MT 26
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Development and charging test of a compact 1 GHz (23.5 T)-class NMR magnet with Bi-2223 inner coils

- Charging test to 800 MHz (18.8 T) -

R. Piao[1], Y. Yanagisawa[1], M. Takahashi[1], T. Yamazaki[1], H. Maeda[1, 7], Y. Suetomi[2], T. Noguchi[3], Y. Miyoshi[4], M. Yoshikawa[4], K. Saito[4], M. Hamada[4], S. Matsumoto[5] and H. Suematsu[6]

[1]RIKEN, [2]Chiba Univ., [3]IKEGAMI GIZYUTU, [4]JASTEC, [5]NIMS, [6]JEOL RESONANCE,
[7]Japan Science and Technology Agency

1.02 GHz (24.0 T)

54 mm RT bore for high-resolution NMR

K. Hashi et al., *J. Mag. Res.* **256** (2015) 30-33

Compact 1 GHz (23.5 T)-class

R. Piao et al., *IEEE Trans. Appl. Supercond.* **29** (2019) 4300407

Contents

1. ***Development strategy of >1 GHz NMR magnets***

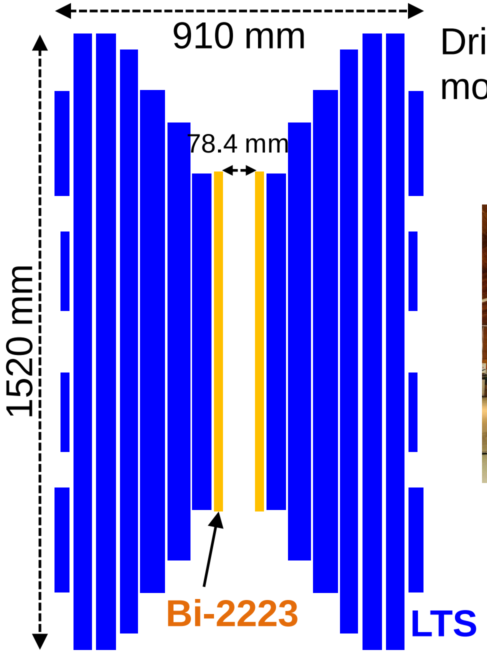
2. ***Technical features of a compact 1 GHz-class NMR magnet***

3. ***Results of a first charging test to 800 MHz (18.8 T)***

Development strategy for >1 GHz NMR magnets (54 mm RT bore)

JST SENTAN

1.02 GHz (24.0 T)



K. Hashi et al., *J. Mag. Res.* **256** (2015) 30-33

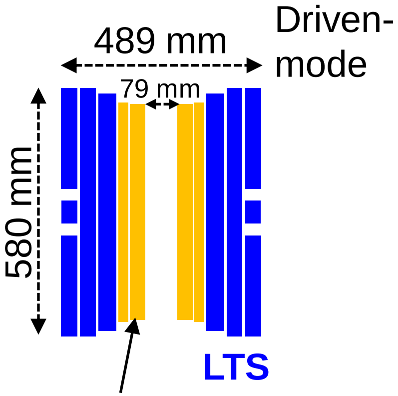
B_0(HTS) B_0(LTS)

156 MHz / 864 MHz

The 1st >1 GHz by small B_0(HTS)

JST S-innovation / Mirai

Compact 1 GHz (23.5 T)-class



R. Piao et al., *IEEE Trans. Appl. Supercond.* **29** (2019) 4300407

B_0(HTS) B_0(LTS)

559 MHz / 501 MHz

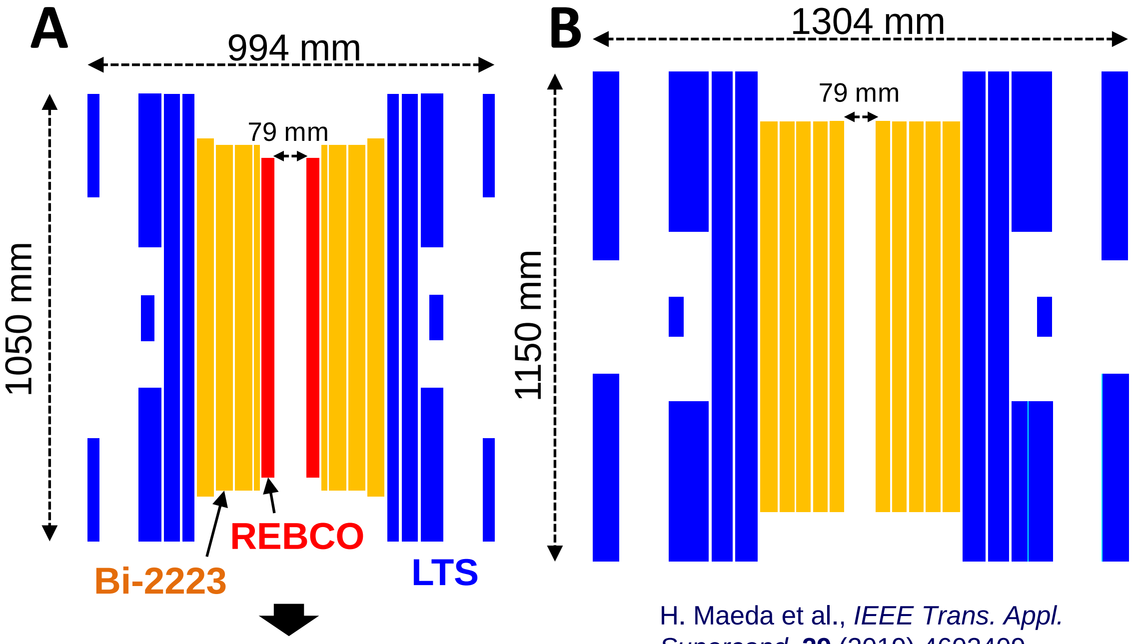
Model development for a highly HTS-dependent compact NMR magnet

