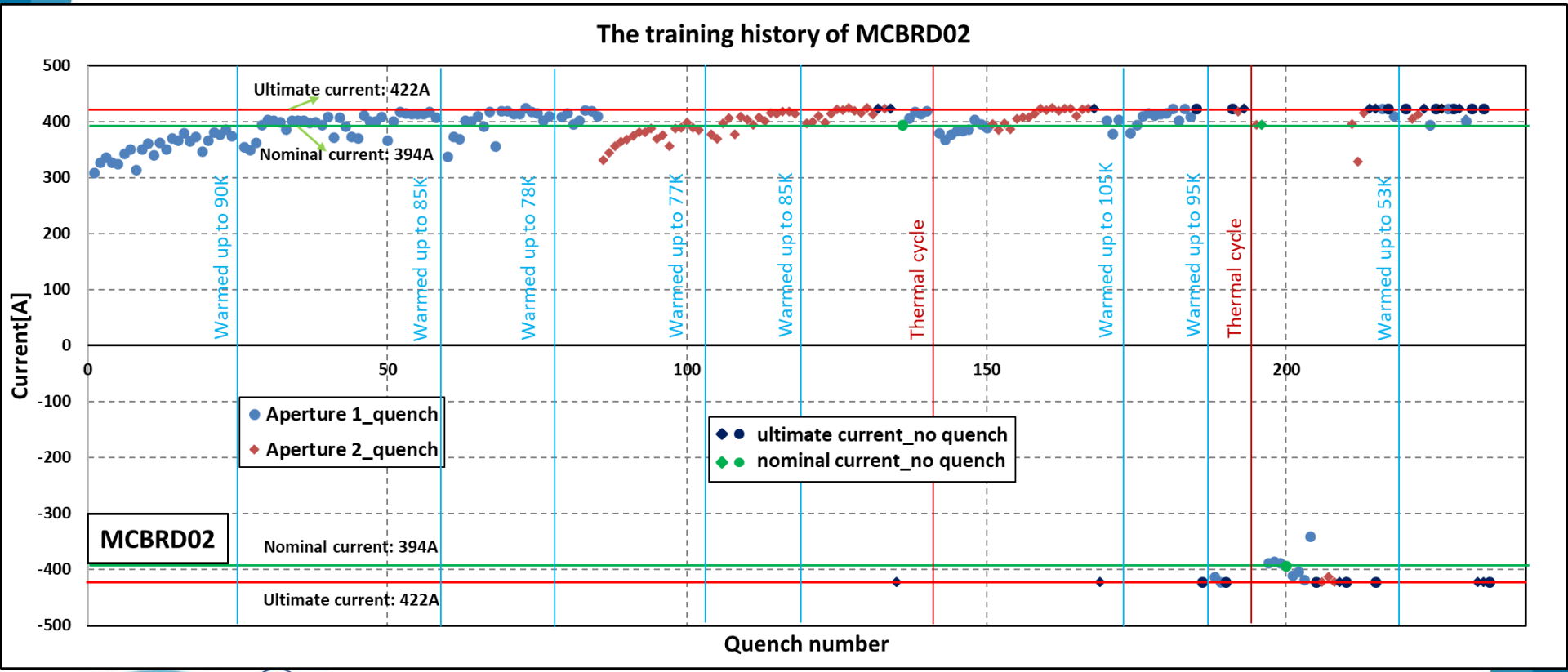
The test process and results of MCBRD02 in China

CCT Magnet Chinese Team
(IHEP, IMP, BAMA)

