Current Decay after a Quench

A 1st look for LHC MBs & MQs

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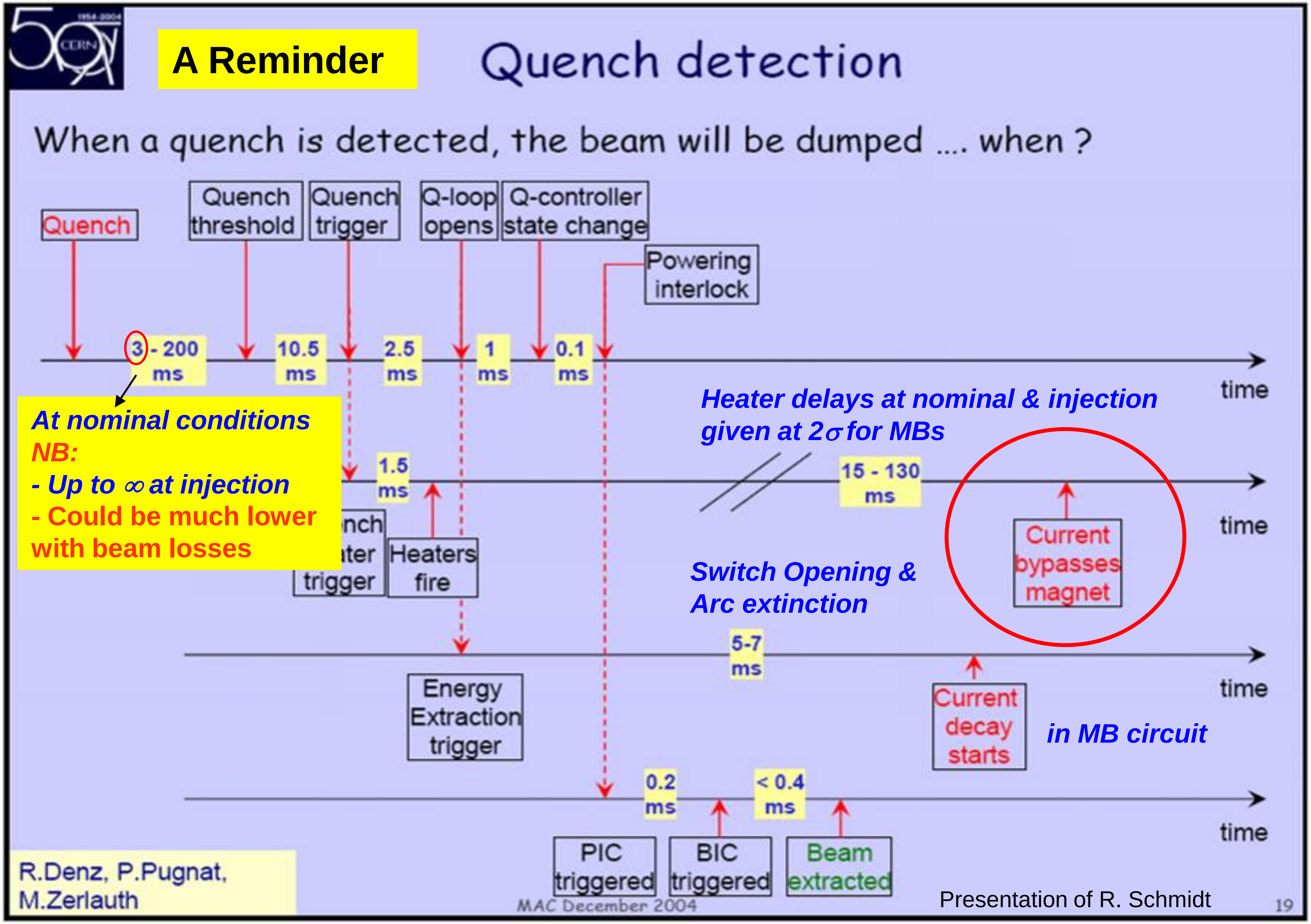
AT/MTM/TF

Ouline

- Introduction
- Measurement results on test benches
- How fast can be the current decay of the quenched magnet in the LHC ?
- Conclusion

A Reminder

Quench detection



When a quench is detected, the beam will be dumped …. when ?

At nominal conditions

NB:

- *Up to ∞ at injection*
- **Could be much lower with beam losses**

Heater delays at nominal & injection given at 2σ for MBs

Switch Opening & Arc extinction

in MB circuit

R.Denz, P.Pugnat, M.Zerlauth

MAC December 2004

Presentation of R. Schmidt

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Key Ingredients to the current decay

- As soon as the power converter is switched off, the current decay of the quenched magnet is governed by the growing of its *R(t)*:

$$I(t) = I_Q \exp\left\{-\int \frac{R(t)\,dt}{L}\right\}$$

- ***1st order approximation, L(~~t~~)***: L(MB) ≈ 110 mH, L(MQ/2) ≈ 5.6 mH

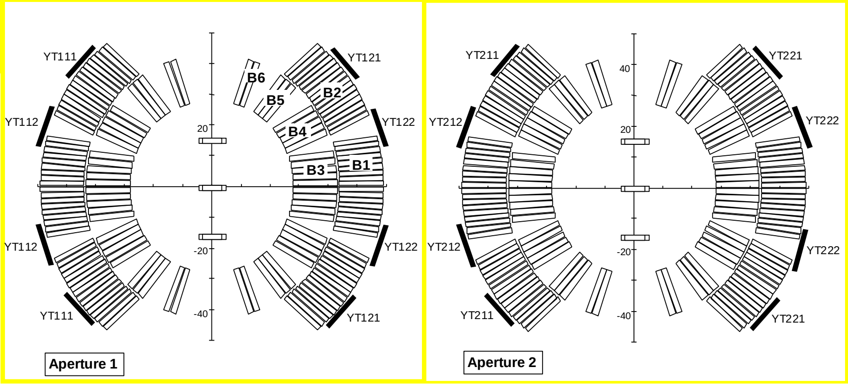
⇒ *Much faster current decay for MQ/2*

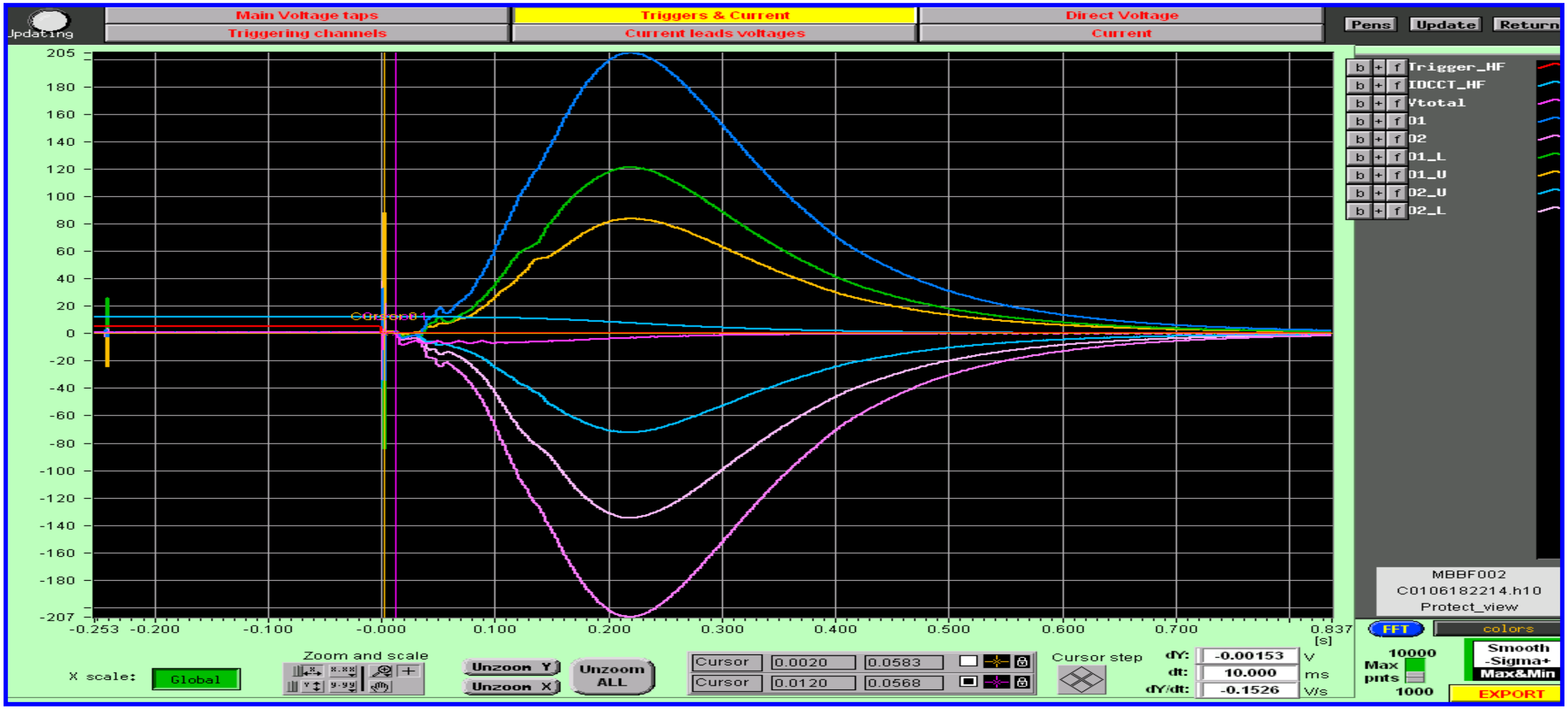
- Mostly two quantities play a major role in the growing of *R(t)*:
  - *RRR = R(300K)/R(10K)* of the stabilizing Cu-conductor (typically 70 – 300)
  - The amount of energy density deposited during the quench i.e. the type of quench *(much larger spectrum)*

  ⇒ *For more & more energy deposited by beams, faster & faster will be the current decay… How faster ?*

Various types of quenches performed on test benches

- Minimum Energy quenches
- Heater Delay quenches
- Training quenches
- Conductor limited quenches