JST-Mirai

1.3 GHz (30.5 T)

Persistent-mode

(Preliminary designs under optimization)



H. Maeda et al., *IEEE Trans. Appl. Supercond.* **29** (2019) 4602409

B_0(HTS) B_0(LTS)

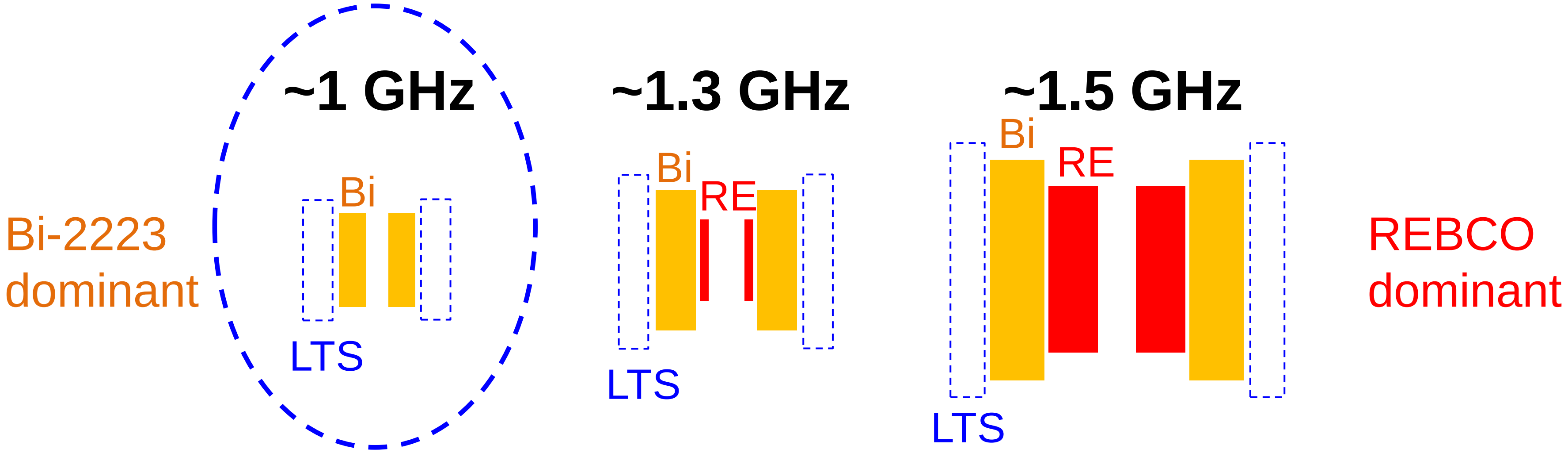
1041 MHz / 274 MHz

Highly HTS-dependent NMR magnet

A view-point: Which tape is better, REBCO or Bi-2223?

	REBCO	Bi-2223
Hoop stress tolerance for high *J* operation	Very high (e.g. 469 MPa)	High (e.g. 370 MPa)
Screening current-induced field	Large (e.g. 1.51 ppm/h*)	Relatively small (e.g. 0.05 ppm/h*)
Degradation due to electromagnetic force	Frequently (in our experiments)	Rare

*Magnetic field drift rate after 100 h elapsed from the excitation of a 500 MHz LTS/HTS NMR magnet.



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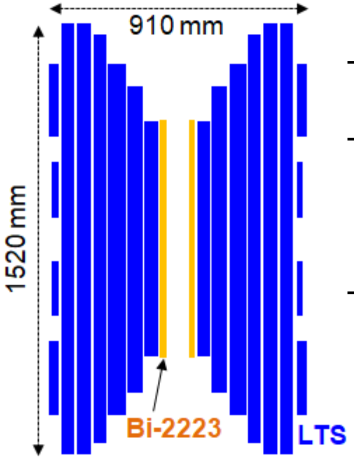
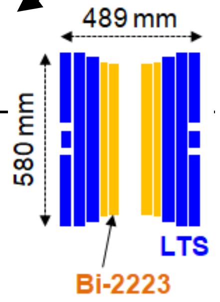
Coil parameters of the compact 1 GHz-class NMR magnet

	1.02 GHz	**Compact 1 GHz-class (at 1.06 GHz)**
HTS	Bi-2223 (CA)	Bi-2223 (NX)
Operation mode	Driven	Driven
I_{op} (A)	240.5	245.5 A
B_0 (T)	HTS / LTS **156 MHz / 864 MHz**	HTS / LTS **559 MHz / 501 MHz**
E (MJ)	33	4.54
J_{cond} of HTS (A/mm^2)	148	236
BJR_{max} in HTS coils (MPa)	189	320.5
$\sigma_{z,max}$ in HTS coils (MPa)	-13	-60.9
Total weight of the superconductors (ton)	4.7	0.6