HL-LHC WP3 meeting – May 30 2022

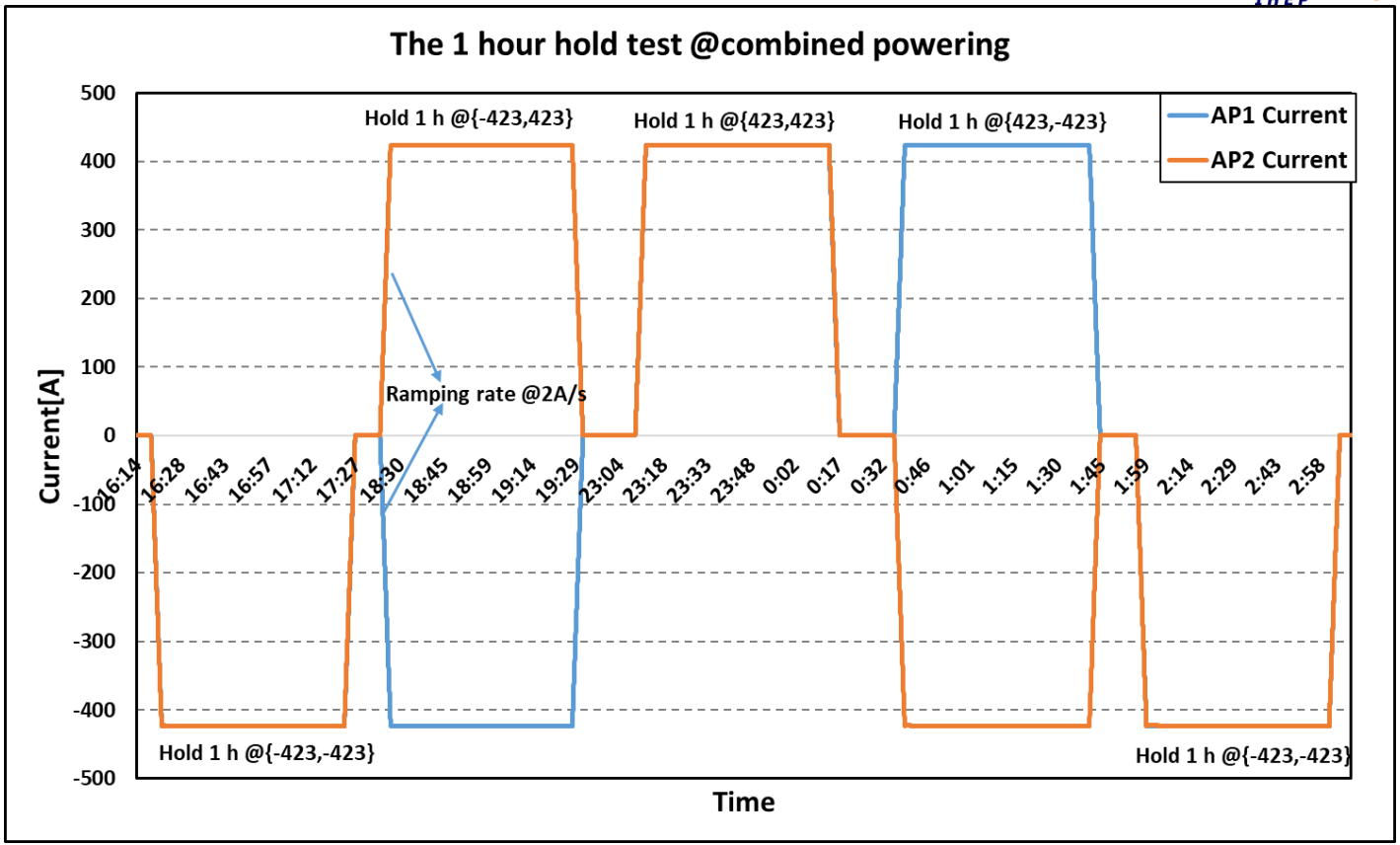
The training history



AP1: a total of 123 quenches
AP2: a total of 72 quenches

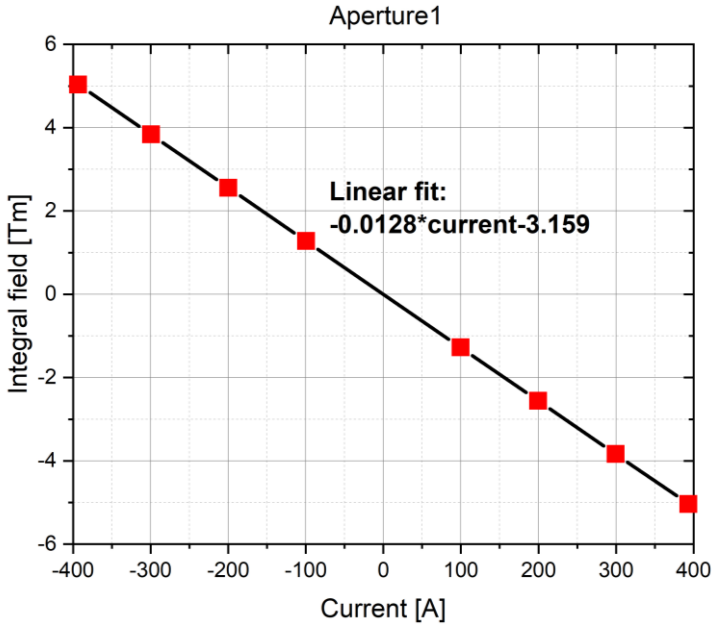
At the end of the second thermal cycle, the magnet tends to be stable.

