Development of LN_2 cooled RE-Ba-Cu-O superconducting magnet for NMR use

Gen NISHIJIMA and Hitoshi KITAGUCHI
National Institute for Materials Science (NIMS)
Kazuyuki TAKEDA
Kyoto University

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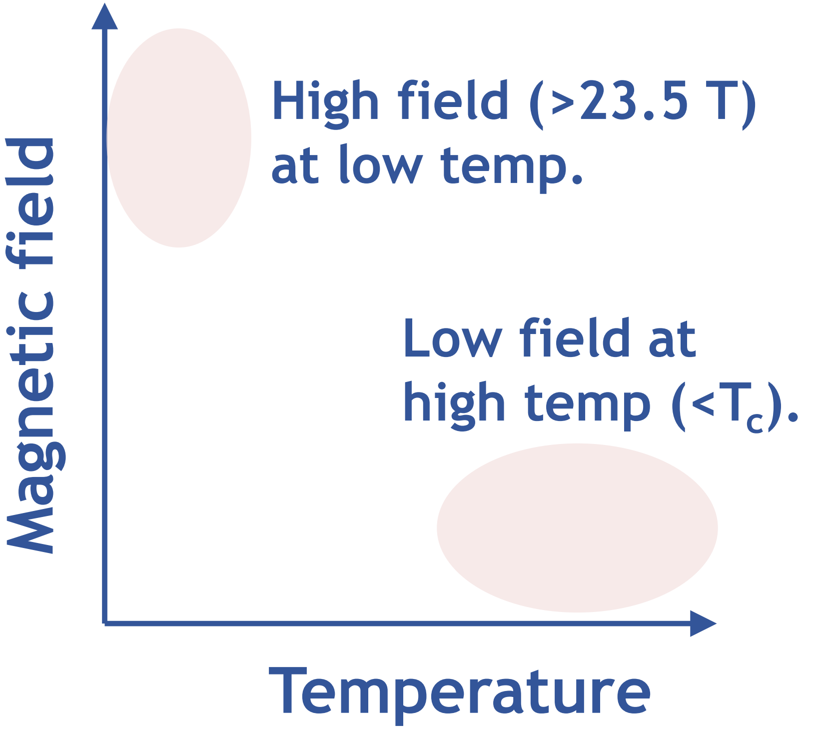
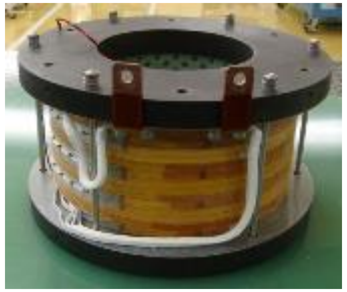
HTS for two extreme areas

1020 MHz NMR

Hashi, JMR 2015
Nishijima, TAS 2016





Bi-2223
1T-ϕ106

Nishijima, RSI 2013

HTS cable

Motivation of LN_2 cooled superconducting magnets

NEWS IN FOCUS

JOCK FISTICK/BLOOMBERG VIA GETTY

Magnetic resonance imaging scanners rely on liquid helium to cool their superconducting magnets.

RESEARCH MATERIALS

Qatar blockade hits helium supply

Researchers braced for shortages as Gulf state forced to close its production plants.

with supplies, if needed. "This can negatively impact his career; all of us who are senior colleagues would do anything we can to avoid that situation," says the scientist.

Qatar is the world's largest exporter of helium and its second-largest producer, accounting for 25% of global demand (see 'Helium supplies'). So the blockade will inevitably cause shortfalls over the next few months, says Phil Kornbluth, a consultant based in Bridgewater, New Jersey, who specializes in the helium industry.

Countries likely to be most affected are those closest to Qatar. But Asian countries such as India, China, Japan, Taiwan and Singapore are also at risk. "But none of us are immune," adds William Halperin, a researcher in low-temperature physics at Northwestern University in Evanston, Illinois.

LOW PRIORITY

Labs account for only around 6% of the helium market; most helium is used in the electronics industry, hospital magnetic resonance imaging scanners, and airships and balloons. This means that suppliers tend to prioritize deliveries to larger customers — not scientists — when supplies are limited.

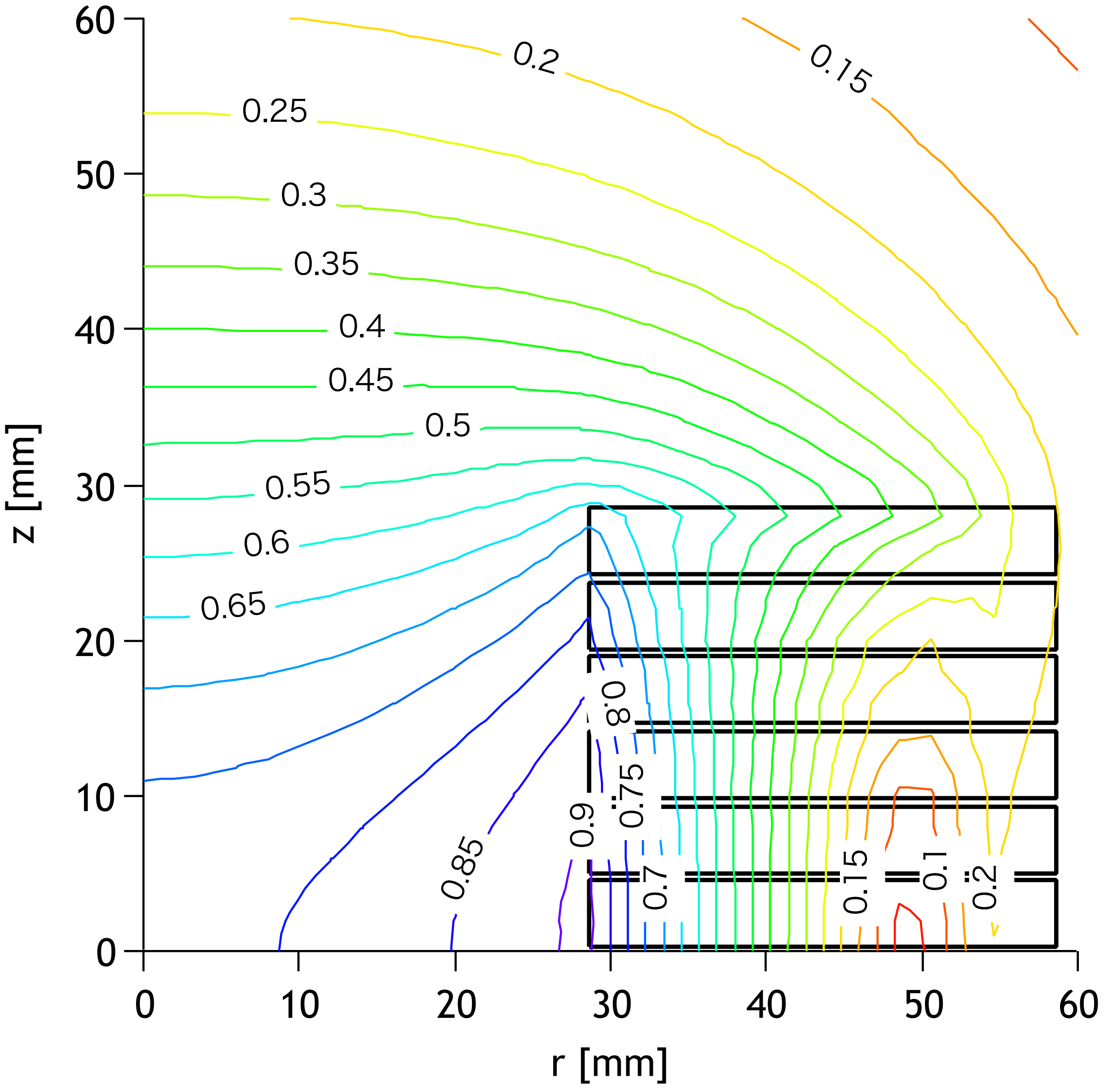
Many researchers had hoped that supply disruptions were a thing of the past, because the installation of substantial new plant in Qatar had expanded and helped to secure the global helium supply. But Hayes says that she warned the community against complacency, given the political volatility in the Middle East.

