

High resolution NMR measurements by using a 400 MHz (9.39 T) LTS/REBCO NMR magnet with a best mix use of various field correction methods

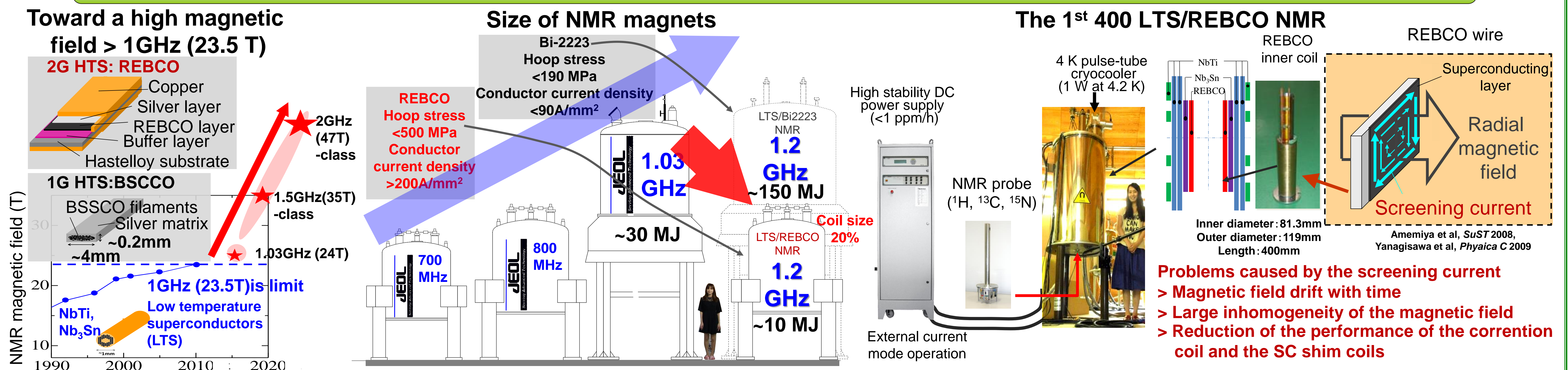
~ Towards a super-high field/compact type of NMR magnet ~

Renzhong Piao^{1,6}, Hideki Nakagome¹, Seiya Iguchi², Tomoaki Takao², Mamoru Hamada³, Shinji Matsumoto⁴, Hiroto Suematsu⁵, Yoshinori Yanagisawa⁶, Xinzhe Jin⁶, Masato Takahashi⁶, Hideaki Maeda⁶
¹ Chiba University; ² Sophia University; ³ JASTEC; ⁴ NIMS; ⁵ JEOL RESONANCE; ⁶ RIKEN



Abstract: We have started a project to develop a high field compact NMR magnet using REBCO high-temperature superconducting (HTS) inner coils. In the present work, we operated the magnet with the best mix technology of field correction methods. Eventually, a high-resolution 2D-NOESY NMR measurement for a protein solution sample, which is inevitable for structural biology, was successfully achieved. The field correction method achieved here is inevitable for a super-high field compact NMR magnet with HTS coils operated beyond 1 GHz (23.5 T).

Background: Development of a super-high field and compact NMR magnet



Resolution and Sensitivity - The 1st 400 MHz LTS/REBCO NMR-

	500MHz LTS NMR ^[1]	500MHz LTS/Bi-2223 NMR ^[1]	400MHz for the 1 st LTS/REBCO NMR ^[2]
Resolution	<2 ppb	1.4 ppb	38 ppb
Sensitivity	600	512	28

