MP3 Recommendation to reduce QPS thresholds in IPQ for enhanced symmetric quench detection to allow more relaxed BLM threshold settings.

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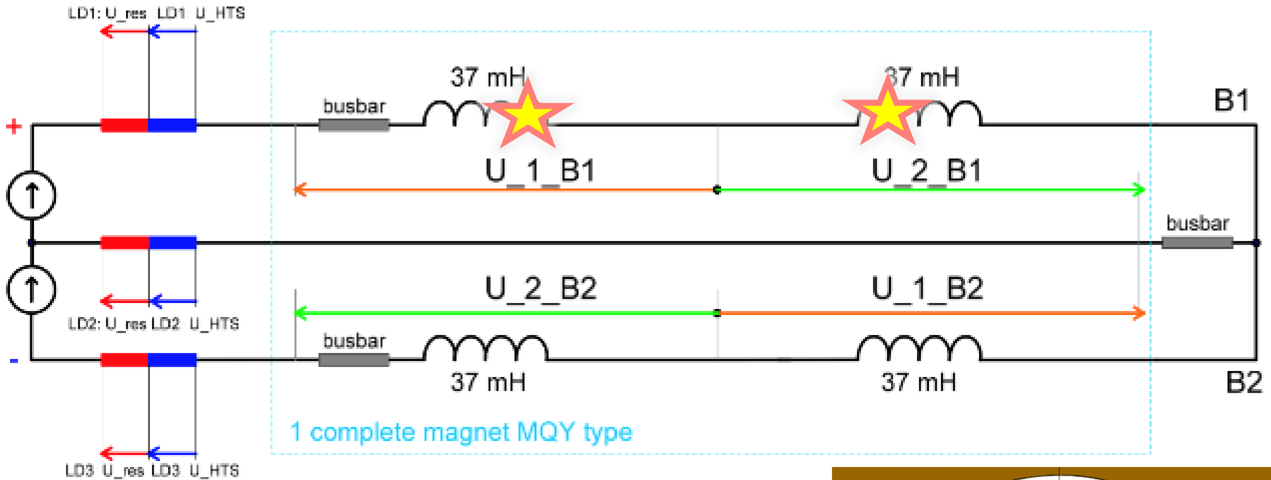
Quench detection

- Most of our protection strategy is based on detection of asymmetric quenches with differential comparison of two parts in the circuit to eliminate inductive components.
  - Between two apertures (MB, MQ)
  - Between two magnets in the same aperture (some IPQ, some IPD)
  - Between two cold masses (IT MQXB)
  - Between coils in the same cold mass, same aperture (some IPQ, D1, IT MQXA)

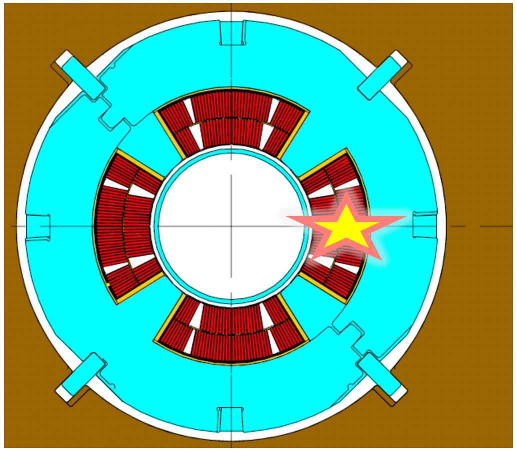
- Symmetric quenches are assumed only to occur between two magnet parts in the same aperture of the same cold mass.

- Other strategies are based on direct voltage measurements, including inductive components
  - Inductive components can be subtracted when measuring dI/dt.
  - Final redundancy to symmetric quenches, but in many cases with a very high threshold.

