Superconducting Electrical Circuits

Superconducting Electrical Circuits

Hardware Commissioning started seriously in April 2007.

It was interrupted many times for various reasons and lasted until the D-day, in total 18 months.

The organization of the work was constantly improved and reached a very satisfactory level .
(except when I maximized the confusion)

The work was done according to ever improving procedures, prepared and polished by MPP.

Superconducting Electrical Circuits

The work was done by numerous people from many groups.

The results were obtained by the ELQA, QPS, OP, MPP, PO, Cryo, and the HC teams (somebody forgotten? Apologies!)

I'm just reporting other peoples observations, as I recall them. I added the mistakes.

This talk is about surprises and mysteries.

The greatest surprise!

It almost worked!

Other surprises

1. Known Non-Conformities (fixed)
2. Discovered Non-Conformities (now fixed ?)
3. Re-Discoveries
4. Unexpected Discoveries

Other surprises

1. Known Non-Conformities (fixed)
2. Discovered Non-Conformities (now fixed ?)
3. Re-Discoveries
4. Unexpected Discoveries

Not treated here

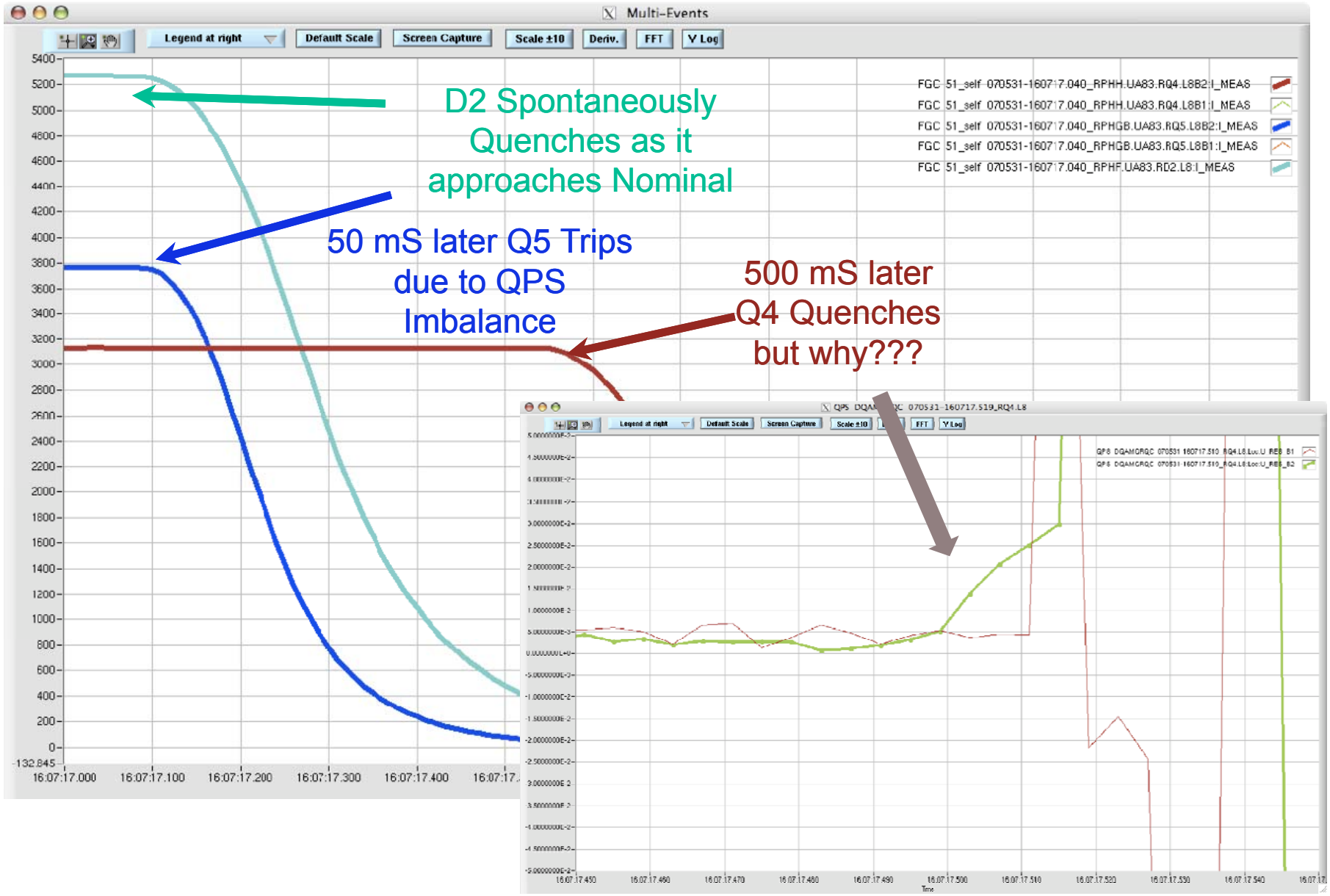
Other surprises

1.

2. Discovered Non-Conformities (now fixed ?)

- The D3, Q4, Q5 puzzle
- The RQT12.R3 etc puzzle
- The MQM5.L8 bus problem
- The Russian #mas present (QF45)

First Indication of Linkage between D2 & Q4 [1]



The D2 Q4 puzzle

The D2 was quenching when the Q4-B1 was at high value

The Quench was likely in the part, where the power busses are in the DFBM “side-by-side”

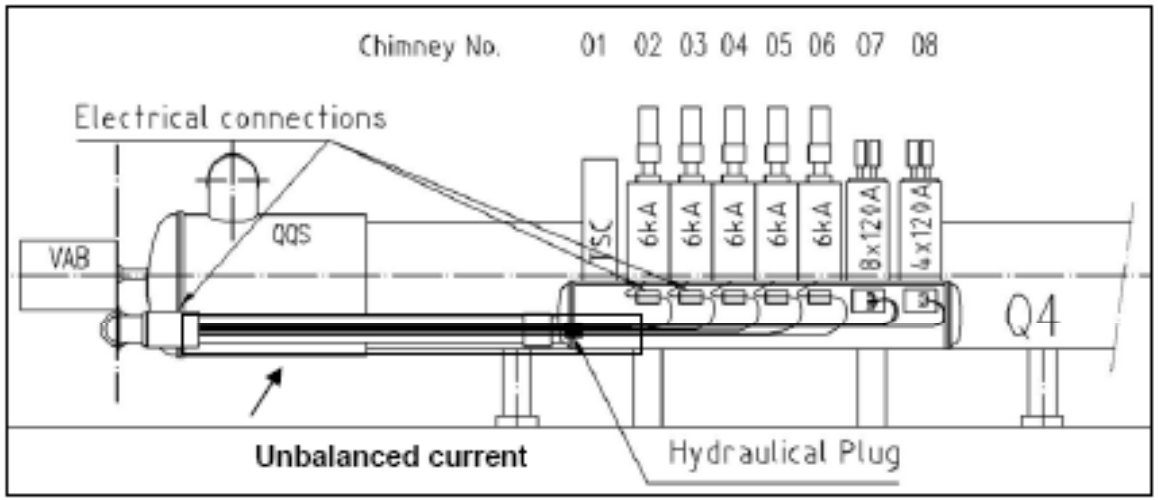
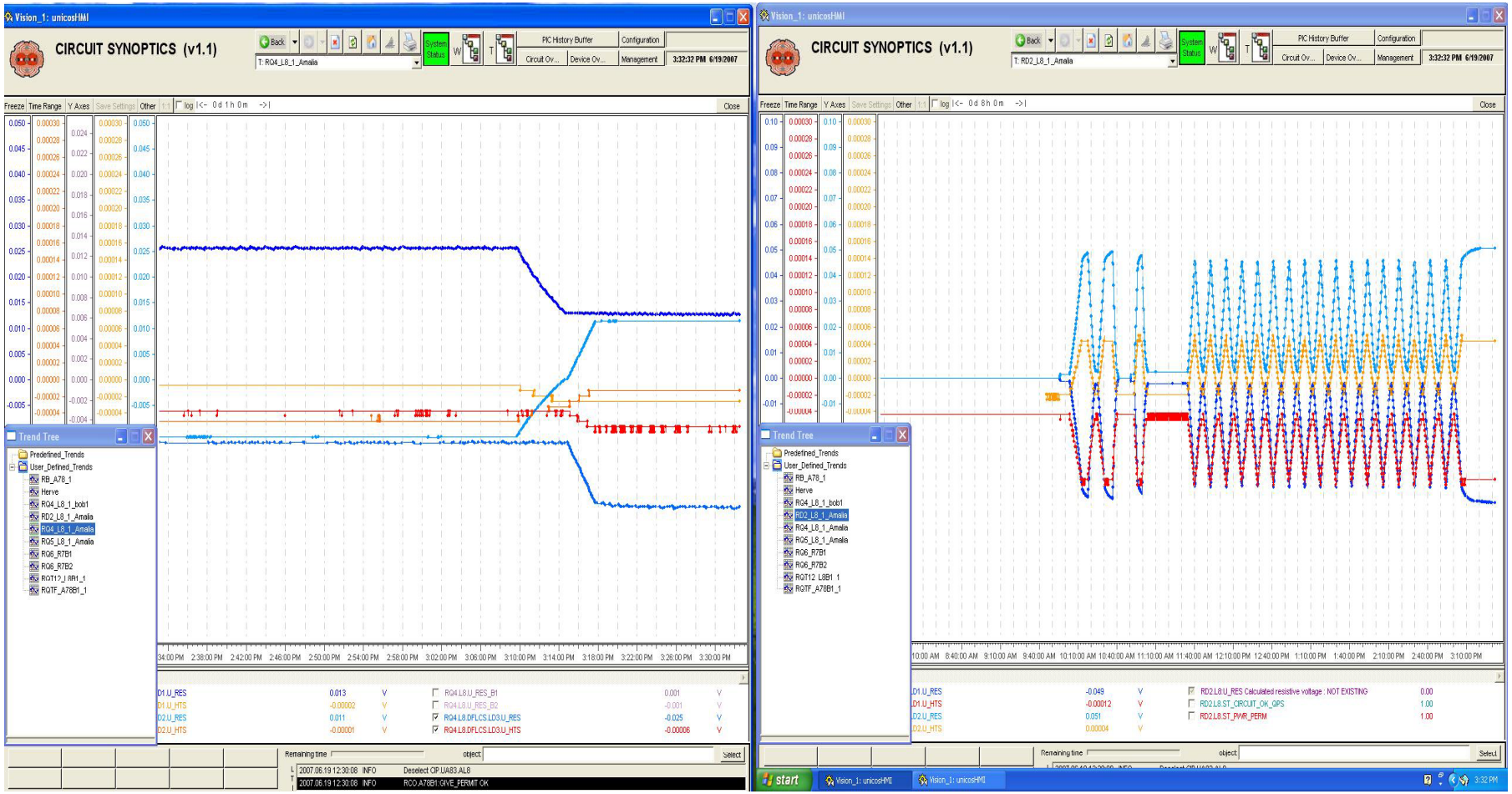


Table 2. Distribution of busbars in DFBMAs with NC

DFB	sector	IR	Cable 1			Cable 2		
DFBMA.4L2	1-2	2L	D2A	D2B	Q4A	Q4B	Q4C	not used
DFBMA.4L8	7-8	8L	D2A	D2B	Q4A	Q4B	Q4C	not used

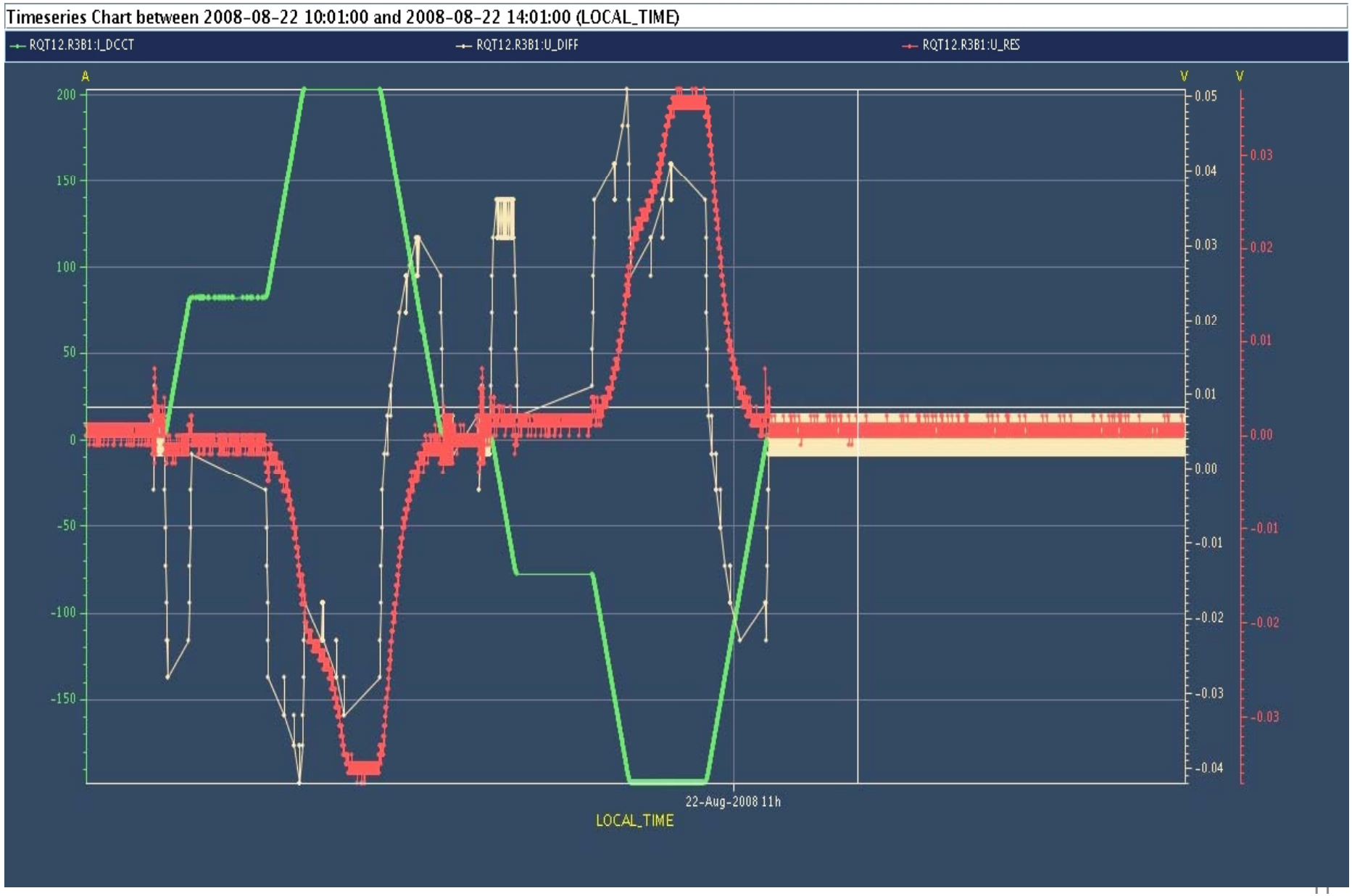
The D2 Q4 puzzle

Once the cable where shaken into place, no quench occurred any more



The fault is still in the LHC and may show up again, here and elsewhere.