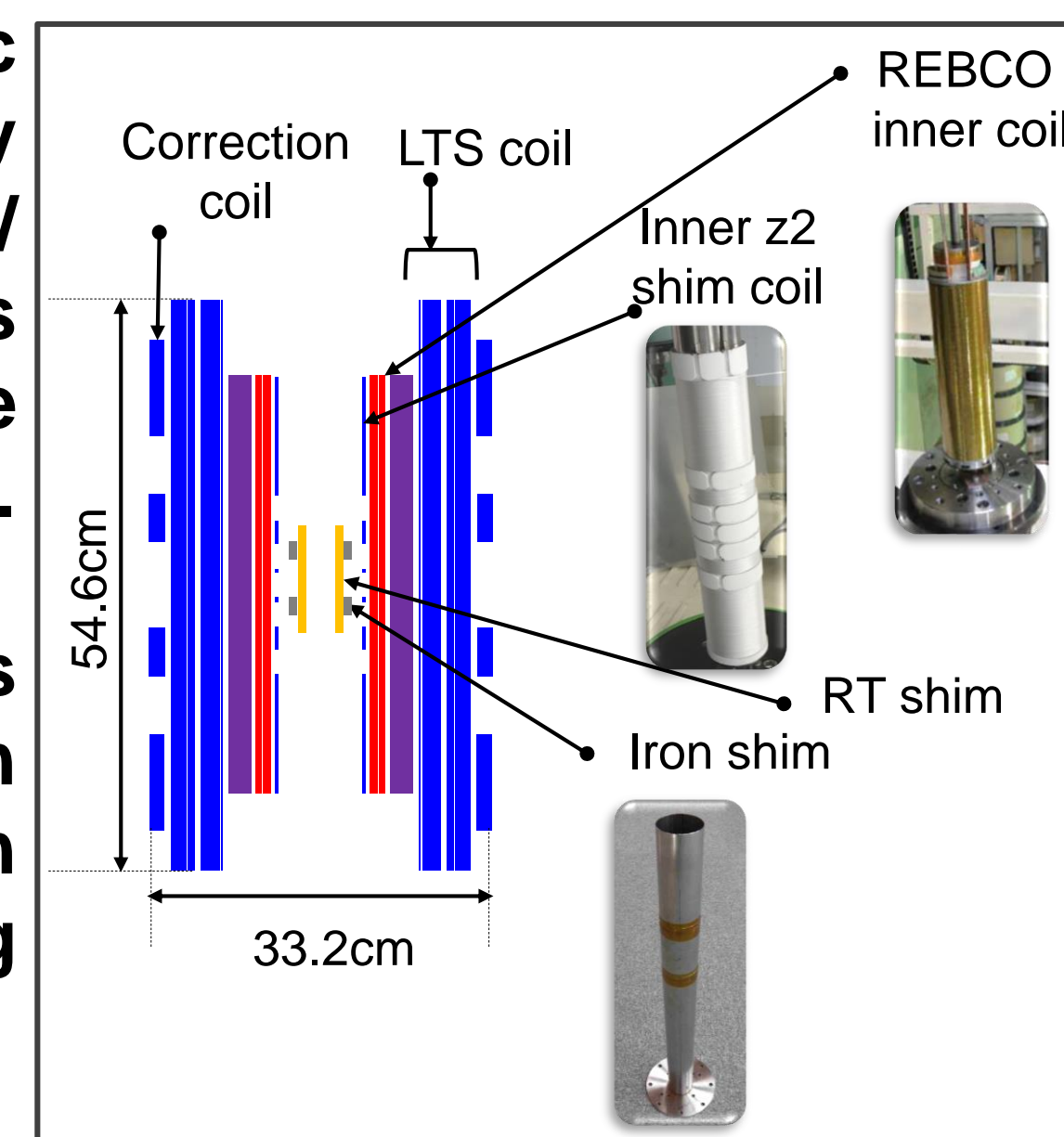
Radial Inhomogeneous components cannot be corrected by superconducting shim due to the effect of the screening current
 High-resolution NMR measurements cannot be capable as resolution and sensitivity is over 10 times lower