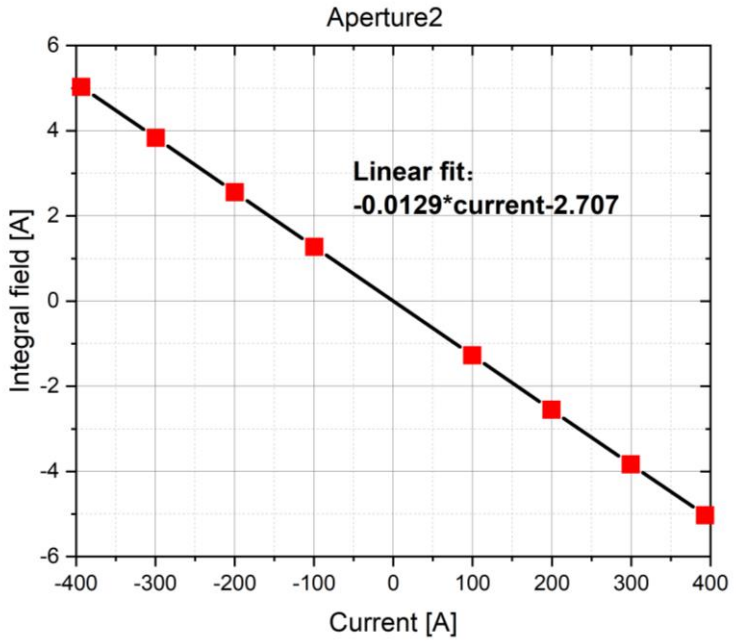
The holding test



Measurement result-1

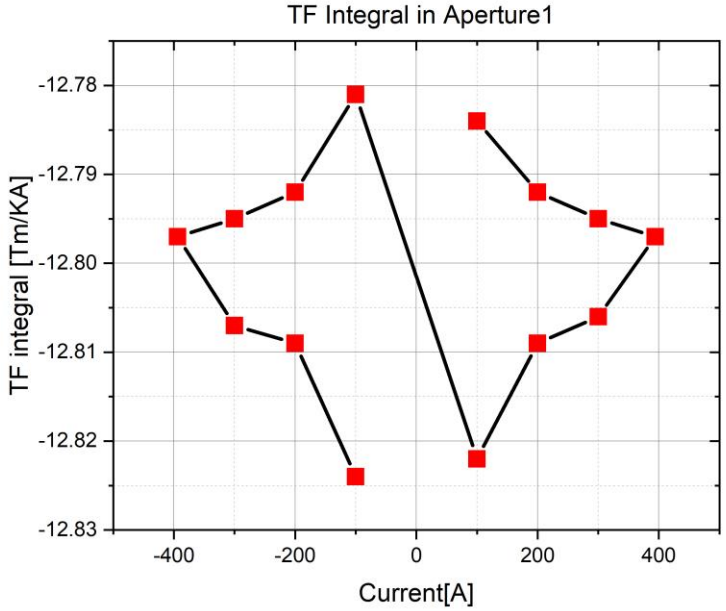
Integral field in single aperture

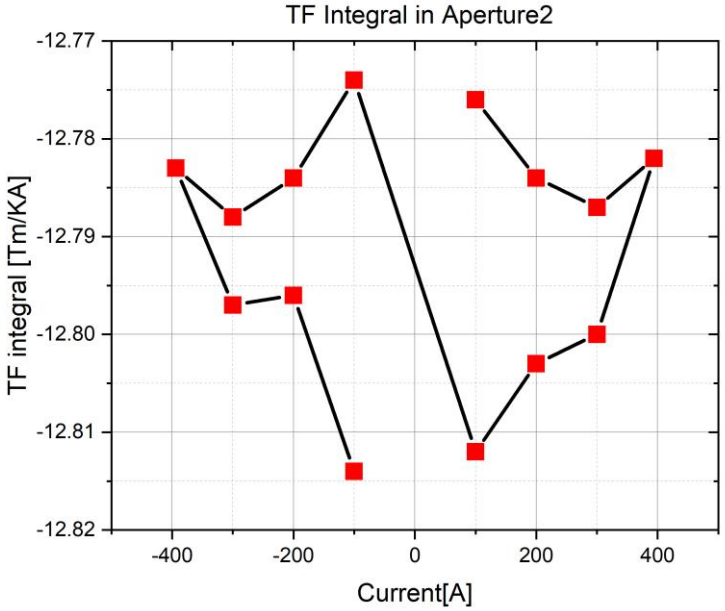




Measurement result-1

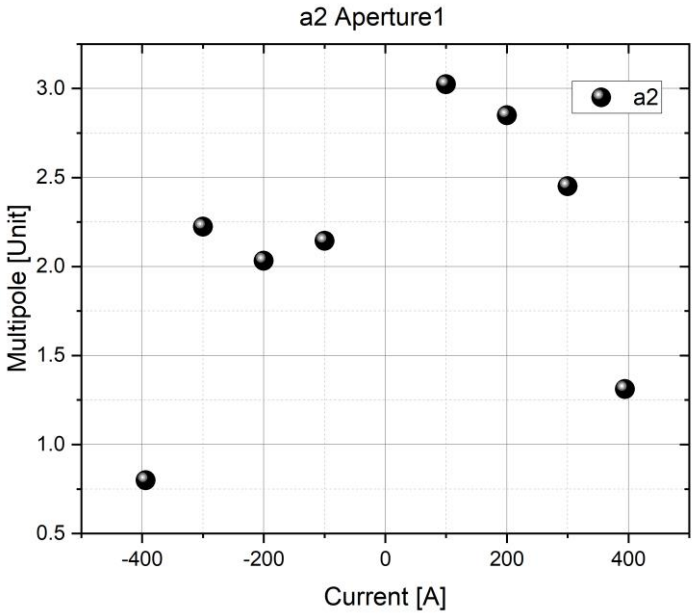
Transfer function in single aperture

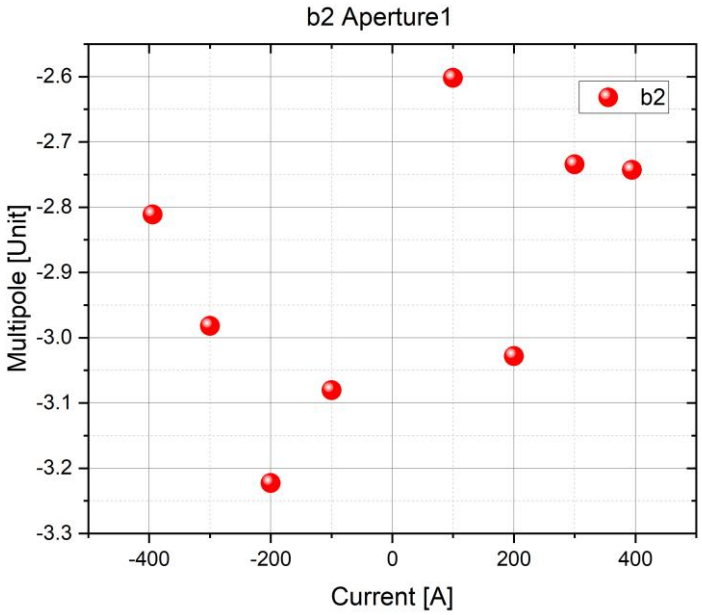




Measurement result-1

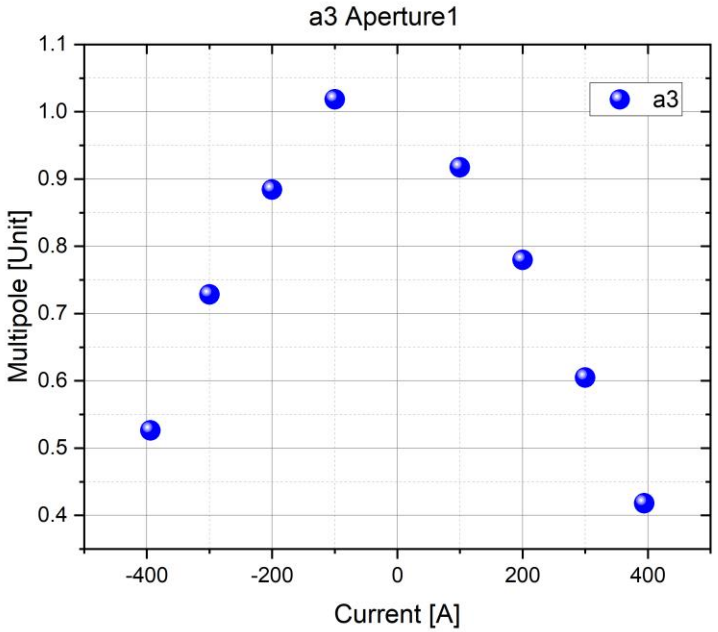
Multipoles—a2 & b2 in Aperture1

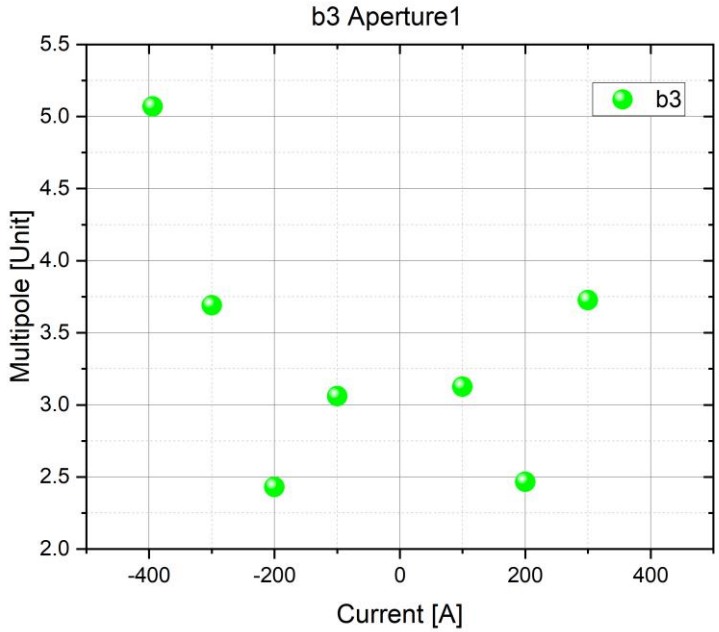




Measurement result-1

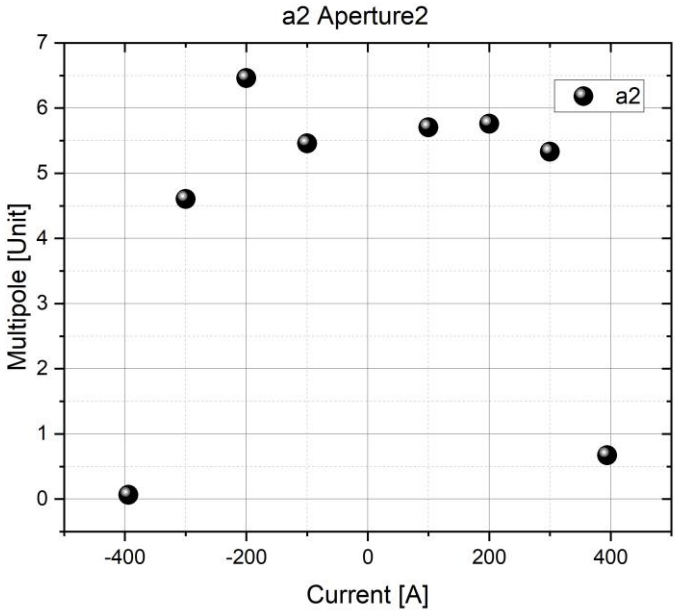
Multipoles—a3 & b3 in Aperture1

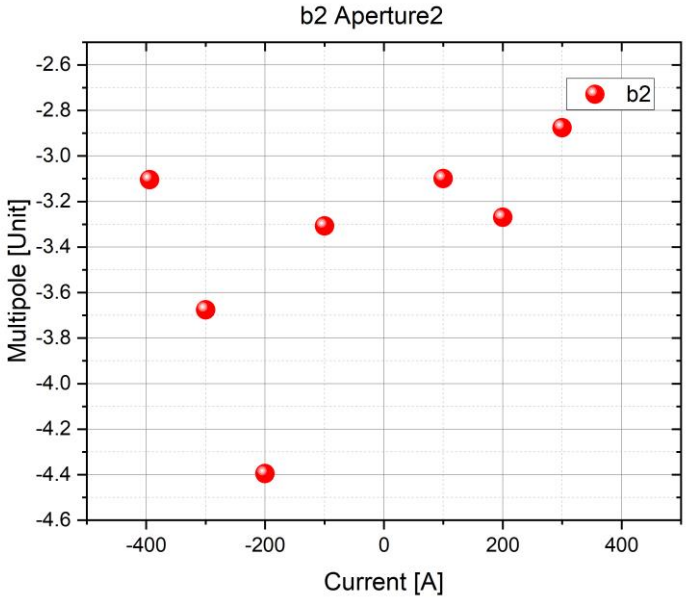




Measurement result-1

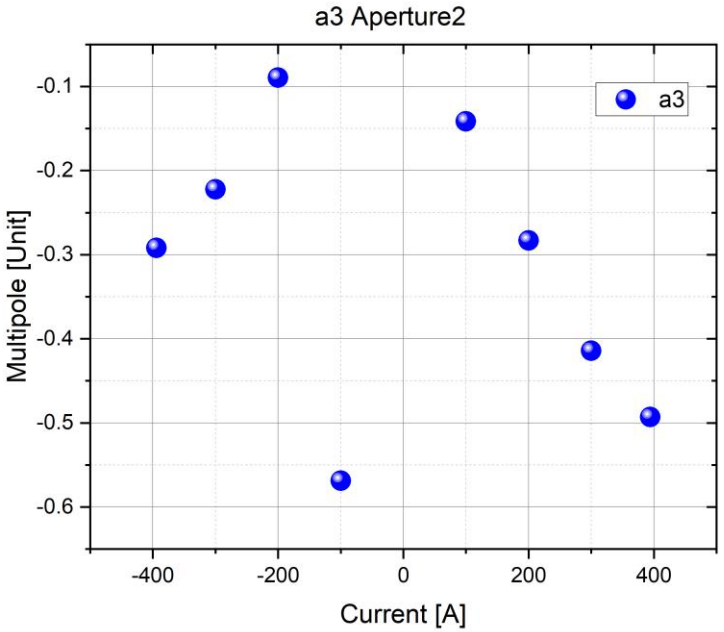
Multipoles—a2 & b2 in Aperture2

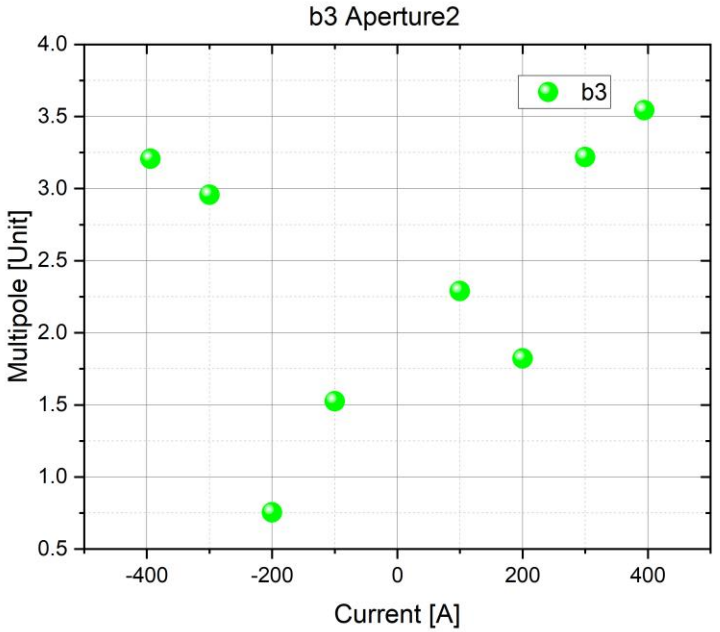




Measurement result-1

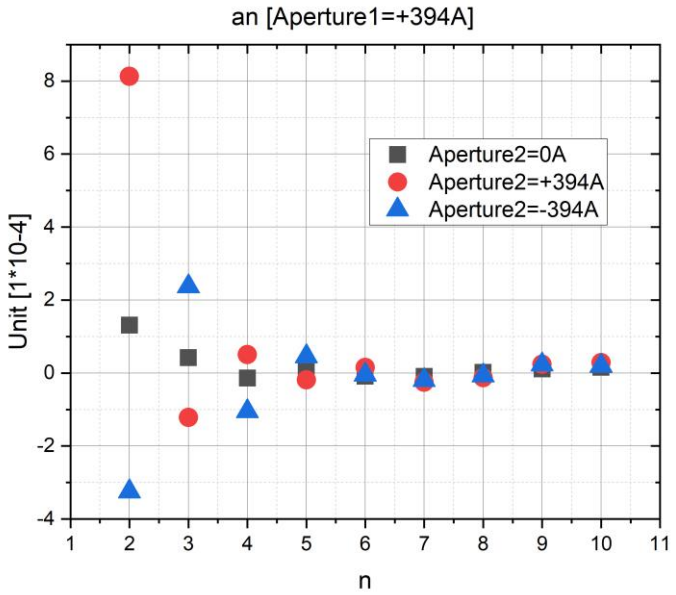
Multipoles—a3 & b3 in Aperture2

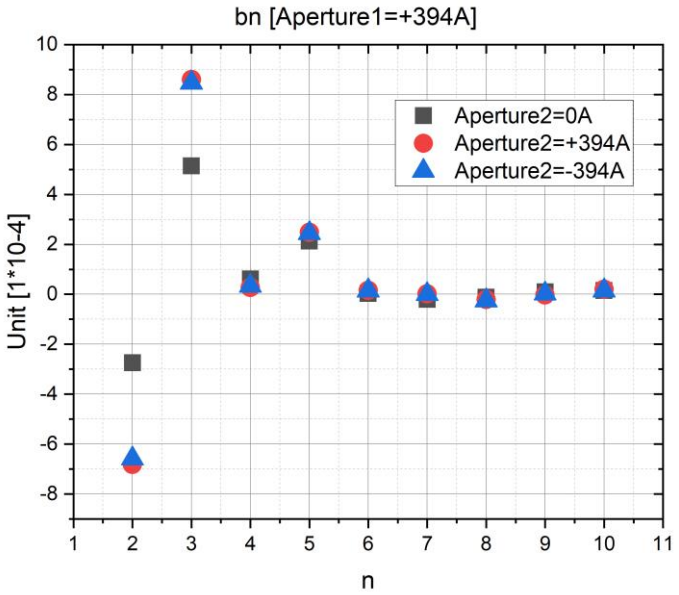




Measurement result-2

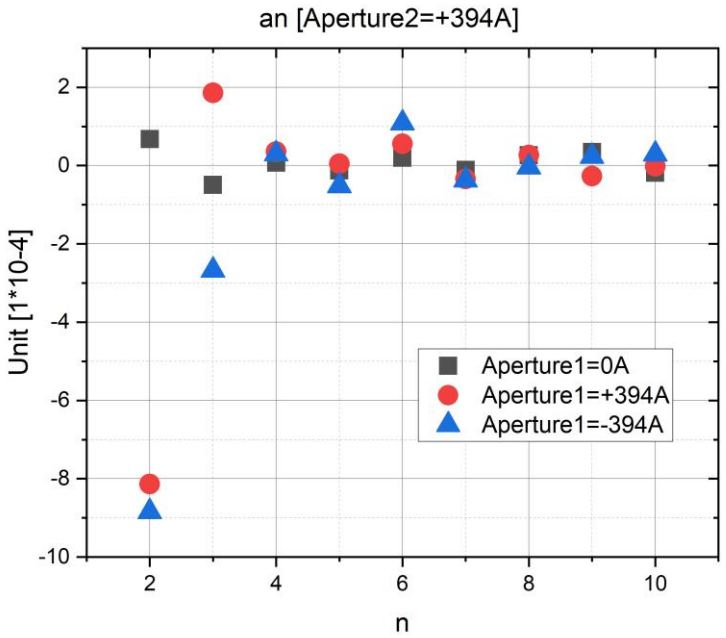
