IEEE/CSC & ESAS SUPERCONDUCTIVITY NEWS FORUM (global edition), January 2016.
Invited presentation 1OrCC_01 given at MT-24, Seoul, Korea, October 18-23, 2015.

Retraining of the 1232 Main Dipole Magnets in the LHC

A. Verweij, B. Auchmann, M. Bednarek, L. Bottura,
Z. Charifoulline, S. Feher, P. Hagen, M. Modena,
S. Le Naour, I. Romera, A. Siemko, J. Steckert,
J-P. Tock, E. Todesco, G. Willering, and D. Wollmann

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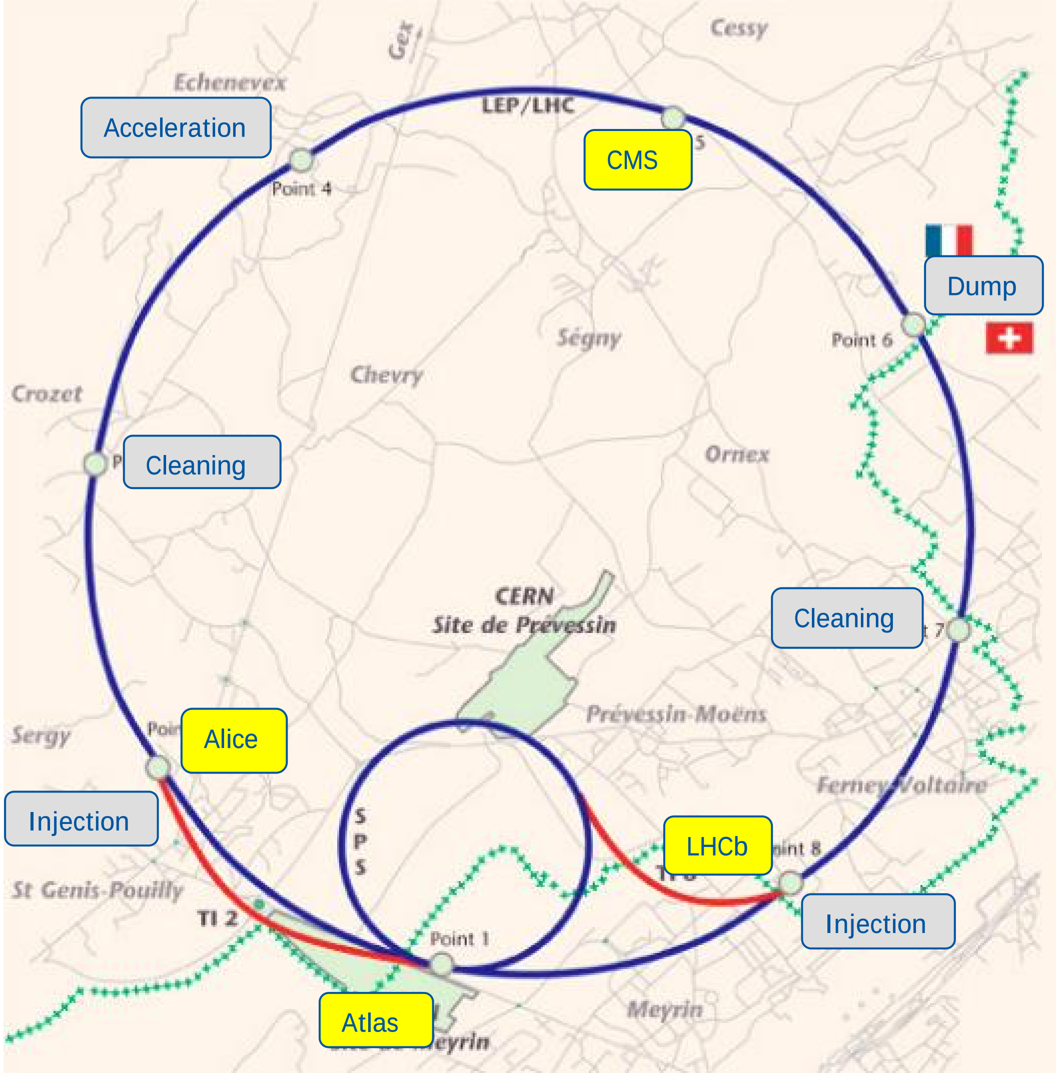
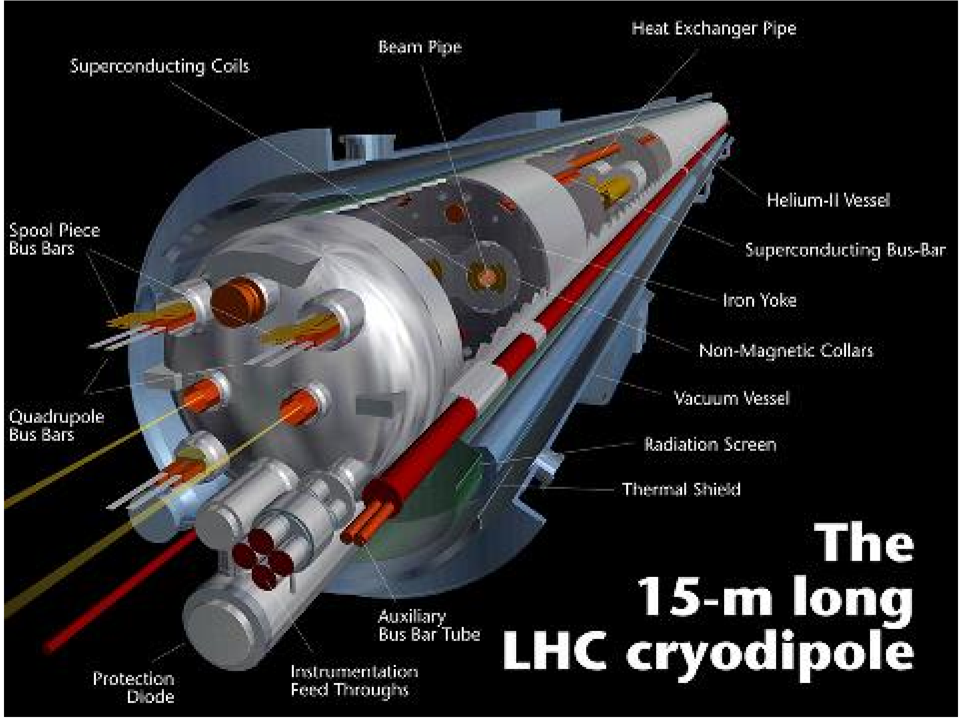
LHC