Purpose of this study

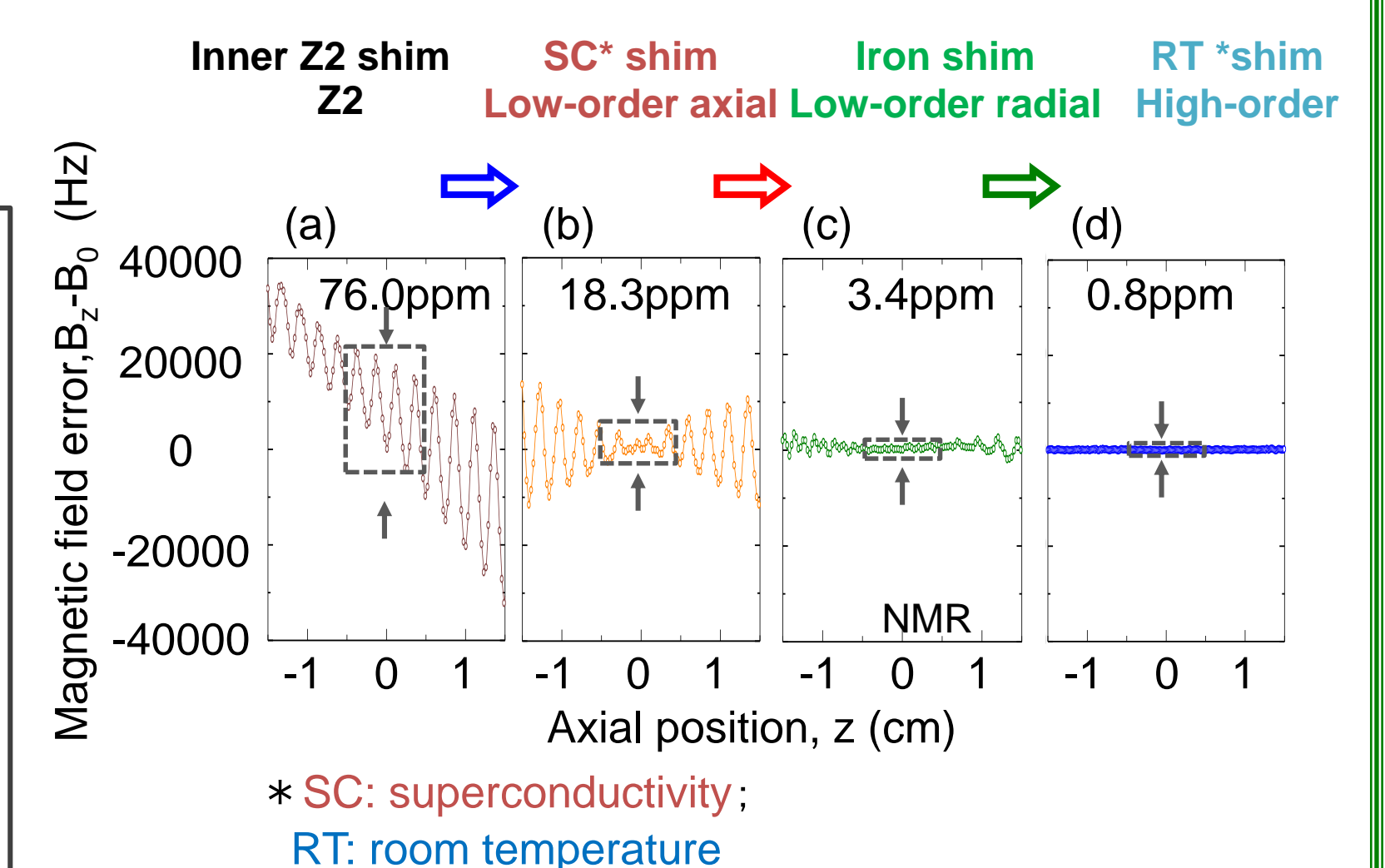
1. to establish a magnetic field correction technology in the 2nd 400MHz LTS / REBCO NMR which is affected largely by the effect of screening current.
2. to demonstrate that it is capable of high-resolution NMR measurements in NMR magnet using REBCO coil.

