MQXFB09: Coil ordering

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06/02/2025

Background

- With the introduction of the **mini-swap** in MQXFB magnets, there is a bit **less margin in the protection at low field to tolerate the spread on QH parameters** (circuit resistance, capacitance/voltage of the HFU…).

- The stablished **requirements** for the **quench heater resistance** are:
  - Quench heater resistance at **293 K** between 5.6 and 7.3 Ω
  - Quench heater resistance at **nominal operation conditions** between 3.2 and 4.2 Ω
  - At least 6 quench heater circuits with at least 3.4 Ω resistance at **nominal operation conditions**

- To assure the fulfill of the requirements with margin, in addition to the usual criteria to select coil ordering (RRR and Cu/Sc ratio), a **check on** the spread of the **QH resistance circuit** is performed systematically before the assembly of every magnets, **starting from MQXFB04**.

Coil sorting according to coil material properties (RRR and Cu/Sc ratio)

Simulation of a quench at nominal current (16230 A).
Cases included in the parametric analysis:
- Case A: No failures
- Case B: QH1+QH3 circuit failures
- Case C: QH5+QH6 circuit failures
- Case D: CLIQ+QH2 circuit failures
- Case E: CLIQ+QH6 circuit failures
- Worst-case: Highest voltage to ground among above-mentioned cases.

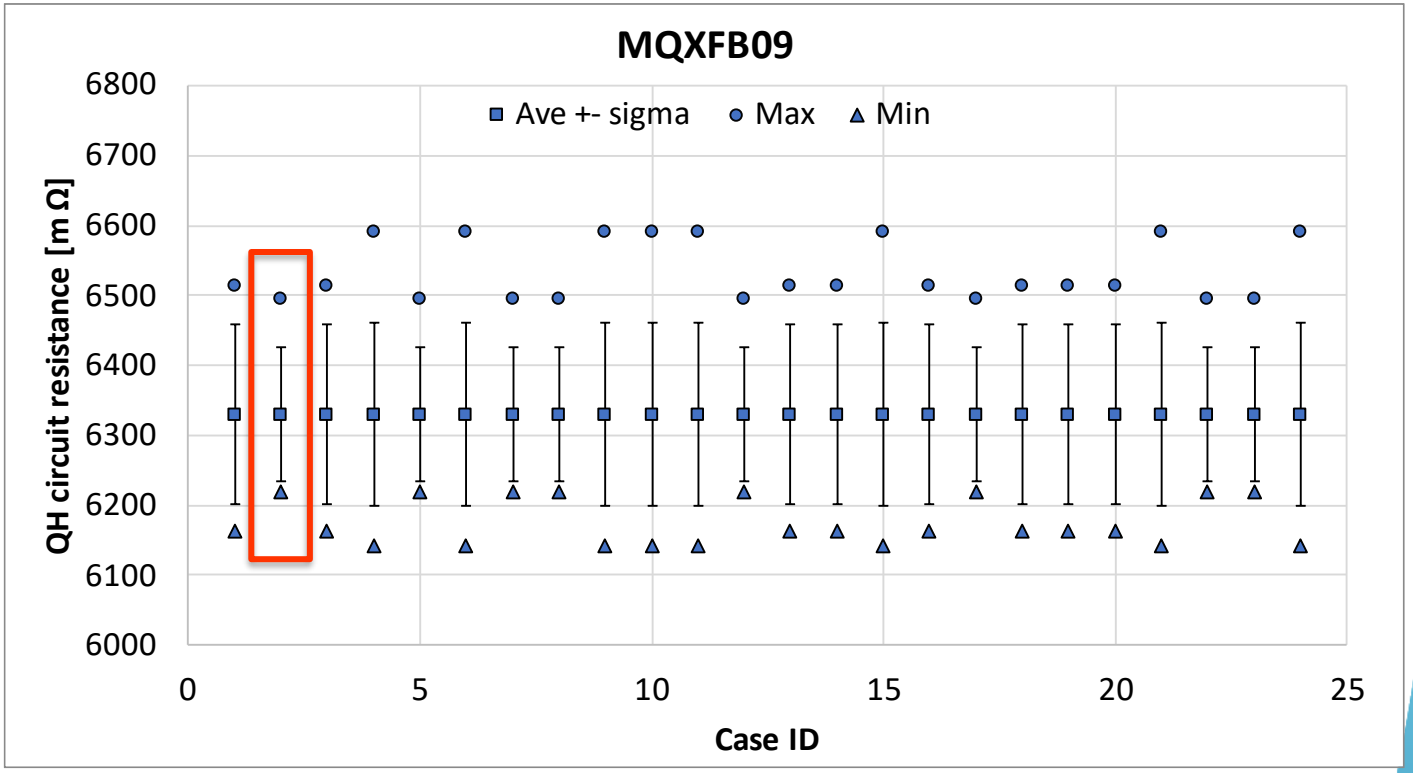
Maximum expected coil voltage defined by electrical design criteria (e.d.c.): 670 V at nominal current (see EDMS 1963398).
Configurations resulting in peak voltage to ground higher than this value are highlighted in red.