IPQ case

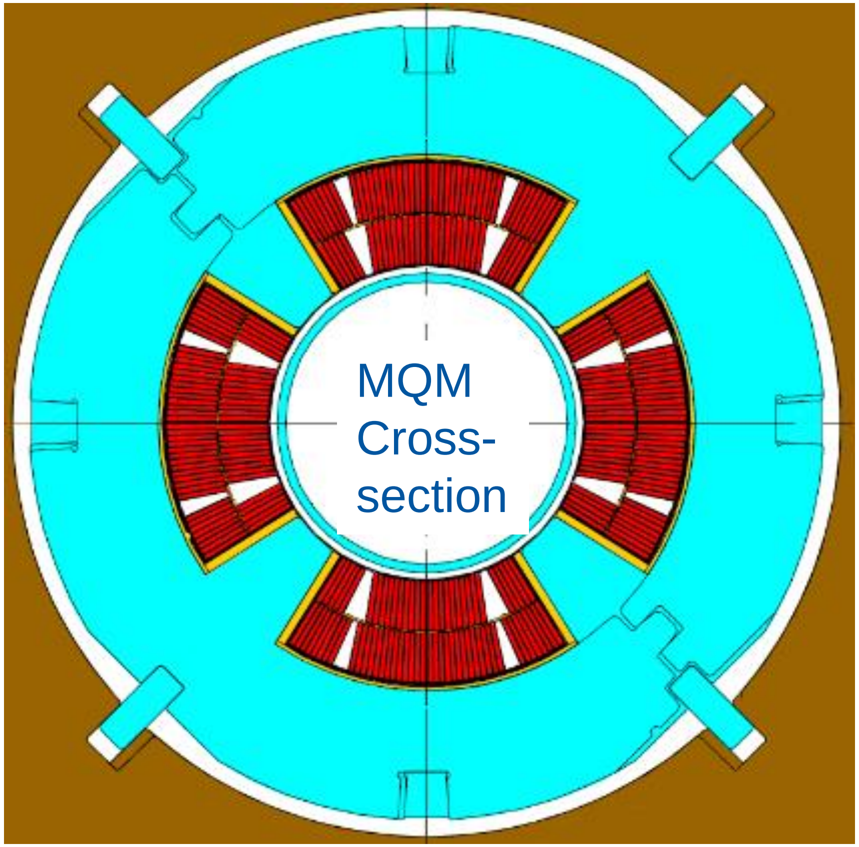


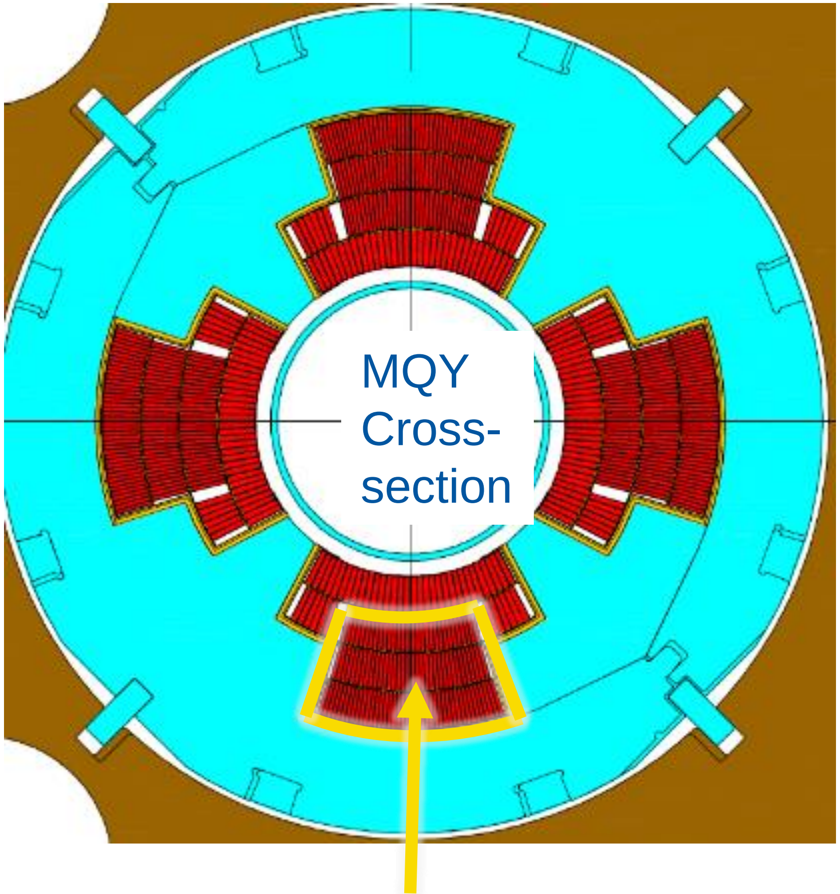
- Assymetric protection: 100 mV, 10 ms discrimination time, 20 ms moving average.
- In the circuits with a **single cold mass**, 2 poles are compared to the other 2 poles



Direct voltage protection at 5 V, reduced to 250 mV during quench tests with beam, but only manually after start of PC.