Scientists have already been banding together to protect themselves against disruption in helium supplies and the rising price of the gas. The American Physical Society

Butler, Nature 2017

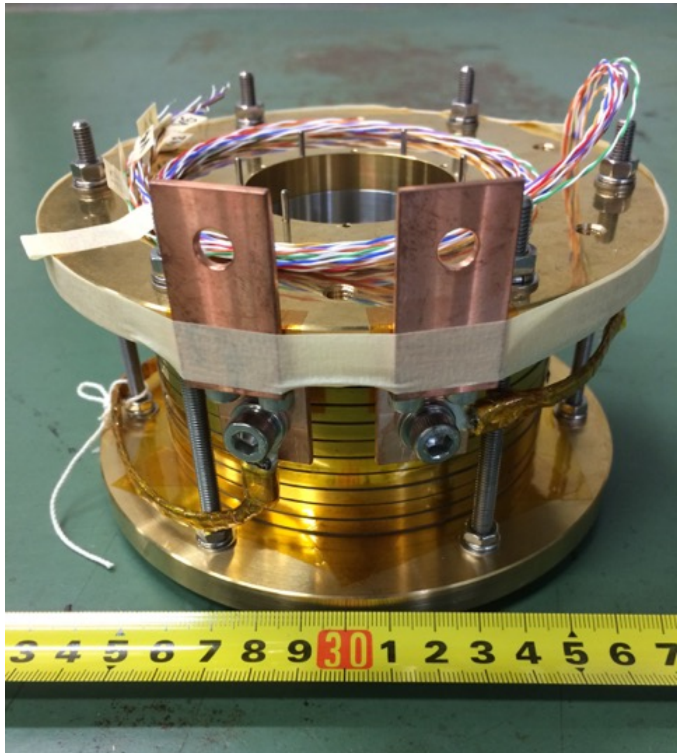
- LN_2 is easier to use and cheaper, and have more cooling power than LHe.
- Risk of He shortage and future running out.

REBCO magnet design



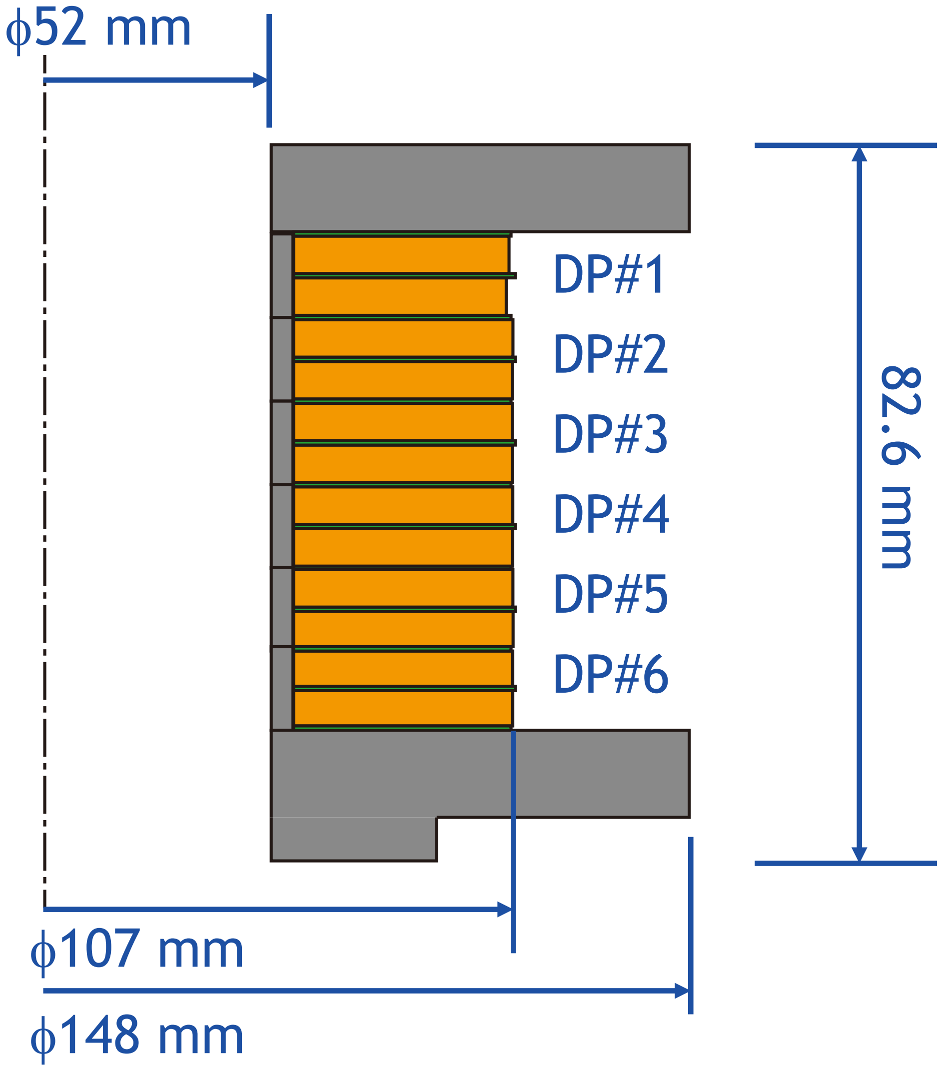
	6xDP
Insulated conductor [mm]	4.3 x 0.2 (thickness 0.192~0.210)
Inner diameter [mm]	57.1
Outer diameter [mm]	109.1
Height [mm]	68.1
Number of turns	1560 (130x12)
Number of DP	6 (12 x SP)
Spacer thickness	0.5 mm
Conductor length [m]	407.2
Coil constant [mT/A]	19.7
Inductance [mH]	149.6
I_{op} [A]	40
B_0 [T]	0.788