Large B_0 contribution

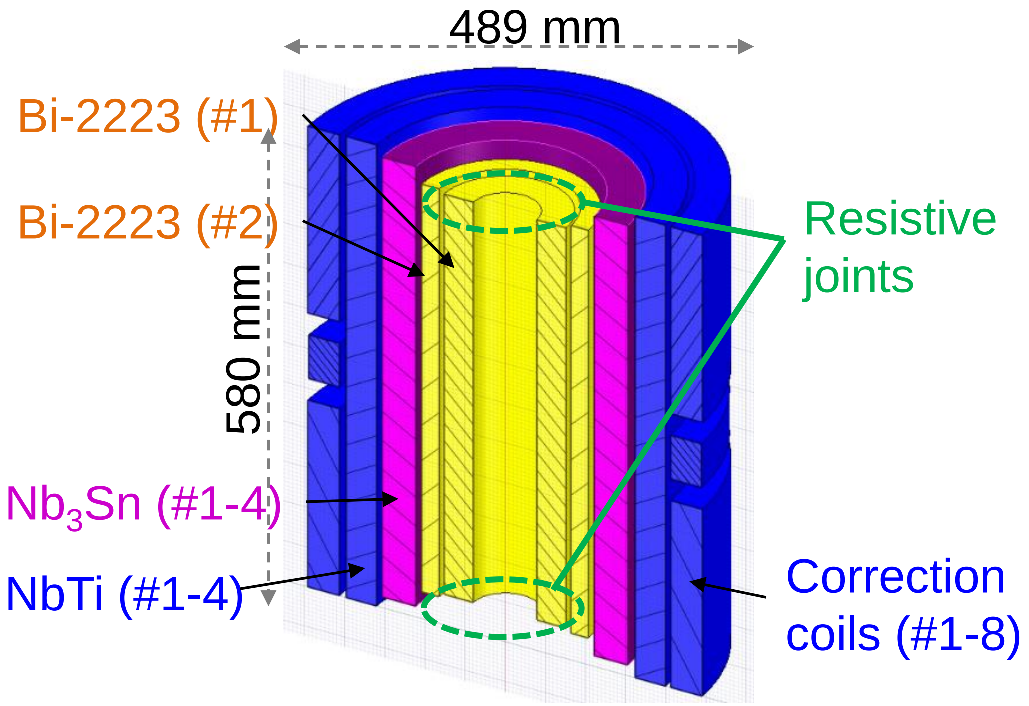
High J_{cond}

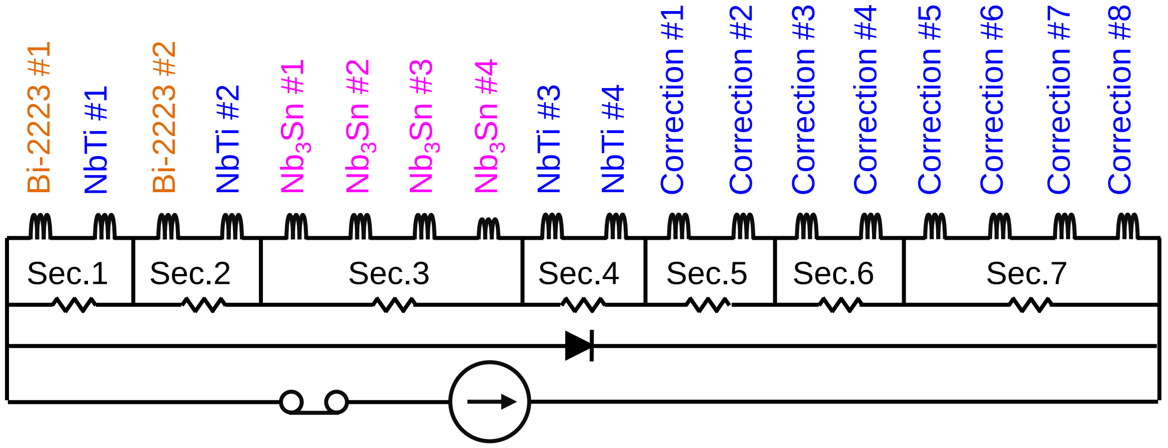




Technical features and issues of the magnet

R. Piao et al., *IEEE Trans. Appl. Supercond.* **29** (2019) 4300407

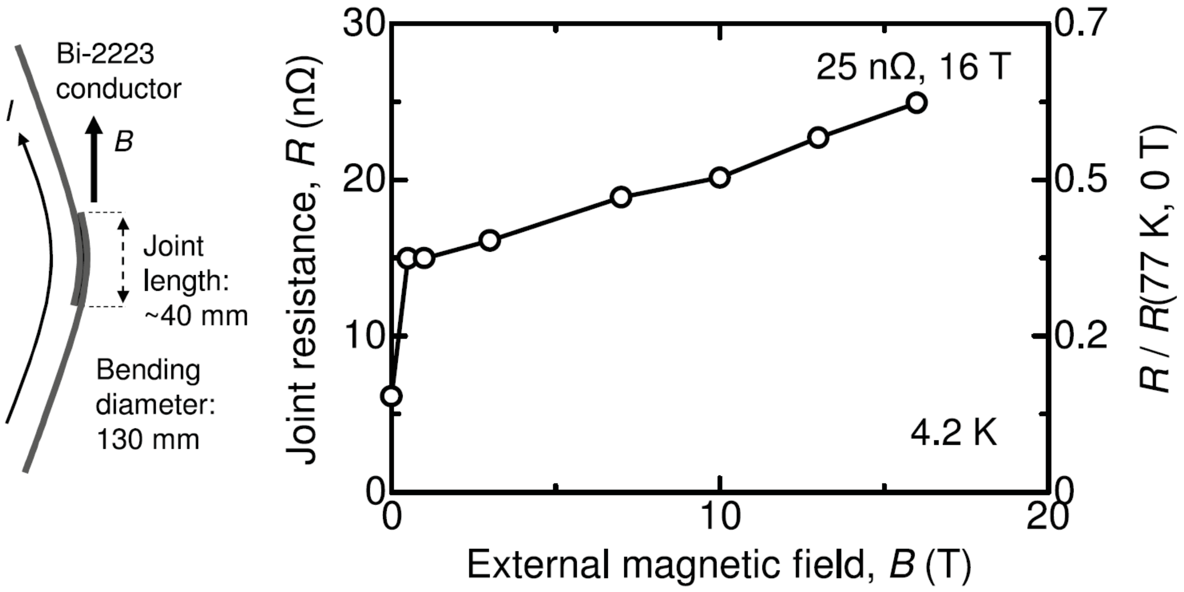




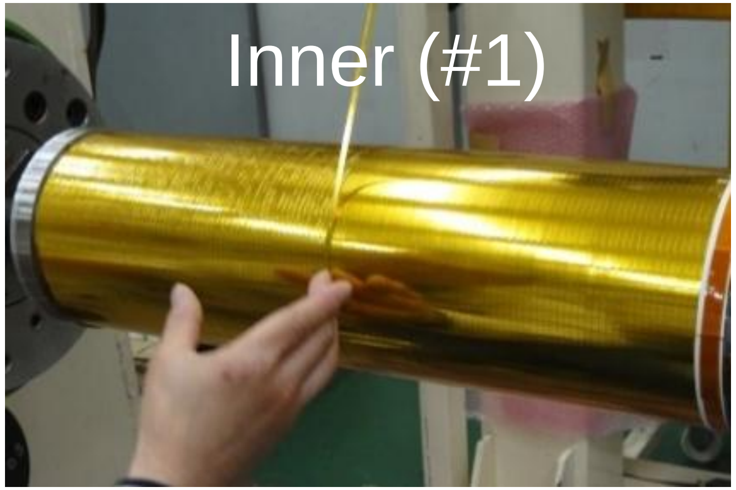
- LTS-HTS series connected coil circuit operated in the power supply-driven mode
- LHe (4.2 K) cooling with two pulse-tube cryocoolers for zero boiloff of LHe