IPQ cross-sections





One cable type for MQM magnets

Outer layer cable block

Outer layer thinner,
-> higher current density
-> higher $T_{hotspot}$ with similar MIIts

Distinguishing cases

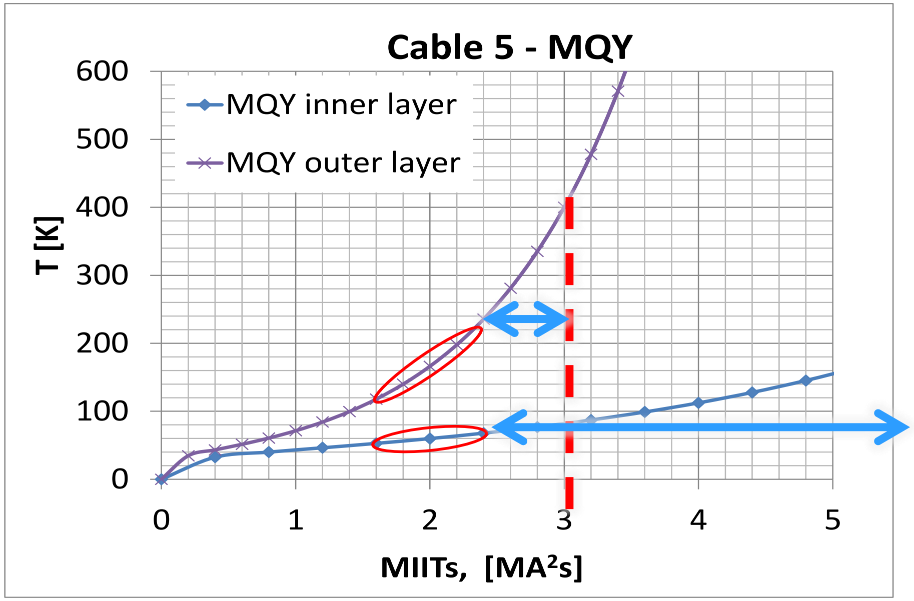
Case 1: Magnets with two cold masses.
Case 2: MQY magnets
Case 3: MQM magnets at 4.5 K, 4310 A
Case 4: MQM magnets at 1.9 K, 5390 A

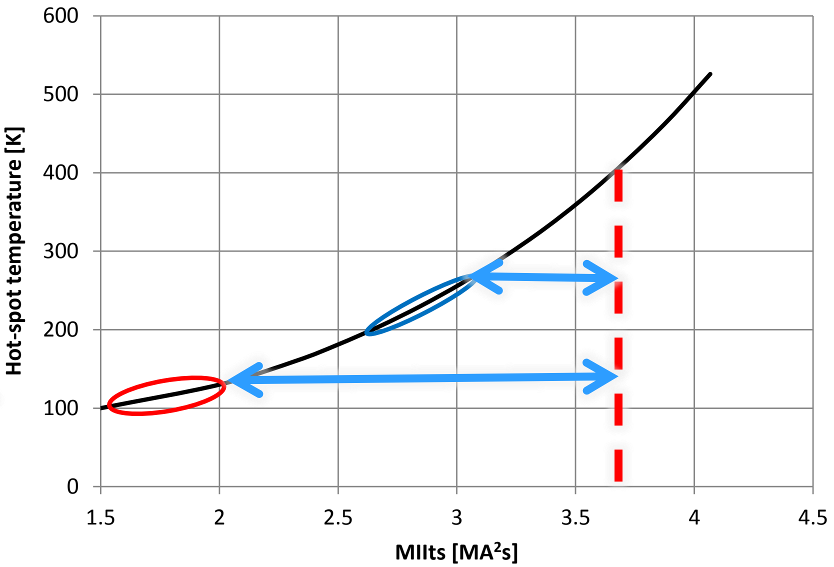
Case	Circuit	Location	Circuit type	Temperature (K)	Magnet design Current (A)
1	RQ4	IR 2,8	MQY + MQY	4.5	3610
1	RQ5	IR 2,8	MQY + MQY	4.5	3610
1	RQ6	IR 2,8	MQM + MQML	4.5	4310
1	RQ7	IR 1,2,5,8	MQM + MQM	1.9	5390
1	RQ9	IR 1,2,4,5,6,8	MQMC+MQM	1.9	5390
2	RQ4	IR 1,5,6	MQY	4.5	3610
2	RQ5	IR 4,6	MQY	4.5	3610
2	RQ6	IR 4	MQY	4.5	3610
3	RQ5	IR 1,5	MQML	4.5	4310
3	RQ6	IR 1,5	MQML	4.5	4310
4	RQ7	IR 4	MQM	1.9	5390
4	RQ8	IR 1,2,4,5,6,8	MQML	1.9	5390
4	RQ10	IR 1,2,4,5,6,8	MQML	1.9	5390