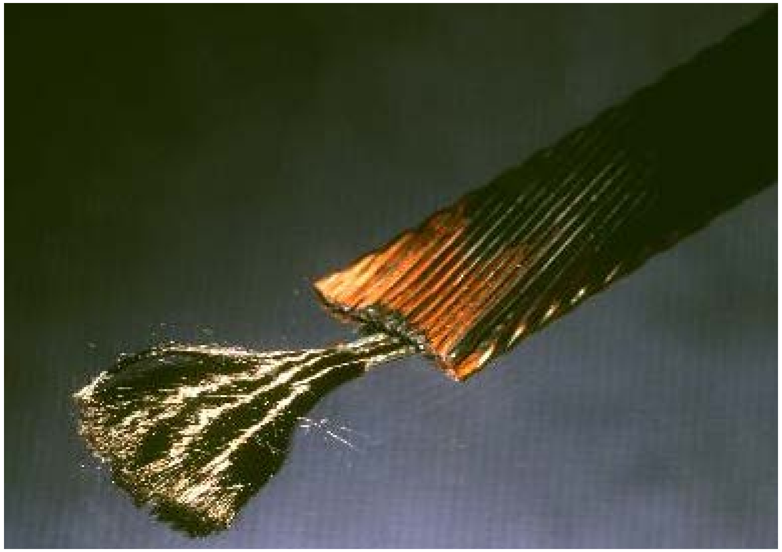
Circumference	27 km
# Sectors	8
# Main dipole circuits per sector	1
# Dipoles per circuit	154
# Dipoles in the LHC	1232
Stored energy per circuit at nominal	1.1 GJ

Twin-aperture Dipole magnets



Magnetic length	14.312 m
Operating temp.	1.9 K
Short sample	13.2 kA, 9.2 T
Nominal	11.85 kA, 8.34 T
Inductance	99 mH
Manufacturers	Firm-1, 2, 3

	Inner coil	Outer coil
Cable width	15. 1 mm	15.1 mm
Mid-thickness	1.90 mm	1.48 mm
# Strands	28	36
Insulation	3 layers of polyimide tape	