The RQT12R3.B1 (etc) puzzle



The RQT12R3.B1 (etc) puzzle

Ures (red) continues to rise while the current (green) is constant. A clear sign of a quench. As this was the case for all correctors served by the outer layer of the SCL cable, it was concluded that the link does not work properly. Problem was found in a cold bridge. Fixed (?)

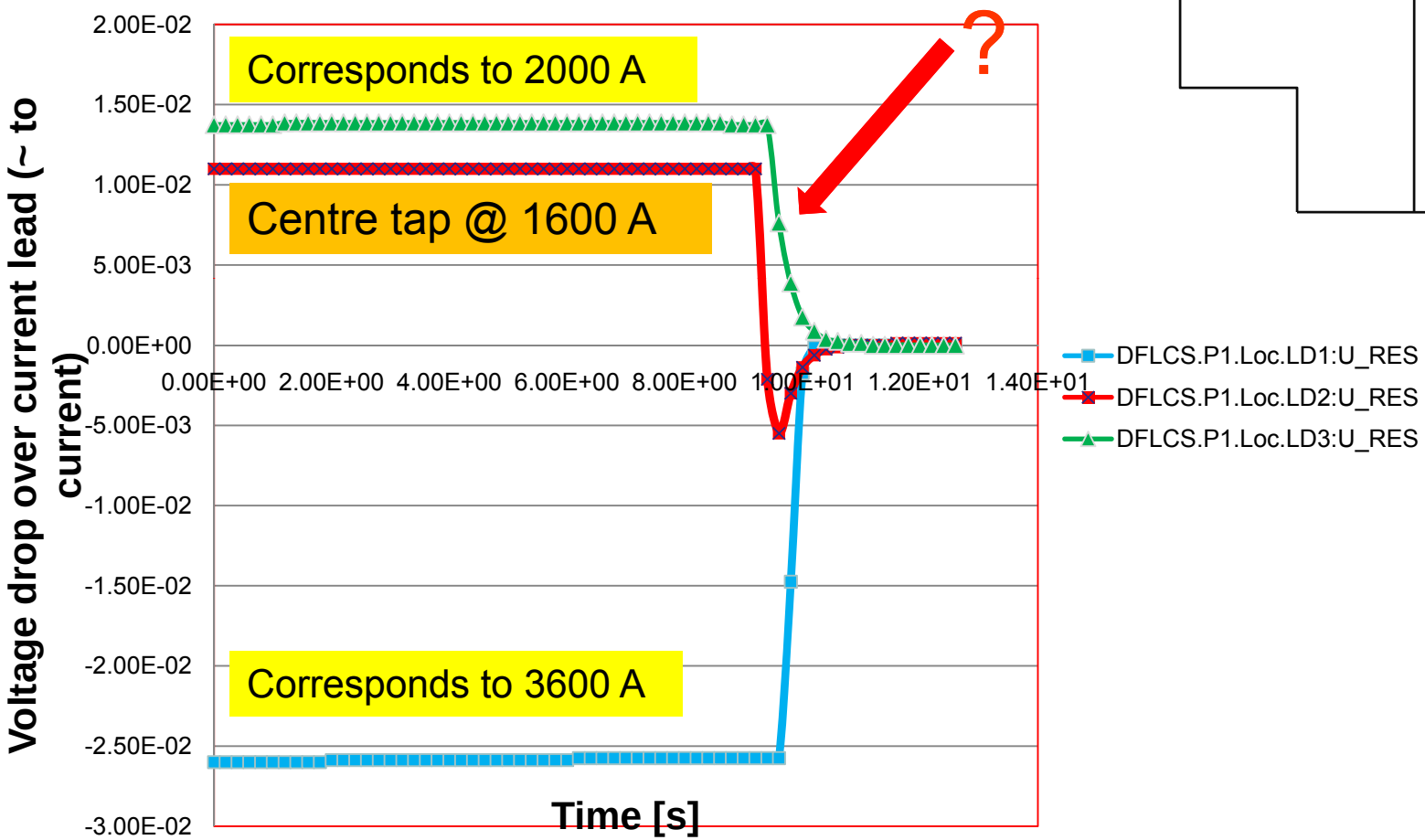
Other surprises

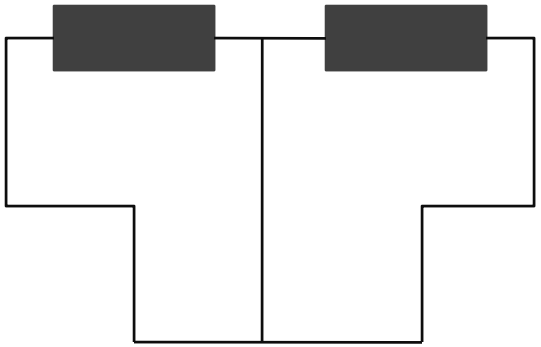
1. Re-Discoveries

- The Q6.R4 (and similar) puzzle
- The inner triplet current distribution puzzle
- The undulator puzzle
- The inner triplet 600A lead problem
- The RB (and similar) re-start problem after a quench

The Q6.R4 puzzle

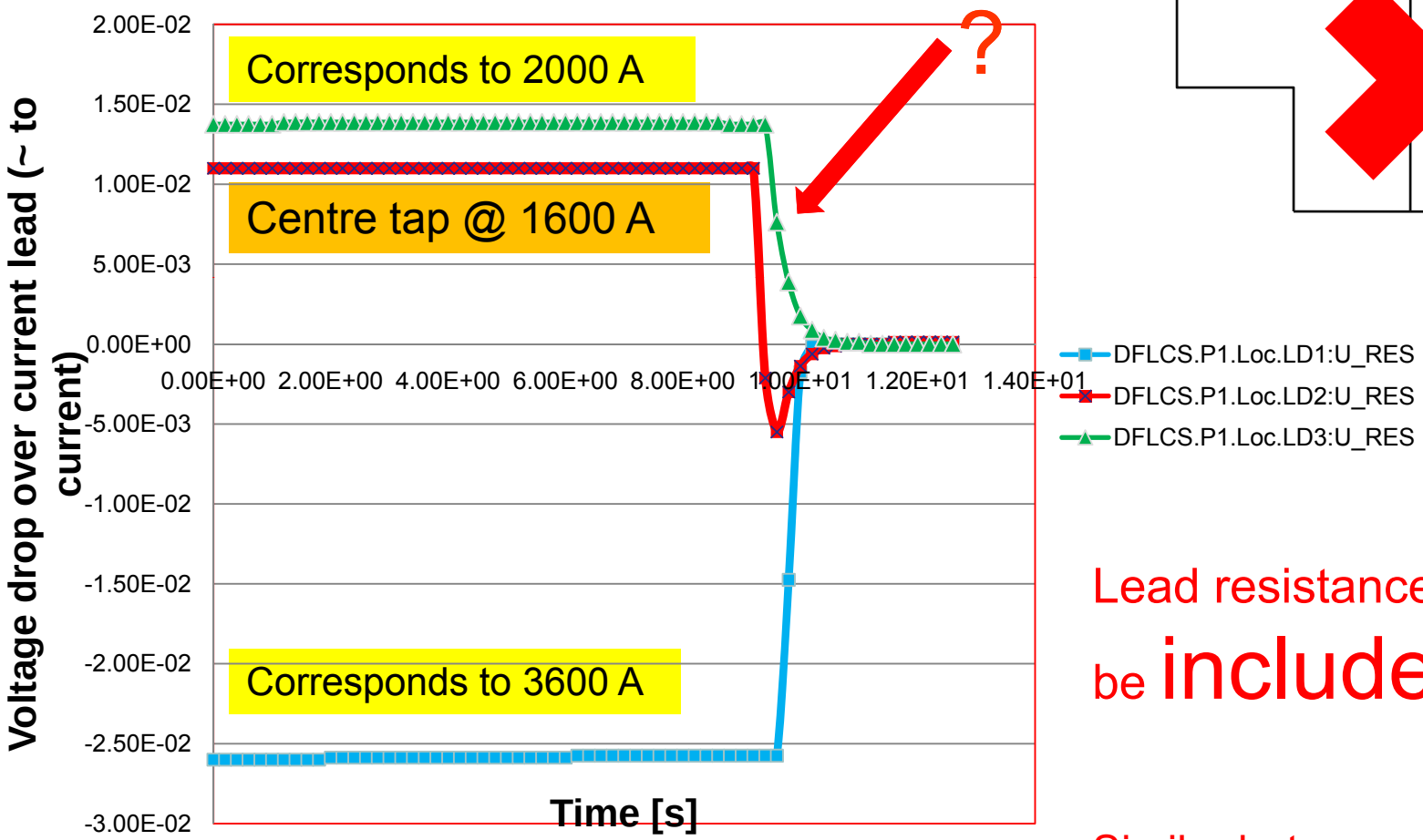
Negative Current ? Q6.R4 assymmetric quench

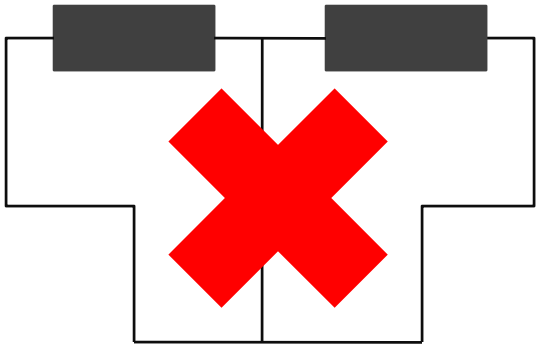




The Q6.R4 puzzle

Negative Current ? Q6.R4 assymmetric quench

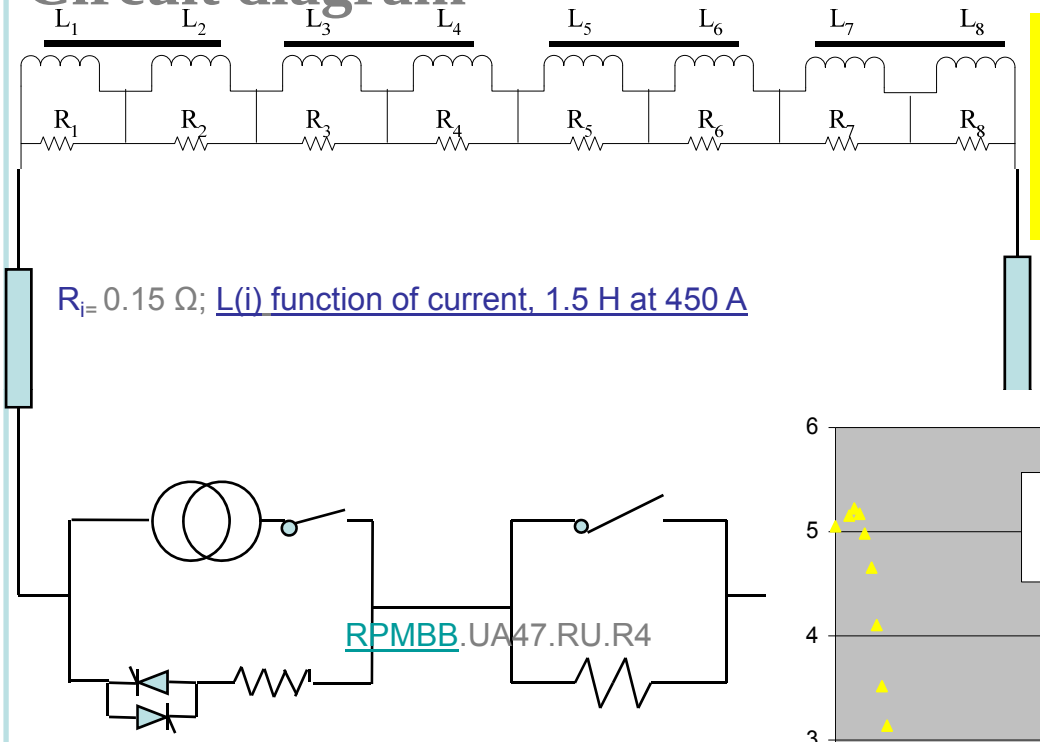




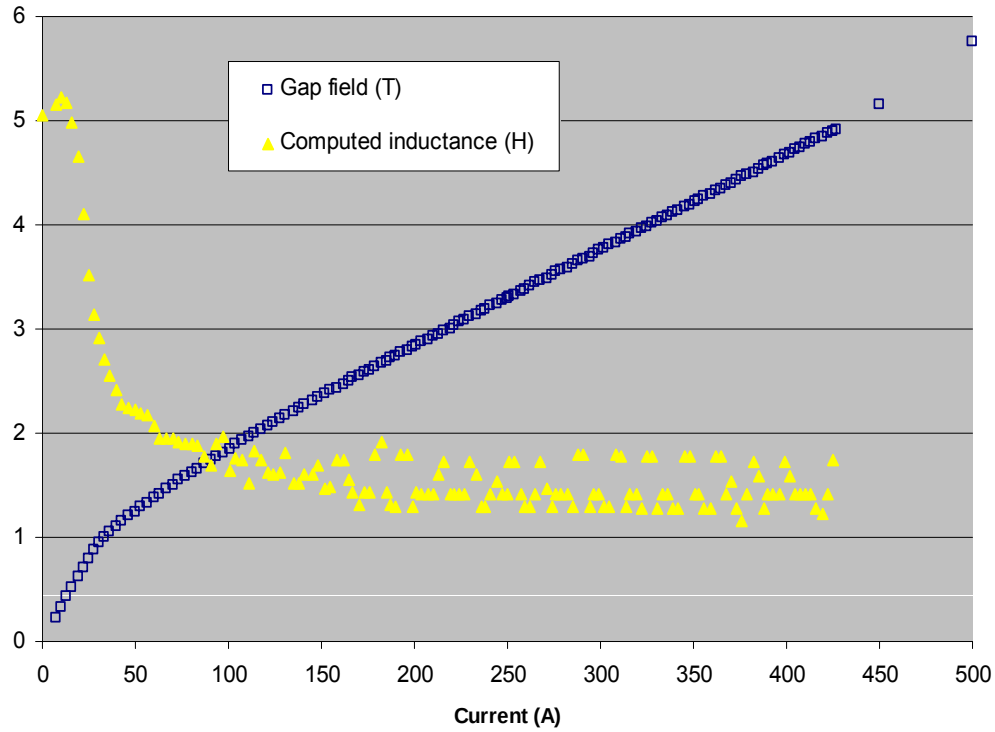
Lead resistance to be **included**

Similar but more complicated for the inner triplets

Circuit diagram



And the other one is missing a resistor.
Different transfer functions.
Slow ramp rates!



