Quench mechanisms and their time constants

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View of SM18

- 12 Test benches
- Possibility to operate at 1.9K & 4.4 K
- 14 kA / 16 V power supplies
- Cryomagnets can be equipped with anticryostats & shafts for:
  - Magnetic Measurements
  - Quench Localisation

Outline

2 quench scenarios of a dipole are considered due to beam loss:

- *450 GeV i.e. 0.54T*
- *7 TeV i.e. 8.33T*

1/ the voltage builds up and exceeds the threshold of the quench detector after t_0

2/ the quench detector detects the voltage after some time t_1

3/ the quench detector fires quench heaters and triggers the energy extraction t_2

4/ the heaters become efficient after t_3

5/ the PIC is informed, and sends a dump request to the BIC t_4

6/ the BIC sends a dump request to the beam dumping system t_5

7/ the voltage exceeds the diode voltage, and the current starts to bypass the magnet t_6

8/ the switch opens, and the current in the string of magnets decays t_7

Generalities: *Apologies for those who know…*

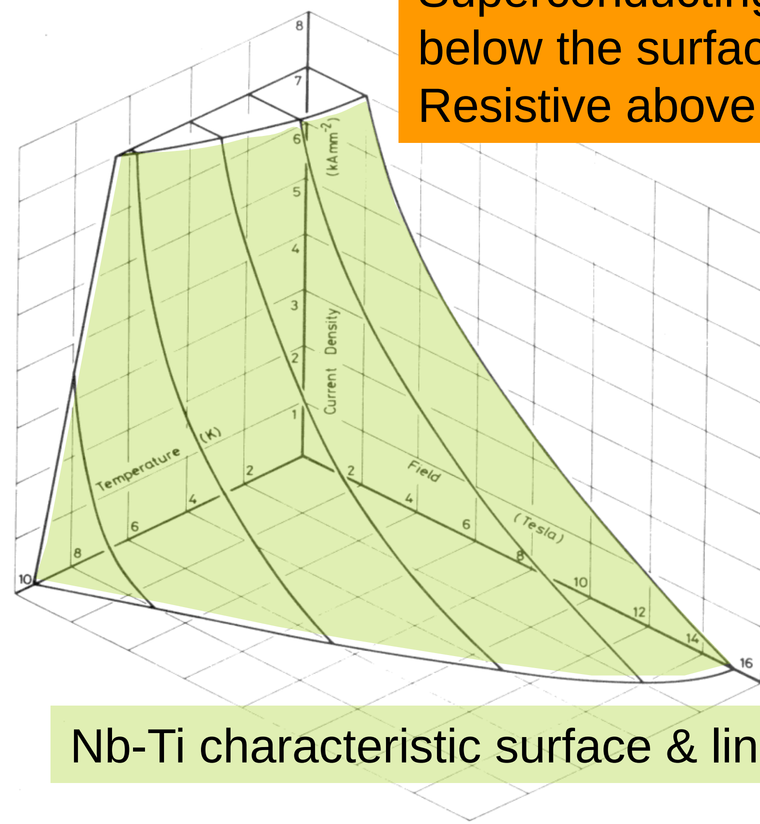
- What is a quench of a superconducting Magnet ?

  ☞ It is the irreversible transition toward the normal state via a thermal run away.

- Quench occurs in general locally and must be spread “globally” to limit the T_{max}
  $\Rightarrow$ use of quench heaters can be necessary (case of LHC main magnets)

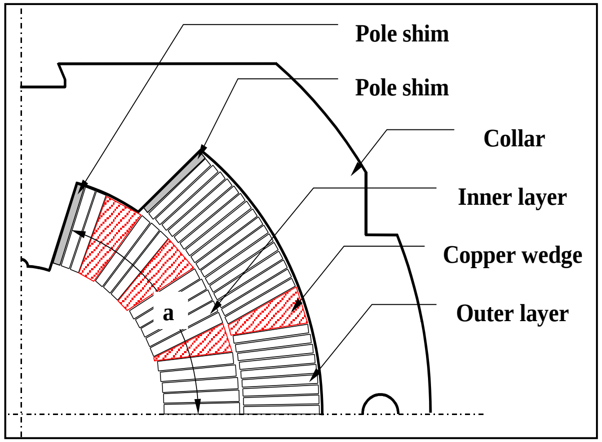
- Resistive transition of a superconductor does not mean necessary a quench…