Experimental

The 2nd 400 MHz LTS/REBCO NMR

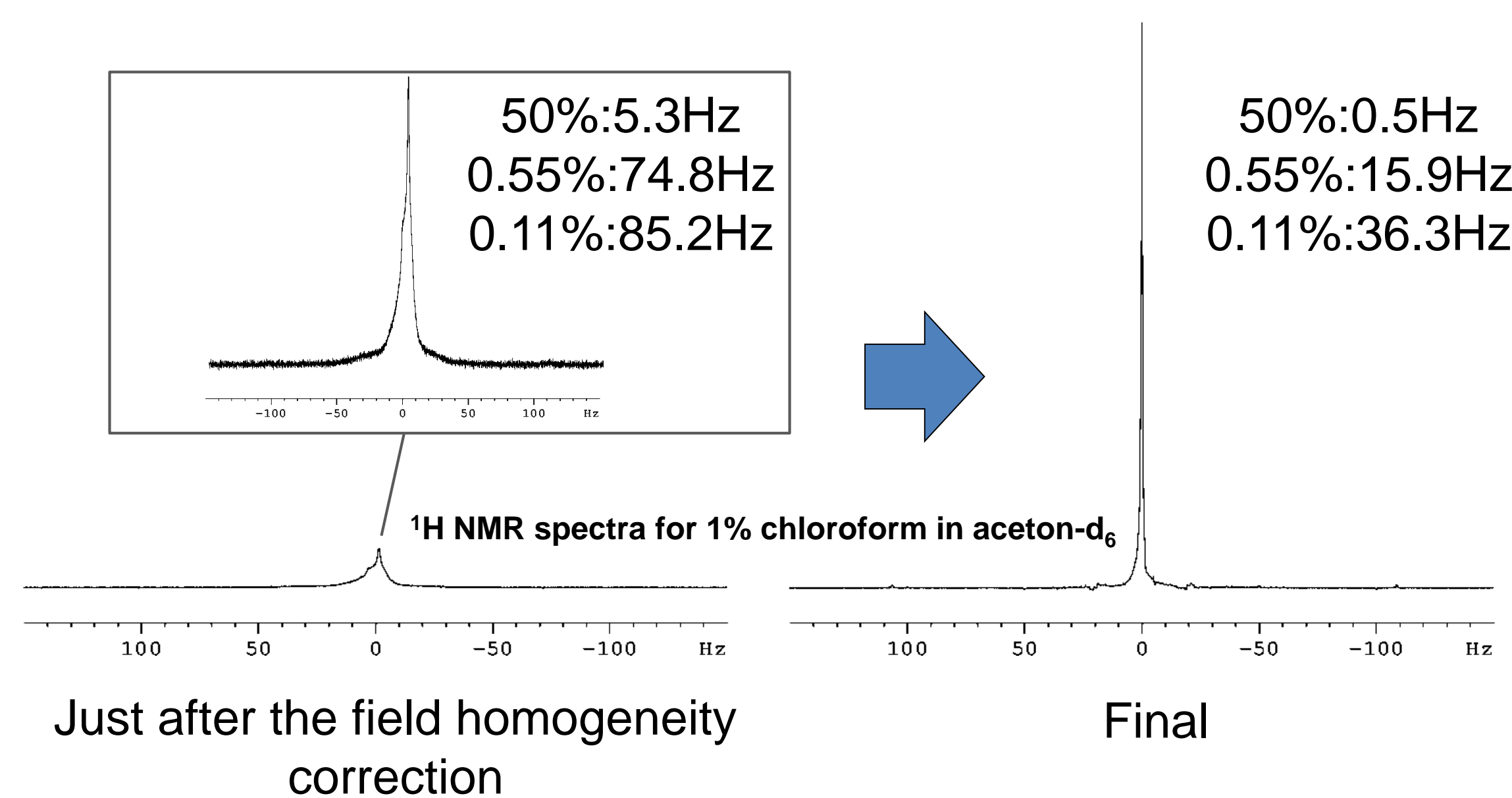


Field homogeneity correction



Large inhomogeneity of the magnetic field can be corrected with the best mix technology even under the harmful effect of the screening current.

Results of the NMR resolution test



Lower-order magnetic field harmonics

Field harmonics	Order, n	Current for the RT shim coils (Hz/cm ²)		Ratio (b)/(a)
		(a) Before the resolution test	(b) After final adjustment for the resolution test	
Z1	1	218	753	3.5
X	1	497	1581	3.2
Y	1	-69	-348	5.1
Z2	2	202	646	3.2
ZX	2	-454	-930	2.0
ZY	2	-91	147	-1.6
C2	2	-133	-139	1.0
S2	2	-94	-53	0.6
Z2X	3	-1140	-1240	1.1
Z2Y	3	-500	-507	1.0
ZC2	3	-740	-635	0.9
ZS2	3	-531	-415	0.8
C3	3	-251	-263	1.1
S3	3	-171	-159	0.9
Z4	4	449	820	1.8
Z3X	4	-541	-680	1.3
Z3Y	4	-294	-404	1.4

Effects of the probe and sample

Higher-order magnetic field harmonics

Field harmonics	Order, n	Amplitude (Hz/cm ²)	
		(a) After SC shim	(b) After iron shim correction
ZX	2	-6277	35
ZY	2	-7668	22
C2	2	39	17
S2	2	1153	2
ZS2	3	139	886
Z3X	4	140	411
Z3Y	4	-134	336
Z2S2	4	-222	-703
ZC3	4	135	290