Problems to re-start after a quench

On Jan. 30th 08 the quench protection trips, while ramping up. It turned out that a “reference magnet” had quenched in the run before. (used as representative for the whole sector to calculate the L di/dt)

Quench Protection Reference Magnets

	Dipoles		Quadrupoles	
"1-2"	MB.C21R1	MB.C21L2	MQ.A21R1	MQ.A20L2
"2-3"	MB.C21R2	MB.C18L3	MQ.A21R2	MQ.A17L3
"3-4"	MB.C21R3	MB.C18L4	MQ.A20R3	MQ.A18L4
"4-5"	MB.C21R4	MB.C21L5	MQ.A20R4	MQ.A20L5
"5-6"	MB.C21R5	MB.C21L6	MQ.A20R5	MQ.A20L6
"6-7"	MB.C21R6	MB.C21L7	MQ.A20R6	MQ.A20L7
"7-8"	MB.C21R7	MB.C21L8	MQ.A21R7	MQ.A20L8
"8-1"	MB.C21R8	MB.C21L1	MQ.A20R8	MQ.A20L1

If one of the above magnets has quenched, a special procedure for repowering has to be applied. This costs extra time to recover, of course.

Other surprises

Unexpected Discoveries

- The symmetric quench problem (see Reiners talk)
- The transient spike problem
- The coupling Q4-D2.L8 (and similar)
- The quench back of correctors incl. coupling
- The RCO.A78B2 splice
- The RQT13.L5B1 splice (or what)
- The RCBCV10.L6B1 threat
- The RD2.L2 and RD3.L4 limitations
- The RCBY mystery
- The extremely fast quench propagation mystery
- ….minor issues….

The transient spike problem

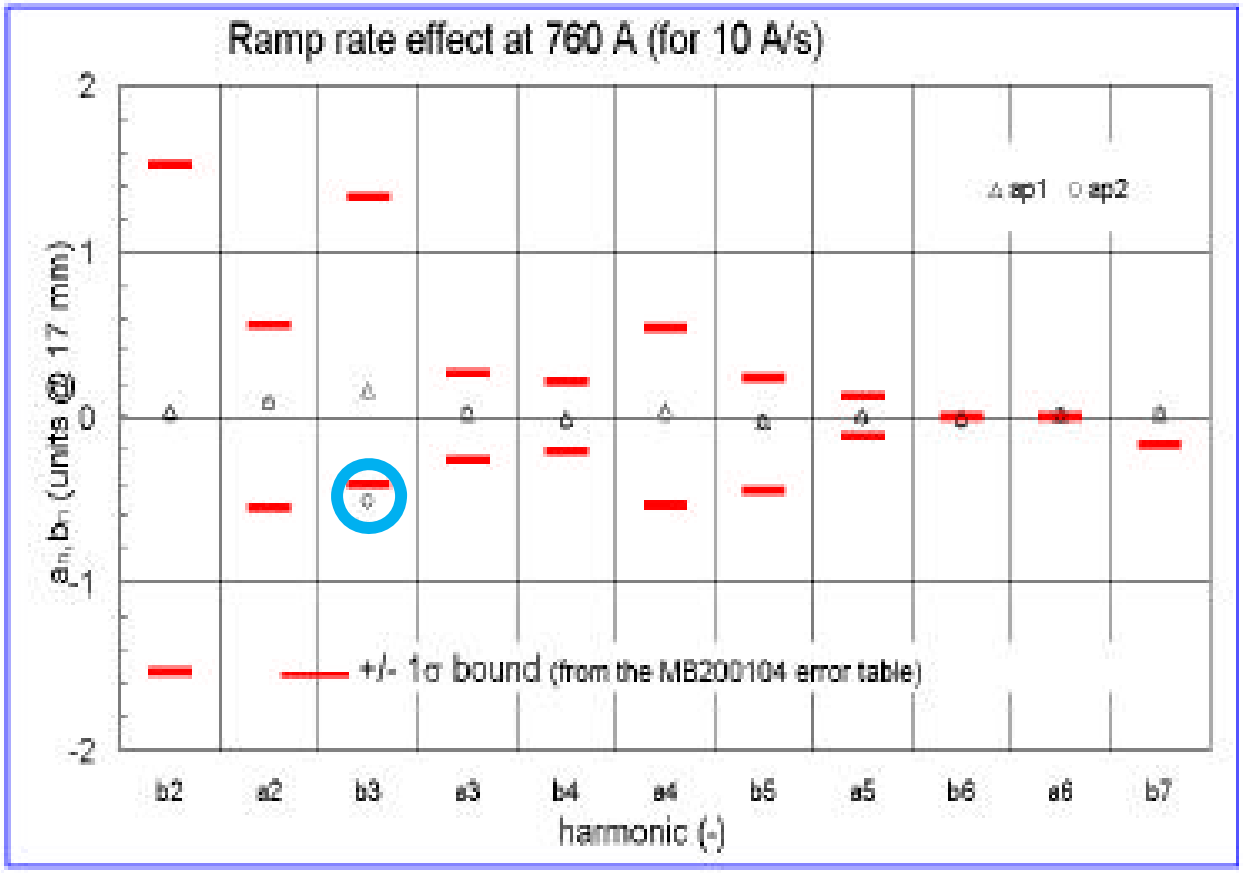
[3]

- Quench detected in MB B30 (MB 1007) during fast discharge at 7000A => dI/dt =-70A/s
- There is no real quench. There is a voltage difference between the two apertures which grows with dI/dt and exceeds 100mV.
- Magnetic measurement in SM18 during ramp had also shown a different dynamic behaviour of the aperture with a unusually high sextupole in one aperture. Also no particular asymmetry between upper and lower poles.
- The behaviour in the machine seems therefore identical to the behaviour in SM18, where this magnet was trained to 12KA as usual.

The transient spike problem

[4]

- Quench detected in MB B30 (MB 1007) during fast discharge at 7000A => dI/dt =-70A/s
- There is no real quench. There is a voltage difference between the s 100mV.



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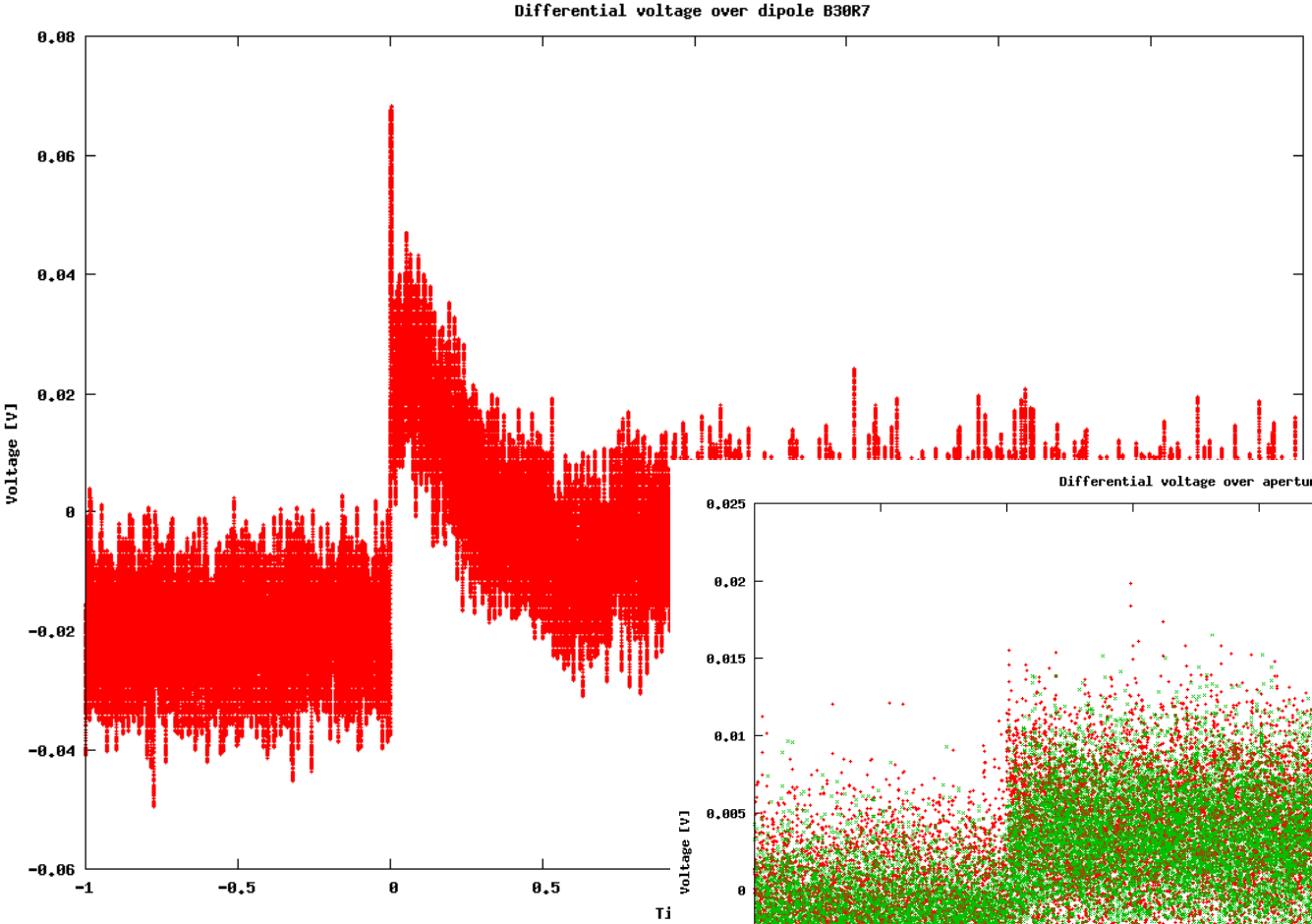
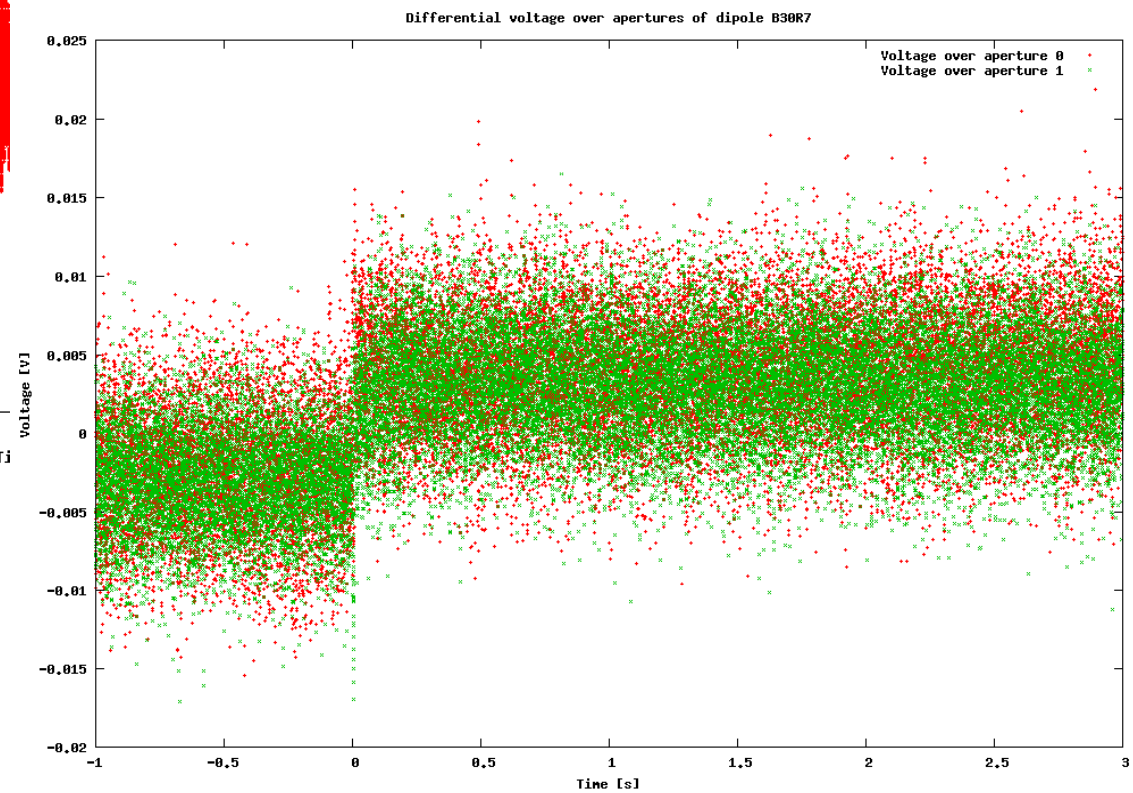
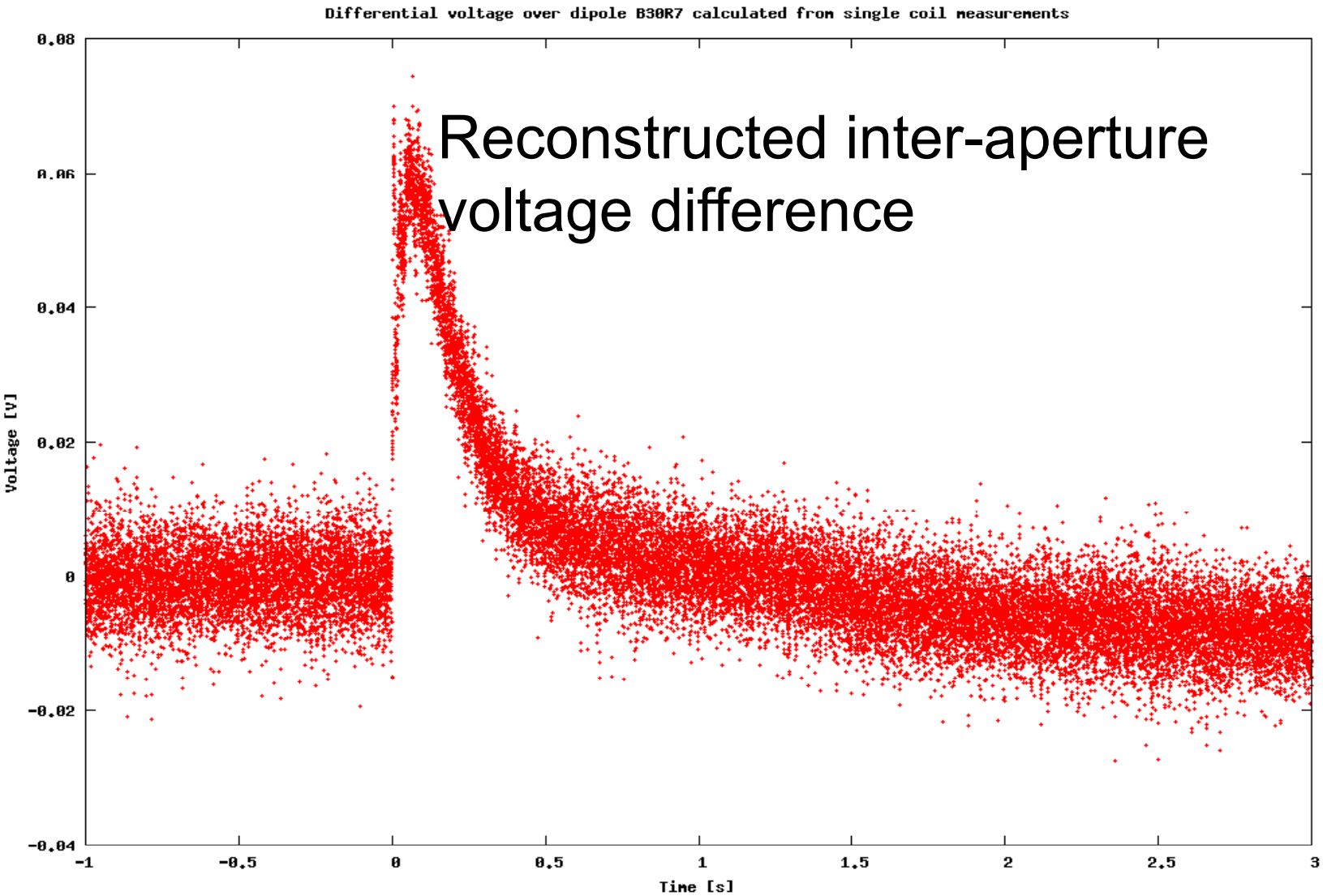
Ua + Ub, Opening EE switch at 3 kA