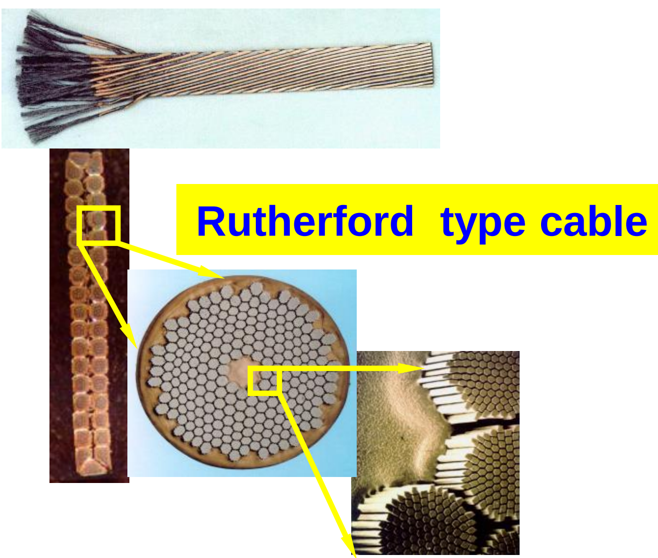
Superconducting below the surface, Resistive above



Nb-Ti characteristic surface & lines

Accelerator superconducting magnets are not “cryostable” at nominal conditions





- Steckly parameter

$$\alpha_{St} = \frac{\rho\, S_{Cu}\, J_c^2}{h\, p\left(T_c(B) - 1.9\right)} >> 1$$

- Margin given by the current sharing temperature

$$\Delta T_{sc}(I,x) \approx \Delta T_c\left(B(x)\right)\left(1 - \frac{I}{I_c(B(x))}\right) \approx 1.4K$$

- To give some comparisons:

*From K.-H. Mess et al. “Superc. Acc. Magnets”(1996)

	Margin
RHIC*	30 %
HERA*	25 %
LHC	14 %

Quench Origin without beam: mainly due to the mechanical activity of the winding

- The Magnet Disturbance Spectrum (Wipf'78):

Time	Space Distribution: Point	Length >> Lmpz	Volume >> Vmpz
Transient $t << k$ Lmpz^2/Cp	J	J/m	J/m^3
Continuous	W	W/m	W/m^3

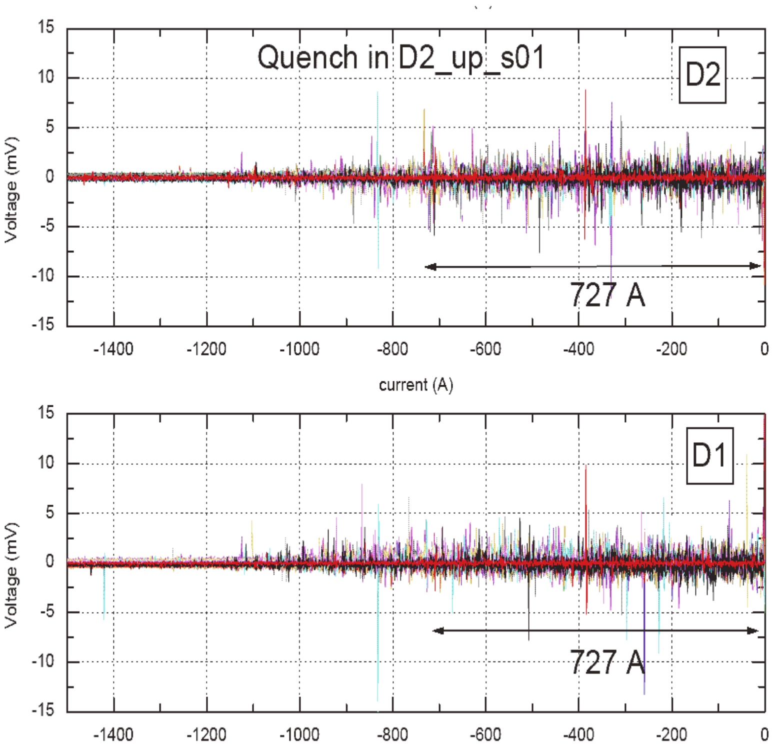
- Quench Mode without beam:

  When a conductor motion

  $\Rightarrow \Delta Q >$ MQE (10-100μJ for 1 strand)

  Then a quench can develop.