Case 1:
Since the differential for circuits with two cold masses is obtained by comparing the two cold masses, which physically far away from each other, no symmetry in a quench is expected.

Expected hotspot temperatures

Case 2: MQY magnets
Case 3: MQM magnets at 4.5 K, 4310 A
Case 4: MQM magnets at 1.9 K, 5390 A

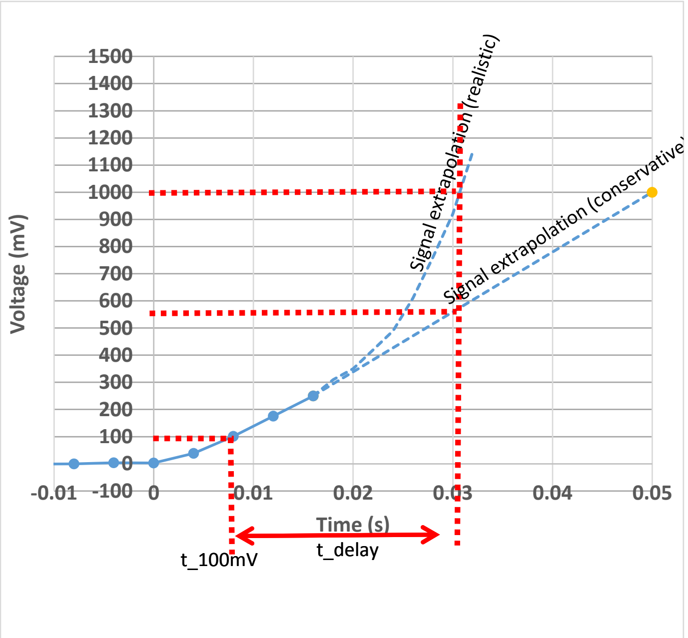




Magnet type	MIIts margin (MA^2s)	Ultimate Current (A)	Delay margin (ms)
MQY outer layer	0.6	3610	46
MQY inner layer	6	3610	460
MQM at 4.5 K	1.7	4310	92
MQM at 1.9 K	0.6	5390	21

In the recommendation we assume a limit of 400 K for worst case scenarios

Voltage buildup during normal asymmetric quench



QPS signal U_res has a limited range of 250 mV
U1 and U2 signals go to higher voltage
Quench heater firing limits the curve.
Extrapolation is needed.

The linear approach from 250 mV and higher is very conservative. The exponential is partially measured in U1 and U2 and more realistic.

The threshold needed to keep the hotspot at 400 K is calculated using the allowed delay, see previous slide.

Type	Time to reach 100 mV (ms)	Time between 100 and 250 mV (ms)	Slope from 250 mV (mV/ms)	Allowed additional time delay for $T_{hotspot}$ of 400 K (ms) (From Table 2)	Threshold setting for $T_{hotspot}$ of 400 K for asymmetric quench (V)
MQY outer layer	9 to 13	4 to 6	25 to 50	46	1.2 to 2.3 V
MQY inner layer	9 to 13	4 to 6	25 to 50	460	12 to 23 V
MQM at 4.5 K	10	5 to 8	20 to 60	92	1.9 to 5.3 V
MQM at 1.9 K	7 to 10	5 to 8	21 to 60	21 (discrimination time 10 ms in Q7 and Q8) 11 (discrimination time 20 ms in Q10)	0.52 to 1.03 V 0.31 to 0.43 V

Discrimination time increased from 10 ms to 20 ms for RQ9 and RQ10 magnets, see EDMS 1523069. this reduces the calculated time margin.