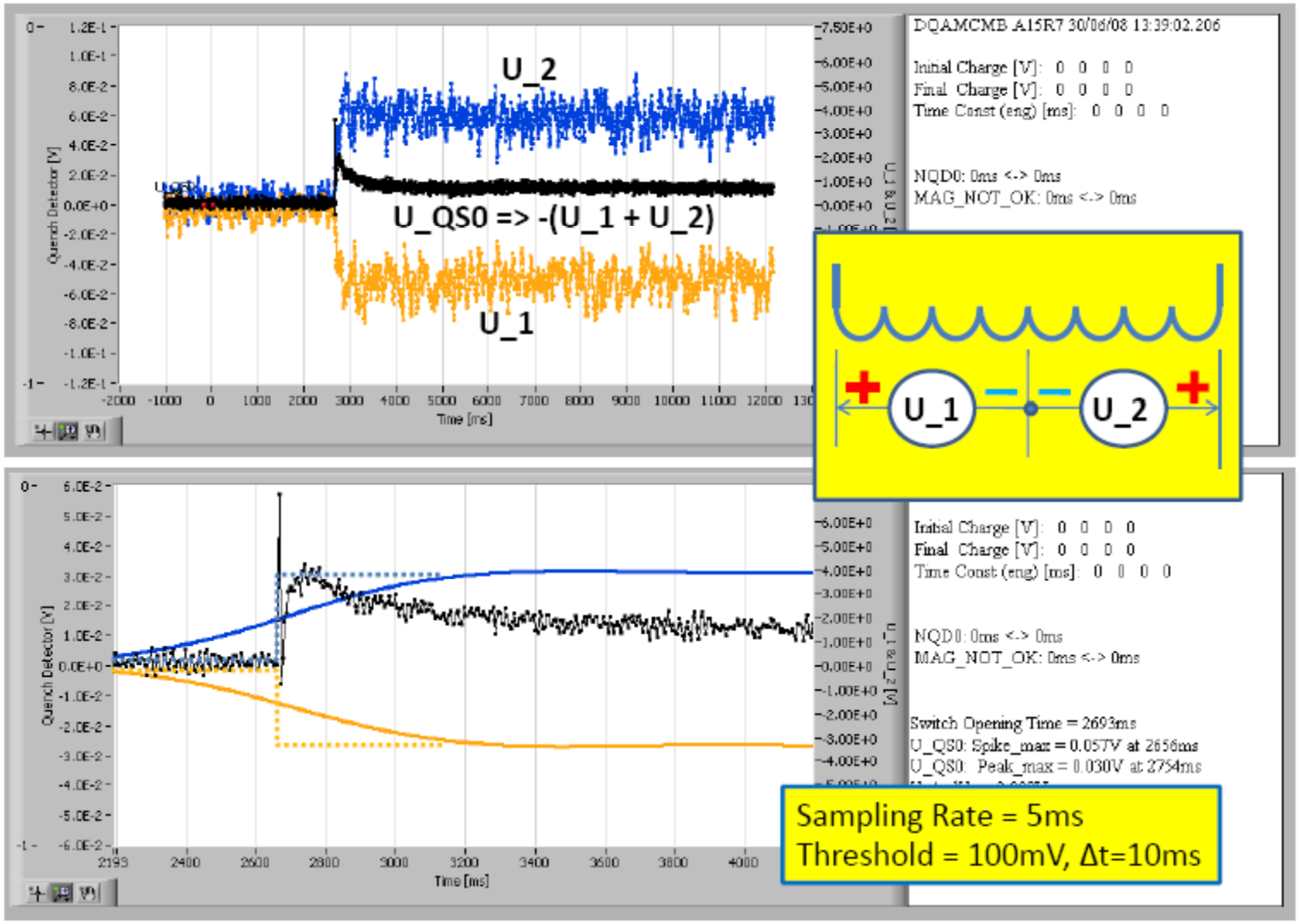


Ua + Ub calculated from U1, U2, U3, U4

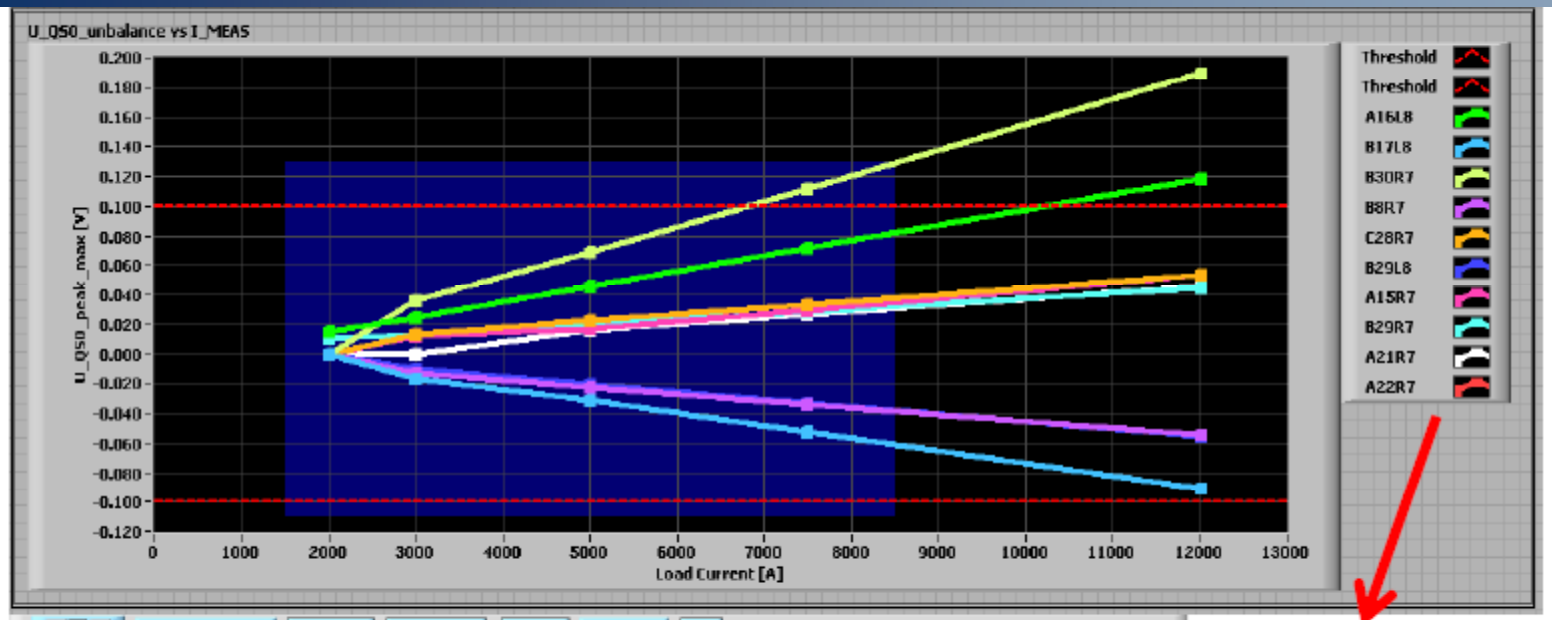


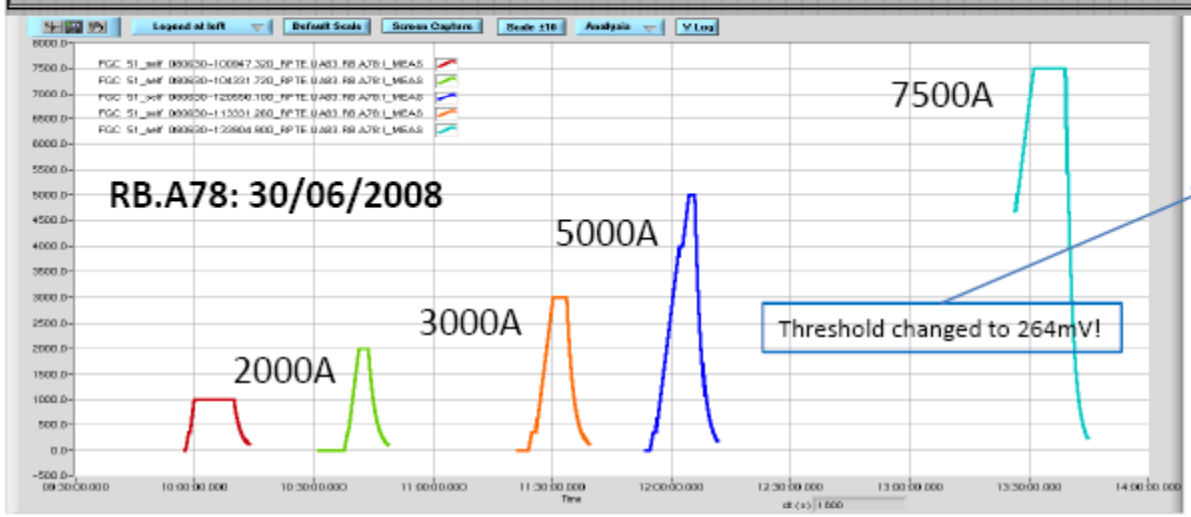
Zinour's snap-shot tool

[6]



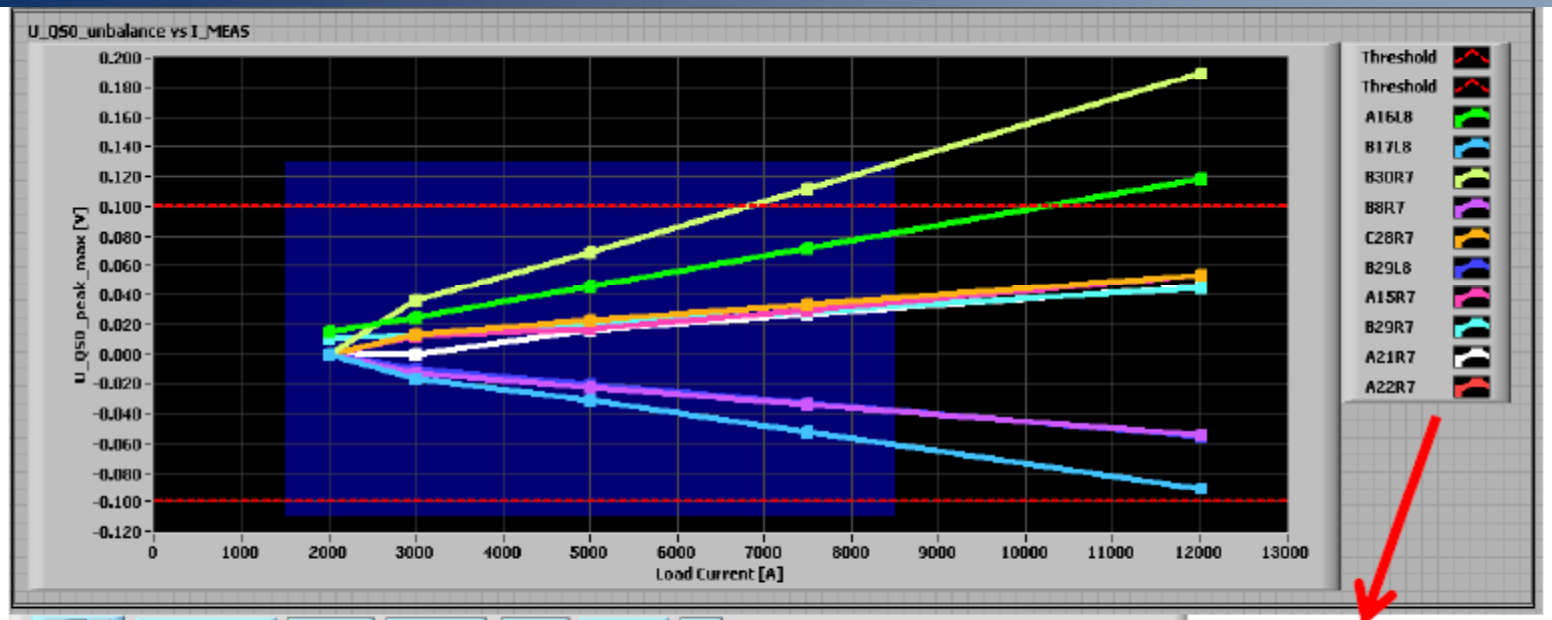
Zinour's snapshot tool

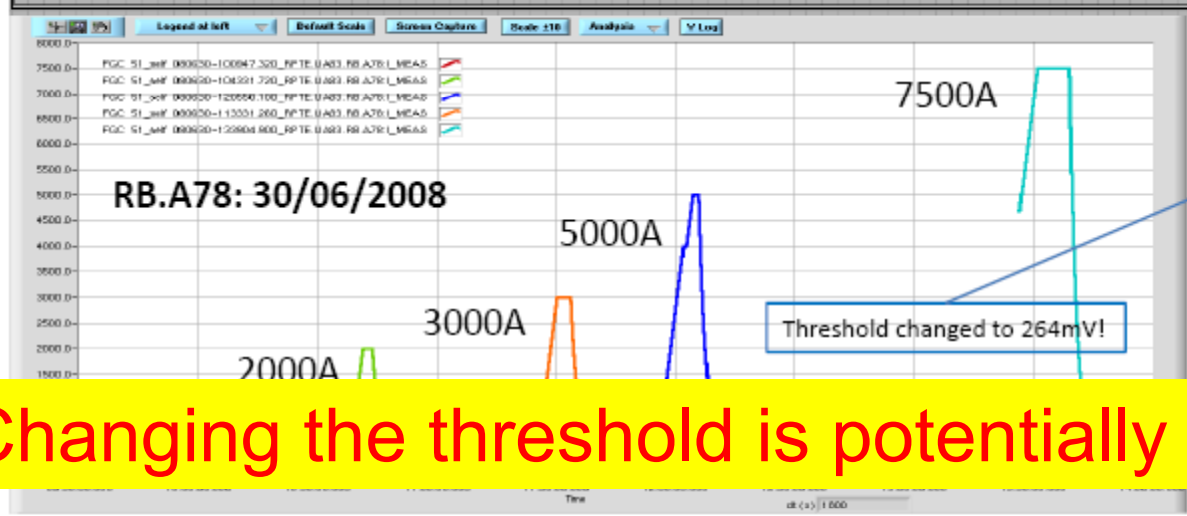




Top 10 magnets:
A16L8 – 3504
B17L8 – 2006
B30R7 – 1007 *
B8R7 – 1031
C28R7 – 2011
B29L8 – 1009
A15R7 – 3020
B29R7 – 1013
A21R7 – 3014
A22R7 -- 1023