- Thick Bi-2223 inner coils (182 layers)
  - High *BJR* (320 MPa) and σ_z (-61 MPa) at 1.06 GHz
  - 24 splice joints inside the winding under 11-16 T and hoop stress of 150-245 MPa
  - Stability and homogeneity of the magnetic field under screening currents

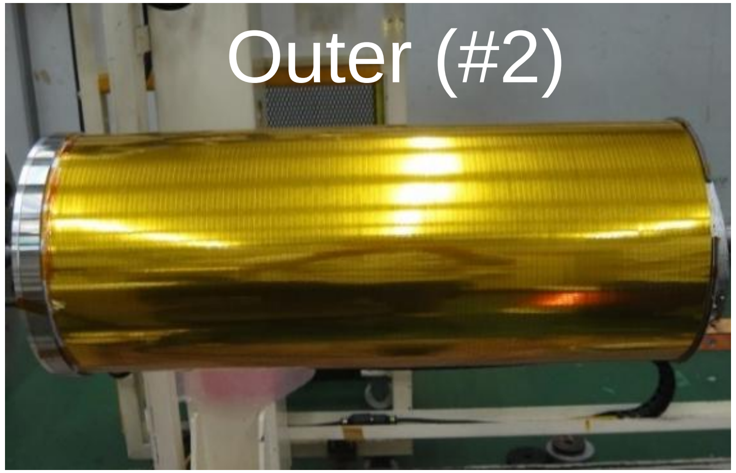
Manufacturing of the Bi-2223 inner coils

The most challenging issue:
splice joint for the Ni-alloy reinforced Bi-2223 conductor