Cursor 0.0020 0.0583

Cursor 0.0120 0.0568

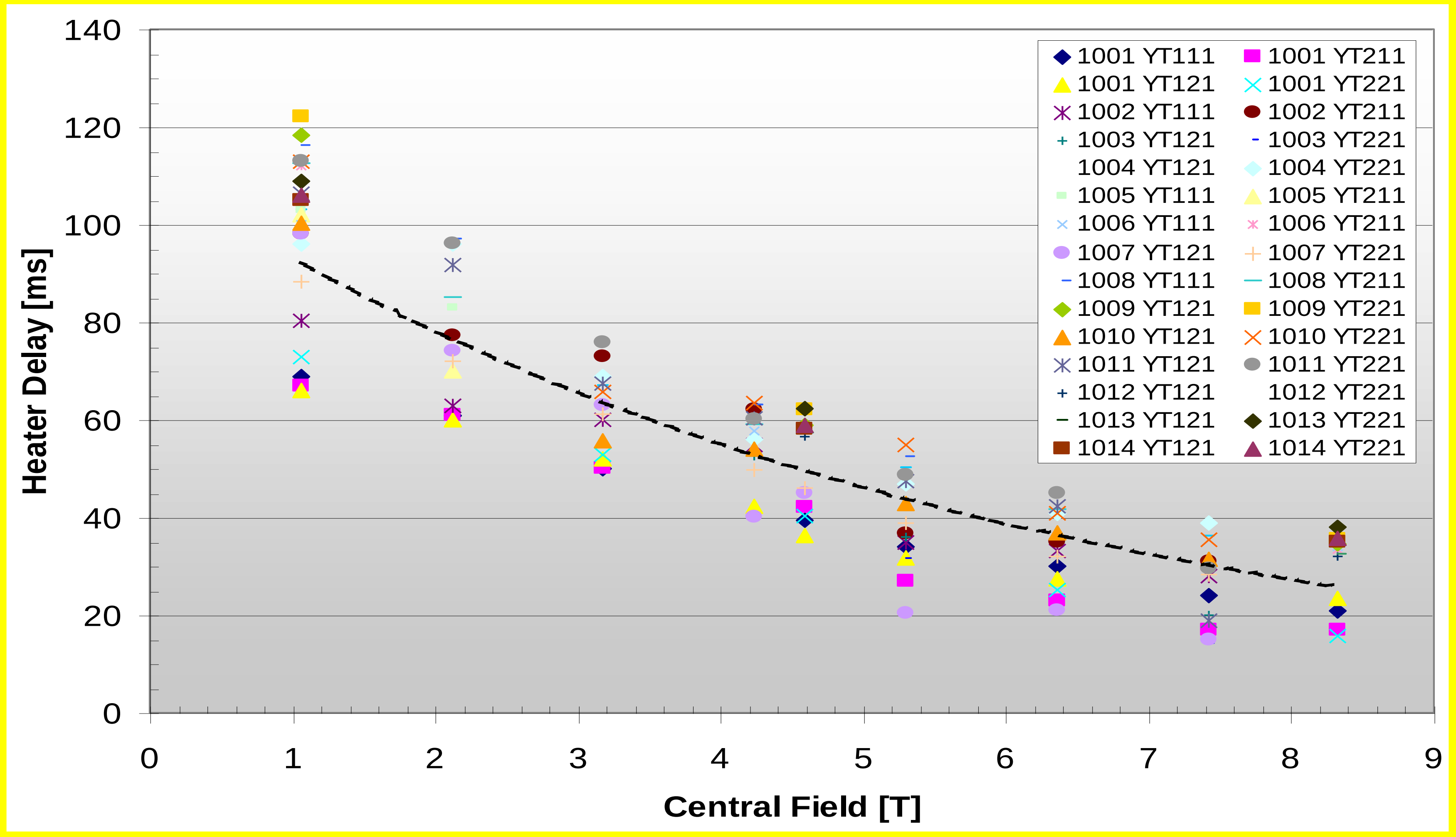
dY: -0.00153 V

dt: 10.000 ms

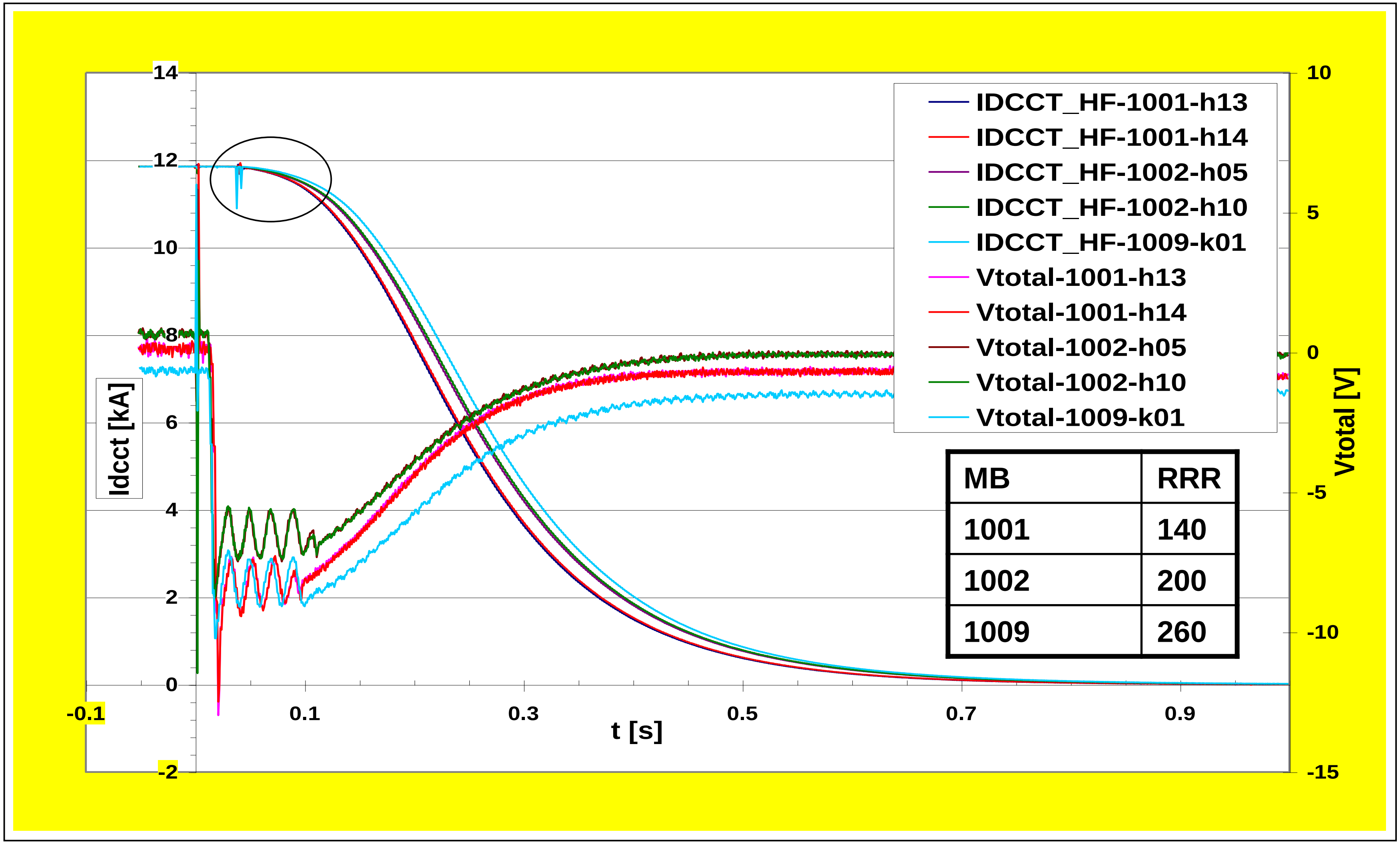
dY/dt: -0.1526 V/s

Quench Heater Delay in MBs

Quenches occurred locally & spread “globally” by QH to limit the T_{max}



Case of provoked quenches in MBs with controlled conditions i.e. energy deposition



MB	RRR
1001	140
1002	200
1009	260

Zooming for the MB current decay

- Measurement of the time at which $\Delta I/I = -10^{-3}$ for provoked quenches at nominal, *i.e a corresponding dipole kick and maximum close orbit deviation:*

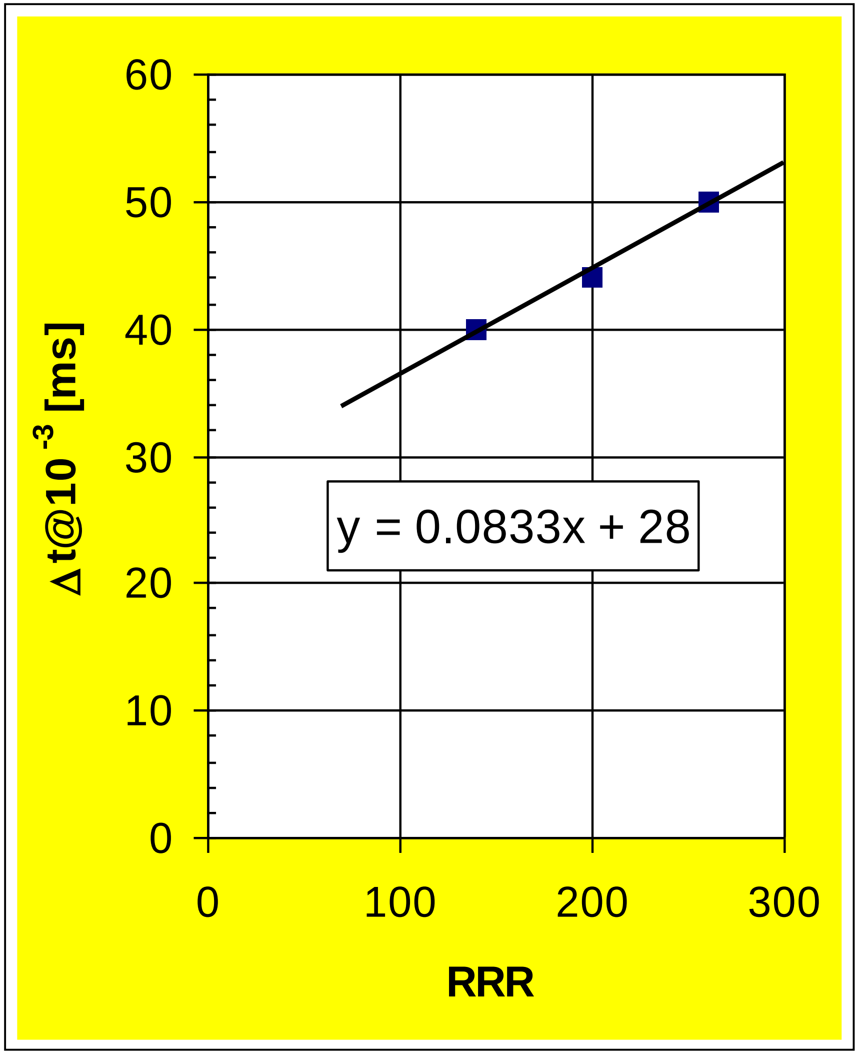
$$\Delta x' = -\frac{\Delta B\, l}{B\,\rho} \approx 5.1\,\mu rad$$

$$\Delta x = \frac{\beta_{\max}}{2\sin(\pi Q_x)}\frac{\Delta B\, l}{B\,\rho} \approx 0.6\, mm$$