Zinour's snap shot tool

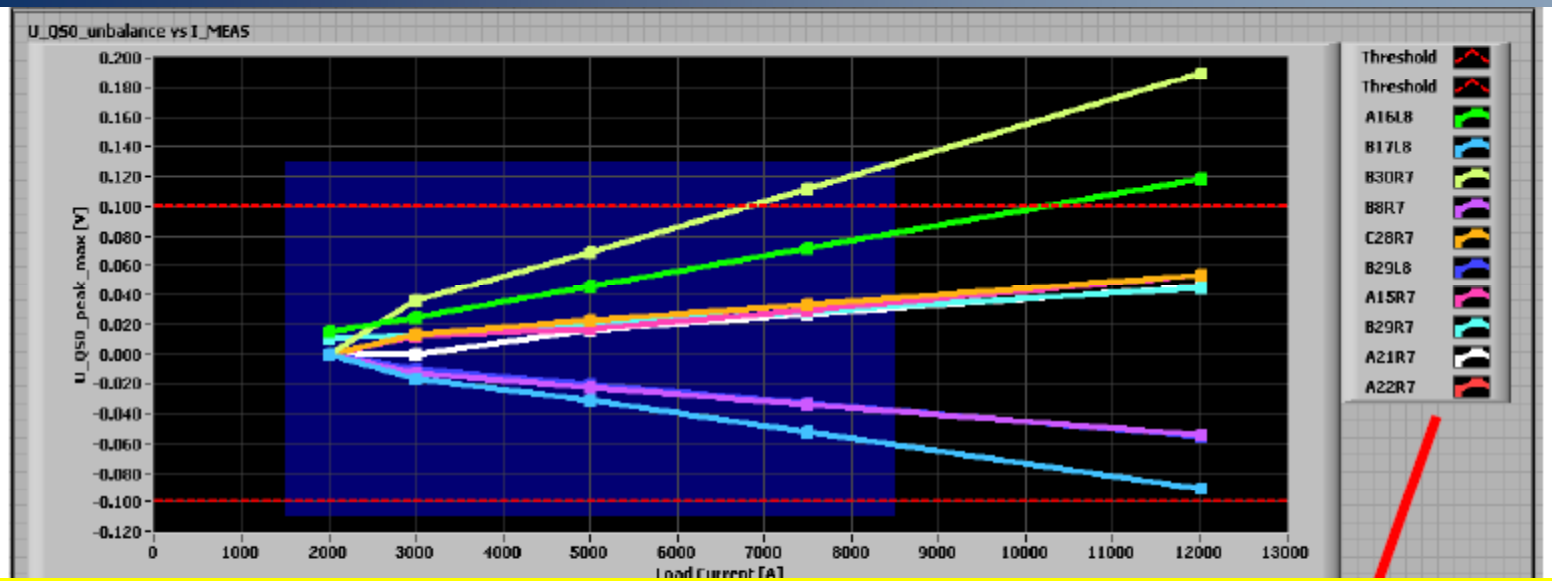




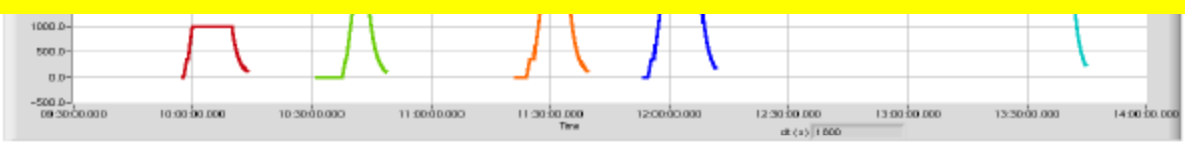
Top 10 magnets:
A16L8 – 3504
B17L8 – 2006
B30R7 – 1007 *
B8R7 – 1031
C28R7 – 2011
B29L8 – 1009
A22R7 -- 1023

Changing the threshold is potentially dangerous!!!!

Zinour's snap shot tool



The same tool is also used to measure the **Difference in resistance** in the two apertures of the main magnets to a precision of ~ 10nΩ.

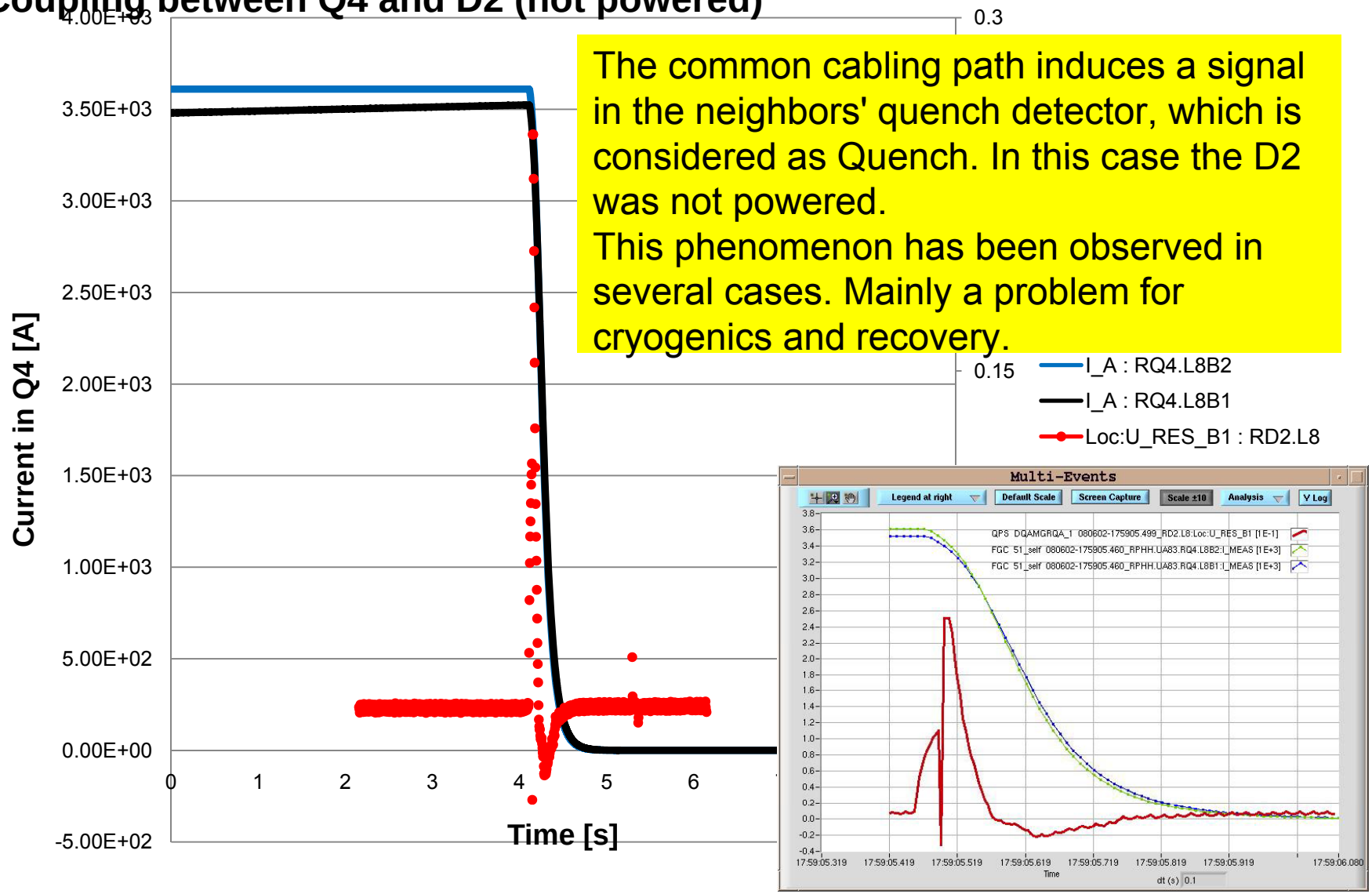


B29R7 – 1013
A21R7 – 3014
A22R7 -- 1023

16/07/2008 MPP meeting, Zinour Charifoulline 5

EM Coupling between standalone magnets

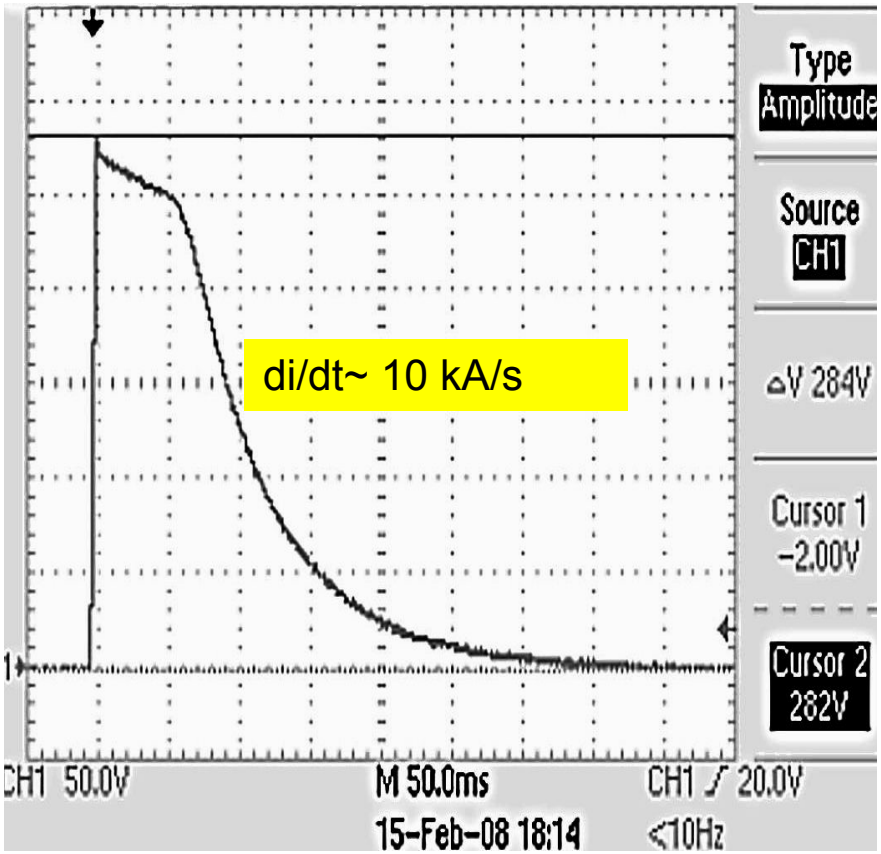
Coupling between Q4 and D2 (not powered)



The common cabling path induces a signal in the neighbors' quench detector, which is considered as Quench. In this case the D2 was not powered.
This phenomenon has been observed in several cases. Mainly a problem for cryogenics and recovery.

The quench back of correctors leads to coupling [7]

Dump of RSD2_A45B2 @ 550 A



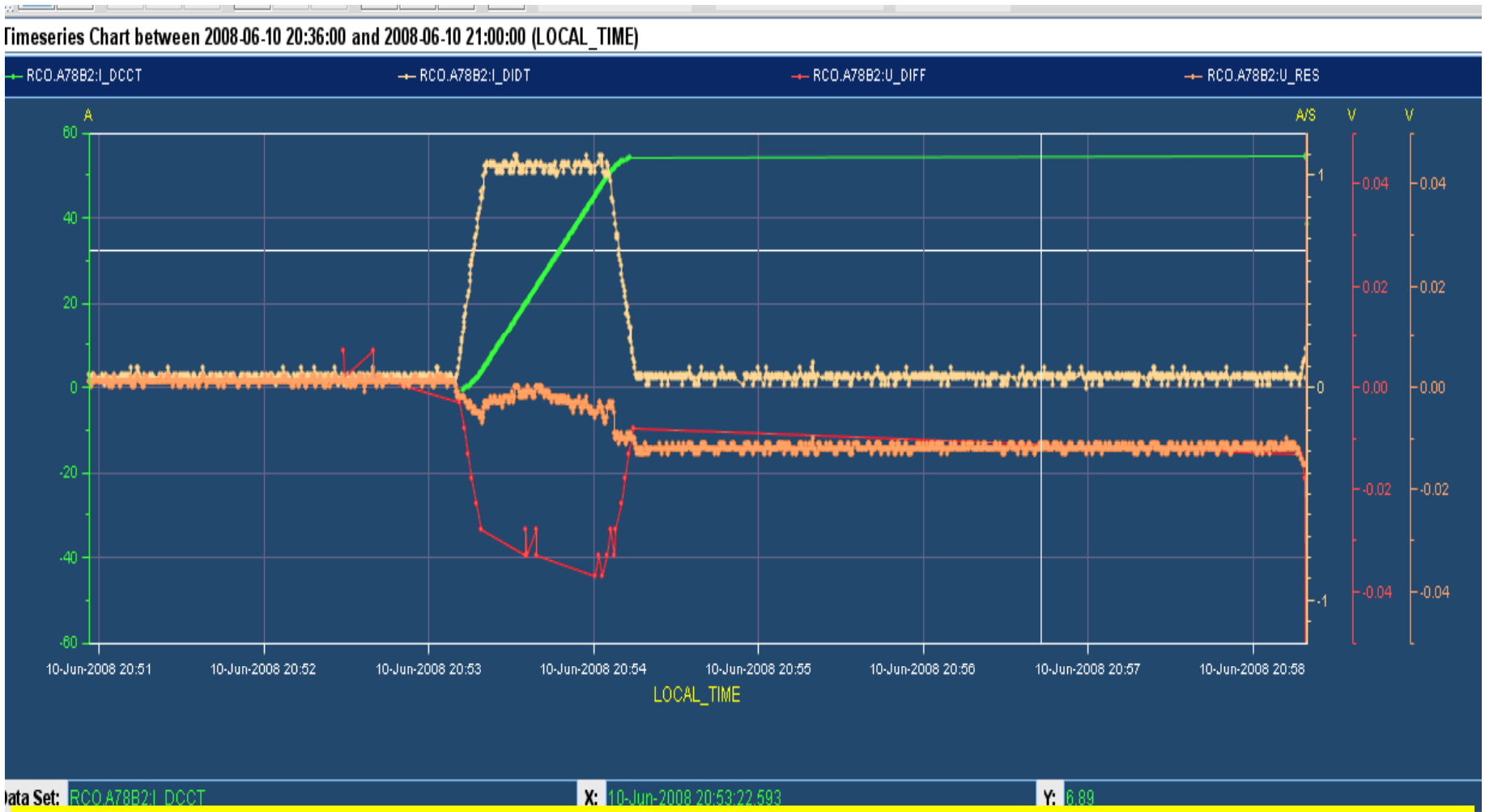
In the beginning the current decay is given by the external resistor. After 50 ms the quench back due to the internal by-pass resistors sets in.
The decay is very fast and is easily picked up on channels, which are “close by”, inducing current changes or quenches.

Basically a nuisance during commissioning but probably also a danger for extended dipole/quadr. Quenches at high excitation. Run away?

Also other transients talk to neighbors, which can lead to sudden, unforeseen current excursions. Danger for beam loss?

The RCO.A78B2 splice

[8]



The voltage (red, orange) rises with the current (green) and explodes (quench) after ~4 minutes. Bad splice. How to find that one?
Out of operation.