Crosstalk—Multipoles in Aperture1

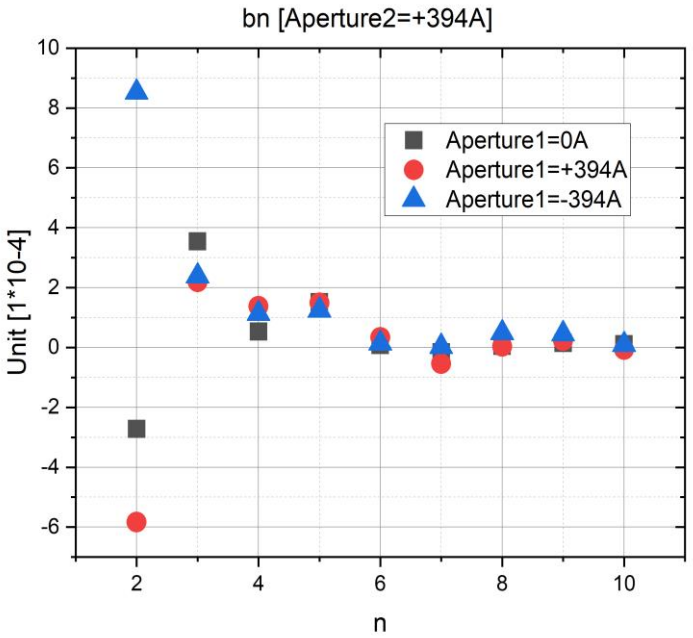




Measurement result-2

Crosstalk—Multipoles in Aperture2





Electrical test of the apertures before assembly

The resistance measurement results are as expected.

Equipment	Coil ID	Object	Function			Resistance/Ω
KEITHLEY 2002	Aperture 1	coil resistance	4 wires	Lead A+ → EE12		0.190
			4 wires	Lead A+ → EE13		0.188
			4 wires	Lead A+ → EE14		70.443
			4 wires	Lead A+ → EE15		70.441
			4 wires	Lead A+ → CLIC LEAD		117.448
			4 wires	Lead A+ → EE16		164.789
			4 wires	Lead A+ → EE17		164.789
			4 wires	Lead A+ → EE18		236.137
			4 wires	Lead A+ → EE19		236.136
			4 wires	Lead A+ → Lead B-		236.062
		CCS resistance		Serial number	R calibration	
			4 wires	322 (Inner)	1065.4Ω@295.818K	1097.769
			4 wires	323 (Outer)	1066.8Ω@295.818K	1099.170
	Aperture 2	coil resistance	4 wires	Lead A+ → EE22		0.184
			4 wires	Lead A+ → EE23		0.187
			4 wires	Lead A+ → EE24		70.821