24 splice joints inside the winding made of 10 km conductor in total

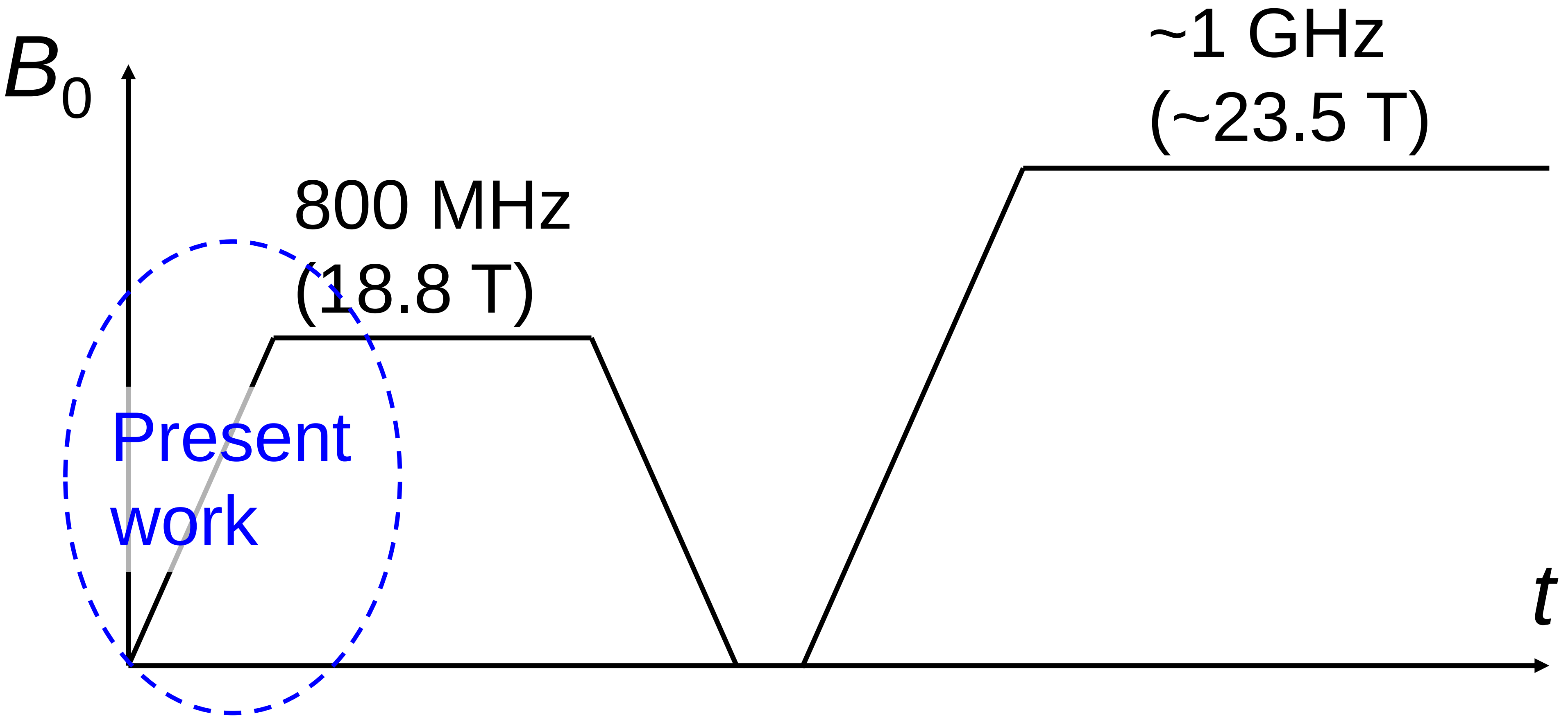




Combination of *small joint resistance* and *high strength*

- Several tens of nΩ at 4.2 K in 16 T
- 99% I_c recovery stress >300 MPa at D = 120 mm