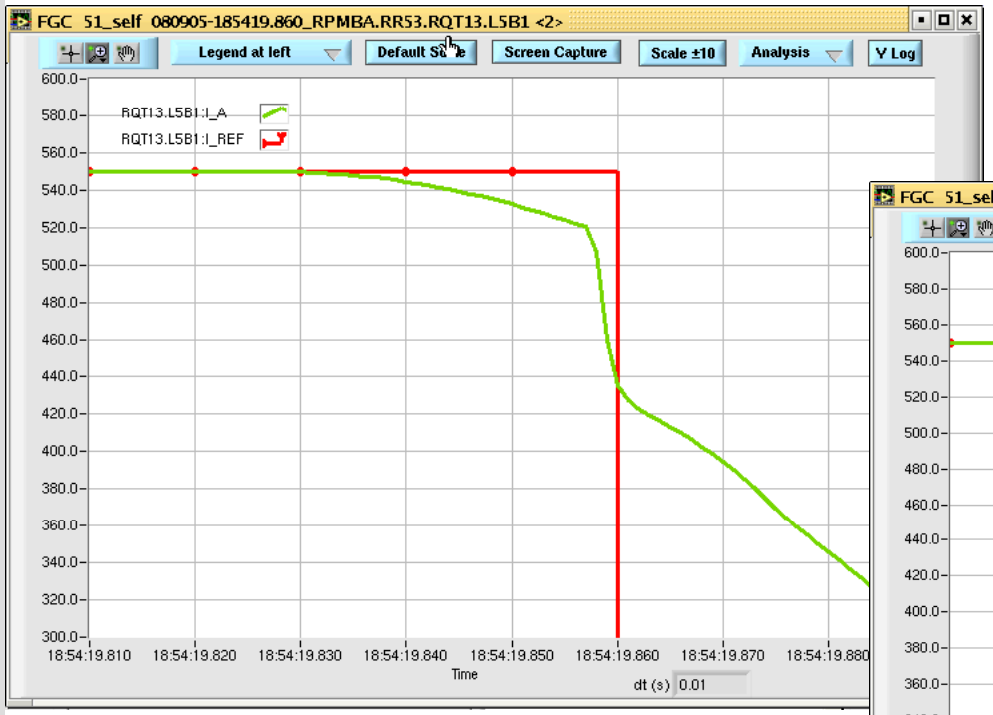
RQT13.L5B1, RQTF.A45B2, ?

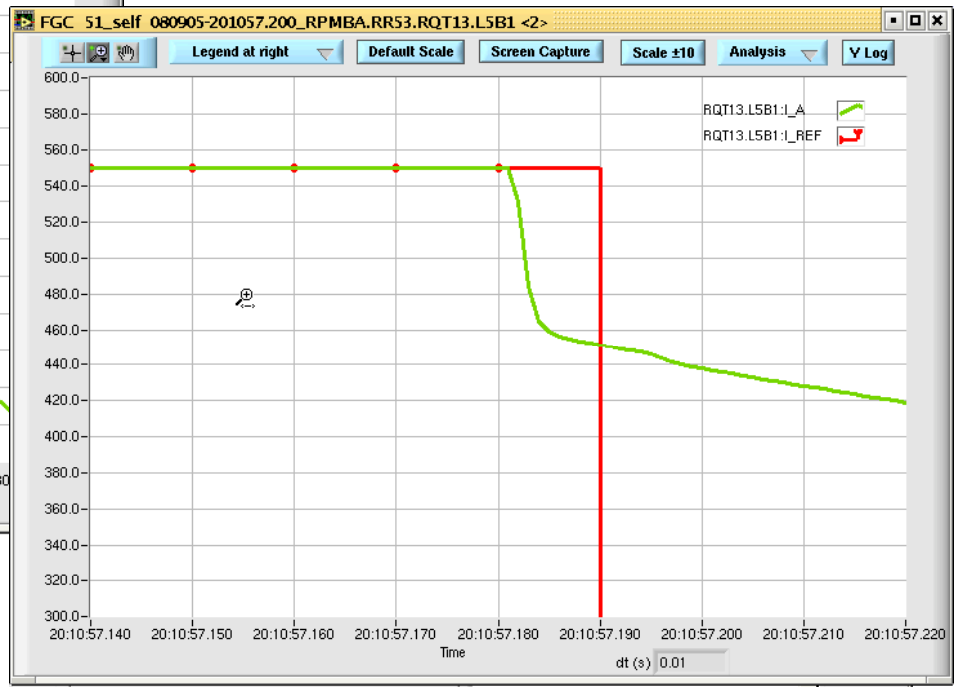
[7]

549.9 A		Quench
550 A	28 S after FT	Quench
550 A	90 S after FT	Trip Reason? (not quench or ground fault)

RQT13.L5B1, RQTF.A45B2, ?

549.9 A		Quench
550 A	28 S after FT	Quench
550 A	90 S after FT	Trip Reason? (not quench or ground fault)





RQT13.L5B1, RQTF.A45B2, ?

549.9 A		Quench
550 A	28 S after FT*)	Quench
550 A	90 S after FT	Trip Reason? (not quench or ground fault)

525 A		Quench
362 A		Quench
454A		Quench
550 A	32 S after FT	Quench
550 A	2 S after FT	Quench
550 A	24 S after FT	Quench
500 A	26 S after FT	EE Dump

Is there a bad splice hidden somewhere?
Is reducing the nominal current enough???

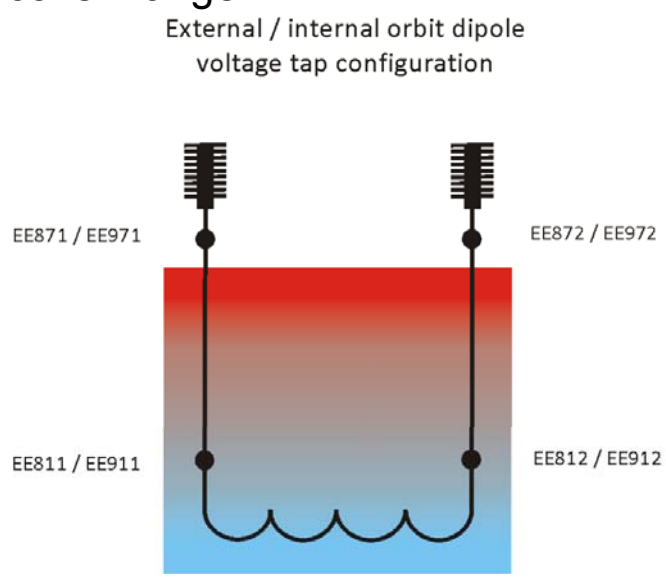
*) Flat Top

The RCBCV10.L6B1 (etc) threat

- ➔ On 11/03/2008, RCBCV10.L6B1 circuit was successfully qualified by ELQA team.
  - On 14/04/2008, AB/PO can not power this circuit, they have a fault on the PC.
  - On 16/04/2008, EE811 (cold voltage tap) is found open, directly from the feed through pin coming from the cover flange => NC 908215 opened.
- ➔ On 05/05/2008:

  Intervention to perform a time domain reflectrometry to localize precisely the defect. It is repairable if it is at the level of the cover flange.

Surprise! The voltage tap EE811 is back!



RCBCV10.L6B1 – EE811 voltage tap missing

➔ Measurements on the external « sick » orbit dipole:

Vtap	Vtap	Resistance [Ω] *:
P25_1 (EE871)	P25_4 (EE872)	0.3
P25_1 (EE871)	P25_2 (EE811)	1.9
P25_2 (EE811)	P25_3 (EE812)	2
P25_3 (EE812)	P25_4 (EE872)	0.4

➔ For comparison, measurements on the internal dipole:

Vtap	Vtap	Resistance [Ω] *:
P25_5 (EE971)	P25_8 (EE972)	0.3
P25_5 (EE971)	P25_6 (EE911)	0.4
P25_6 (EE911)	P25_7 (EE912)	0.5
P25_7 (EE912)	P25_4 (EE972)	0.4

*: Measurement performed with a portable multimeter.

RCBCV10.L6B1 – EE811 voltage tap missing

➔ Measurements on the external « sick » orbit dipole:

Vtap	Vtap	Resistance [Ω] *:
P25_1 (EE871)	P25_4 (EE872)	0.3
P25_1 (EE871)	P25_2 (EE811)	1.9
P25_2 (EE811)	P25_3 (EE812)	2

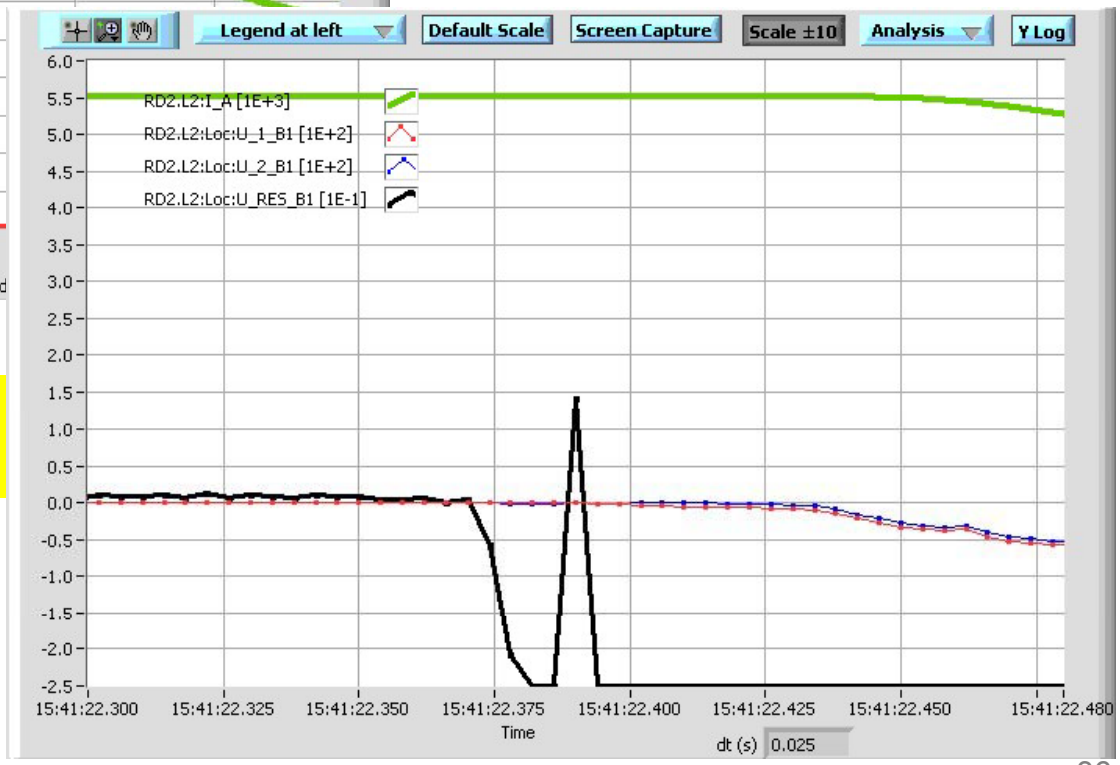
Avoid the use,
it may switch off at any time!

➔

Vtap	Vtap	Resistance [Ω] *:
P25_5 (EE971)	P25_8 (EE972)	0.3
P25_5 (EE971)	P25_6 (EE911)	0.4
P25_6 (EE911)	P25_7 (EE912)	0.5
P25_7 (EE912)	P25_4 (EE972)	0.4

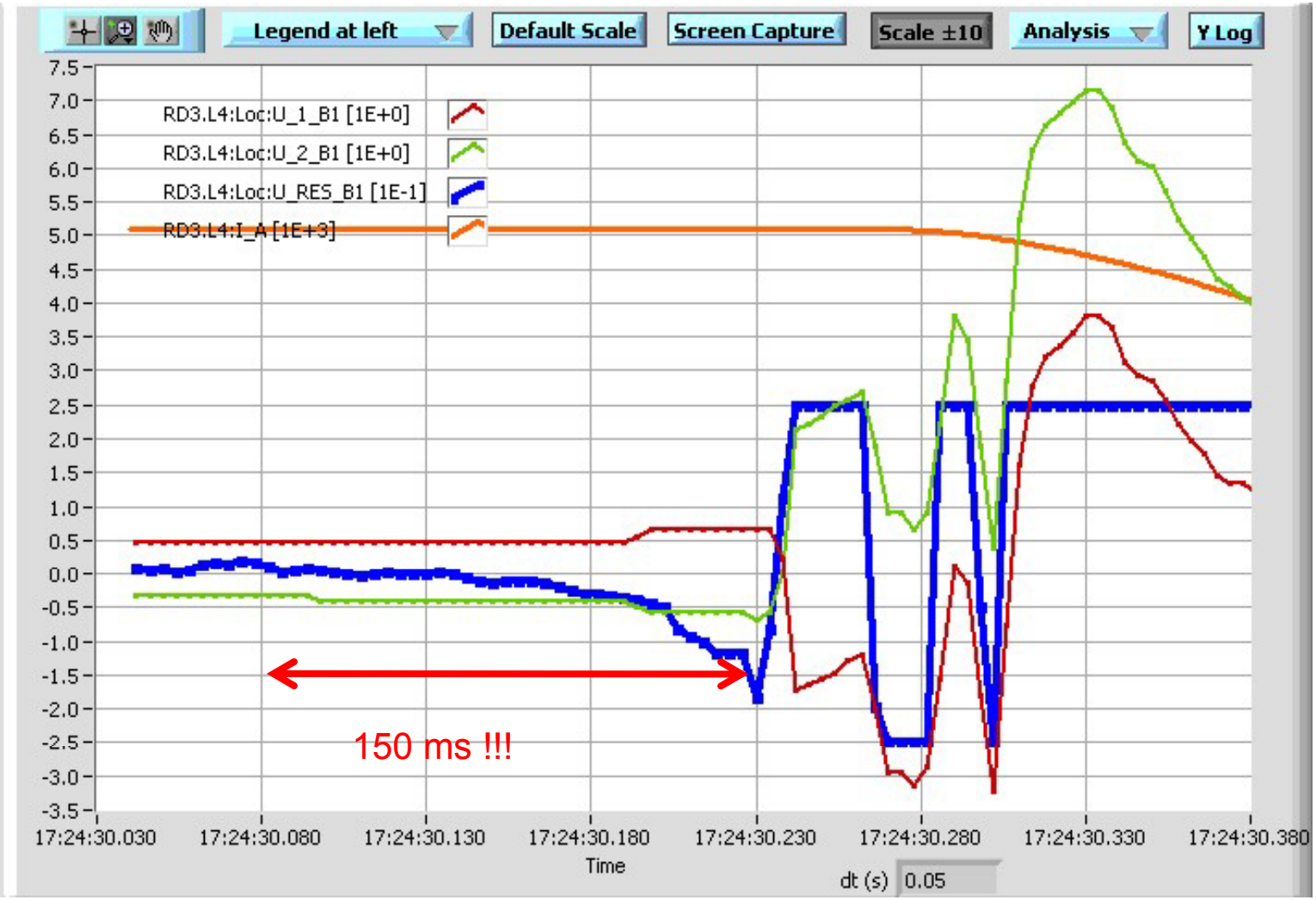
*: Measurement performed with a portable multimeter.