REBCO DP fabrication



	DP #					
	1	2	3	4	5	6
Average thickness (bare) [mm]	0.131	0.132	0.127	0.127	0.131	0.131
Average thickness (insulated) [mm]	0.209	0.193	0.192	0.189	0.201	0.195
Number of polyimide tape insertion	0	42	50	51	38	40
Number of turns	262	256	256	256	256	256
O.D. [mm]	106.2	107.4	107.3	107.4	107.5	107.4
Inspection report I_c [A]	251	245	196	220	210	245
Short sample I_c [A]	261	262	214	225	239	246
DP I_c [A]	84.1	83.7	74.9	78.6	81.1	83.9

REBCO DP fabrication



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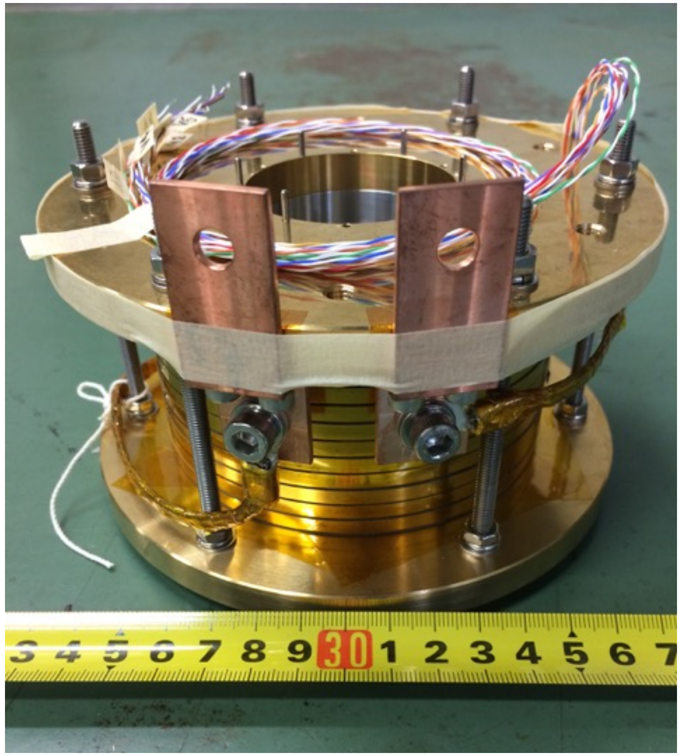
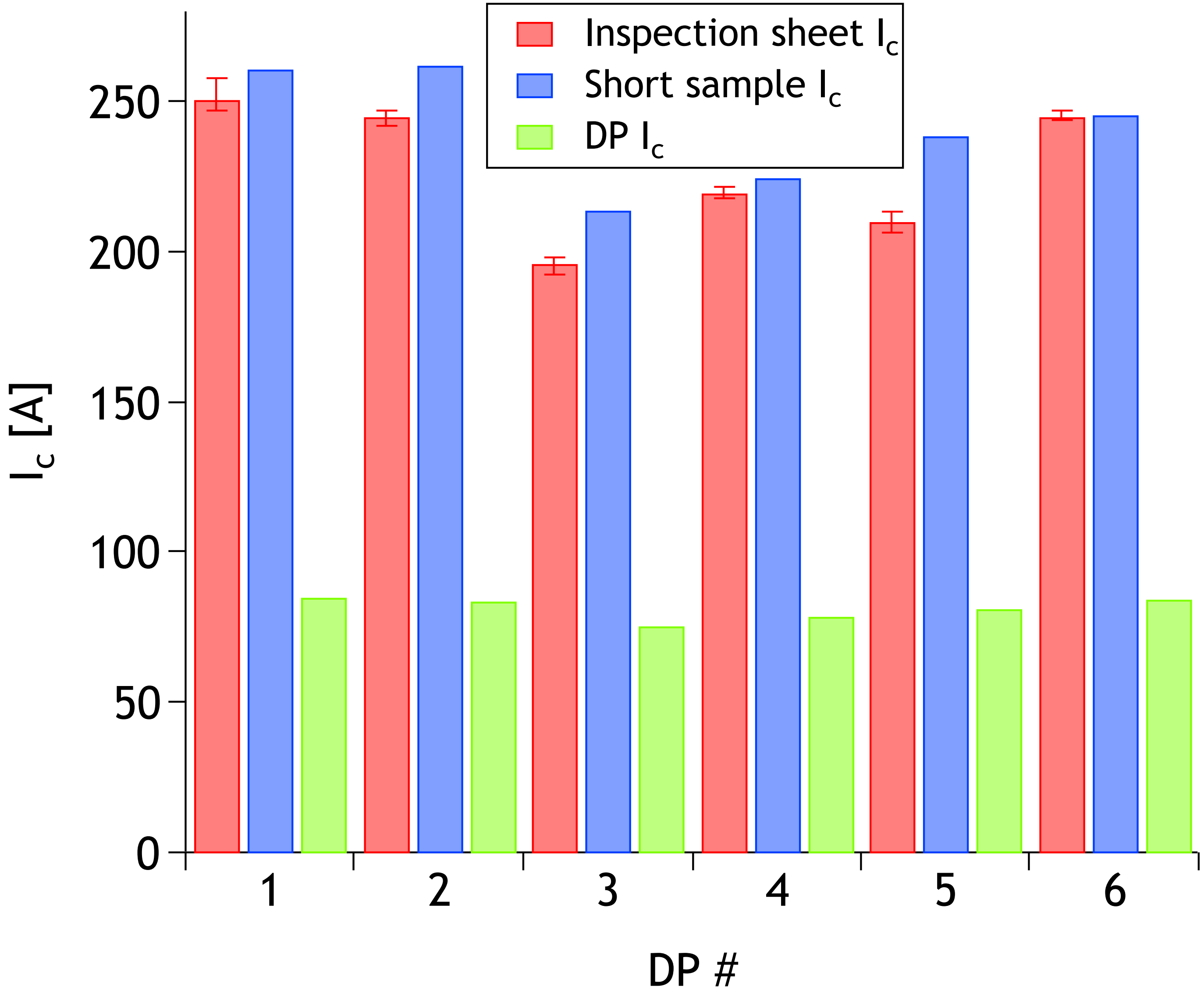
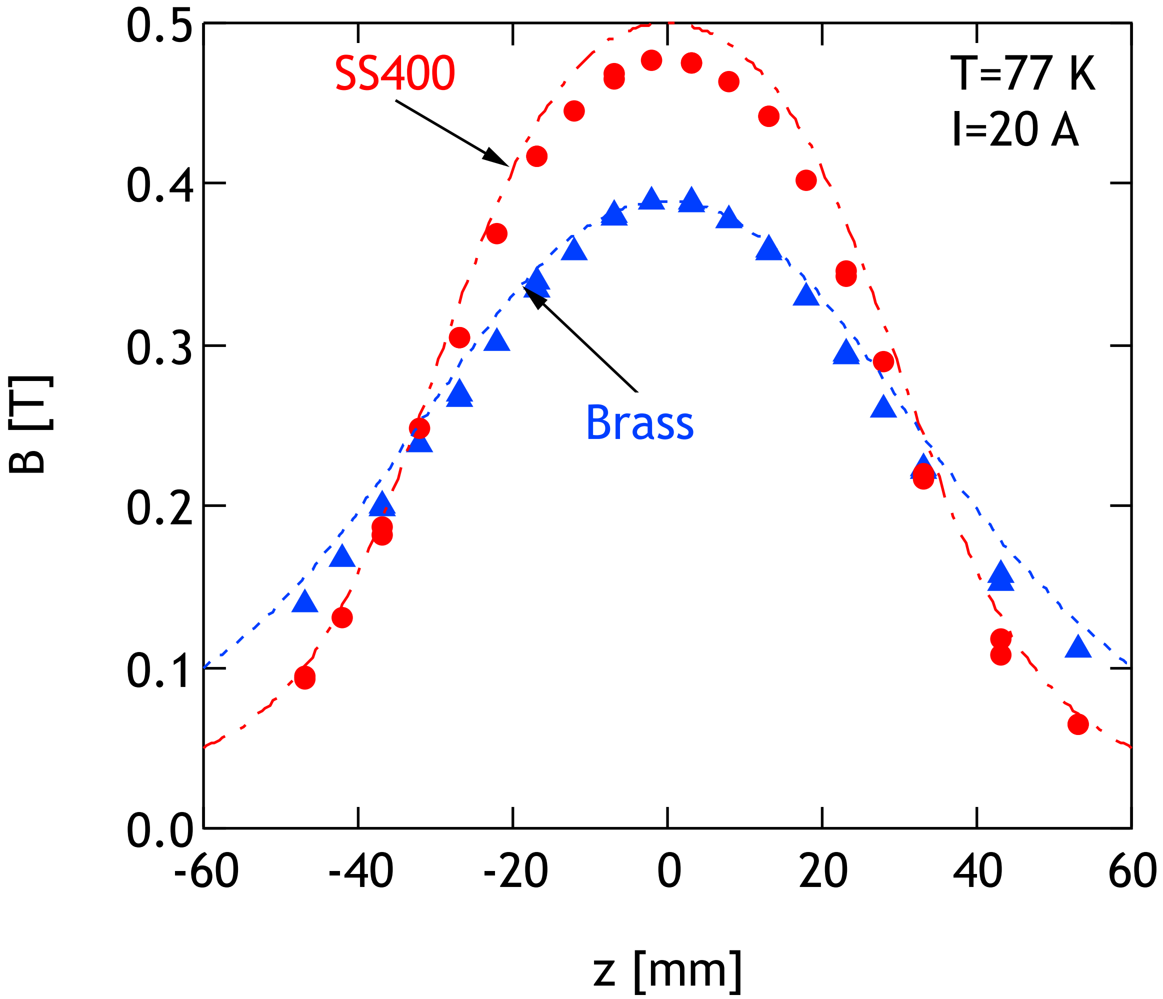
I_c variation among DPs