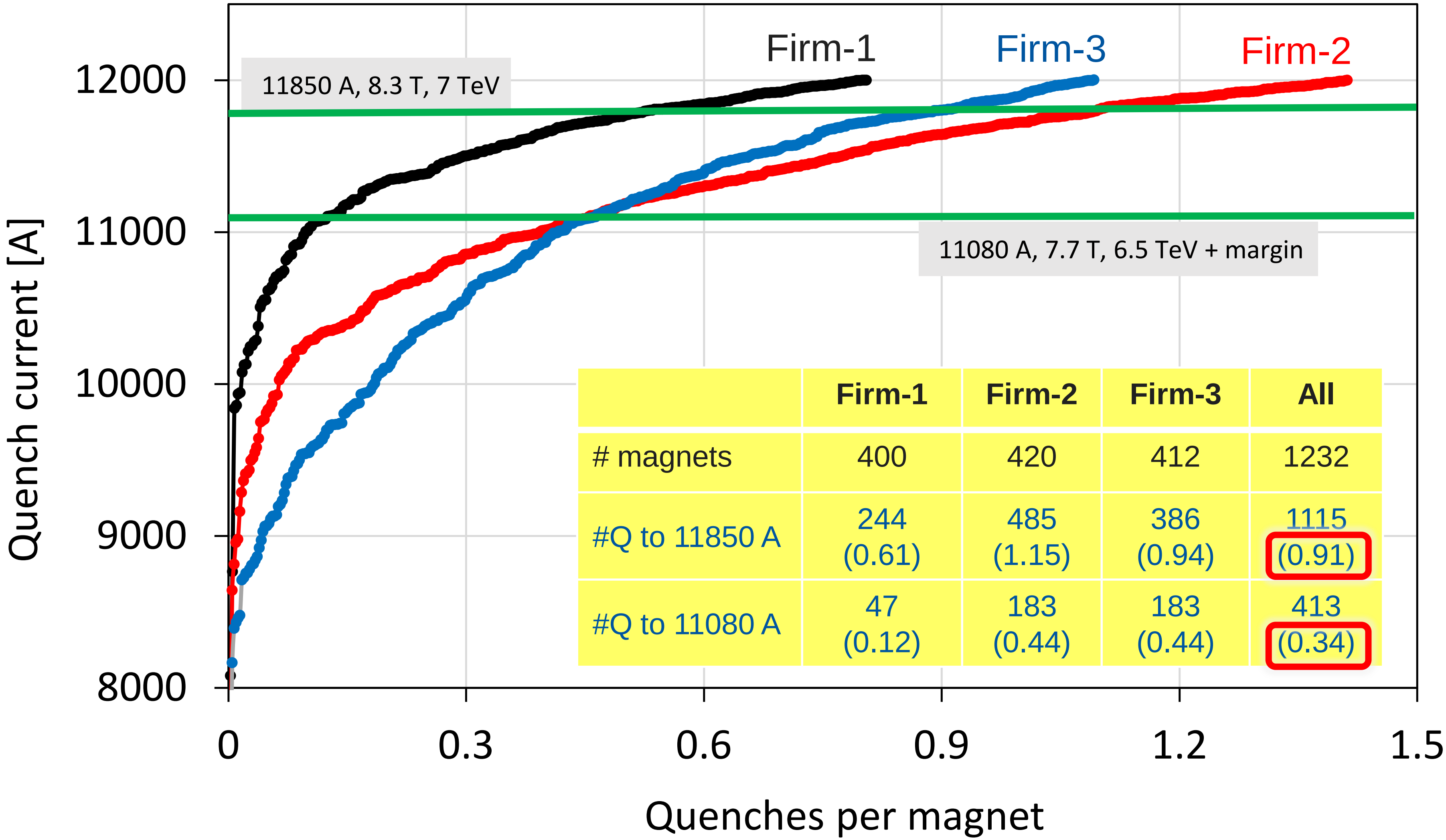
Timeline	Period	#magnets (LHC + spare)	Current level
Initial training	2002-2007	1232 + 44	12-13 kA
Thermal cycle + re-training	2002-2007	116 + 29	12-13 kA
Re-training LHC in 1 sector	2008	154	11.2 kA
Incident	19 Sep 2008		
“Run 1”	2009-2012	1232	6.8 kA
Long Shutdown 1	2013-2014		
Re-training LHC in 8 sectors	2015	1232	11.1 kA
“Run 2”	ongoing	1232	11.0 kA


storage


transport


installation

Reception test (2002-2007) – 1st cool-down



	Firm-1	Firm-2	Firm-3	All
# magnets	400	420	412	1232
#Q to 11850 A	244 (0.61)	485 (1.15)	386 (0.94)	1115 (0.91)
#Q to 11080 A	47 (0.12)	183 (0.44)	183 (0.44)	413 (0.34)