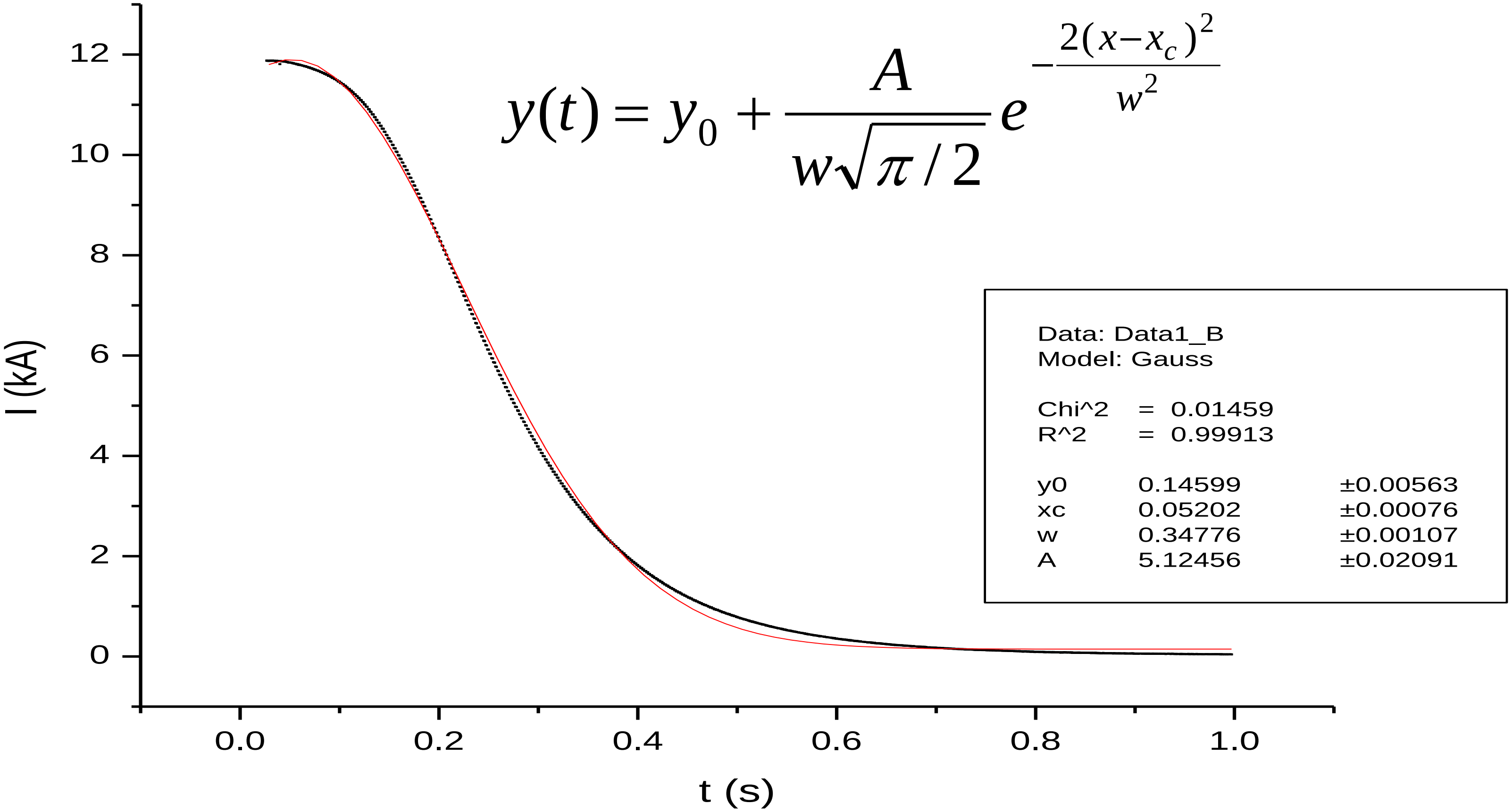
with β_{max} = 177 m, Q_x = 64.31 and $B\,\rho$ = 23.357x10^3 T x m.

▶ Scale σ = *0.2-0.3 mm*

- $\Delta I/I = -10^{-4}$ at nominal after ~ 25 ms



Overall current decay of MBs



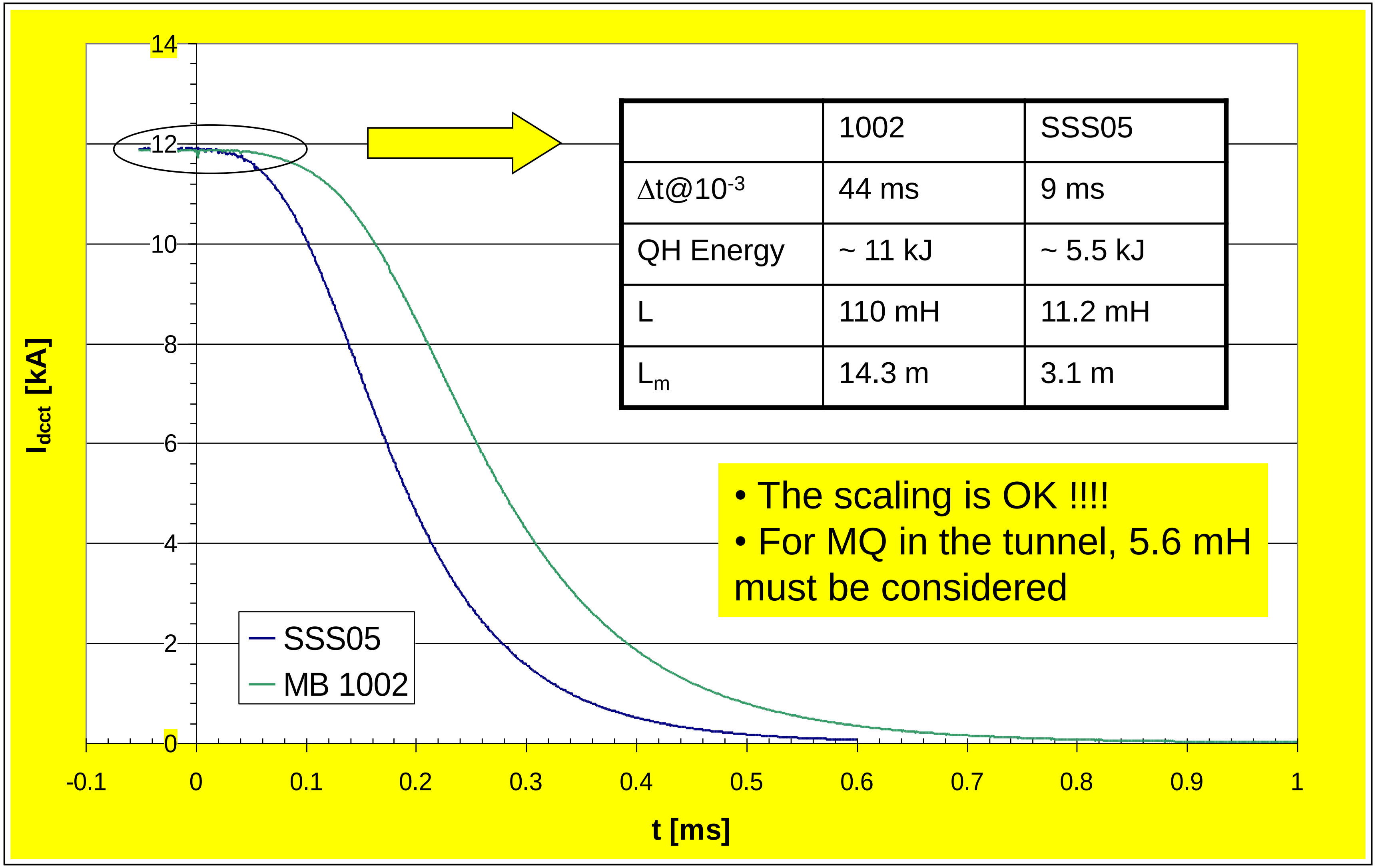
$$y(t) = y_0 + \frac{A}{w\sqrt{\pi/2}} e^{-\frac{2(x-x_c)^2}{w^2}}$$