			4 wires	Lead A+ → EE25		70.824
			4 wires	Lead A+ → CLIC LEAD		118.293
			4 wires	Lead A+ → EE26		166.130
			4 wires	Lead A+ → EE27		166.130
			4 wires	Lead A+ → EE28		238.467
			4 wires	Lead A+ → EE29		238.467
			4 wires	Lead A+ → Lead B-		238.389
		CCS resistance		Serial number	R calibration	
			4 wires	317 (Inner)	1065.3Ω@295.818K	1099.420
			4 wires	324 (Outer)	1065.1Ω@295.818K	1098.706
Test condition：12.1℃ & relative humidity 25.9%						

Electrical test of the apertures before assembly

Table 2. The Inductance measurement results of both coils

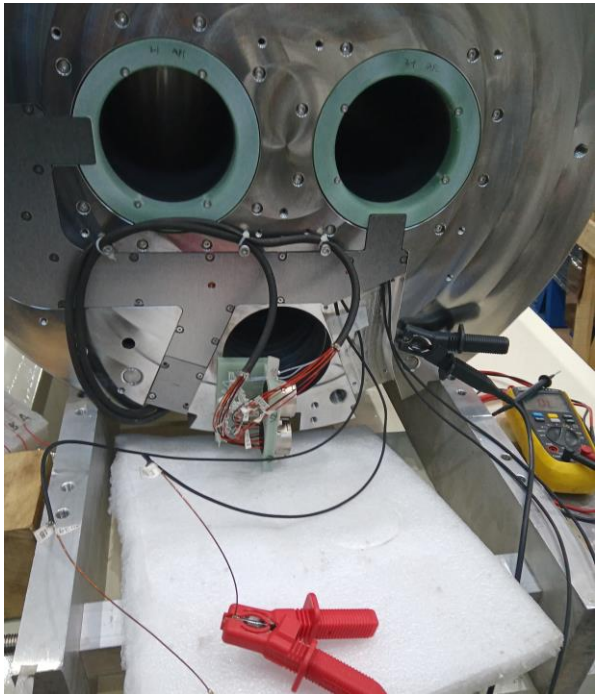
Equipment	Coil ID	Object			Function	
HIOKI IM 3536 LCR METER	Aperture 1	Inductance (mH)	Measures made		Series	Parallel
			Frequency	100 Hz	65.89	3352.0
				1000 HZ	2.305	1558.7
	Aperture 2	Inductance (mH)	Measures made		Series	Parallel
			Frequency	100 Hz	64.870	3431.0
				1000 HZ	1.930	1868.330
Test condition：12.1℃ & relative humidity 25.9%						