Reception test (2002-2007), 2nd cool-down

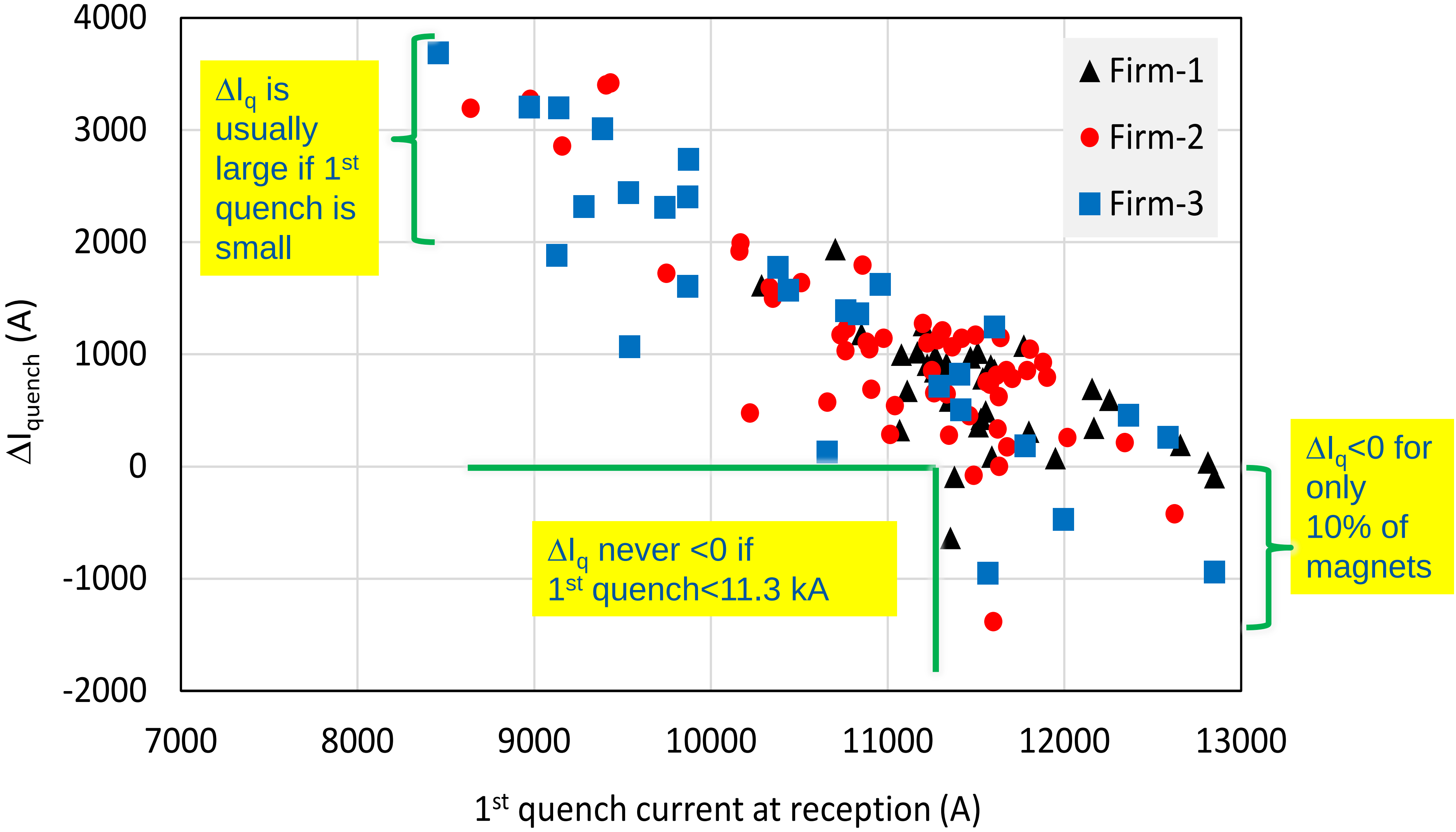
Magnets **from all 3 firms** show a good “memory” when tested a few weeks later, after a thermal cycle.