Symmetric quench detection

Full symmetry will never be detected with the asymmetric quench detection.

The level of symmetry is calculated as $(V_{400K} - V_{QPS})/V_{400K}$

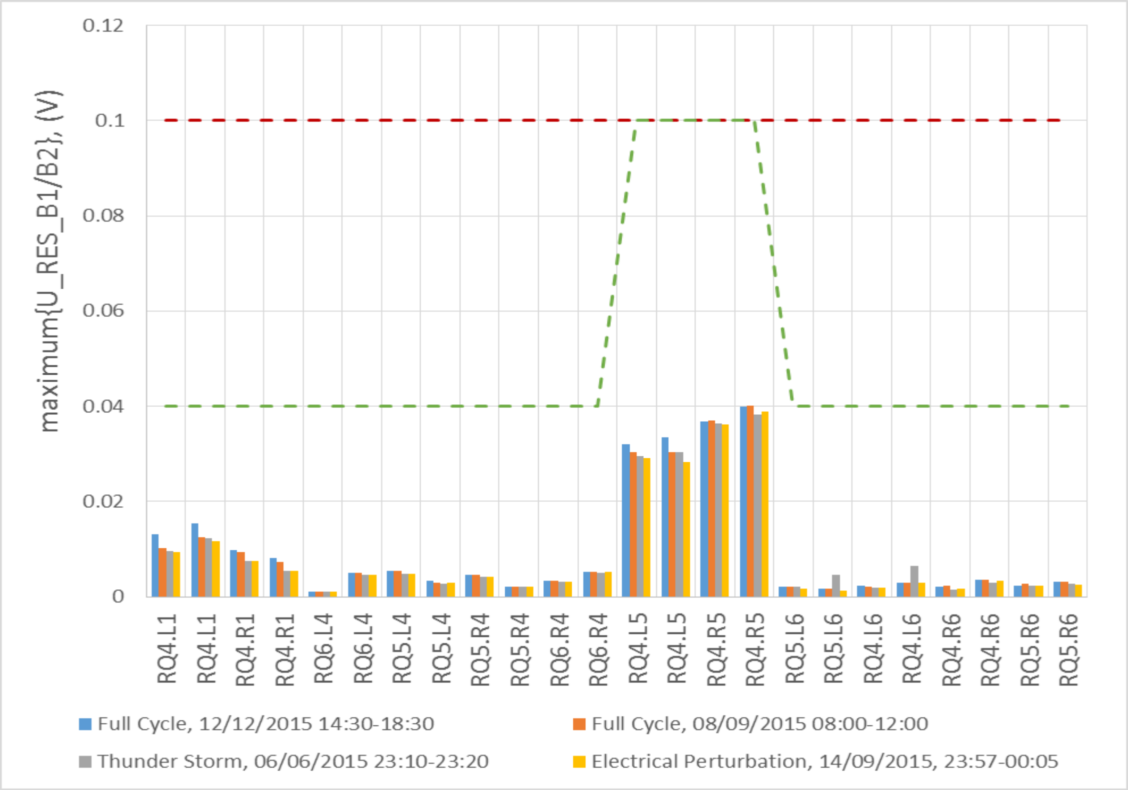
90 % symmetry seems a reasonable but arbitrary limit.

Magnet type	Threshold setting for $T_{hotspot}$ of 400 K for asymmetric quench (V)	QPS threshold setting	Protection level to % of symmetry in a quench
MQY outer layer	1.2 to 2.3 V 1.2 to 2.3 V	40 mV 100 mV	97 to 98 % symmetry
MQY inner layer	14 to 28 V	100 mV	> 99 % symmetry
MQM at 4.5 K	1.9 to 5.3 V	100 mV	95 to 98 % symmetry
MQM at 1.9 K	0.52 to 1.03 V 0.31 to 0.43 V	50 mV, 10 ms 100 mV, 20 ms	90 to 95 % symmetry 67 to 75 % symmetry

Not acceptable.
Symmetric quenches need to be prevented
Tight BLM thresholds are needed.