Table 3. The Capacitance measurement results of both coils

Equipment	Coil ID	Object		Function	
HIOKI IM 3536 LCR METER	Aperture 1	Capacitance (nF)	Measures made	Series	Parallel
			Coil to External tube/ground: 1kHz	31.970	31.938
	Aperture 2	Capacitance (nF)	Measures made	Series	Parallel
			Coil to External tube/ground: 1kHz	32.755	32.716
Test condition：12.1℃ & relative humidity 25.9%					

Electrical test of the apertures before assembly

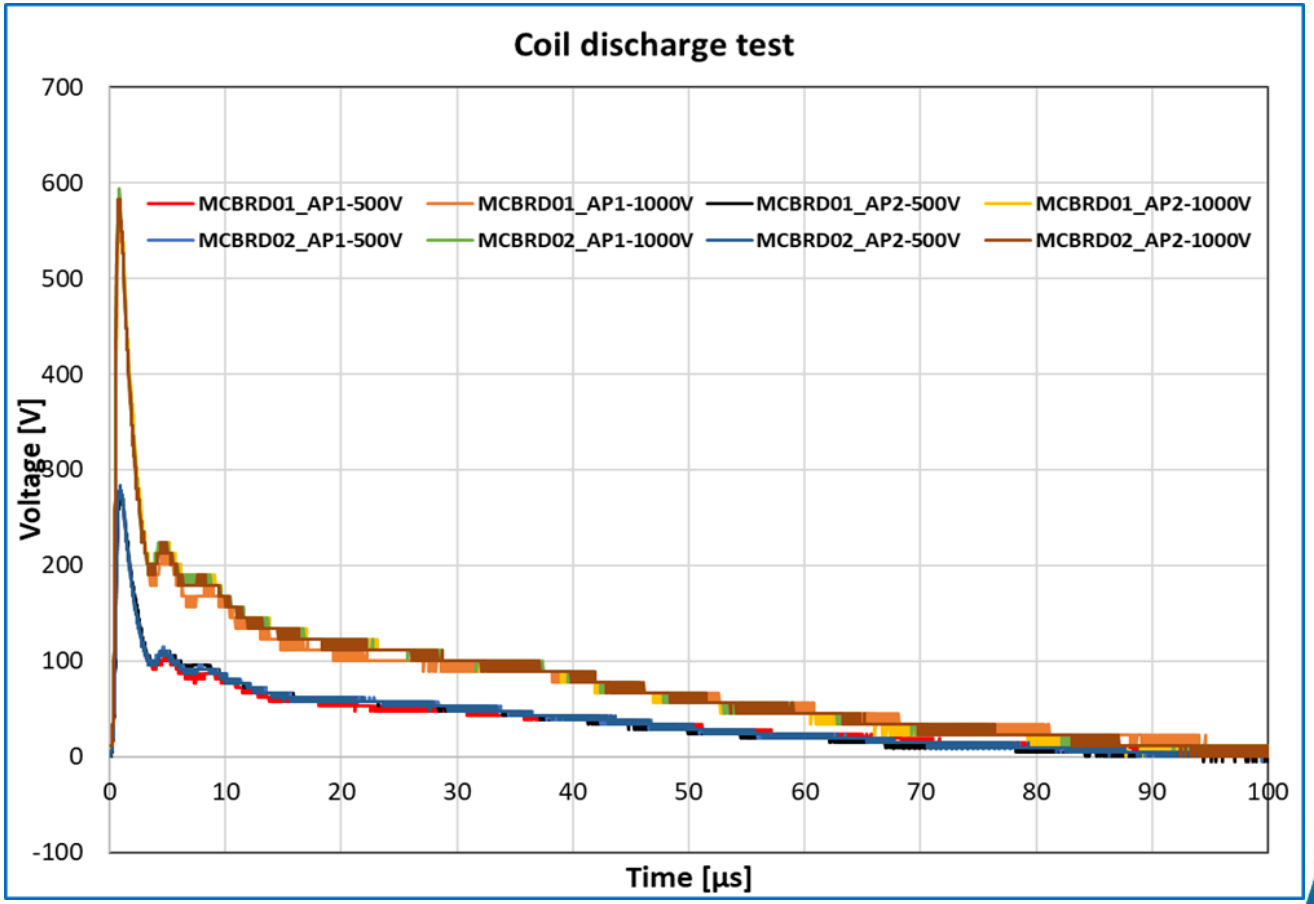
Equipment	Coil ID	Object	Function	Voltage/Current	Test Time	Resistance/GΩ
Megger MIT 525	Aperture 1	Coil to Ground	IR	102V/0.35nA	30s	>100
		Coil to Ground	IR	204V/0.56nA	30s	>100
		Coil to Ground	IR	306V/1.02nA	30s	299.00
		Coil to Ground	IR	338V/0.69nA	30s	487.00
		CCS322 to Ground	IR	103V/0.05nA	30s	>100
		CCS322 to Ground	IR	254V/0.00nA	30s	>500
		CCS322 to Ground	IR	339V/0.00nA	30s	>500
		CCS323 to Ground	IR	103V/0.00nA	30s	>100
		CCS323 to Ground	IR	254V/0.00nA	30s	>500
		CCS323 to Ground	IR	339V/0.00nA	30s	>500
		Coil to CCS322	IR	104V/0.00nA	30s	>100
		Coil to CCS322	IR	254V/0.75nA	30s	337.00
		Coil to CCS322	IR	339V/0.00nA	30s	>500
		Coil to CCS323	IR	104V/0.00nA	30s	>100
		Coil to CCS323	IR	254V/0.00nA	30s	>500
		Coil to CCS323	IR	339V/0.00nA	30s	>500
	Aperture 2	Coil to Ground	IR	104V/0.23nA	30s	>100
		Coil to Ground	IR	200V/1.45nA	30s	>100
		Coil to Ground	IR	307V/1.71nA	30s	179.70
		Coil to Ground	IR	339V/1.82nA	30s	186.10
		CCS317 to Ground	IR	101V/0.00nA	30s	>100
		CCS317 to Ground	IR	254V/0.00nA	30s	>500
		CCS317 to Ground	IR	339V/0.04nA	30s	>500
		CCS324 to Ground	IR	101V/0.00nA	30s	>100
		CCS324 to Ground	IR	254V/0.00nA	30s	>500
		CCS324 to Ground	IR	339V/0.00nA	30s	>500
		Coil to CCS317	IR	101V/0.33nA	30s	>100
		Coil to CCS317	IR	254V/0.00nA	30s	>500
		Coil to CCS317	IR	336V/0.00nA	30s	>500
		Coil to CCS324	IR	104V/0.00nA	30s	>100
		Coil to CCS324	IR	254V/0.00nA	30s	>500
		Coil to CCS324	IR	336V/0.00nA	30s	>500
Test condition：12.1℃ & relative humidity 25.9%						



The two apertures of the magnet have done the stand-alone test before, so the highest test voltage is 330V, all passed.