Data: Data1_B
Model: Gauss

Chi^2 = 0.01459
R^2 = 0.99913

y0	0.14599	±0.00563
xc	0.05202	±0.00076
w	0.34776	±0.00107
A	5.12456	±0.02091

Case of MQs for a similar provoked quench



	1002	SSS05
$\Delta t@10^{-3}$	44 ms	9 ms
QH Energy	~ 11 kJ	~ 5.5 kJ
L	110 mH	11.2 mH
L_m	14.3 m	3.1 m

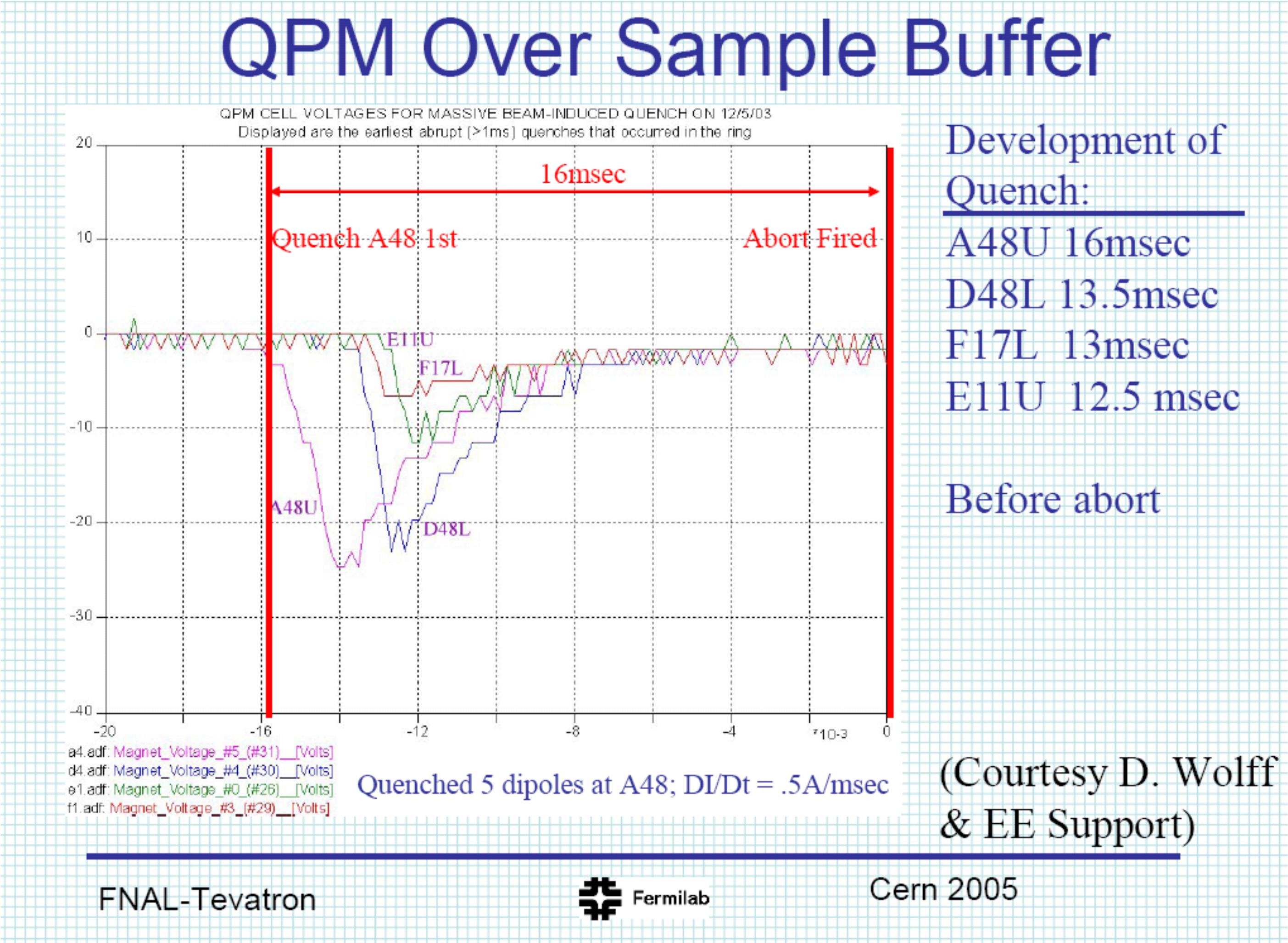
- The scaling is OK !!!!
- For MQ in the tunnel, 5.6 mH must be considered

- This is ~OK for “slow” quenches
but what about for “fast” ones ?

- How fast could be R(t) ↗ with beams ?

NB: To reach the 6 V threshold to commute the diode at 11850 A, less than 1% of the MB need to be quenched with T around 10 K…

Case of FermiLab Quenches



QPM Over Sample Buffer

Development of Quench:

A48U 16msec

D48L 13.5msec

F17L 13msec

E11U 12.5 msec

Before abort

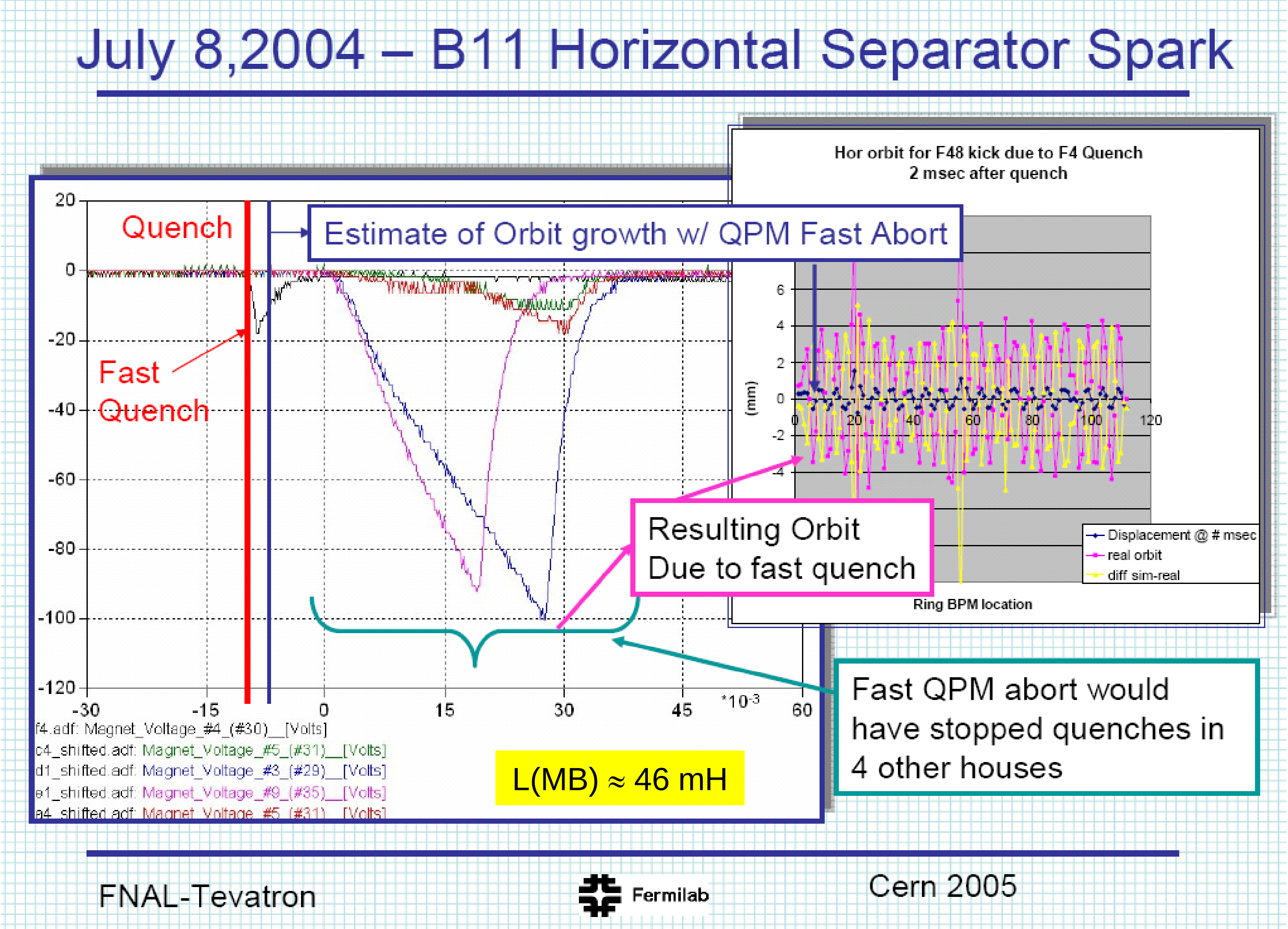
Quenched 5 dipoles at A48; DI/Dt = .5A/msec