	Electrical order	Case A	Case B	Case C	Case D	Case E	Worst-case	% wrt lowest	% wrt e.d.c.
1	154 152 153 155	544	601	633	632	597	633	+0%	-6%
2	154 153 152 155	544	602	634	631	595	634	+0%	-5%
3	154 152 155 153	546	602	636	614	616	636	+0%	-5%
4	154 155 153 152	546	602	636	622	593	636	+0%	-5%
5	154 153 155 152	546	603	636	629	592	636	+0%	-5%
6	154 155 152 153	546	602	637	605	614	637	+1%	-5%
7	153 154 152 155	571	634	661	630	592	661	+4%	-1%
8	153 154 155 152	573	635	663	628	590	663	+5%	-1%
9	155 154 152 153	577	638	664	605	611	664	+5%	-1%
10	155 154 153 152	577	638	664	621	590	664	+5%	-1%
11	153 152 154 155	583	641	673	627	597	673	+6%	+0%
12	155 152 154 153	589	646	676	601	616	676	+7%	+1%
13	153 155 154 152	586	642	676	617	593	676	+7%	+1%
14	155 153 154 152	588	646	676	617	592	676	+7%	+1%
15	153 152 155 154	587	643	677	586	641	677	+7%	+1%
16	153 155 152 154	588	643	678	578	639	678	+7%	+1%
17	155 152 153 154	590	647	678	579	641	678	+7%	+1%
18	155 153 152 154	590	647	679	578	639	679	+7%	+1%
19	152 154 153 155	592	656	681	629	592	681	+8%	+2%
20	152 154 155 153	595	657	684	611	611	684	+8%	+2%
21	152 153 154 155	604	663	693	625	594	693	+9%	+3%
22	152 155 154 153	607	664	696	599	614	696	+10%	+4%
23	152 155 153 154	608	664	697	577	639	697	+10%	+4%
24	152 153 155 154	608	665	697	584	639	697	+10%	+4%