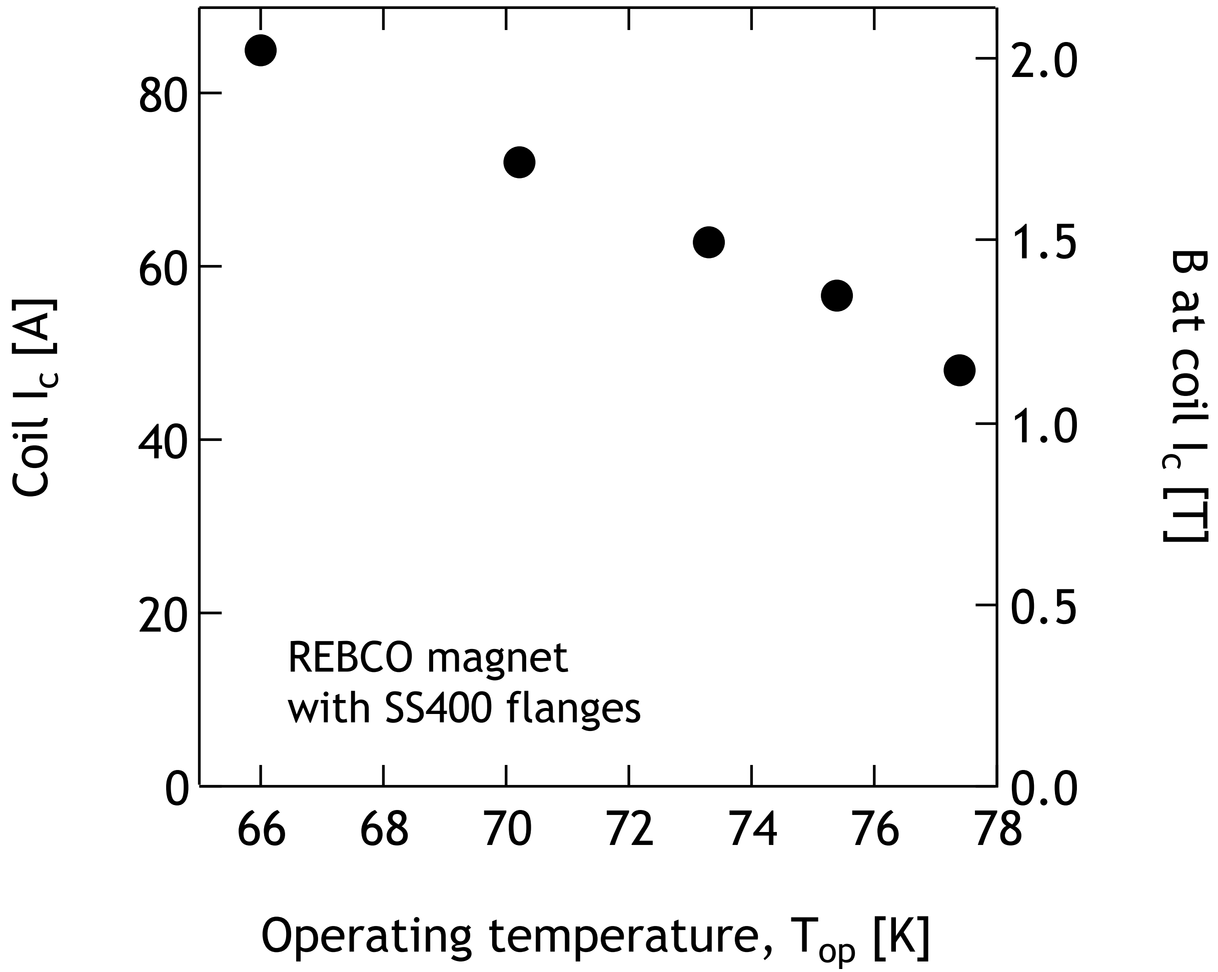


Magnetic field profile along z-axis (Hall probe)

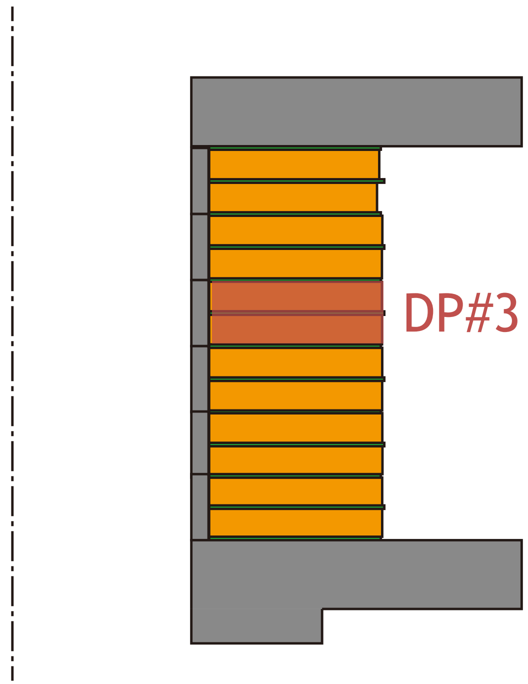


- Fabricated as designed
- Ferromagnetic flanges → +0.1 T
- Magnetic permeability at cryogenic temperature to be considered in design

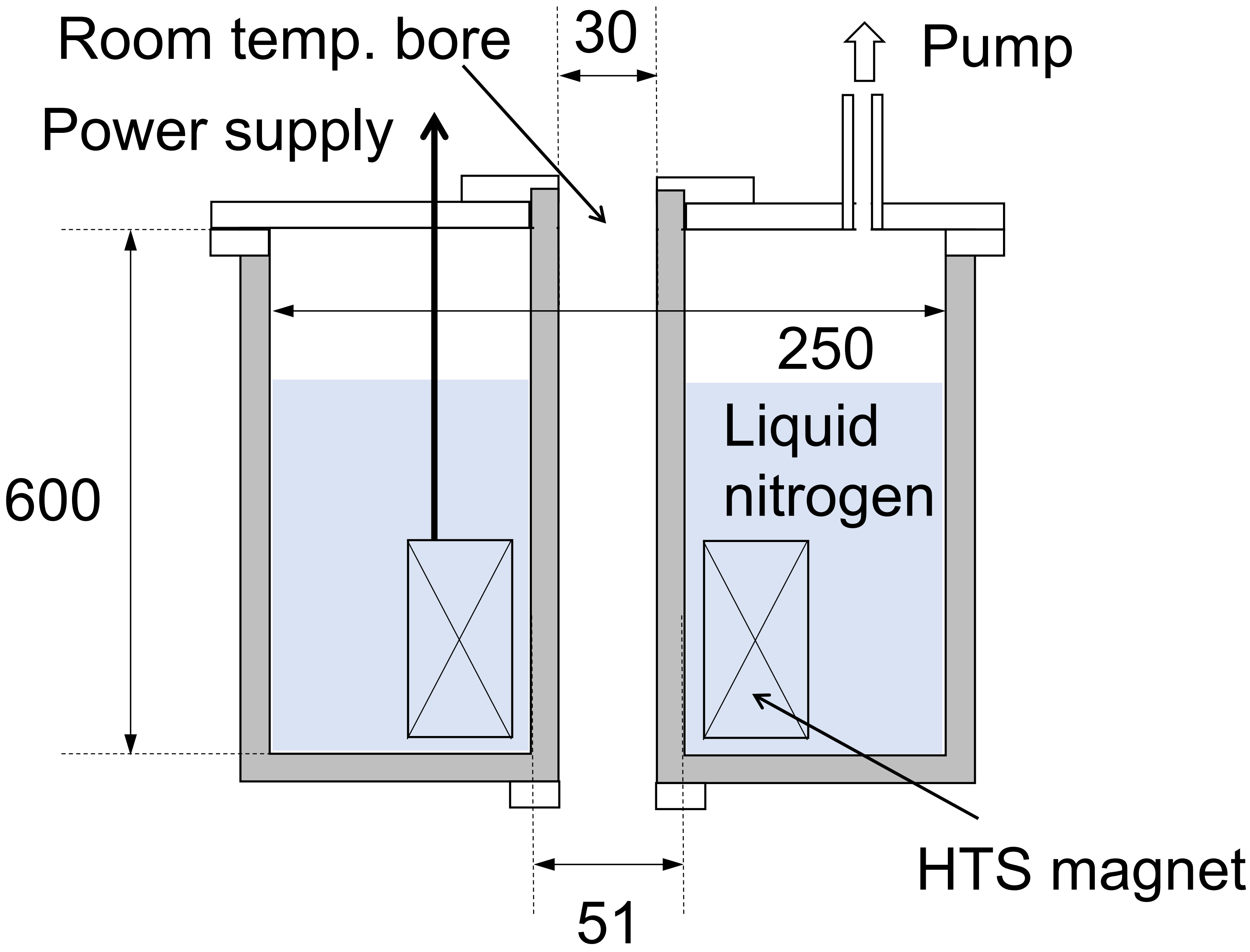
Temperature dependence of coil I_c (SS400 flanges)