(Courtesy D. Wolff & EE Support)

FNAL-Tevatron Fermilab Cern 2005

From http://lhc-collimation.web.cern.ch/lhc-collimation/files/DStill_2005-04-15.pdf

Case of FermiLab **Fast** Quenches



July 8,2004 – B11 Horizontal Separator Spark

Quench

Fast Quench

Estimate of Orbit growth w/ QPM Fast Abort

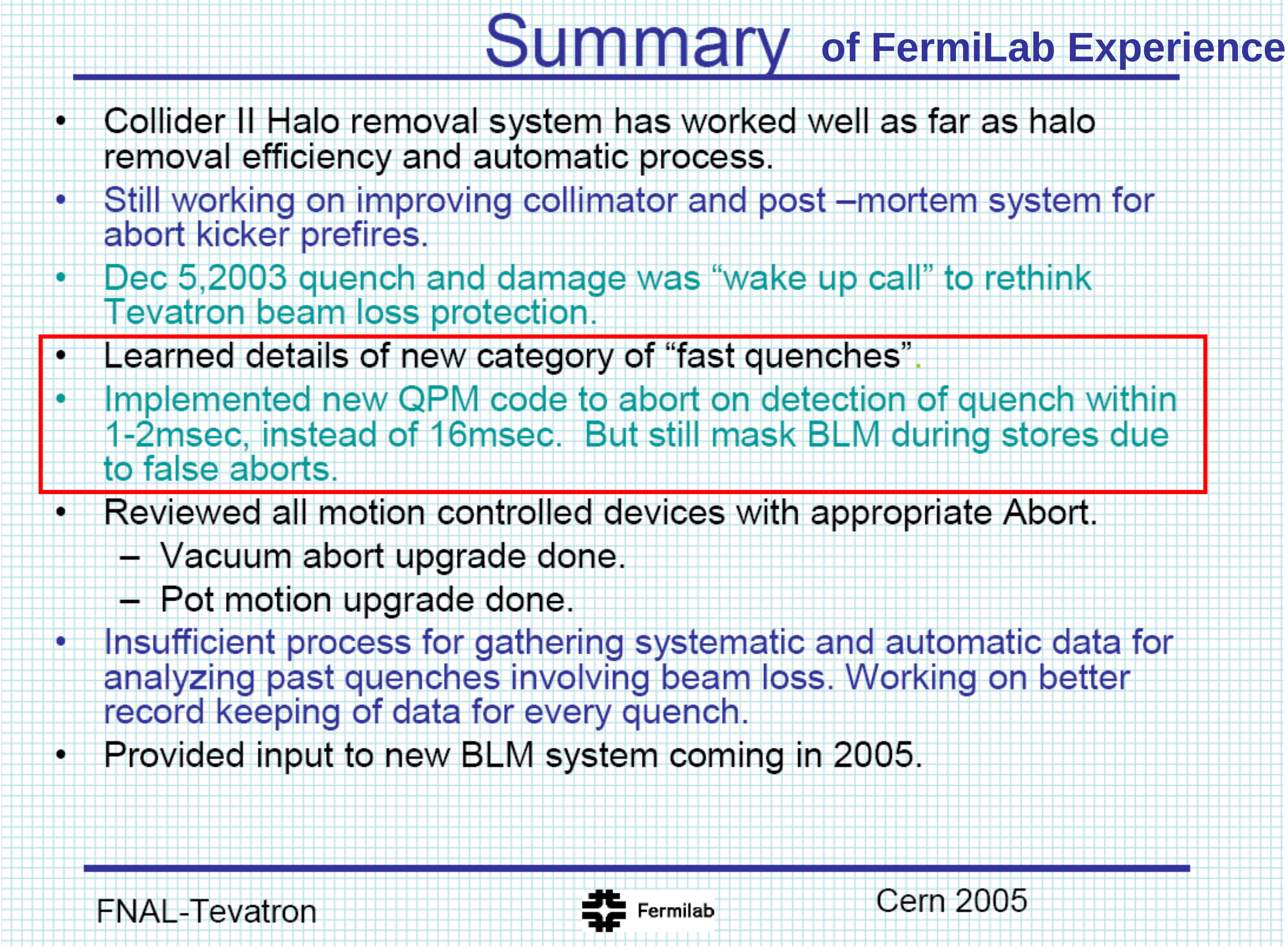
Resulting Orbit
Due to fast quench

Fast QPM abort would have stopped quenches in 4 other houses

L(MB) ≈ 46 mH

FNAL-Tevatron Fermilab Cern 2005

From http://lhc-collimation.web.cern.ch/lhc-collimation/files/DStill_2005-04-15.pdf