		Firm-1	Firm-2	Firm-3	All
# magnets		33	55	28	116
#Q to 11850 A	1st cool-down	54	119	67	**240**
	2nd cool-down	6	21	10	**37**
#Q to 11080 A	1st cool-down	4	34	30	**68**
	2nd cool-down	1	3	4	**8**

6.5 x faster

8.5 x faster

Reception test (2002-2007), 2nd cool-down



ΔI_q is usually large if 1st quench is small

ΔI_q never <0 if 1st quench<11.3 kA

ΔI_q<0 for only 10% of magnets

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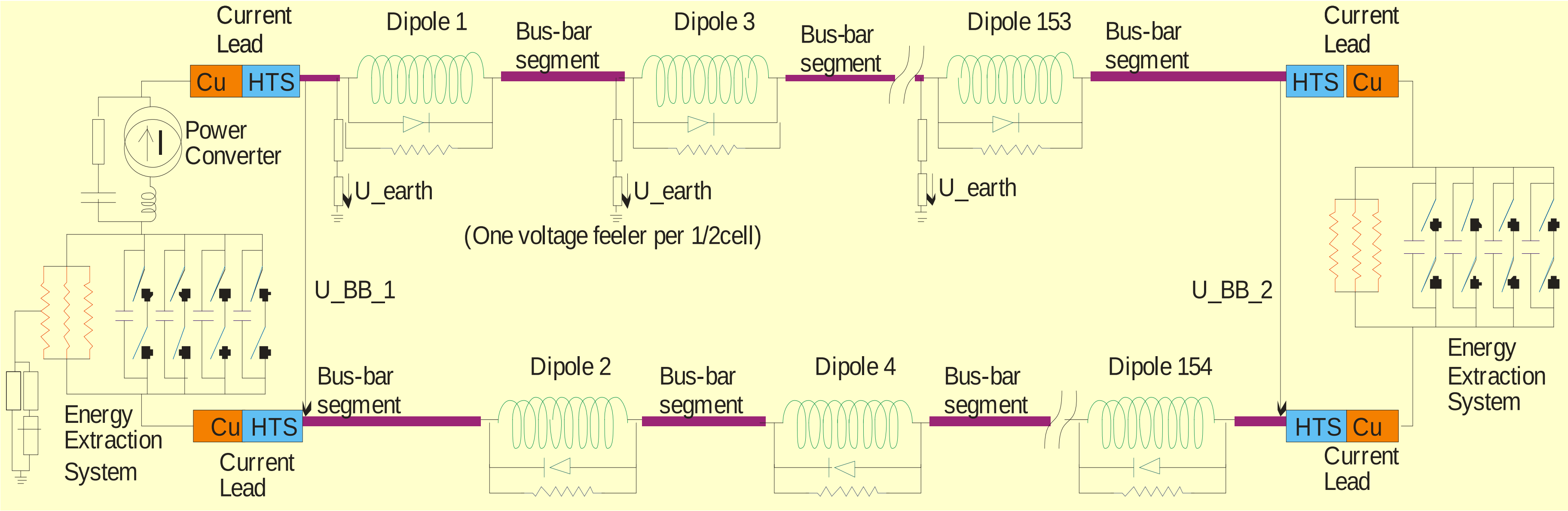
Quenching in a series of 154 dipoles



Quench detection based on $\Delta U_{aperture}$ and ΔU_{magnet}.

Quench heaters to protect the magnets.

Cold diodes to bypass the current in a quenched magnet.

Switches + dump to protect the circuit (τ=100 s).

During decay of circuit current usually several neighboring magnets quench due to propagation of warm helium

LHC – 1 sector (2008)