The RD2.L2 and RD3.L4 limitation



Looks like re/de-training.
What to do?

The RD2.L2 and RD3.L4 limitation



What to do? Are there more? Quadrupoles?

So far, most of what I said is understood, now comes

So far most of what I said is understood, now come

The Mysteries

The RCBY mystery and other strange 120 A magnets

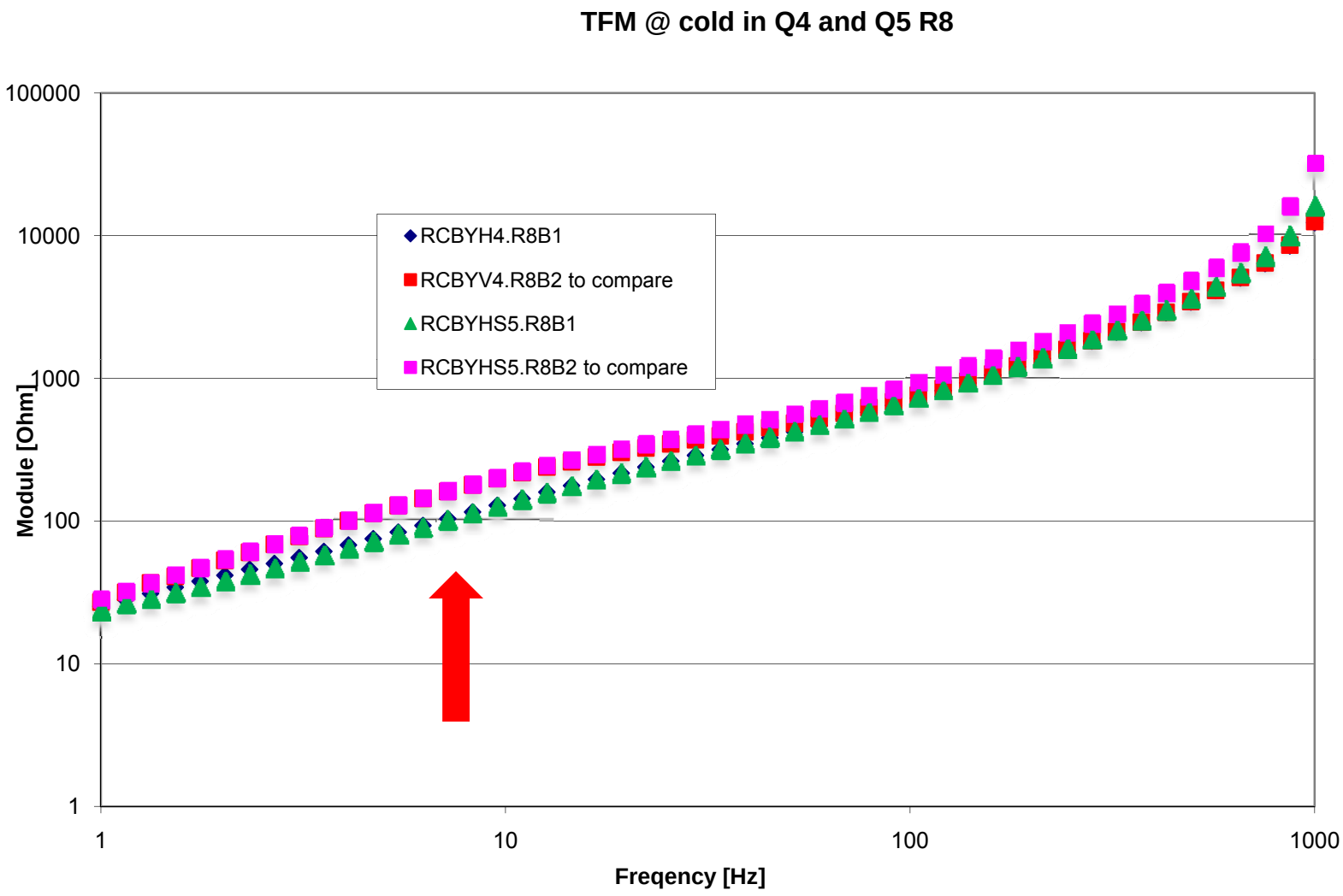
Transp. prepared by Mirko

Some 120 A magnets quench (?) at a critical di/dt, sometimes very close to nominal, during discharge

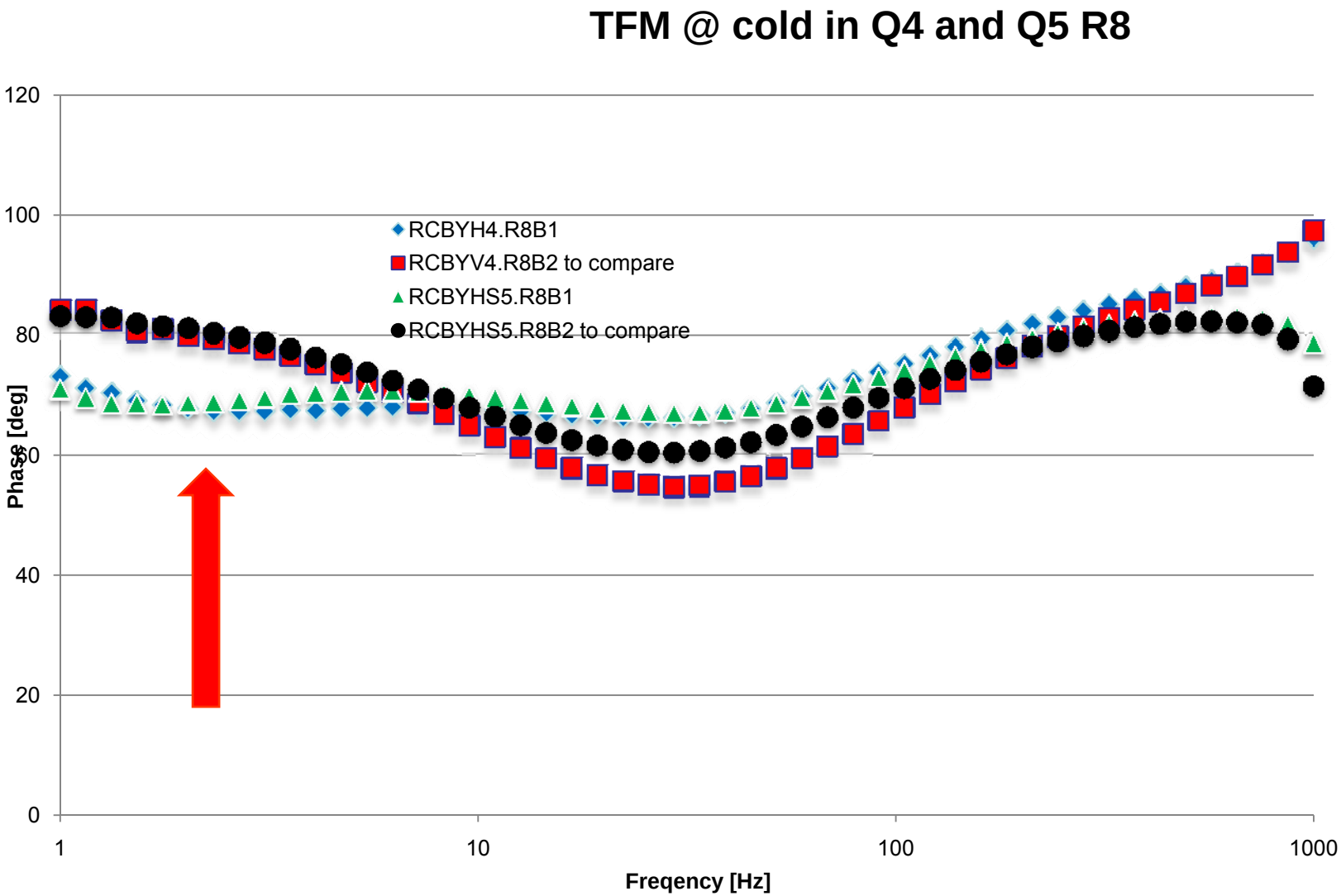
- ✓It is ALWAYS when current goes towards 0 A
- ✓Some magnets, which show this strange behavior also have a different transfer function, and have to be specifically trimmed for control
- ✓High inductances (2.84 - 5.27 H)

The RCBY mystery and other strange 120 A magnets

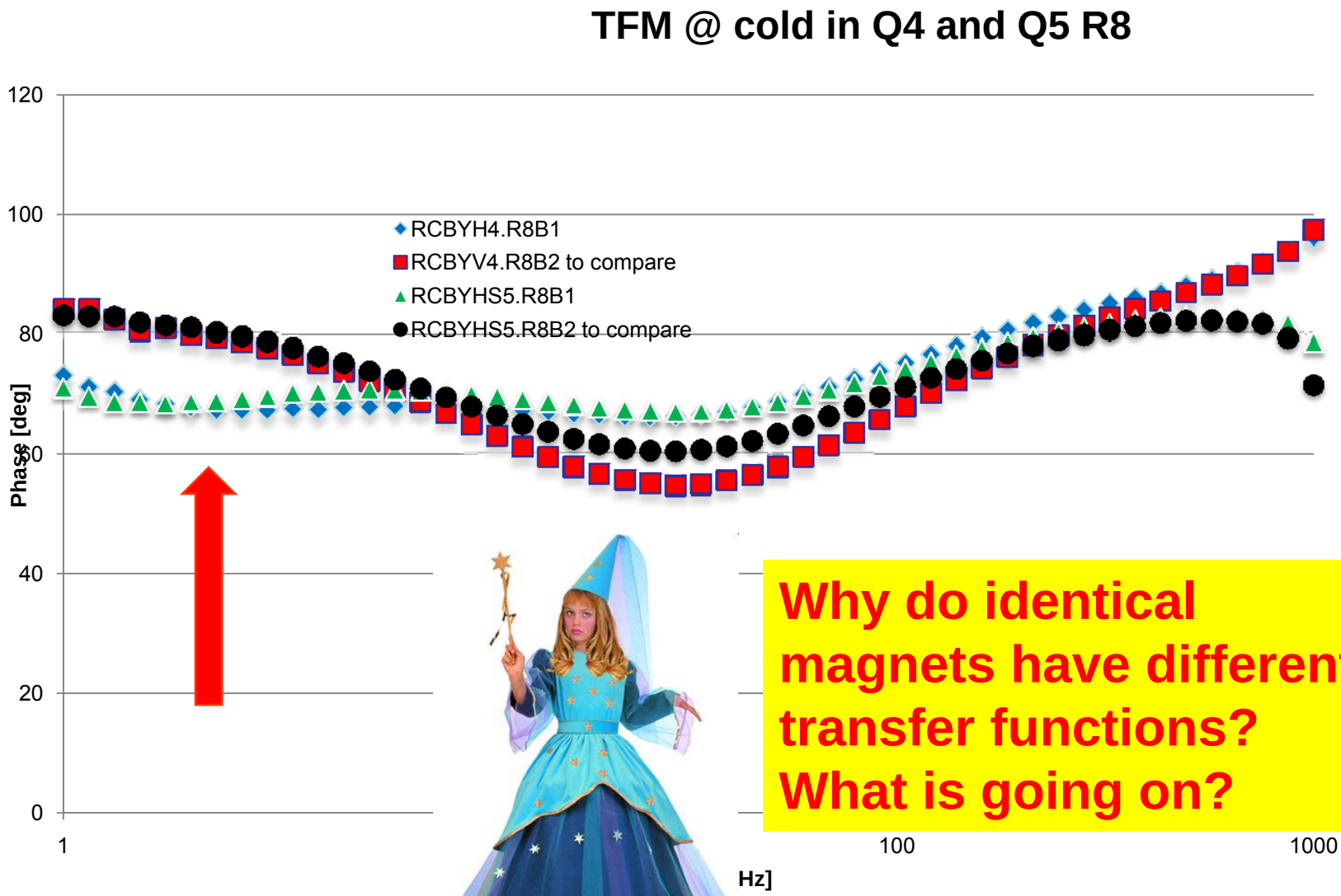
[9]



The RCBY mystery and other strange 120 A magnets



The RCBY mystery and other strange 120 A magnets



Why do identical magnets have different transfer functions? What is going on?

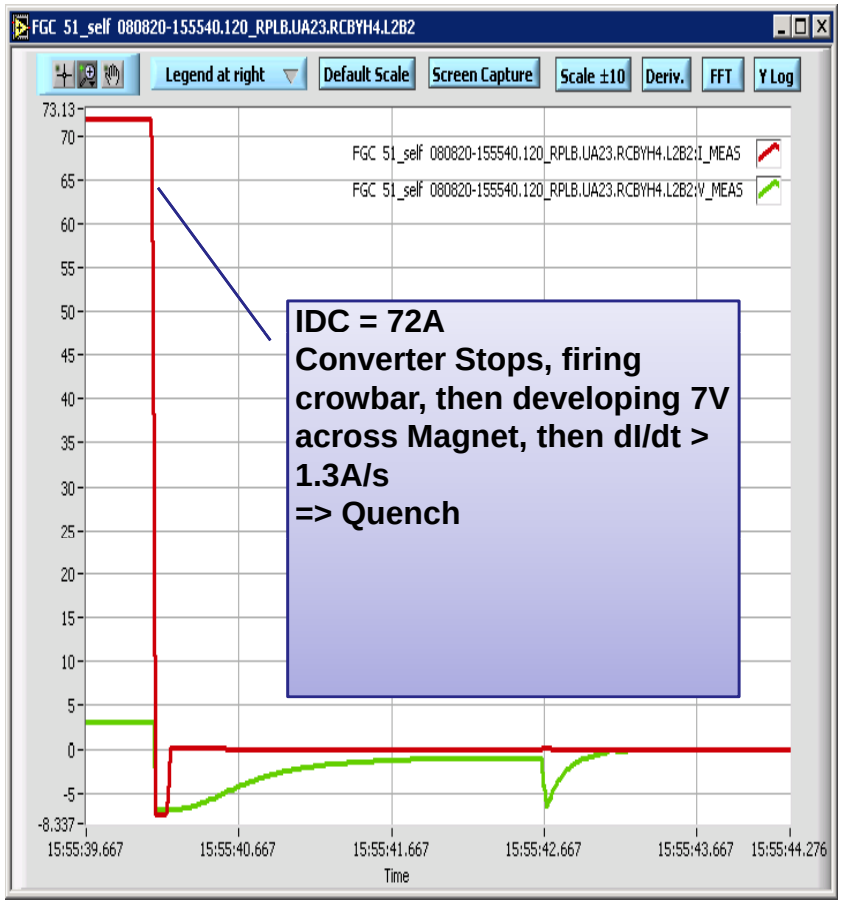
The RCBY mystery and other strange 120 A magnets