Summary of FermiLab Experience

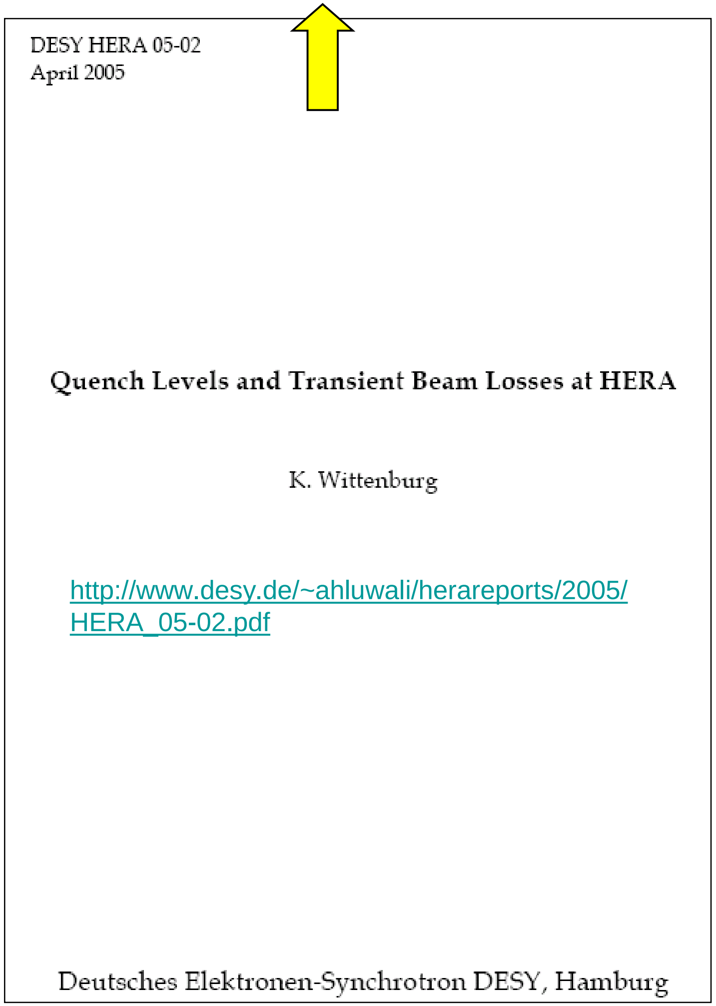
- Collider II Halo removal system has worked well as far as halo removal efficiency and automatic process.
- Still working on improving collimator and post –mortem system for abort kicker prefires.
- Dec 5,2003 quench and damage was "wake up call" to rethink Tevatron beam loss protection.
- Learned details of new category of "fast quenches".
- Implemented new QPM code to abort on detection of quench within 1-2msec, instead of 16msec. But still mask BLM during stores due to false aborts.
- Reviewed all motion controlled devices with appropriate Abort.
  - Vacuum abort upgrade done.
  - Pot motion upgrade done.
- Insufficient process for gathering systematic and automatic data for analyzing past quenches involving beam loss. Working on better record keeping of data for every quench.
- Provided input to new BLM system coming in 2005.

FNAL-Tevatron Fermilab Cern 2005

From http://lhc-collimation.web.cern.ch/lhc-collimation/files/DStill_2005-04-15.pdf

And HERA ?

Conclusions
(Avoiding quenches at the LHC)



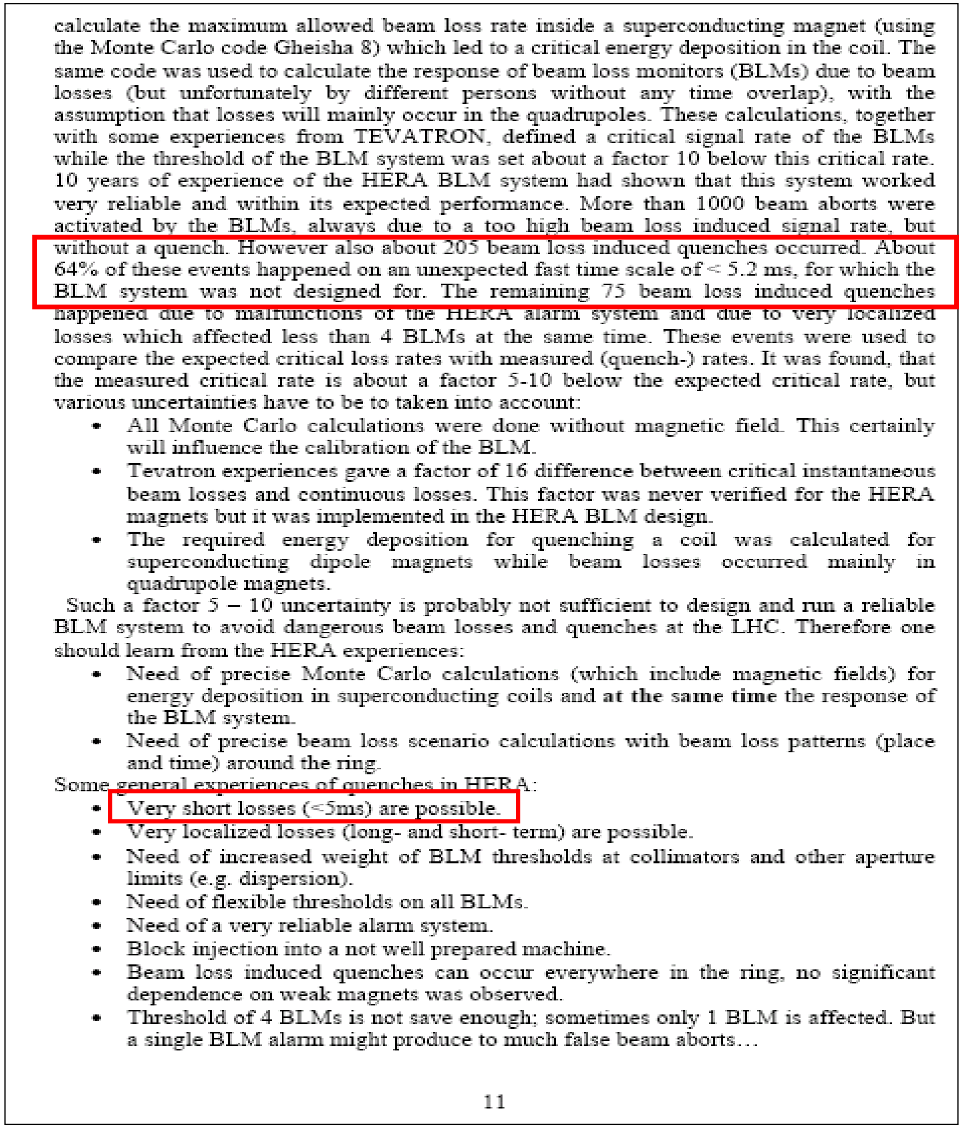
DESY HERA 05-02
April 2005

Quench Levels and Transient Beam Losses at HERA

K. Wittenburg

Deutsches Elektronen-Synchrotron DESY, Hamburg

http://www.desy.de/~ahluwali/herareports/2005/HERA_05-02.pdf



calculate the maximum allowed beam loss rate inside a superconducting magnet (using the Monte Carlo code Gheisha 8) which led to a critical energy deposition in the coil. The same code was used to calculate the response of beam loss monitors (BLMs) due to beam losses (but unfortunately by different persons without any time overlap), with the assumption that losses will mainly occur in the quadrupoles. These calculations, together with some experiences from TEVATRON, defined a critical signal rate of the BLMs while the threshold of the BLM system was set about a factor 10 below this critical rate. 10 years of experience of the HERA BLM system had shown that this system worked very reliable and within its expected performance. More than 1000 beam aborts were activated by the BLMs, always due to a too high beam loss induced signal rate, but without a quench. However also about 205 beam loss induced quenches occurred. About 64% of these events happened on an unexpected fast time scale of < 5.2 ms, for which the BLM system was not designed for. The remaining 75 beam loss induced quenches happened due to malfunctions of the HERA alarm system and due to very localized losses which affected less than 4 BLMs at the same time. These events were used to compare the expected critical loss rates with measured (quench-) rates. It was found, that the measured critical rate is about a factor 5-10 below the expected critical rate, but various uncertainties have to be taken into account:

- All Monte Carlo calculations were done without magnetic field. This certainly will influence the calibration of the BLM.
- Tevatron experiences gave a factor of 16 difference between critical instantaneous beam losses and continuous losses. This factor was never verified for the HERA magnets but it was implemented in the HERA BLM design.
- The required energy deposition for quenching a coil was calculated for superconducting dipole magnets while beam losses occurred mainly in quadrupole magnets.