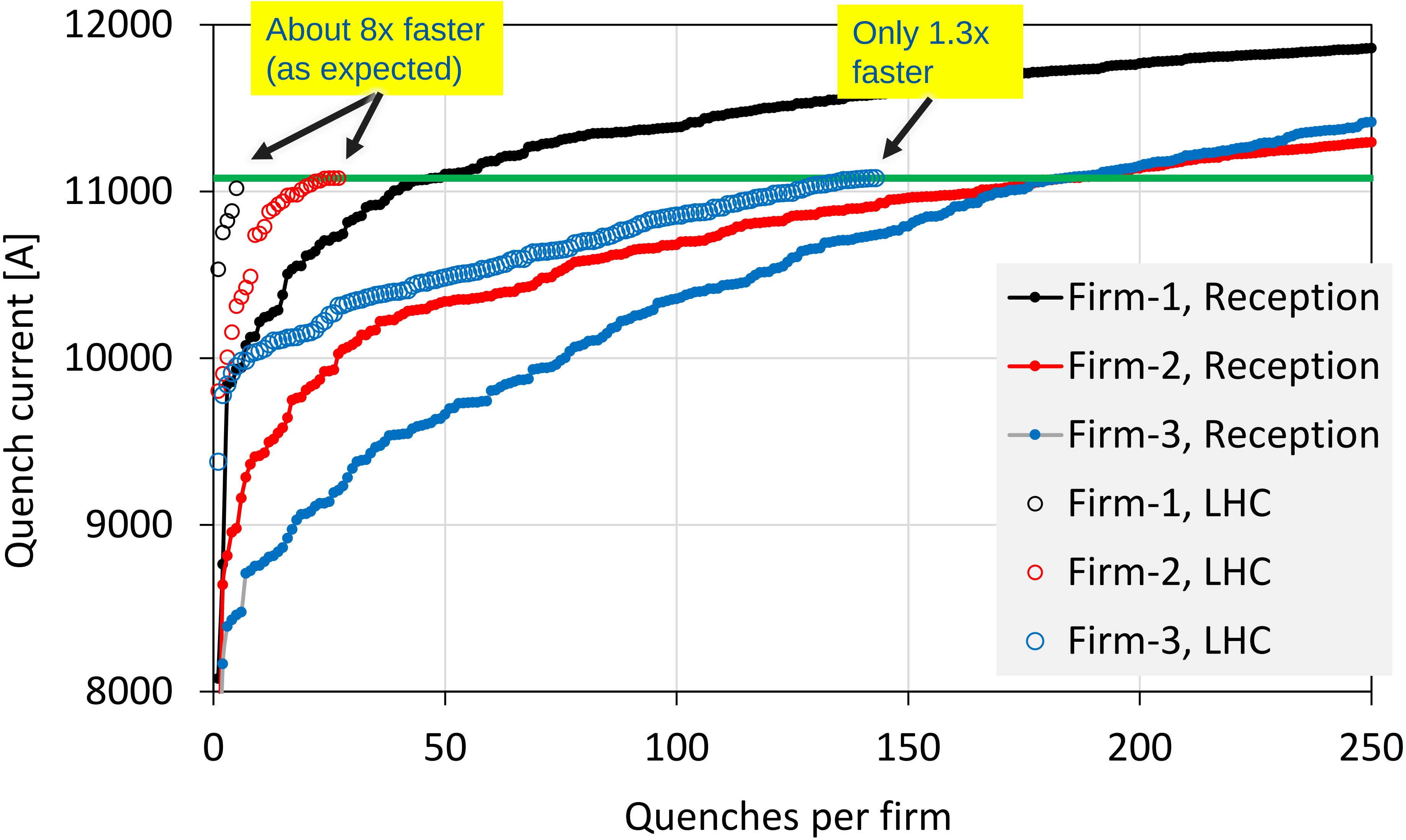
		Firm-1	**Firm-2**	**Firm-3**	**All**
# magnets		28	42	84	154
#Q to 11080 A	Reception	1	15	44	60
	LHC - 2008	0	2	22	24

Only 2 x faster

Magnets from Firm-1 and Firm-2 behave as expected, i.e. good “memory” with about 8 times faster training.

Magnets from Firm-3 train much more than expected.

LHC – 8 sectors (2015)



About 8x faster (as expected)

Only 1.3x faster

LHC – 8 sectors (2015)

	Firm-1	**Firm-2**	**Firm-3**
# magnets	400	420	412
#Q to 11080 A – reception	47	183	183
Estimate based on reception (1st vs 2nd cool-down)	12	16	24
Estimate based on sector test in LHC (2008)	0-15	20	103
LHC – 8 sectors (2015)	**5**	**27**	**143**