Electrical test of the apertures before assembly

The electrical test results before assembly indicate that the overall performance of the magnet is OK.



Electrical test before the first cold test

For Aperture 1, it can only pass the maximum insulation test of 509V, when performing a higher test voltage, the test protection is triggered.

Table 5. The insulation test results of Aperture 1 & Aperture 2 (before cool down)

Equipment	Coil ID	Object	Function	Voltage/Current	Test Time	Resistance
Megger MIT 525	Aperture 1	Coil to Ground	IR	102V/1.62nA	30s	62.8GΩ
		Coil to Ground	IR	204V/1.61nA	30s	>100GΩ
		Coil to Ground	IR	306V/1.41nA	30s	218GΩ
		Coil to Ground	IR	338V/1.23nA	30s	275GΩ
	Aperture 2	Coil to Ground	IR	103V/0.51nA	30s	>100GΩ
		Coil to Ground	IR	205V/1.35nA	30s	>100GΩ
		Coil to Ground	IR	307V/2.27nA	30s	135.5GΩ
		Coil to Ground	IR	339V/2.01nA	30s	168.6GΩ
Test condition：In cryostat with the helium gas						

Table 6. The insulation test results of Aperture1 & Aperture 2 (4.2K)

Equipment	Coil ID	Object	Function	Voltage/Current	Test Time	Resistance
Megger MIT 525	Aperture 1	Coil to Ground	IR	103V/166nA	30s	620MΩ
		Coil to Ground	IR	253V/165nA	30s	1.54GΩ
		Coil to Ground	IR	511V/186nA	30s	2.75GΩ
		Coil to Ground	IR	750V/184nA	30s	7.32MΩ
	Aperture 2	Coil to Ground	IR	101V/130nA	30s	780MΩ
		Coil to Ground	IR	255V/129nA	30s	1.98GΩ
		Coil to Ground	IR	513V/128nA	30s	3.99GΩ
		Coil to Ground	IR	766V/128nA	30s	5.99GΩ
Test condition：In cryostat and in Liquid helium						

Electrical test before the second cold test

For Aperture 1, the test results are similar as the first cold test.

Table 7. The insulation test results of Aperture 1 & Aperture 2 (first thermal cycle at RT)

Equipment	Coil ID	Object	Function	Voltage/Current	Test Time	Resistance
Megger MIT 525	Aperture 1	Coil to Ground	IR	101V/76.9nA	30s	1.32GΩ
		Coil to Ground	IR	201V/78.9nA	30s	2.55GΩ
		Coil to Ground	IR	308V/81.0nA	30s	3.80GΩ
		Coil to Ground	IR	340V/83.0nA	30s	4.09GΩ
	Aperture 2	Coil to Ground	IR	103V/19.5nA	30s	5.27GΩ
		Coil to Ground	IR	200V/56.2nA	30s	3.56GΩ
		Coil to Ground	IR	308V/67.9nA	30s	4.53GΩ
		Coil to Ground	IR	340V/73.7nA	30s	4.60 GΩ
Test condition：In cryostat with the helium gas						

Table 8. The insulation test results of Aperture1 & Aperture 2 (4.2K)

Equipment	Coil ID	Object	Function	Voltage/Current	Test Time	Resistance
Megger MIT 525	Aperture 1	Coil to Ground	IR	103V/213nA	30s	484MΩ
		Coil to Ground	IR	254V/110nA	30s	2.30GΩ
		Coil to Ground	IR	509V/88.3nA	30s	5.77GΩ
		Coil to Ground	IR	750V/82.6nA	30s	18.05MΩ
	Aperture 2	Coil to Ground	IR	104V/111nA	30s	936MΩ
		Coil to Ground	IR	255V/130nA	30s	1.97GΩ
		Coil to Ground	IR	513V/133nA	30s	3.84GΩ
		Coil to Ground	IR	766V/133nA	30s	5.76GΩ
Test condition：In cryostat and in Liquid helium						

Electrical test before the third cold test

For Aperture 1, the test results are similar as before.

Table 9. The insulation test results of Aperture 1 & Aperture 2 (second thermal cycle at RT)

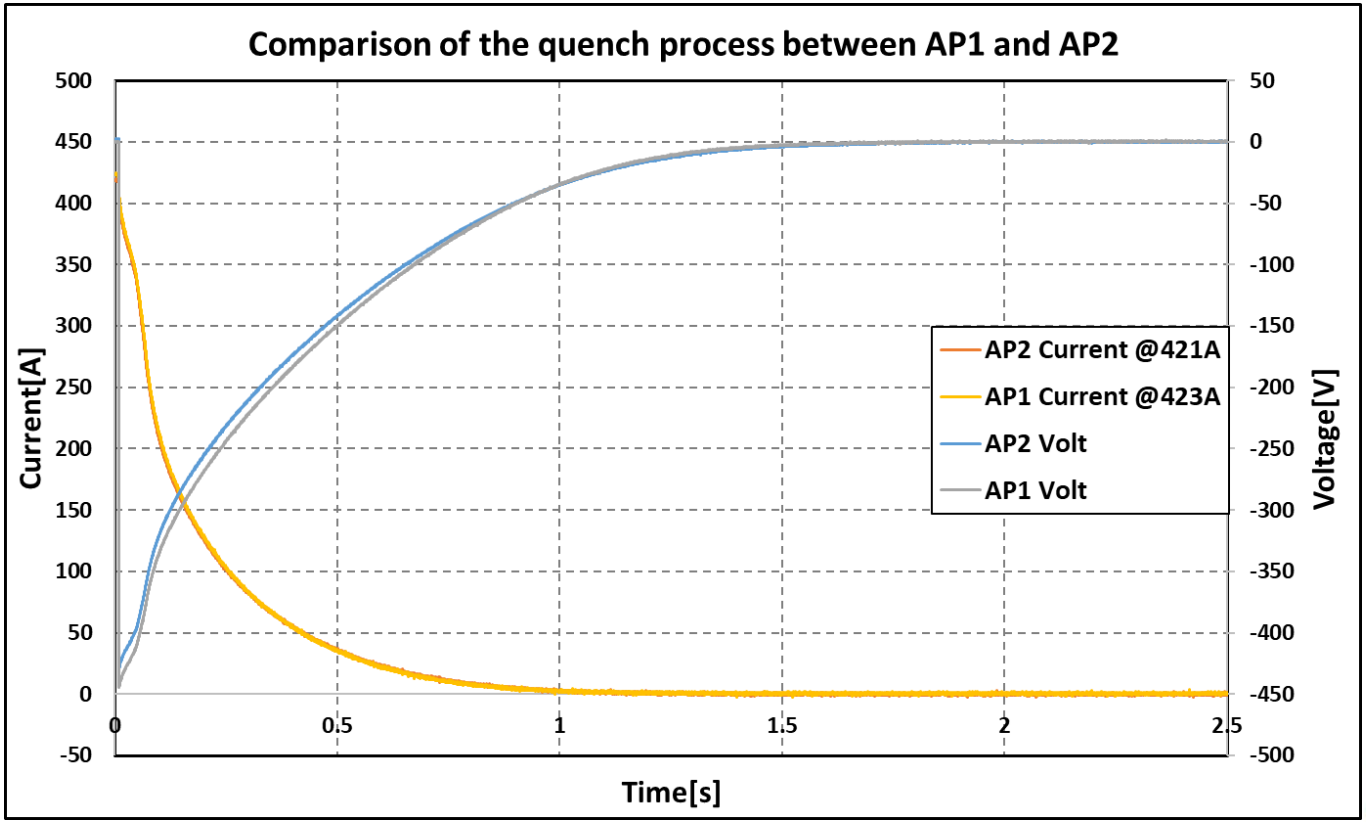
Equipment	Coil ID	Object	Function	Voltage/Current	Test Time	Resistance
Megger MIT 525	Aperture 1	Coil to Ground	IR	102V/63.0nA	30s	1.61GΩ
		Coil to Ground	IR	201V/67.4nA	30s	2.98GΩ
		Coil to Ground	IR	305V/70.9nA	30s	4.31GΩ
		Coil to Ground	IR	340V/74.0nA	30s	4.59GΩ
	Aperture 2	Coil to Ground	IR	104V/19.4nA	30s	5.35GΩ
		Coil to Ground	IR	201V/38.5nA	30s	5.21GΩ
		Coil to Ground	IR	308V/49.6nA	30s	6.20GΩ
		Coil to Ground	IR	340V/58.1nA	30s	5.84GΩ
Test condition：In cryostat with the helium gas						