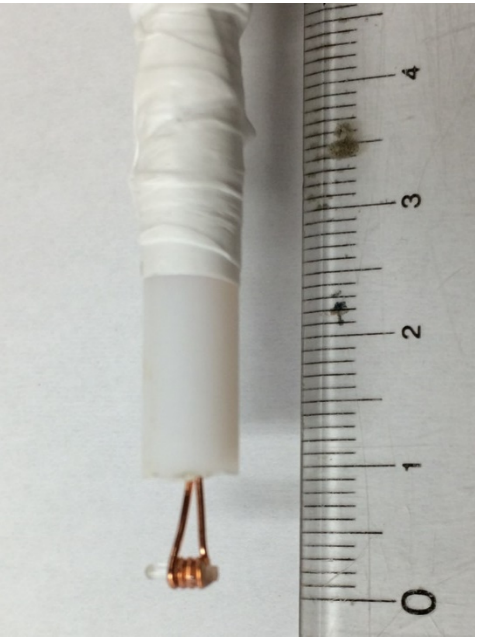
- 2.02 T at 85 A (66 K)
- I_c decreased with increasing T_{op}
- Normal transition occurred at DP#3

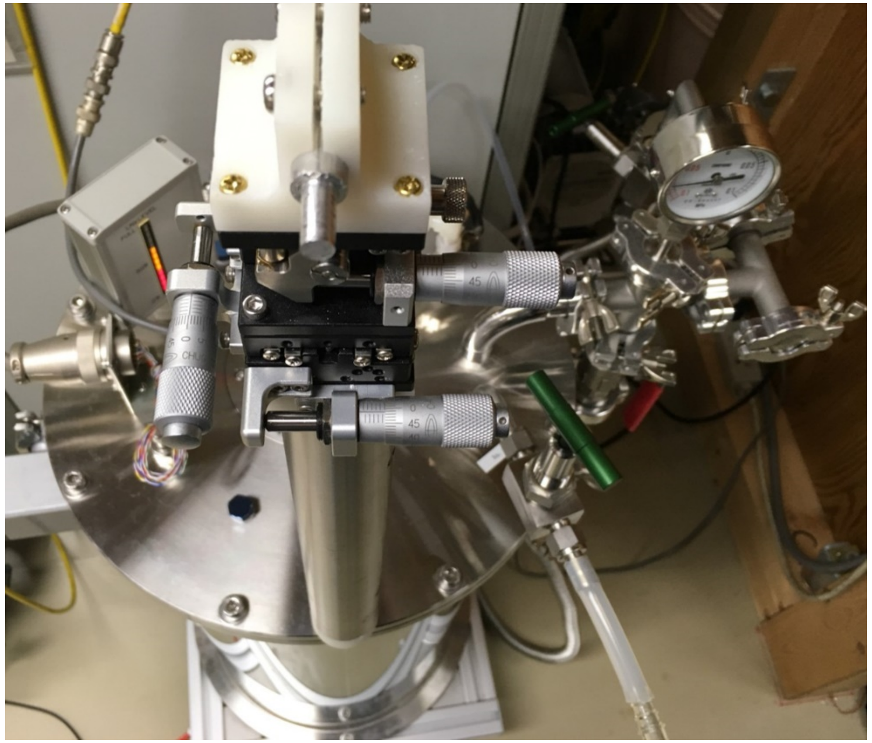


Cryostat for NMR measurement



NMR probe

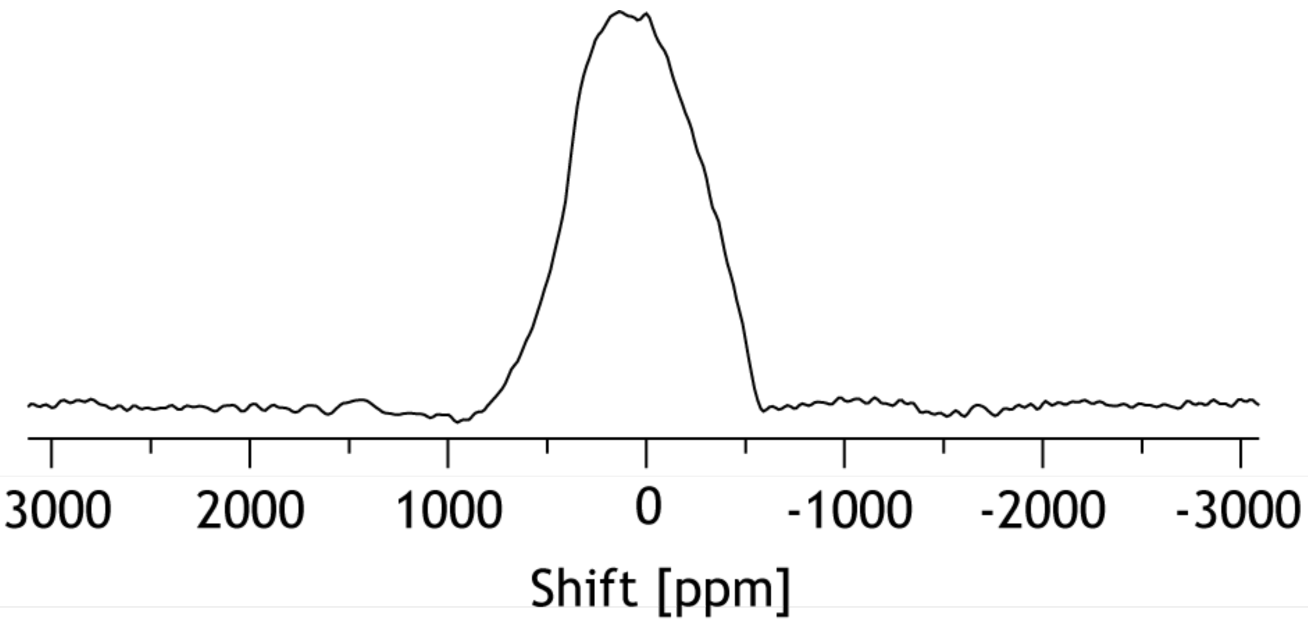