1.3 x faster

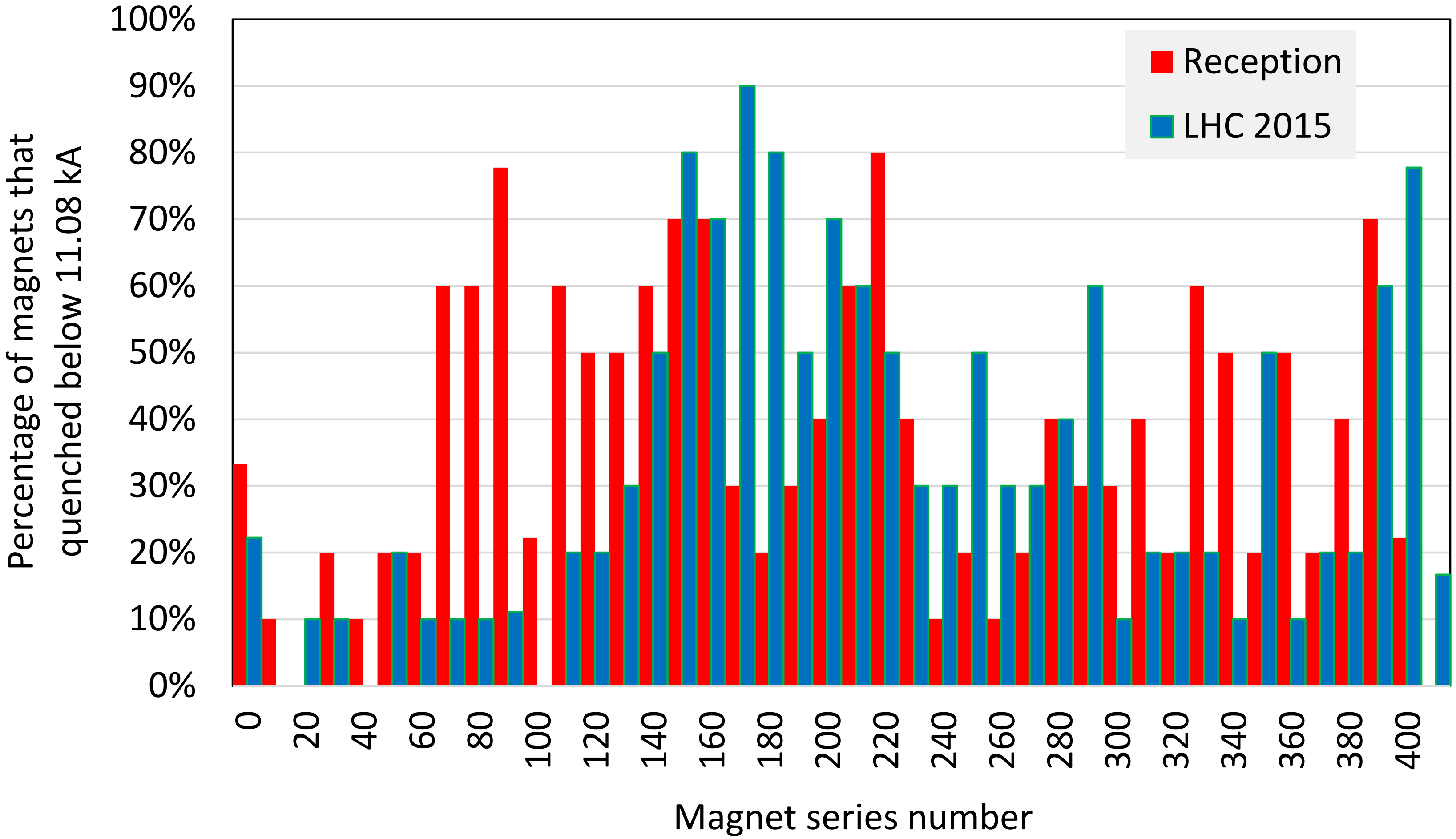
8 x faster

1.5 x slower

Magnets from Firm-1 and Firm-2 are in line with expectations.

Magnets from Firm-3 have basically lost their memory; training in 2015 is only 1.3x faster than during initial reception.