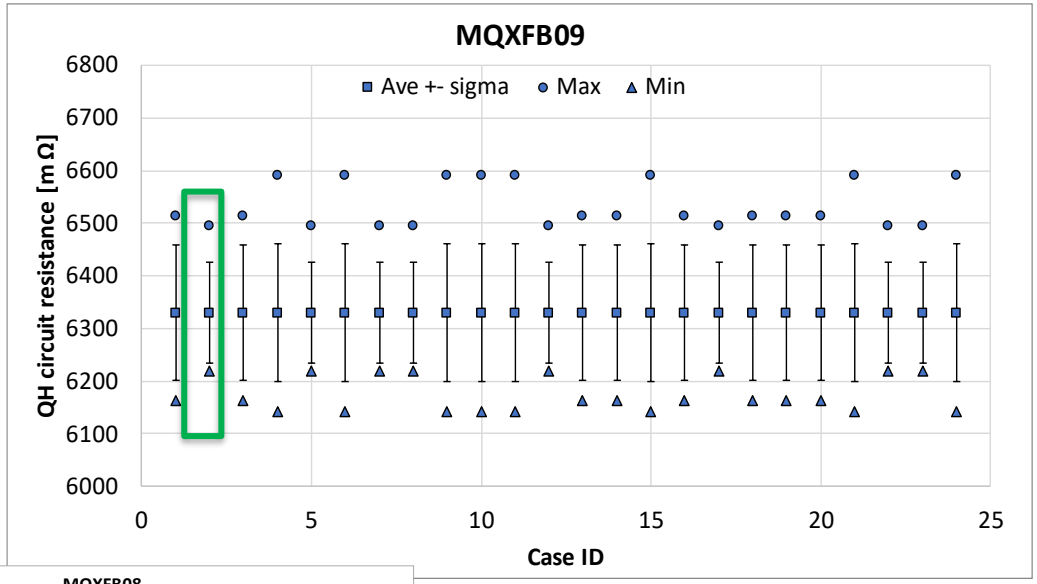
Generated by E. Ravaioli, TE-MPE-PE

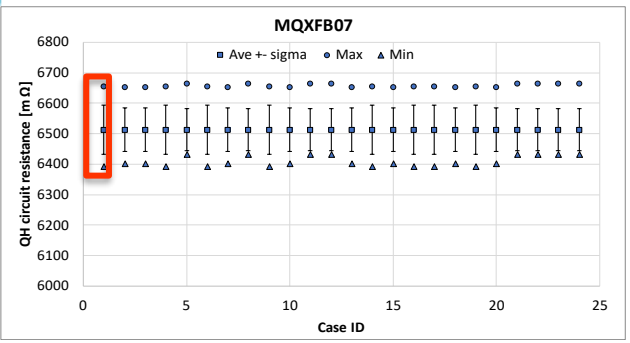
Coil sorting according to QH resistance

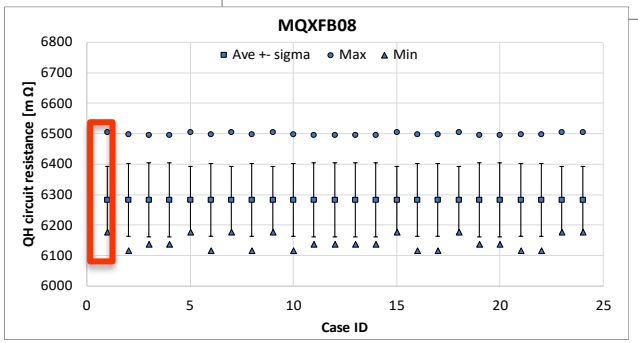
	Electrical order			
CASE ID	P1	P2	P3	P4
1	154	152	153	155
2	154	153	152	155
3	154	152	155	153
4	154	155	153	152
5	154	153	155	152
6	154	155	152	153
7	153	154	152	155
8	153	154	155	152
9	155	154	152	153
10	155	154	153	152
11	153	152	154	155
12	155	152	154	153
13	153	155	154	152
14	155	153	154	152
15	153	152	155	154
16	153	155	152	154
17	155	152	153	154
18	155	153	152	154
19	152	154	153	155
20	152	154	155	153
21	152	153	154	155
22	152	155	154	153
23	152	155	153	154
24	152	153	155	154