Correction target of iron shim, side effects of the iron shim

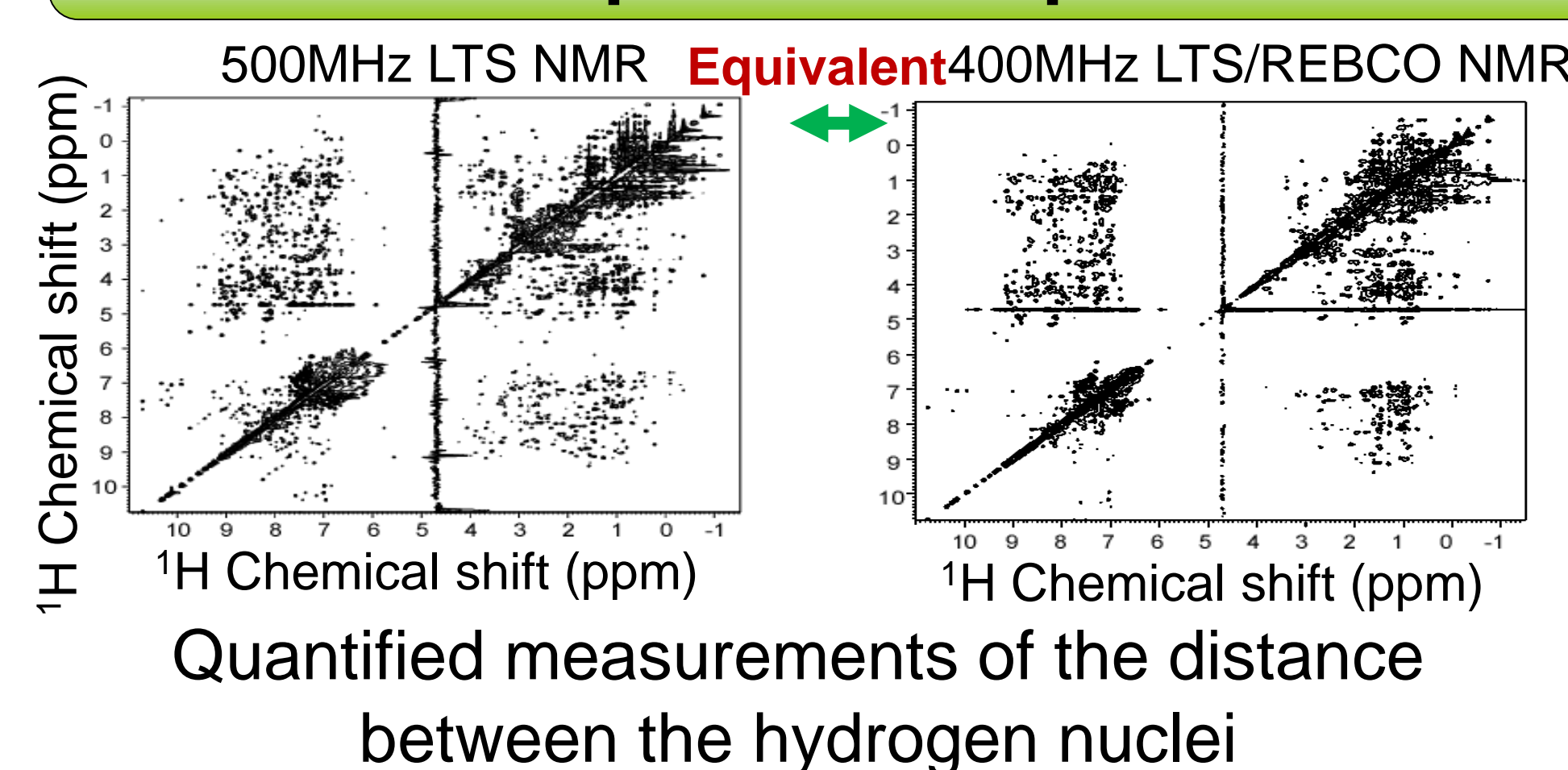
Comparison with LTS NMR, LTS/Bi2223 NMR

	500MHz LTS NMR	500MHz LTS/Bi2223 NMR ^[1]	400MHz LTS/REBCO NMR-#1 ^[2]	400MHz LTS/REBCO NMR-#2
Resolution	<2 ppb	1.4 ppb	38 ppb	1.3 ppb
Sensitivity	600	512	28	318

Resolution: Same level of LTS NMR
 Sensitivity: 78% of LTS NMR, 92% of LTS/Bi2223 NMR