- Example of mechanical activity signature just before a quench:

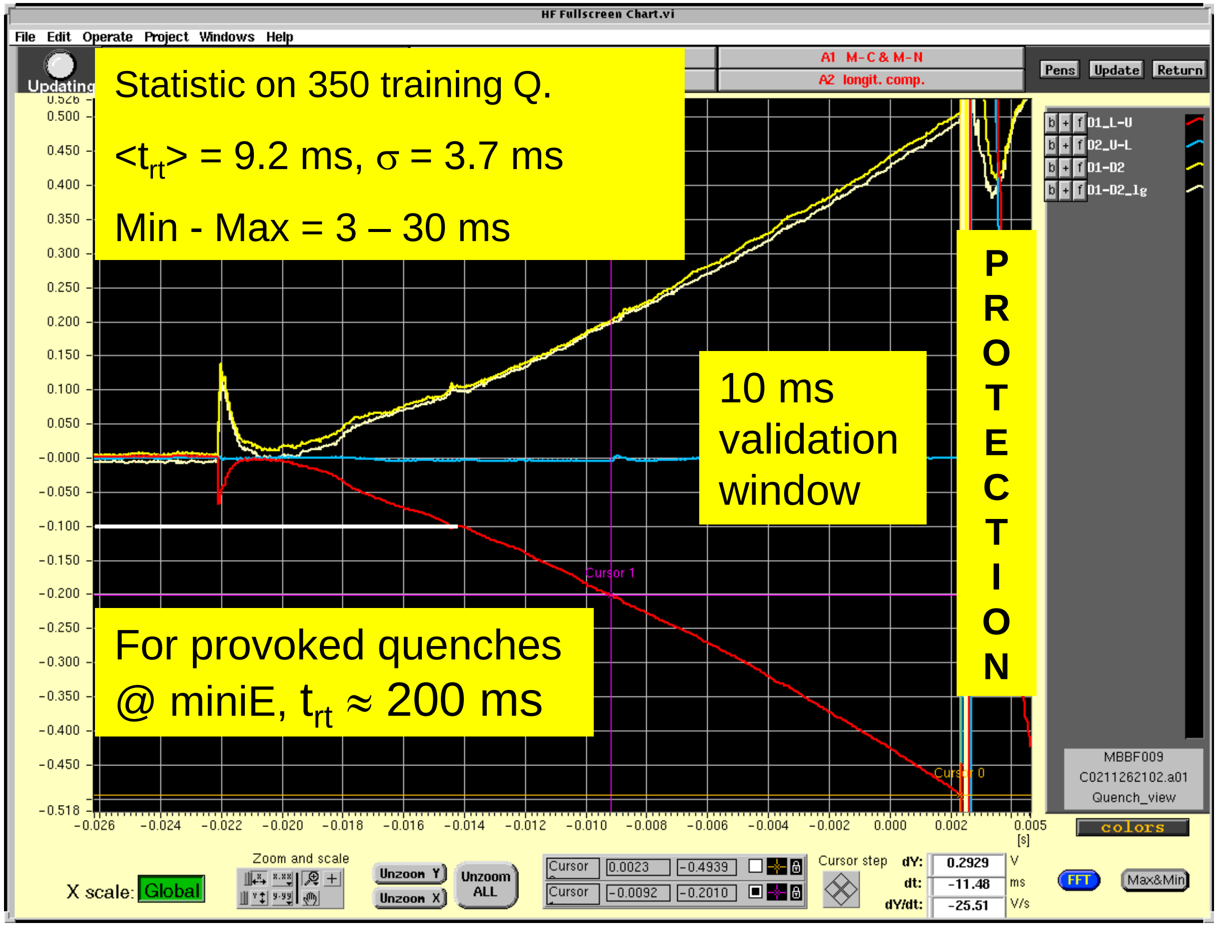


Quench Origins: t_{rt} @ 100mV & High Field

- Very few dipoles with relevant conductor problems

  $\Rightarrow$ Rejected

- For all other, quenches originate from conductor motion(s) (training & detraining)