^{1}H NMR sample
0.1 mol/L aqueous solution of $CuSO_4$
Glass capillary ϕ0.63 mm x 1 mm

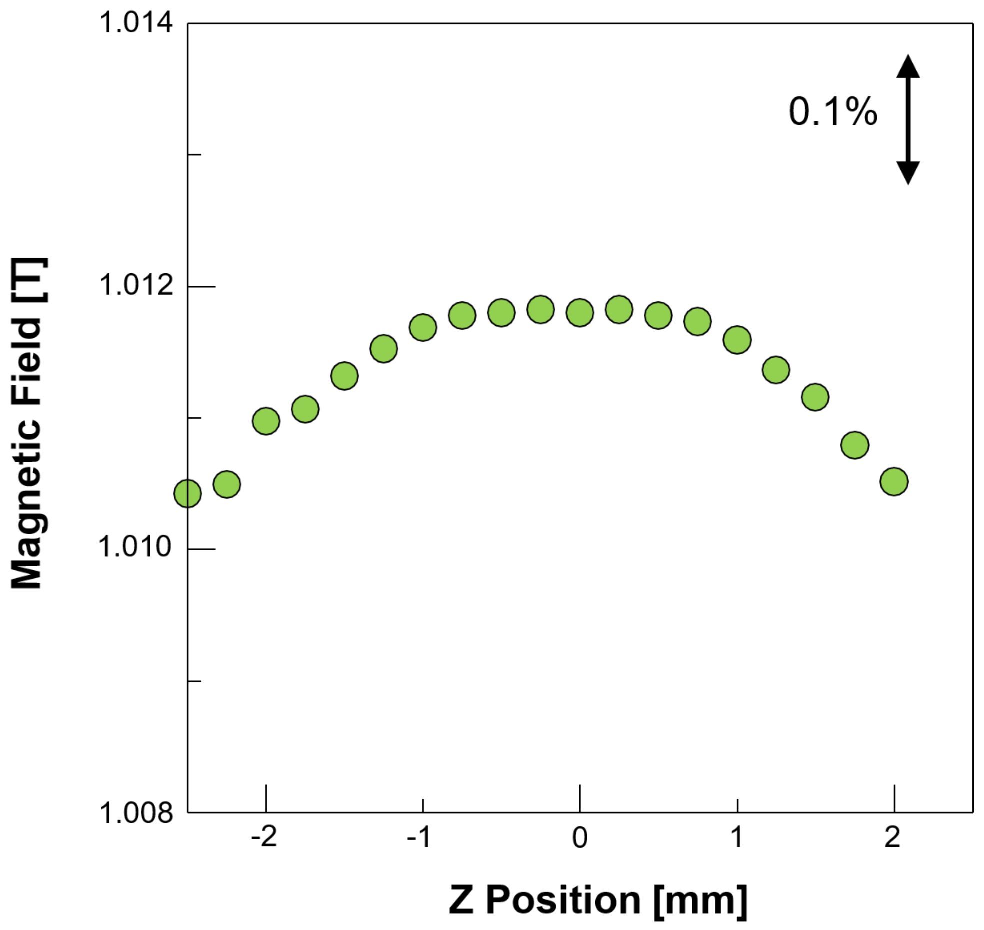
3-axis linear stage to control
NMR probe

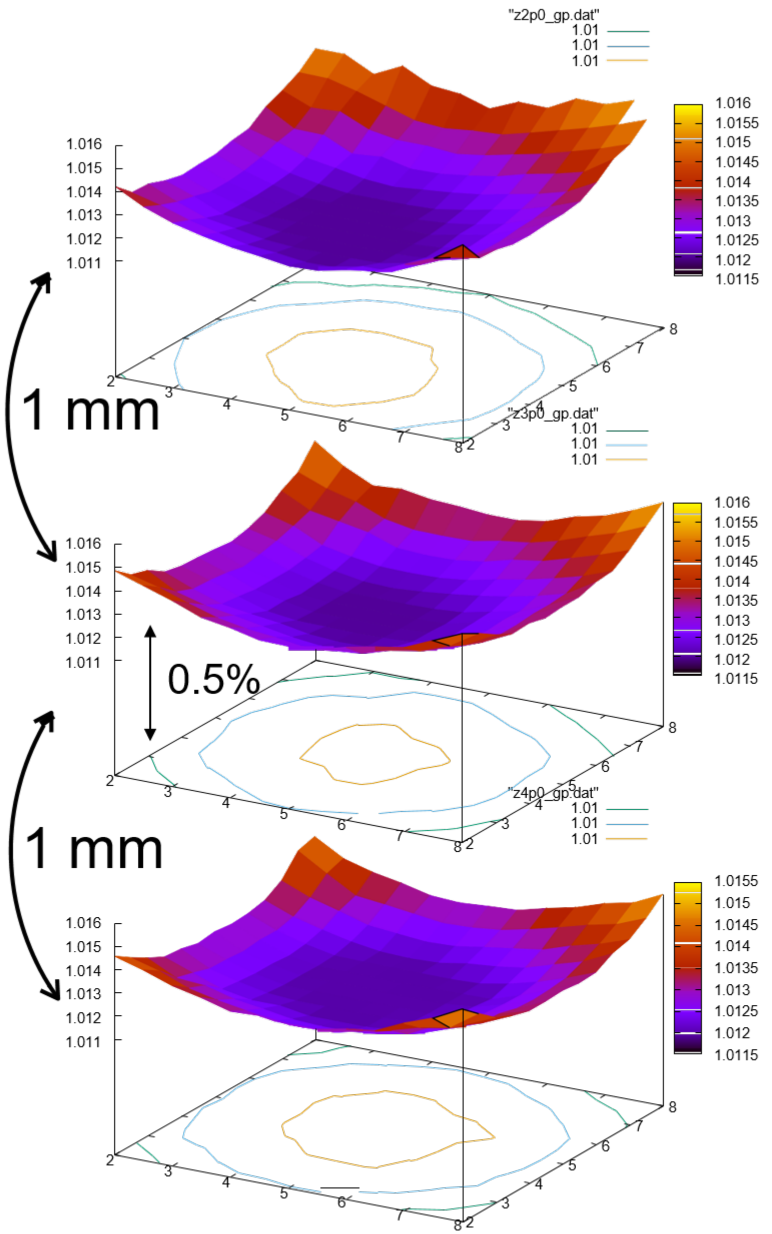
^{1}H NMR spectrum at 64.48 MHz (1.51 T)