Table 10. The insulation test results of Aperture1 & Aperture 2 (4.2K)

Equipment	Coil ID	Object	Function	Voltage/Current	Test Time	Resistance
Megger MIT 525	Aperture 1	Coil to Ground	IR	102V/51.8nA	30s	1.98GΩ
		Coil to Ground	IR	253V/96.5nA	30s	2.62GΩ
		Coil to Ground	IR	509V/108nA	30s	4.73GΩ
		Coil to Ground	IR	550V/117nA	30s	13.14MΩ
	Aperture 2	Coil to Ground	IR	104V/92.3nA	30s	1.125GΩ
		Coil to Ground	IR	254V/98.6nA	30s	2.58GΩ
		Coil to Ground	IR	512V/118nA	30s	4.34GΩ
		Coil to Ground	IR	766V/106nA	30s	7.20GΩ
Test condition：In cryostat and in Liquid helium						

Comparison of the quench process between AP1 and AP2

Although the Aperture 1 appear low resistance during the insulation test, there is no difference during the quench process between the two apertures at similar current.



Electrical test before packaging

Table 11. The insulation test results (final tests)

Equipment	Coil ID	Object	Function	Voltage/Current	Test Time	Resistance
Megger MIT 525	Aperture 1	Coil to Ground	IR	102V/1.28nA	30s	79.5GΩ
		Coil to Ground	IR	201V/1.28nA	30s	>100GΩ
		Coil to Ground	IR	308V/1.64nA	30s	188.1GΩ
		Coil to Ground	IR	340V/1.98nA	30s	172.2GΩ
		Coil to CCS322	IR	103V/0nA	30s	>100GΩ
		Coil to CCS322	IR	254V/0nA	30s	>500GΩ
		Coil to CCS323	IR	104V/0nA	30s	>100GΩ
		Coil to CCS323	IR	254V/0nA	30s	>500GΩ
	Aperture 2	Coil to Ground	IR	102V/0.54nA	30s	>100GΩ
		Coil to Ground	IR	201V/1.74nA	30s	>100GΩ
		Coil to Ground	IR	308V/2.07nA	30s	149.1GΩ
		Coil to Ground	IR	340V/2.13nA	30s	159.3GΩ
		Coil to CCS317	IR	101V/0nA	30s	>100GΩ
		Coil to CCS317	IR	254V/0nA	30s	>500GΩ
		Coil to CCS324	IR	101V/0nA	30s	>100GΩ
		Coil to CCS324	IR	254V/0nA	30s	>500GΩ
Test condition：23.7℃ & relative humidity 38.9% & before packaging						

The magnet's two apertures pass all insulation tests.

Electrical test before packaging

Equipment	Coil ID	Object	Function			Resistance
KEITHLEY 2002	Aperture 1	coil resistance	4 wires	Lead A+ → EE12		0.196Ω
			4 wires	Lead A+ → EE13		0.194Ω
			4 wires	Lead A+ → EE14		72.921Ω
			4 wires	Lead A+ → EE15		72.917Ω
			4 wires	Lead A+ → CLIC LEAD		121.582Ω
			4 wires	Lead A+ → EE16		170.588Ω
			4 wires	Lead A+ → EE17		170.586Ω
			4 wires	Lead A+ → EE18		244.451Ω
			4 wires	Lead A+ → EE19		244.451Ω
			4 wires	Lead A+ → Lead B-		244.365Ω
		CCS resistance		Serial number	R calibration	
			4 wires	322 (Inner)	1065.4Ω@295.818K	1065.84Ω
			4 wires	323 (Outer)	1066.8Ω@295.818K	1067.04Ω
	Aperture 2	coil resistance	4 wires	Lead A+ → EE22		0.190Ω
			4 wires	Lead A+ → EE23		0.192Ω
			4 wires	Lead A+ → EE24		73.323Ω
			4 wires	Lead A+ → EE25		73.3235Ω
			4 wires	Lead A+ → CLIC LEAD		122.447Ω
			4 wires	Lead A+ → EE26		171.974Ω
			4 wires	Lead A+ → EE27		171.973Ω
			4 wires	Lead A+ → EE28		246.855Ω
			4 wires	Lead A+ → EE29		246.857Ω
			4 wires	Lead A+ → Lead B-		246.765Ω
		CCS resistance		Serial number	R calibration	
			4 wires	317 (Inner)	1065.3Ω@295.818K	**1068.33Ω**
			4 wires	324 (Outer)	1065.1Ω@295.818K	**1066.56Ω**
Test condition：23.7℃ & relative humidity 38.9% & before packaging						

The test results of CCS 317 and CCS 324 are larger than the theoretical values.

Other measurement results

Table 13. The splice measurements

	Current [A]	Splice Resistance [nΩ]	
		EE14-EE15	EE16-EE17
Aperture 1	100	5.48	7.4
	200	5.65	6.9
	300	5.57	7.1
	394	5.61	7.2
	Current [A]	Splice Resistance [nΩ]	
		EE24-EE25	EE26-EE27
Aperture 2	100	13.9	8.2
	200	13.1	8.02
	300	13.7	8.77
	394	13.4	8.56

Table 14. The RRR measurement results

MAGNET	APERTURE	Transition resistance	Resistance at 273K	RRR
MCBRD02	Aperture 1	1.245Ω	217.48Ω	174.7
	Aperture 2	1.256Ω	219.85Ω	175.0

IHEP

IMP

Supercondutor Technology

苏州八匹马超导科技有限公司

Thanks for your attention

CERN