Test procedure



Basic evaluation on the magnet,
shimming and NMR measurements

NMR measurement
for proteins

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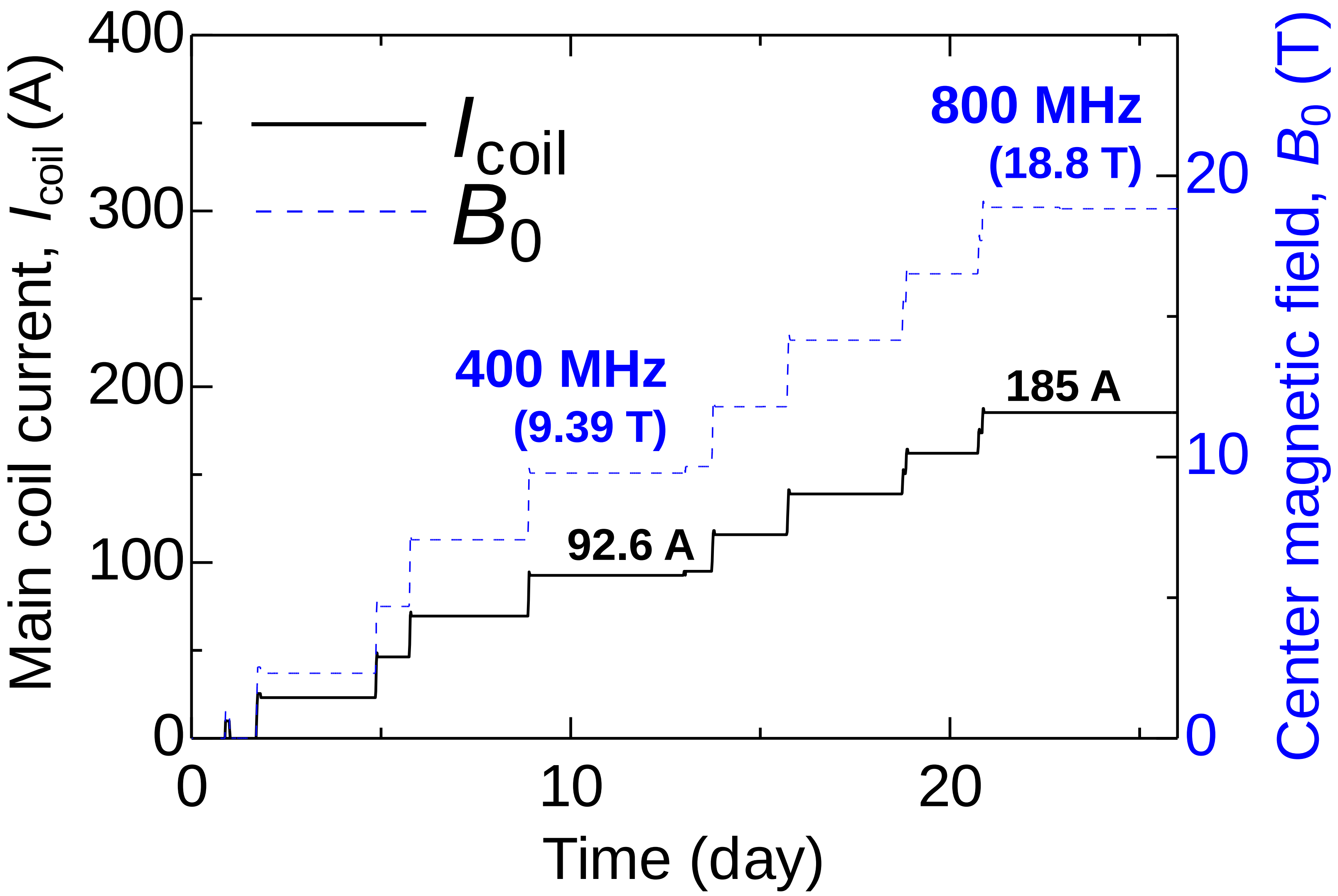
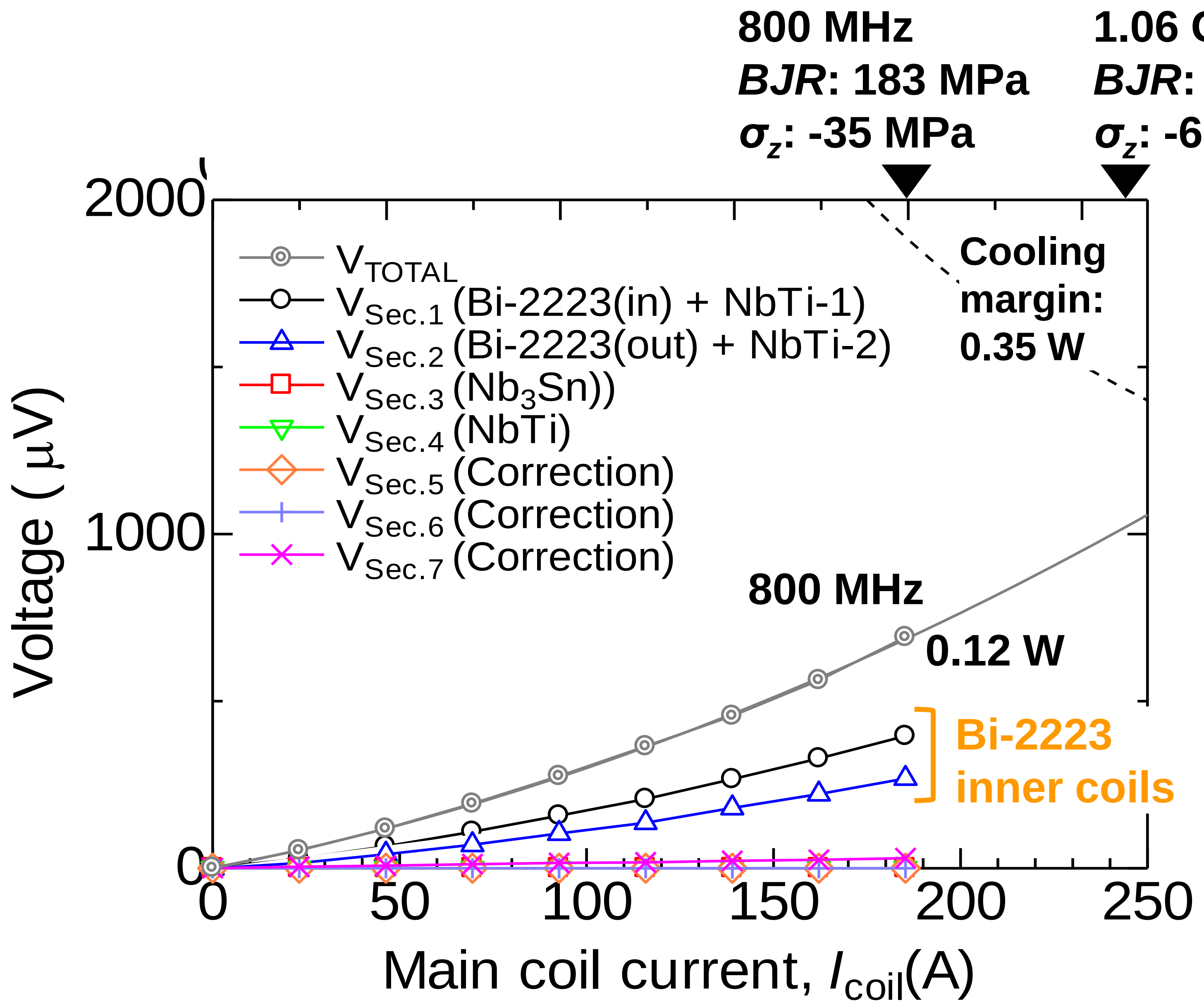
Overview of the charging test to 800 MHz (18.8 T)