Such a factor 5 – 10 uncertainty is probably not sufficient to design and run a reliable BLM system to avoid dangerous beam losses and quenches at the LHC. Therefore one should learn from the HERA experiences:

- Need of precise Monte Carlo calculations (which include magnetic fields) for energy deposition in superconducting coils and **at the same time** the response of the BLM system.
- Need of precise beam loss scenario calculations with beam loss patterns (place and time) around the ring.

Some general experiences of quenches in HERA:

- Very short losses (<5ms) are possible.
- Very localized losses (long- and short- term) are possible.
- Need of increased weight of BLM thresholds at collimators and other aperture limits (e.g. dispersion).
- Need of flexible thresholds on all BLMs.
- Need of a very reliable alarm system.
- Block injection into a not well prepared machine.
- Beam loss induced quenches can occur everywhere in the ring, no significant dependence on weak magnets was observed.
- Threshold of 4 BLMs is not save enough; sometimes only 1 BLM is affected. But a single BLM alarm might produce to much false beam aborts…

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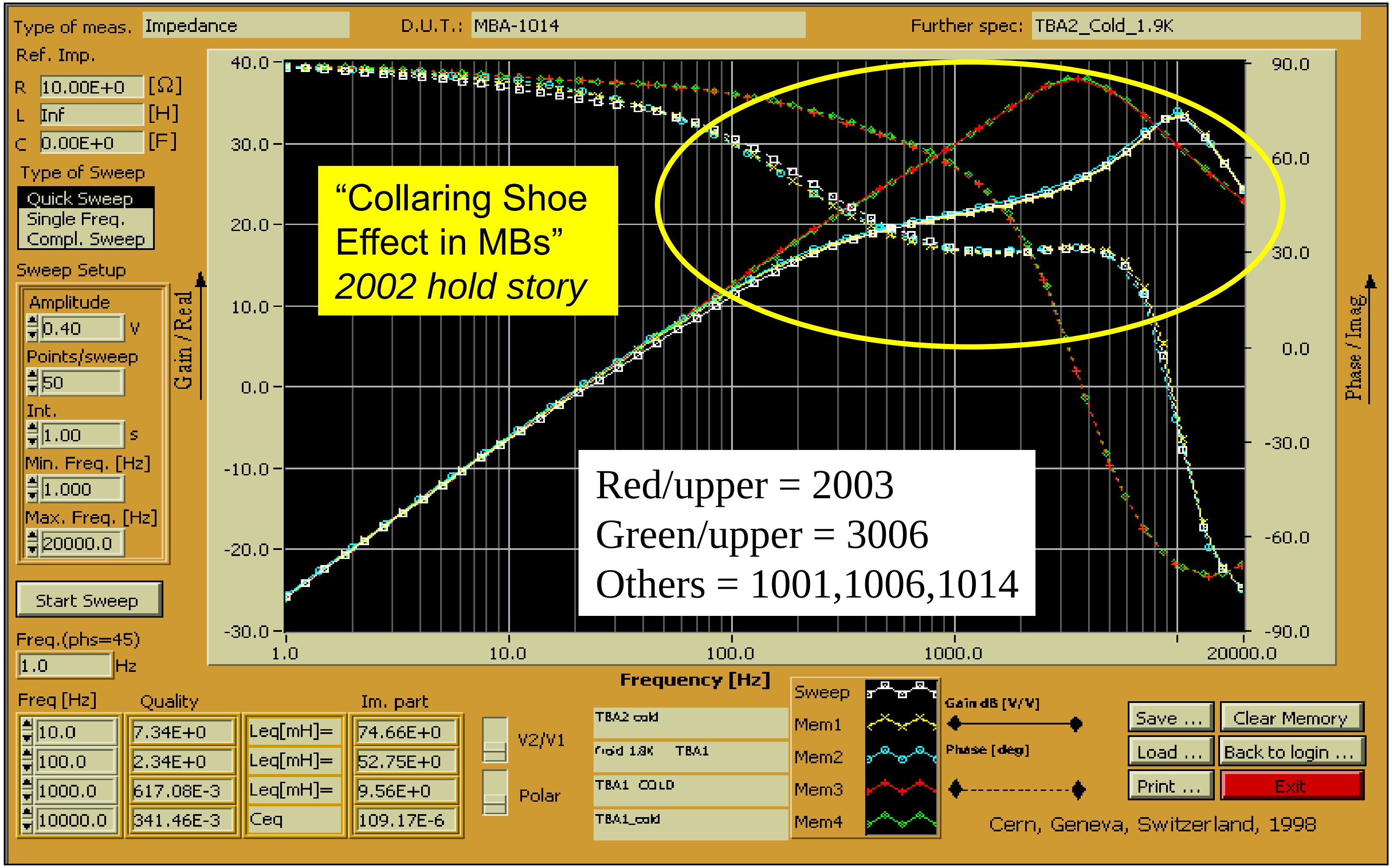
Conclusion

- From the “slow” quenches performed on test benches (5-12 kJ deposited in 100 ms at nominal current), the minimal $\Delta t@10^{-3}$ which can be deduced are:
  - 34 ms for MBs
  - 3-4 ms for MQs.
- In case of fast or/and “massive” beam losses ⇒ “fast” quenches ⇒ Serious problems will occur if BLMs fail…

► Change of strategy by optimizing the reliability/efficiency of QPS before the availability of the machine ?

i.e. start with much lower QPS validation time window (say 1-2 ms instead of 10.5 ms ?) and increase it progressively to reduce false aborts down to the acceptable level ? *(A. Siemko validated 5 ms window in the past…)*

In addition, for “Fast” quenches the magnet dI/dt *will be enhance by the decrease of L at high frequency*…



Type of meas. Impedance

D.U.T.: MBA-1014

Further spec: TBA2_Cold_1.9K

Ref. Imp.

R 10.00E+0 [Ω]

L Inf [H]

C 0.00E+0 [F]

Type of Sweep: Quick Sweep

Sweep Setup

Amplitude 0.40 V

Points/sweep 50

Int. 1.00 s

Min. Freq. [Hz] 1.000

Max. Freq. [Hz] 20000.0

Freq.(phs=45) 1.0 Hz

Freq [Hz]	Quality		Im. part
10.0	7.34E+0	Leq[mH]=	74.66E+0
100.0	2.34E+0	Leq[mH]=	52.75E+0
1000.0	617.08E-3	Leq[mH]=	9.56E+0
10000.0	341.46E-3	Ceq	109.17E-6

TBA2 cold

old 1.8K TBA1

TBA1 COLD

TBA1_cold

Cern, Geneva, Switzerland, 1998

“Collaring Shoe Effect in MBs”
2002 hold story

Red/upper = 2003
Green/upper = 3006
Others = 1001,1006,1014

Equivalent AC-inductance vs. frequency at 1.9 K

NB: only for the trend, for a detail analysis the relevant inductance must be considered… (from https://edms.cern.ch/file/369859/1/6_Pugnat.pdf)