Firm-3 quench behavior along production

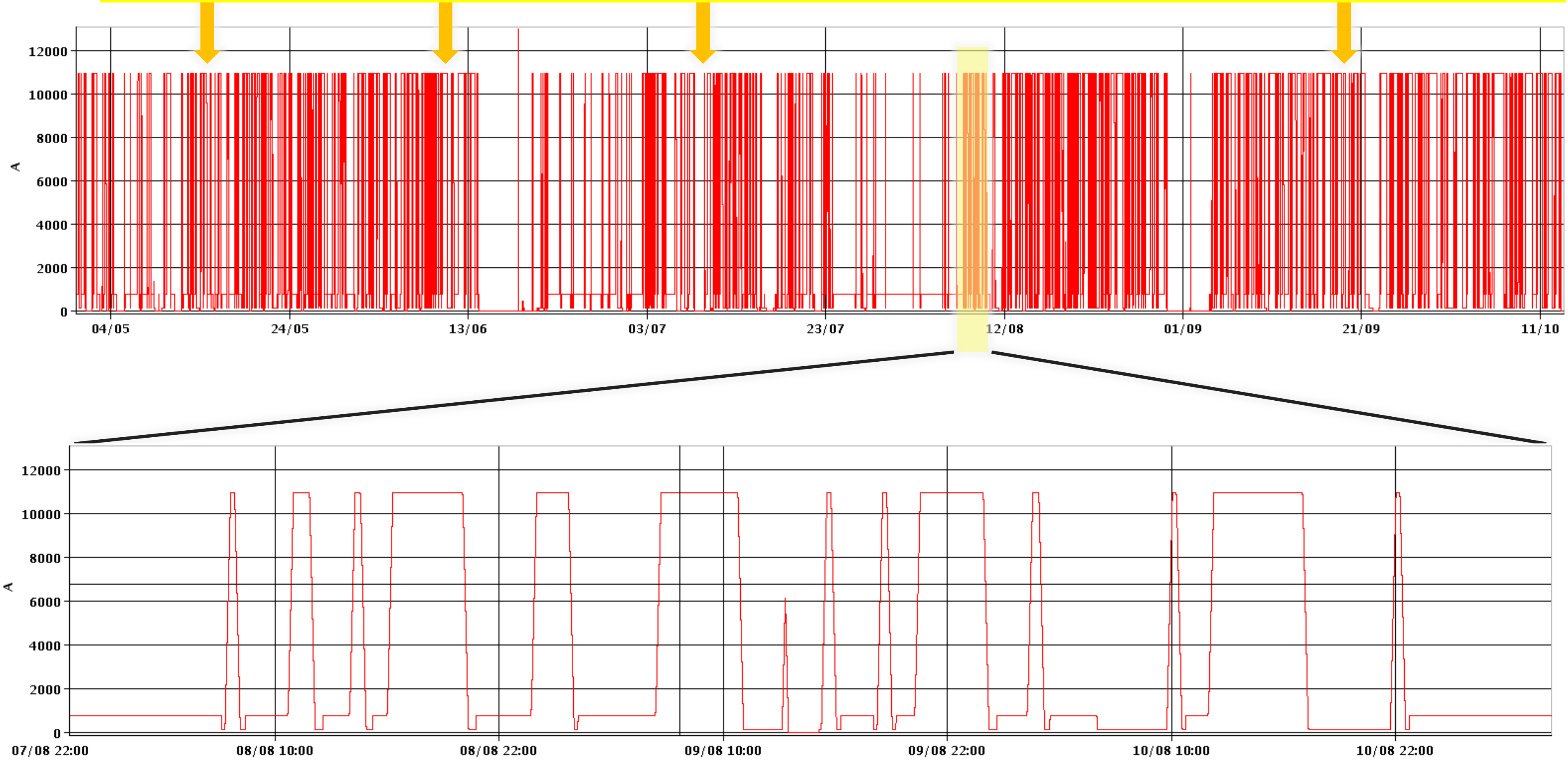


No clear correlation between training during reception and in the LHC.

Part of the production seems to quench relatively more.

Training quenches during operation

4 training quenches occurred at 10980 A (=11080 A -100 A margin), all in Firm-2



Several hundreds of current cycles up to 11 kA in the last 5 months.

Conclusions

The quench performance of 1232 twin-aperture LHC dipole magnets has been followed over many years including thermal cycles and thousands of current cycles.

Reception (2002-2007):

- Training: 1115 quenches to reach 11850 A, 413 quenches for 11080 A.
- “Memory” after a “fast” thermal cycle was good for the 3 firms (8x faster training).

Sector test (2008):

- Part of the “memory” was faded away for Firm-3.

To avoid massive quenching in the LHC, it was decided to run the LHC in 2015 at 6.5 TeV (10980 A) and train the magnets to 11080 A (i.e. a margin of 100 A).

LHC 8 sector test (2015):

- Firm-1 and Firm-2 still had good “memory”.
- Firm-3 trained only 1.3 times faster than during reception.

Operation:

- 4 quenches in Firm-2 magnets in 5 months of LHC operation.

Thank you