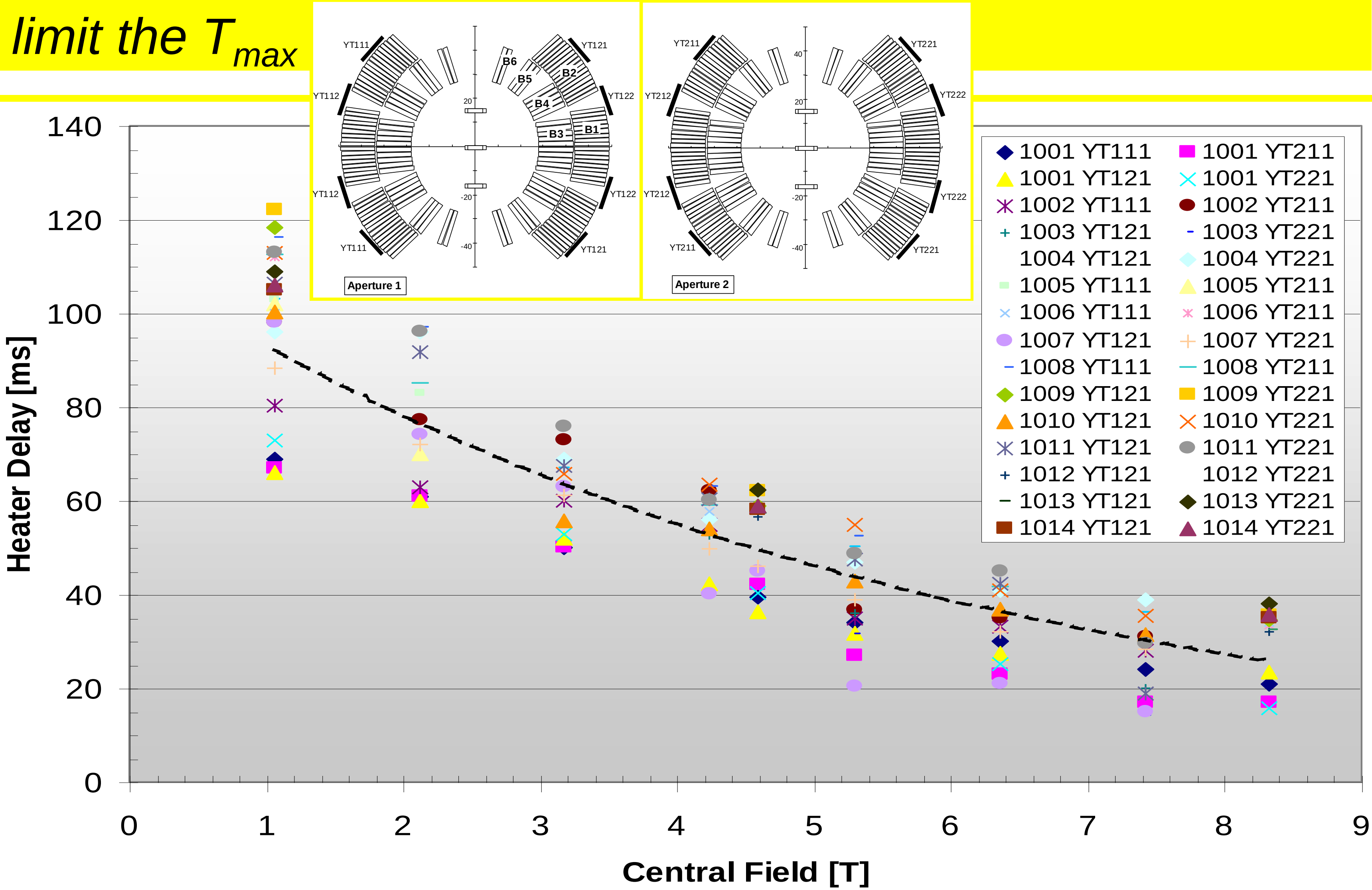


Chronological sequence of events

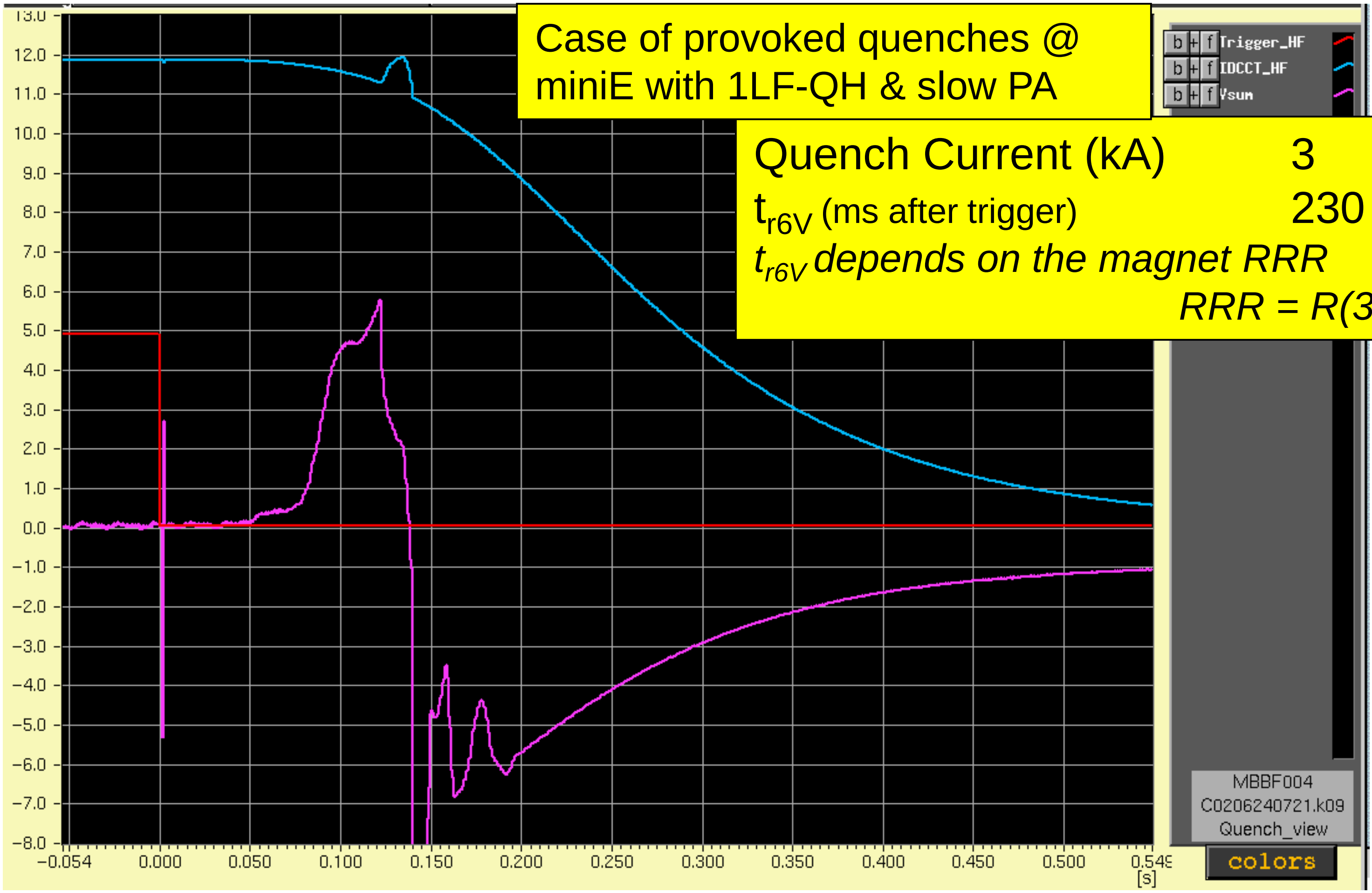
- Energy or power deposition sufficient to quench locally a part of the superconducting cable,
- The quench propagates (1-4 m/s or 20-30 m/s) $\Rightarrow$ the voltage threshold of 100 mV for the detection is reached,
- Time window of 10 ms to validate the quench,
- The quench occurred in general locally and must be spread "globally" to limit the T_{max} $\Rightarrow$ Use of Quench Heaters i.e heater delays function of the current
- After QHs became effective, the 6V threshold of the diode is reached $\Rightarrow$ bypass of the applied current

Quench Heater Delay

Quenches occurred locally & must be spread "globally" to limit the T_{max}



By-pass to the diode:
Are results obtained on Test Benches relevant ?



Case of provoked quenches @ miniE with 1LF-QH & slow PA

Quench Current (kA)	3	11.85
t_{r6V} (ms after trigger)	230	80-120

t_{r6V} depends on the magnet RRR

RRR = R(300K)/R(10K)

Summary

- Chronology of Events

	Comments	Injection, 0.54T	Nominal, 8.33T
t_0	100 mV reached after Q. start, Spread of physical origin depend of the deposited E	can be > 5 s	3-200 ms
t_1-t_0	Validation time for quench detector (see the presentation of Reiner)	10 ms	10 ms
t_3-t_2	Heater delay, range at $\pm 2\ \sigma$ Spread of physical origin	70-130 ms	15-40 ms
t_6-t_2	Are typical values measured on TB relevant for the machine ? Function of the RRR of conductors	> 230 ms	~ 80-120 ms

- Open questions:
  - Effect on the beam of the field perturbation at the local quench start?
  - Effect on the beam of the field perturbation at the “global” quench start?