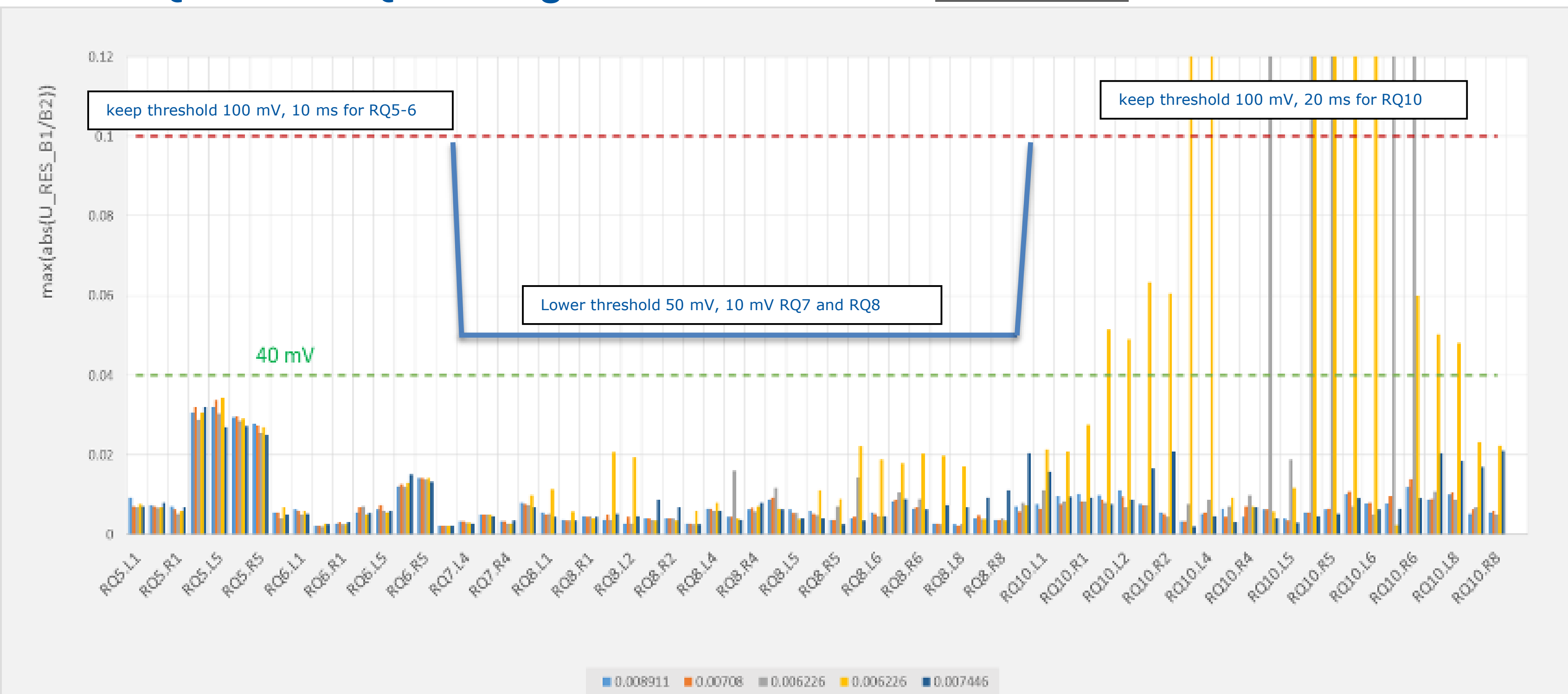
QPS noise levels – MQY circuits

- At the beginning of this year most thresholds in circuits with single MQY magnets have been reduced to 40 mV. This did not lead to trips yet, so there is no reason to change.



QPS noise levels – MQM circuits

- RQ10 is cricital for noise during perturbation, thunderstorms, etc, therefore the discrimination time increased from 10 ms to 20 ms for RQ9 and RQ10 magnets, see EDMS 1523069.



We do not see a chance to increase the threshold, nor discrimination time.

