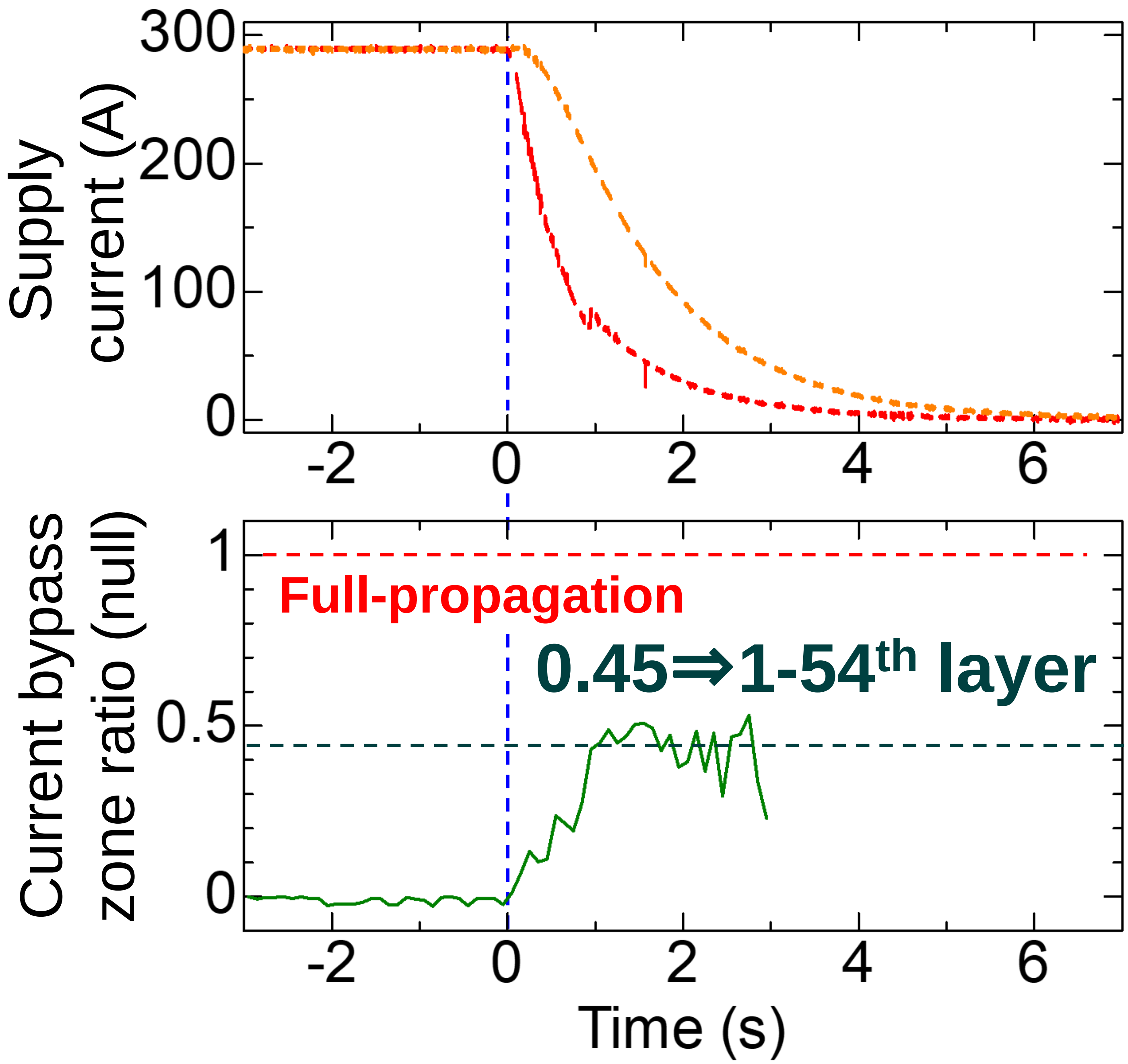
Assumption

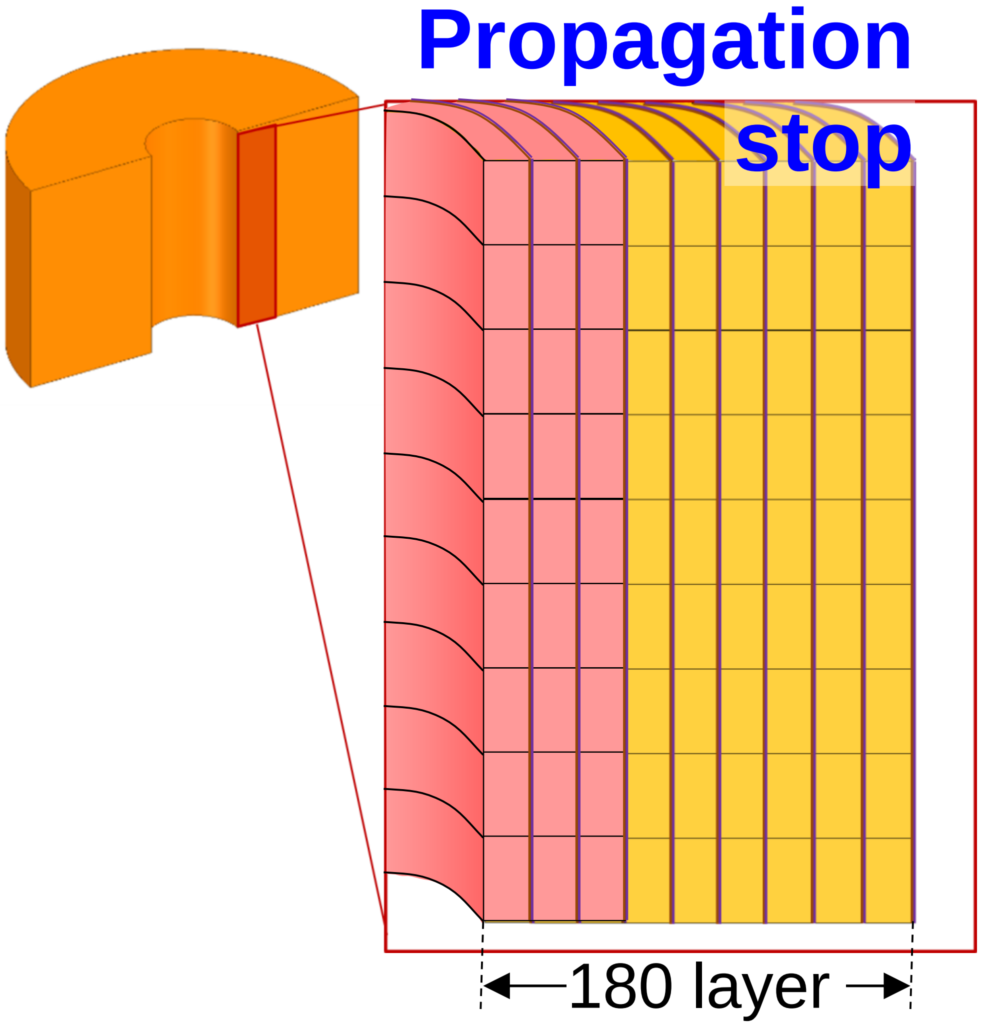
- Quench was initiated inner layer.
- Current bypassed on layer basis.
- At bypass region, circumferential currents were zero.

✓ **Current bypass zone propagation started at the same time as the shutting down of supply currents.**

Thanks to set V_d to 0.2 V

Propagation ratio





Key points

✓Homogeneously field decay in the axial direction.

✓Bypass zone propagation started at the same time as the shutting down of supply currents.

✓Bypass zone propagation stopped at the middle of the winding.

Suppress unbalanced electro magnetic forces during the quench.