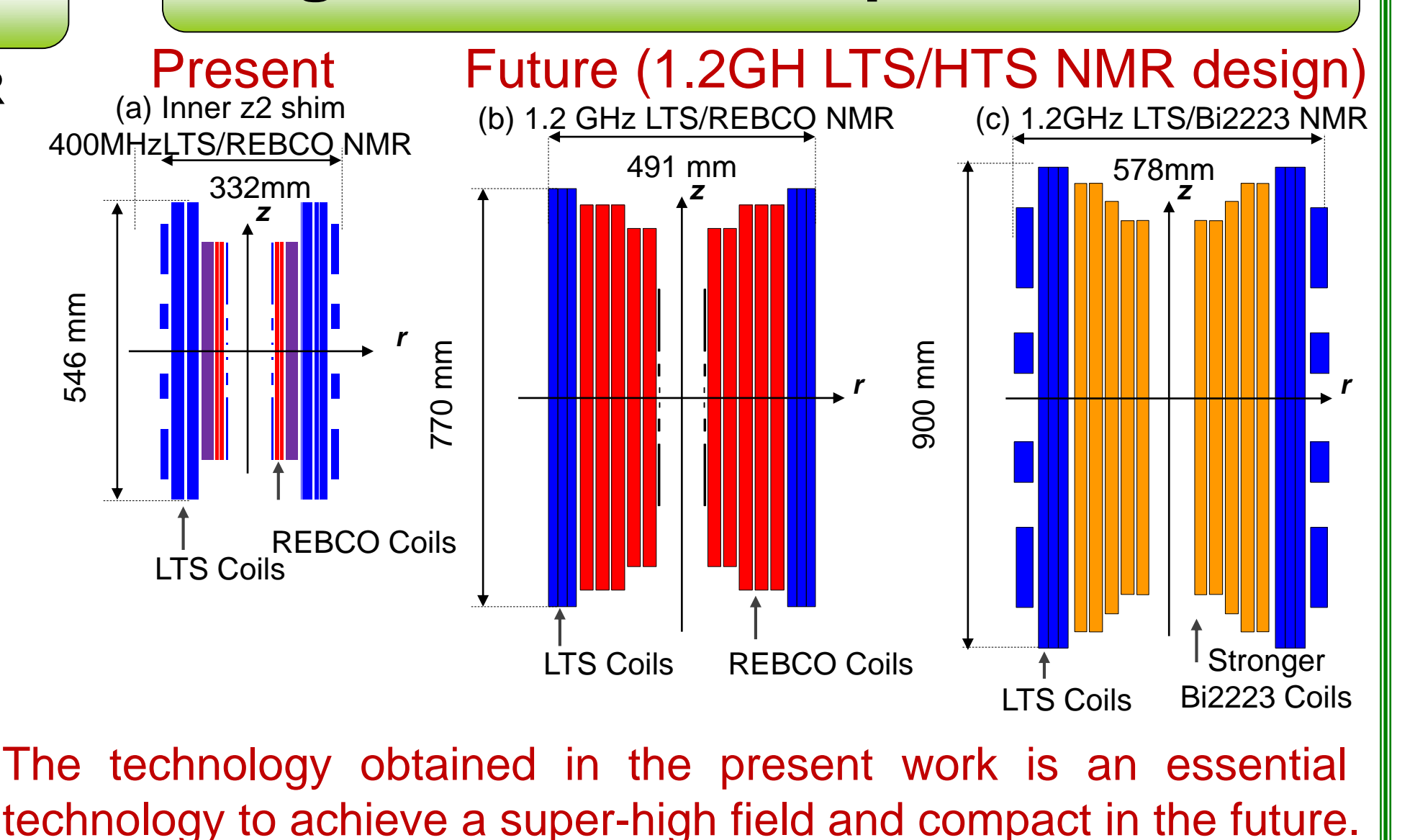
Sufficient resolution and sensitivity were achieved.

High-resolution NMR measurements for a protein sample



A high-resolution NMR measurement was succeeded

Significance of the present work



The technology obtained in the present work is an essential technology to achieve a super-high field and compact in the future.

References

[1] Y. Yanagisawa, et. : "Operation of a 500 MHz high temperature superconducting NMR: Towards an NMR spectrometer operating beyond 1 GHz," J. Magn. Reson. 203 (2010) 274-282
 [2] Y. Yanagisawa, "Operation of a 400 MHz NMR magnet using a (RE:Rare Earth)Ba₂Cu₃O_{7-x} high-temperature superconducting coil: Towards an ultra-compact super-high field NMR spectrometer operated beyond 1 GHz", Accepted for Magn. Reson. JMR-14-204R1, (2014.10)

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Conclusions

A field homogeneity correction, NMR line shape optimization, NMR sensitivity test and NOESY measurement were made for a 400MHz LTS/REBCO NMR magnet has difficulties in generating a homogeneous magnetic field due to the effects of a screening current. High-resolution NMR measurement, can be made with (1) the advanced field homogeneity correction technology including the iron shim and (2) the appropriate procedure for the NMR line shape optimization considering the existence of the large higher field error harmonics.