Recommendation 1/3

Circuits	QPS thresholds	BLM threshold rationale	Protection level to symmetric quenches
IPQ circuits with 2 cold masses. ***RQ4 IR2,8*** ***RQ5 IR2,8*** ***RQ6 IR2,8*** ***RQ7 IR1,2,5,8*** ***RQ9 IR1,2,4,5,6,8***	No changes, keep the 100 mV, 10 ms protection levels.	No risk of symmetric beam loss induced quenches due to separate cold masses in U1 and U2. ***No tight BLM setting needed for magnet protection.***	Not applicable
IPQ circuit with 1 MQY cold mass ***RQ4 IR1,5,6*** ***RQ5 IR4,6*** ***RQ6 IR4***	Changed already in March 2016. Keep 100 mV for 2 circuits and 40 mV for the other 10 circuits, If many trips occur with 40 mV, raise to 100 mV.	The protection of the inner layer cable is not critical. The outer layer is less prone to quench due to beam loss. ***No tight BLM setting needed for magnet protection.***	97 to 98 % symmetry (40 mV) 92 to 96 % symmetry (100 mV)

CERN

Recommendation 2/3

Circuits	QPS thresholds	BLM threshold rationale	Protection level to symmetric quenches
IPQ circuits with 1 MQM cold mass, operated at 4.5 K ***RQ5 IR1,5*** ***RQ6 IR1,5***	Keep 100 mV protection settings.	Symmetry protection level deemed high enough. ***No tight BLM setting needed for magnet protection.***	95 to 98 % symmetry
IPQ circuits with 1 MQM cold mass, operated at 1.9 K in locations Q7 and Q8. ***RQ7 IR4*** ***RQ8 IR1,2,4,5,6,8***	Reduce threshold to 50 mV.	Symmetry protection level deemed high enough. ***No tight BLM setting needed for magnet protection.***	90 to 95 % symmetry

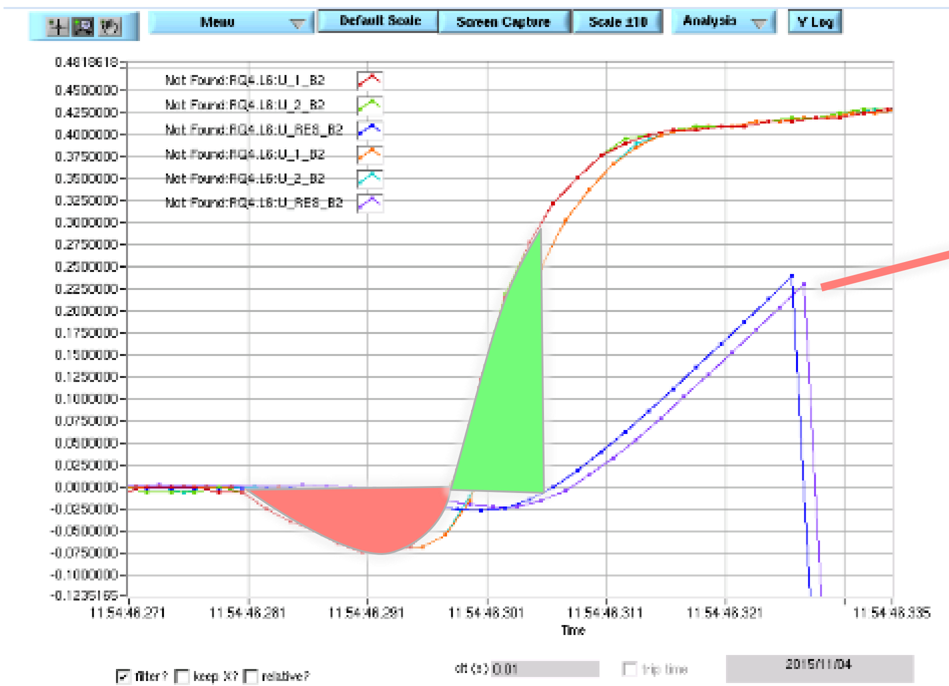
Recommendation 3/3

Circuits	QPS thresholds	BLM threshold rationale	Protection level to symmetric quenches
IPQ circuits with 1 cold mass in location Q10 ***RQ10 IR1,2,4,5,6,8***	Keep threshold at 100 mV and discrimination time at 20 ms. .	This case is the most critical and reduction of threshold is not possible. Investigation from MPP is needed to estimate chance of beam loss in the dispersion suppressor region, compared to MB magnets and to the symmetry of beam losses. ***Tighter setting of BLMs are needed for magnet protection.***	67 to 75 % symmetry

The MP3 encourages the development of quench protection cards with inductive compensation, since they will give an adequate protection of symmetric quenches in the IPQ circuits.

Actual beam induced quench,

B2, BIQ, signature of asymmetric part of quench. U1 = U2! U_RES lags due to 20 ms mov. avg.



Small U_Res

- NB: PM time scale x10 too long due to special high-resolution mode.