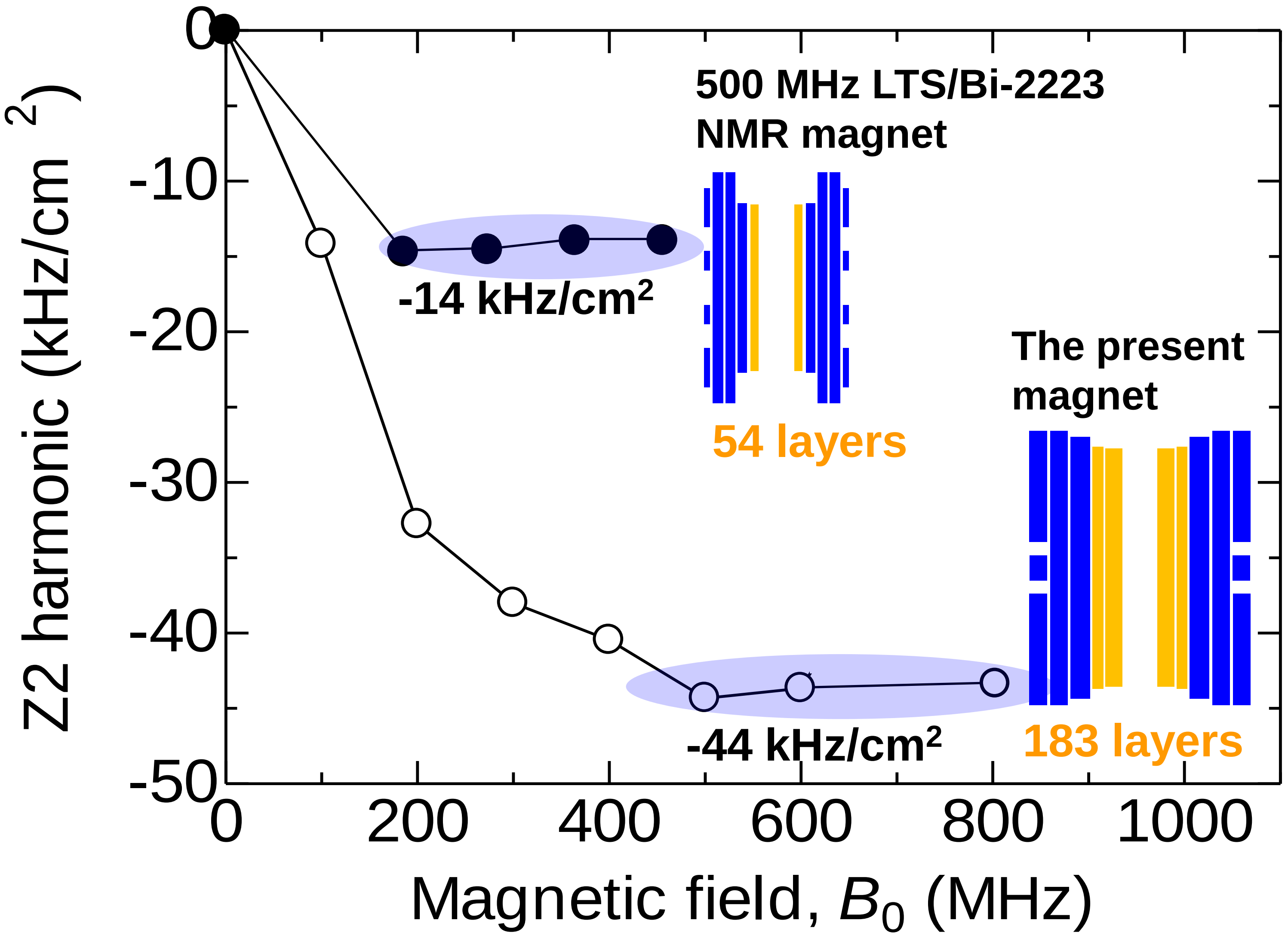
- **Step by step charge to 800 MHz (18.8 T) for ~1 month**
- **No LHe level reduction in the charging process (zero boiloff)**