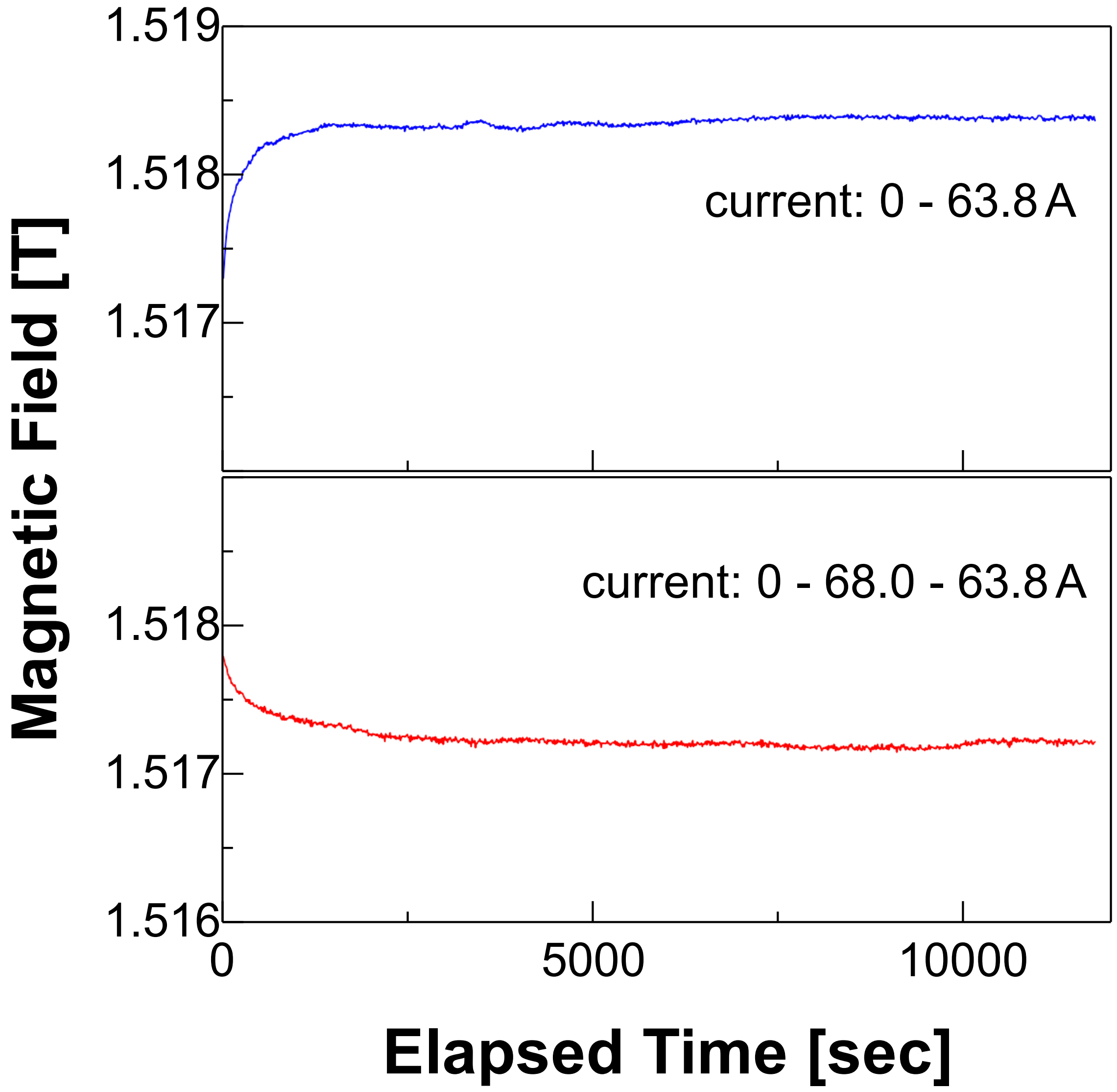
- ^{1}H NMR spectrum successfully measured.
  - feasibility of DP stack for NMR use
  - Solid state physics
- Broad resonance line ~1000 ppm
  - Inhomogeneous magnetic field
  - Long solenoid
  - shimming

Magnetic field profile measured by NMR





Temporal stability measured by NMR



Current reversal (overshooting) is effective to shorten the time to approach the stationary field.

Summary

- Designed and fabricated LN_2 cooled REBCO magnet.
- Specification variation among the conductor is to be improved.
- Generated 1.55 T stably at 67 K, 2.02 T at 66 K.
- ^{1}H NMR spectrum successfully measured.
  - feasibility of DP stack for NMR use
  - Broad resonance line ~1000 ppm
- Investigated spatial homogeneity and temporal stability by NMR.
  - Inhomogeneous magnetic field
  - Long solenoid
  - shimming