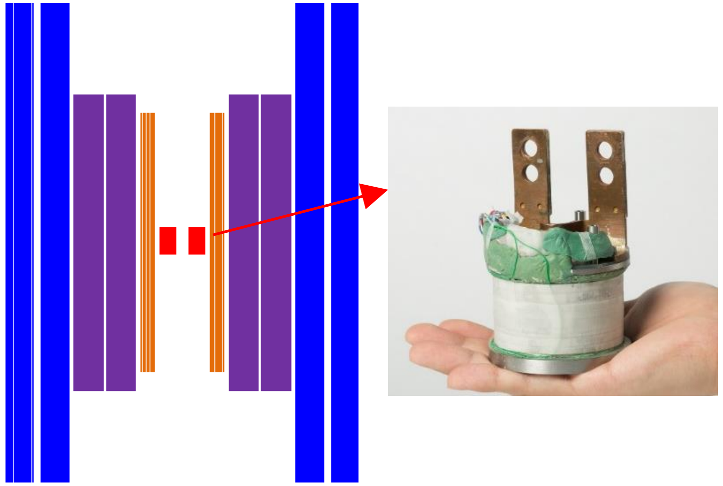
Summary

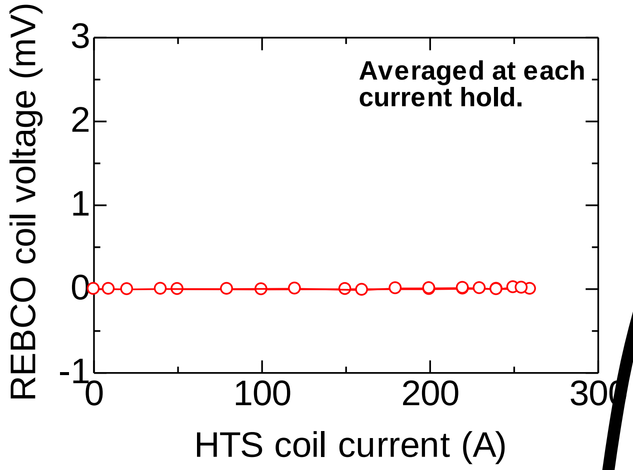
Summary

- 31 T generation by LTS/Bi-2223/REBCO layer-wound coils
- Protection on the LNI-REBCO coil which has practical number of layers against the quench under 31 T

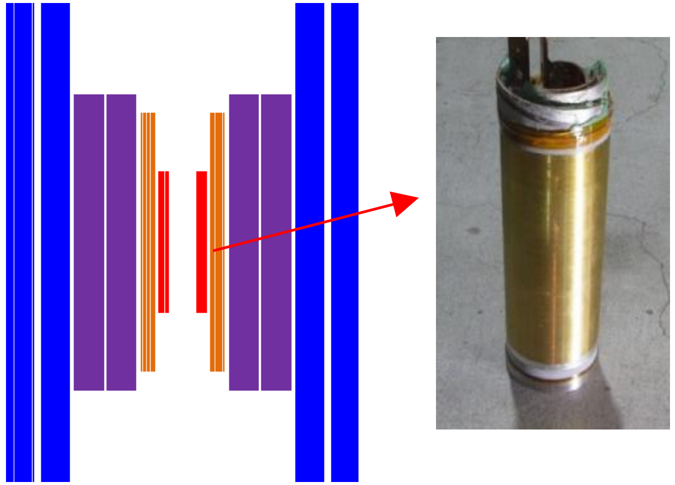
A big step towards a 1.3 GHz NMR magnet.

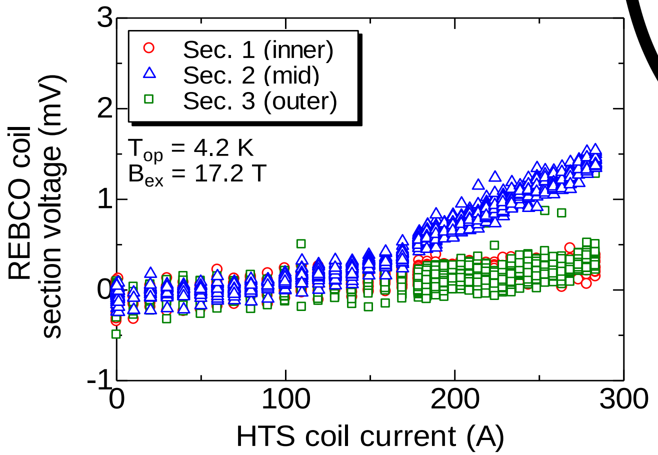
REBCO coil (30 T magnet)





REBCO coil (27.6 T magnet)





During charging

✓ No degradation

Quench

✓ Protected

The LNI method worked.

Why?

During charging

× Premature degradation

Quench

× Burnout