V-I characteristics of the Bi-2223 inner coils



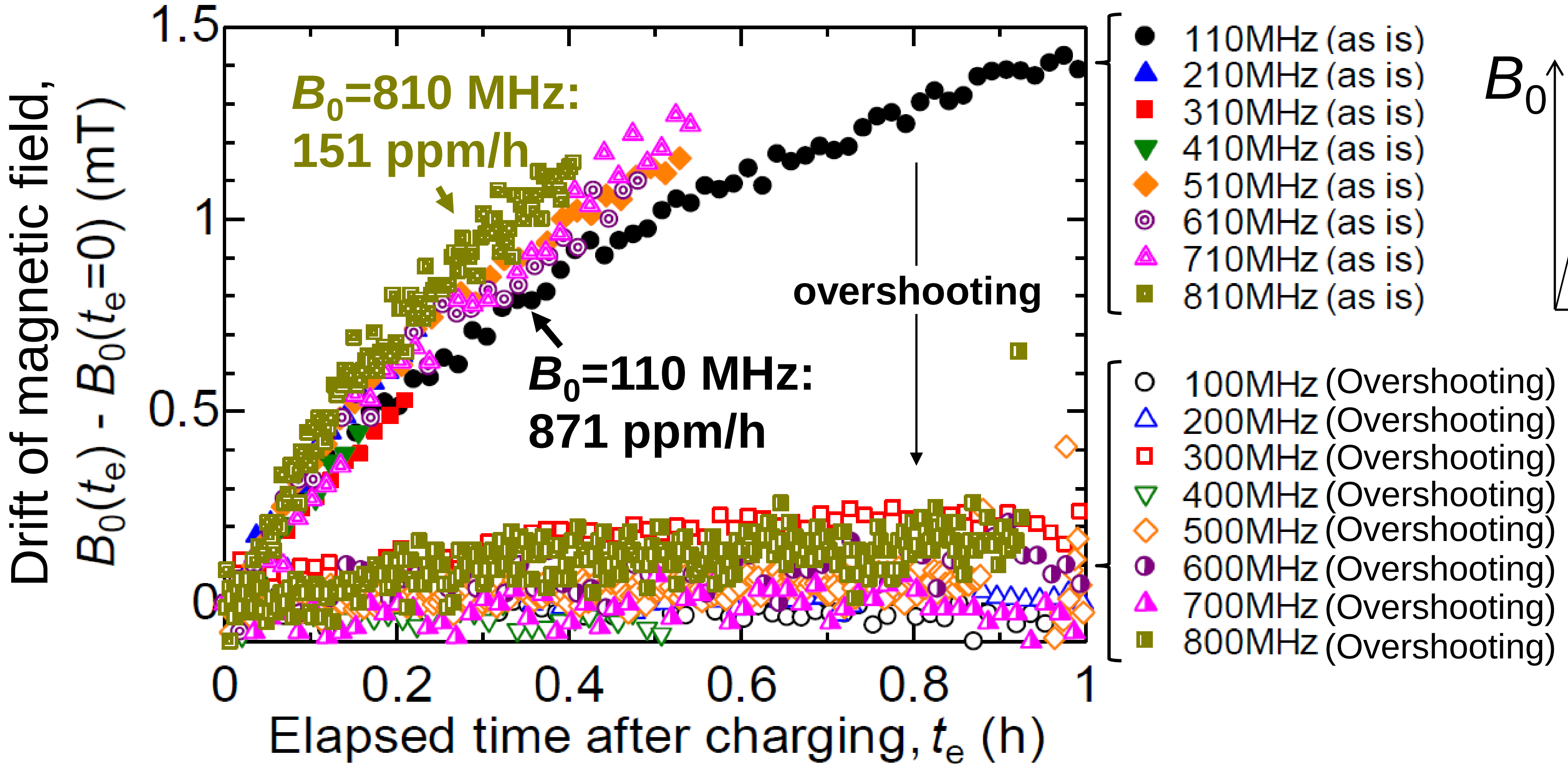
- **Splice joints work well.**
- **Joule heating from the joints is sufficiently small under the cooling margin.**
- **1 GHz-class operation seems feasible.**

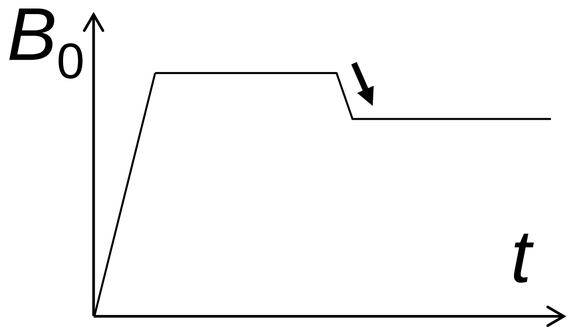
Magnetic field inhomogeneity due to screening currents



- **Z2 harmonic caused by the screening currents saturates at -44 kHz/cm^2, which can be compensated with ferro. shim.**
- **Z2 is proportional to the number of layers of the Bi-2223 inner coil(s).**
- **The saturation behavior is advantageous compared to an REBCO inner coil.**

Magnetic field instability due to screening currents



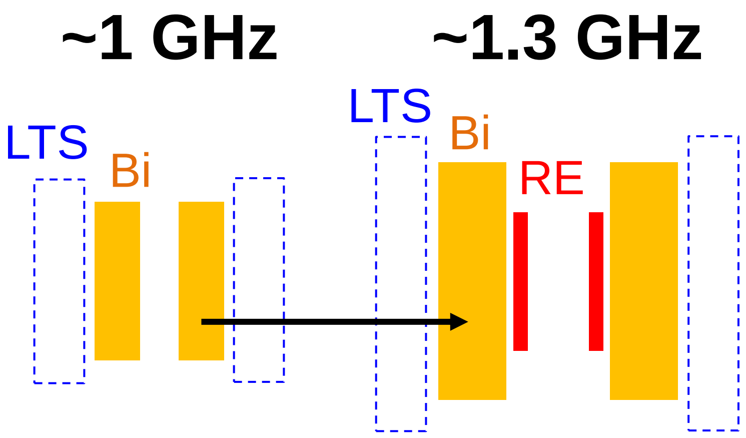


- **Amplitudes of the magnetic field drifts are almost constant regardless of B_0.**
  => The drift rate reduced with B_0.
- **Overshooting (current sweep reversal) suppresses the drifts.**

Summary

- *A compact 1 GHz (23.5 T)-class NMR magnet (highly HTS-dependent NMR magnet)*

- *Successful charge to 800 MHz (18.8 T)*
  - *Good V-I performance with 24 joints*
  - *No LHe level reduction*
  - *The effect of screening currents was moderate and manageable.*



- *We will continue the magnet test and make NMR evaluation.*