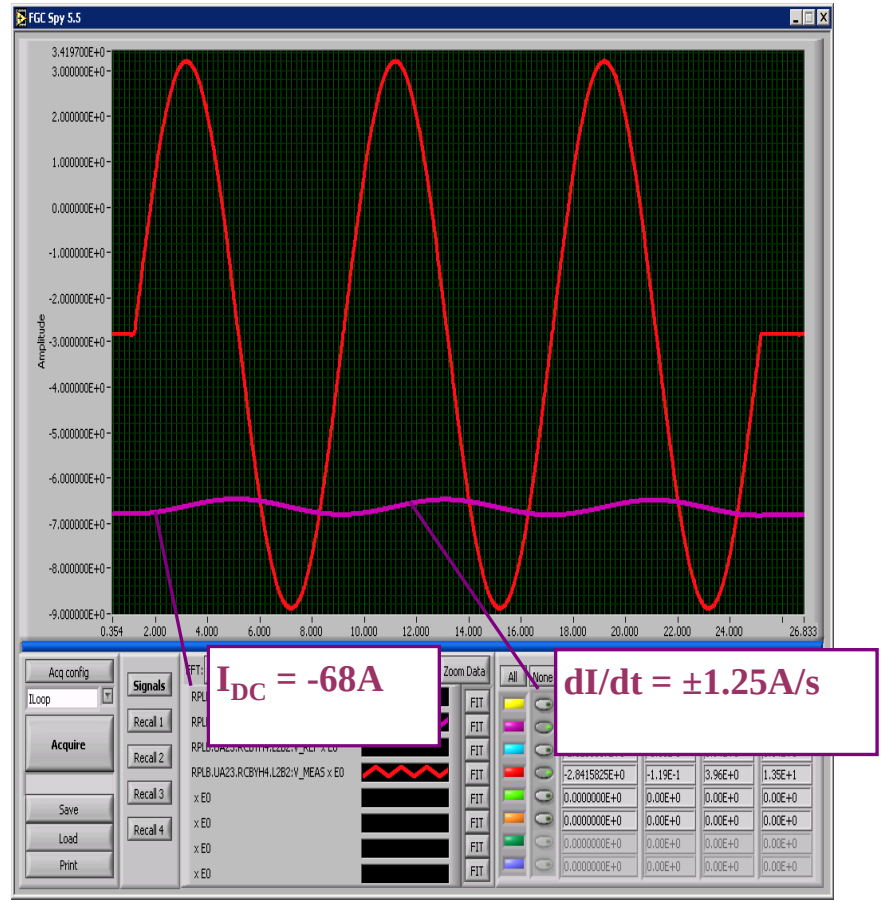
Transp. prepared by Mirko

RCBYHS4.L5B1

The RCBY mystery and other strange 120 A magnets

Transp. prepared by Mirko





The RCBY mystery and other strange 120 A magnets

Transp. prepared by Mirko

Electrical circuit	Fault	Critical ramp rate
RPLB.RR53.RCBYHS4.L5B1	Cannot handle LHC di/dt	0.6 A/s (LHC: 0.66A/s)
RPLB.UA87.RCBYHS5.R8B1	Cannot handle LHC di/dt	0.46 A/s (LHC: 0.66A/s)
RPLB.UA87.RCBYH4.R8B1	Cannot handle LHC di/dt	0.6 A/s (LHC: 0.66A/s)
RPLB.UJ83.RCBCH7.L8B1	Quench @ discharge	> 2.5 A/s (LHC: 1A/s)
RPLB.UA23.RCBYH4.L2B2	Quench @ discharge	> 1.25 A/s (LHC: 0.66A/s)
RPLB.RR13.RCBCV8.L1B2	Quench @ discharge	1.2 A/s (LHC: 1A/s)
RPLB.UJ23.RCBCV7.L2B2	Quench @ discharge	> 2.5A/s (LHC: 1A/s)
RPLB.UA43.RCBYV5.L4B2	Cannot reach nominal current	Rated 72 A, it cannot go higher than 65 A

The next mystery: very fast quench propagation

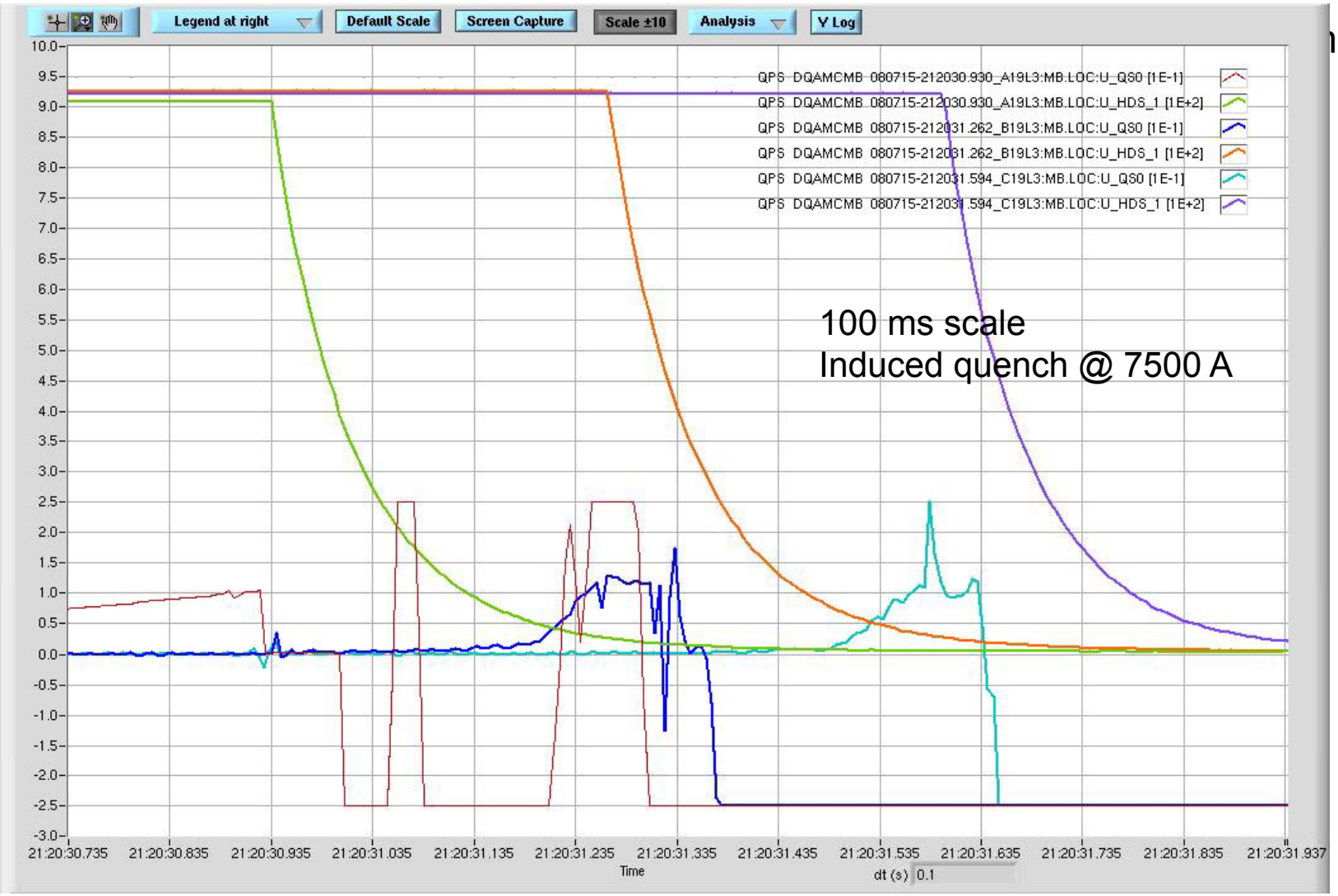
Observations:

We have em transmission ~ 150 µs/dipole. This includes the spike problems.
We have 30 … 40 s heat wave transmission.

We observed in a few cases times of ~ 100 … 200 ms.

The next mystery: very fast quench propagation

Observations:



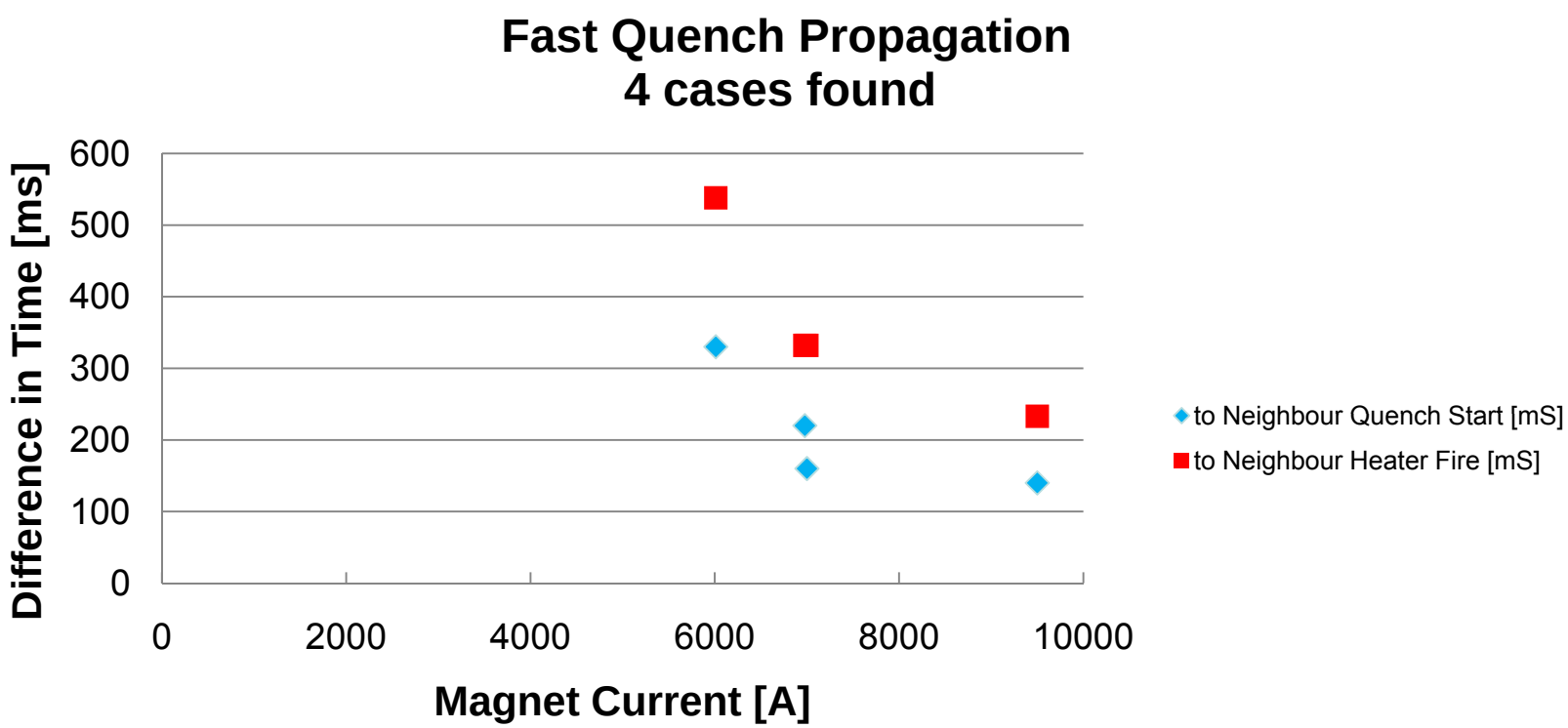
ns.

The next mystery: very fast quench propagation

Observations:

We have em transmission ~ 150 µs/dipole. This includes the spike problems.
We have 30 … 40 s heat wave transmission

We [12] observed in 4 cases times of some 100 ms.



The next mystery: very fast quench propagation

Observations:

We ... ems.
We

We

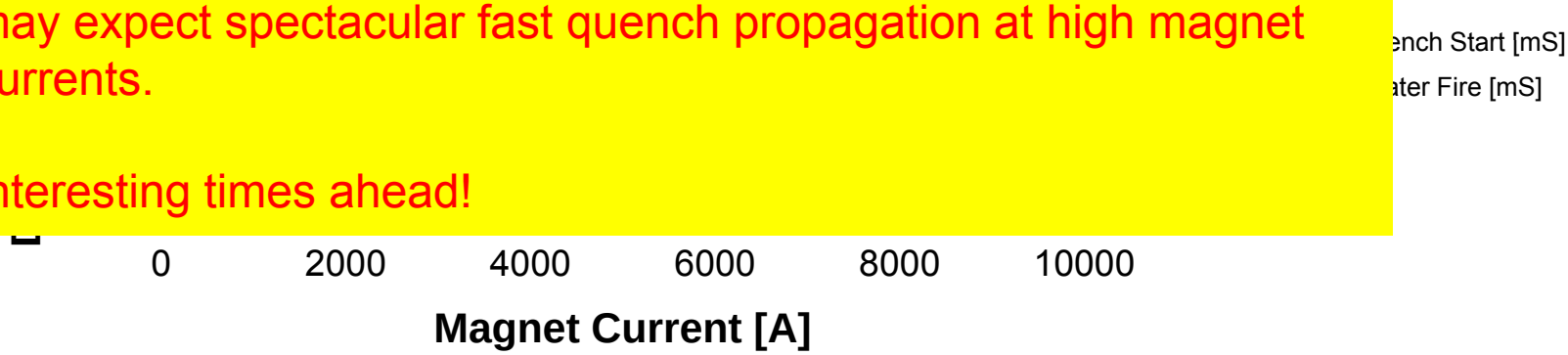
The observed current dependence is, at least partially, due to the current & field dependence of the critical current & temperature. The data are compatible with a constant time delay between magnets + a current dependent quench development/ detection.

Note that also in the event of the 19. a similar (not the same) behavior can be found. [13]

The observation was unexpected and may contain physics.

If the phenomenon is more likely at higher peak temperatures, we may expect spectacular fast quench propagation at high magnet currents.

Interesting times ahead!



Summary

•We rediscovered Ohms law.

•We rediscovered that superconductivity happens at low temperatures.

•We rediscovered Faradays law.

•We rediscovered Kirchhoffs law.

•We discovered shortcomings & operational complications.

•We discovered that we have not understood everything.

There are more things in heaven and earth, Horatio,
Than are dreamt of in your philosophy.

•The re-commissioning will be very exciting!

Summary

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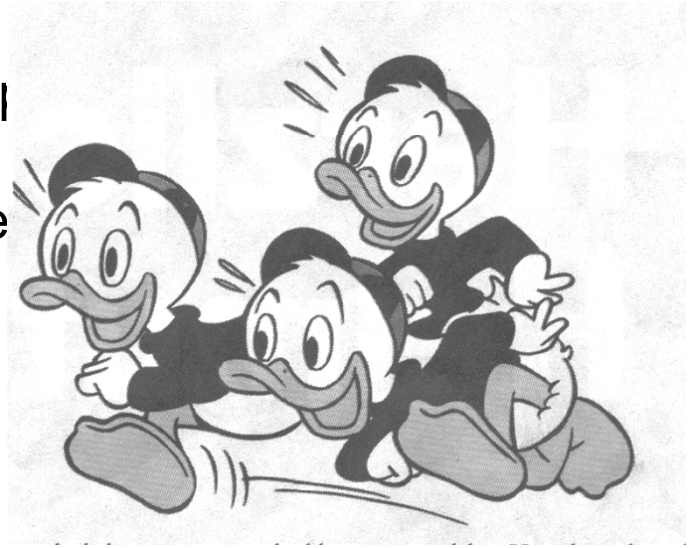
•The re-commissioning will be very exciting!

•A challenge again! Good luck!



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