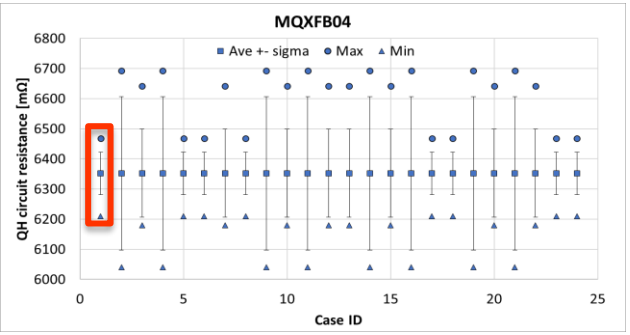


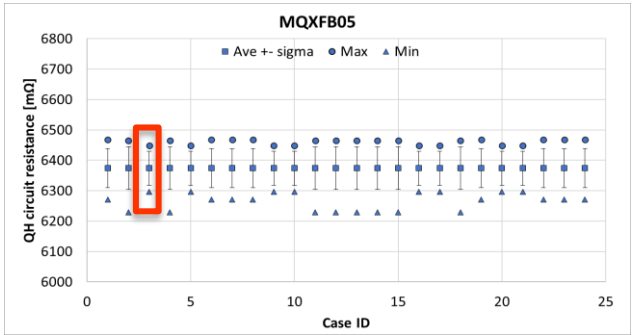
MQXFB09, B08, B07, B06, B05 and B04

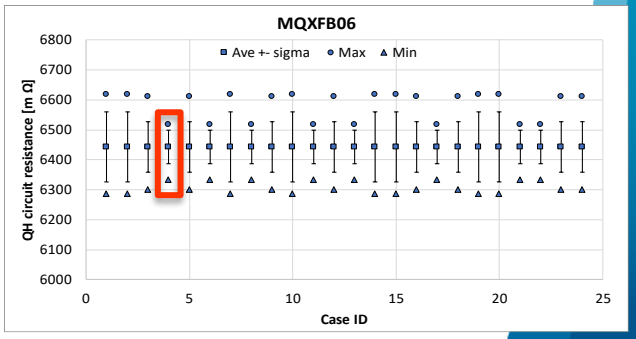






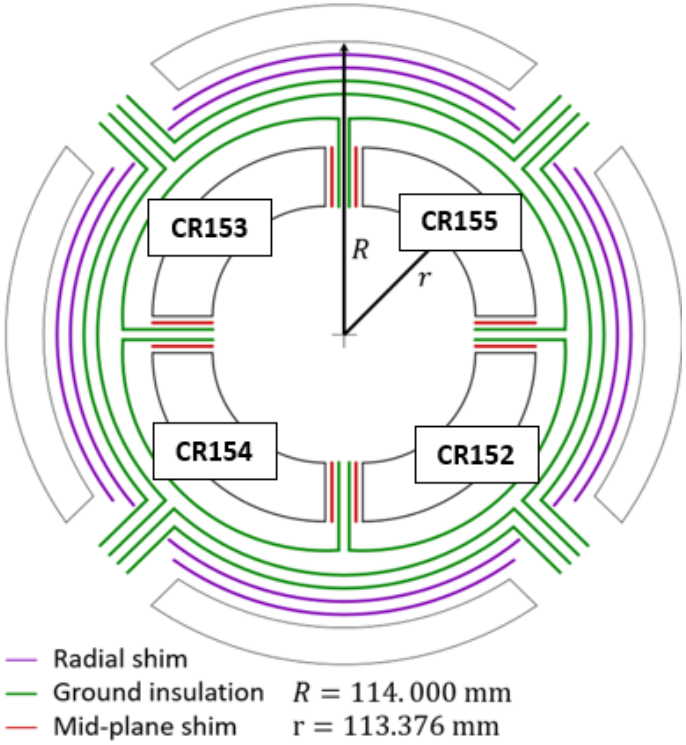






Conclusion

- Here is presented the coils ordering for MQXFB09

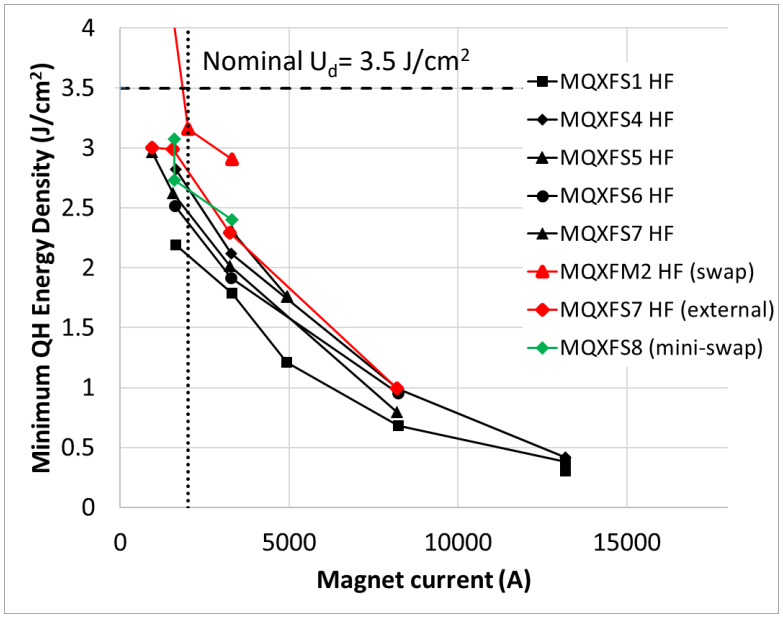


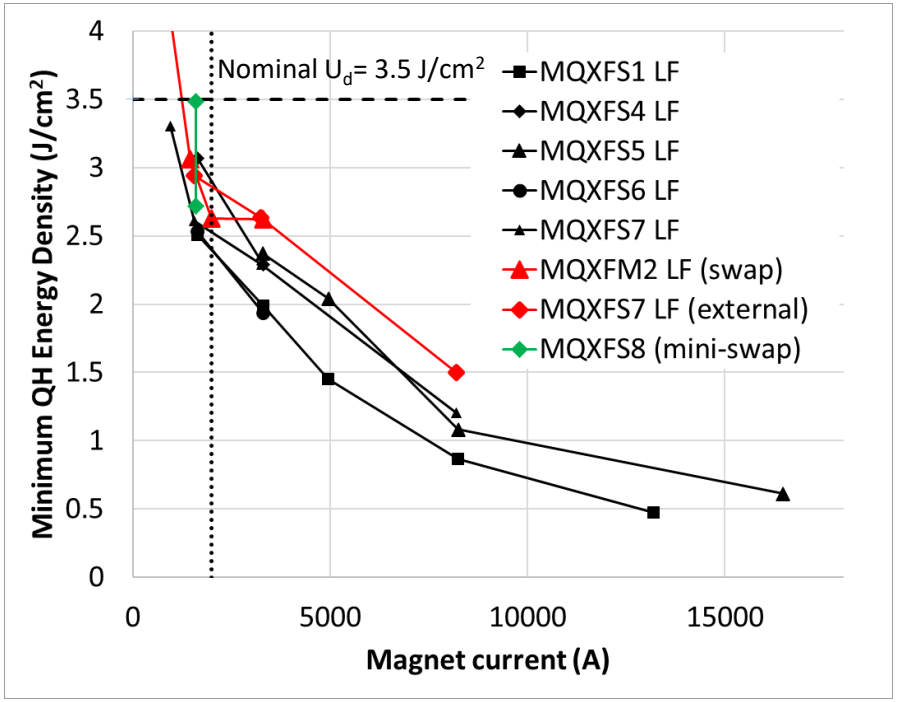
References

- Quench heater parameters MQXF (22/01/2022) https://indico.cern.ch/event/1119409/
- NCR MQXFBP3 QH resistance EDMS 2782298
- Quench heater parameters MQXF (09/07/2021) https://indico.cern.ch/event/950696/
- NCR MQXFBP2 QH resistance EDMS 2643444
- HL-MCF Meeting #121 Update on the MQXFB QH Resistances https://indico.cern.ch/event/1305402/

Additional slides

Minimum energy density





Minimum Energy Density = 2.5 – 2.7 J/cm^2 (to initiate a quench at 2 kA)

Final QH configuration:

MQXFB mini swap (more protection tests planned in S8, to have more statistics)

MQXFA impregnated heaters in direct contact with the coil (S1-S6)

QH resistance – individual strips

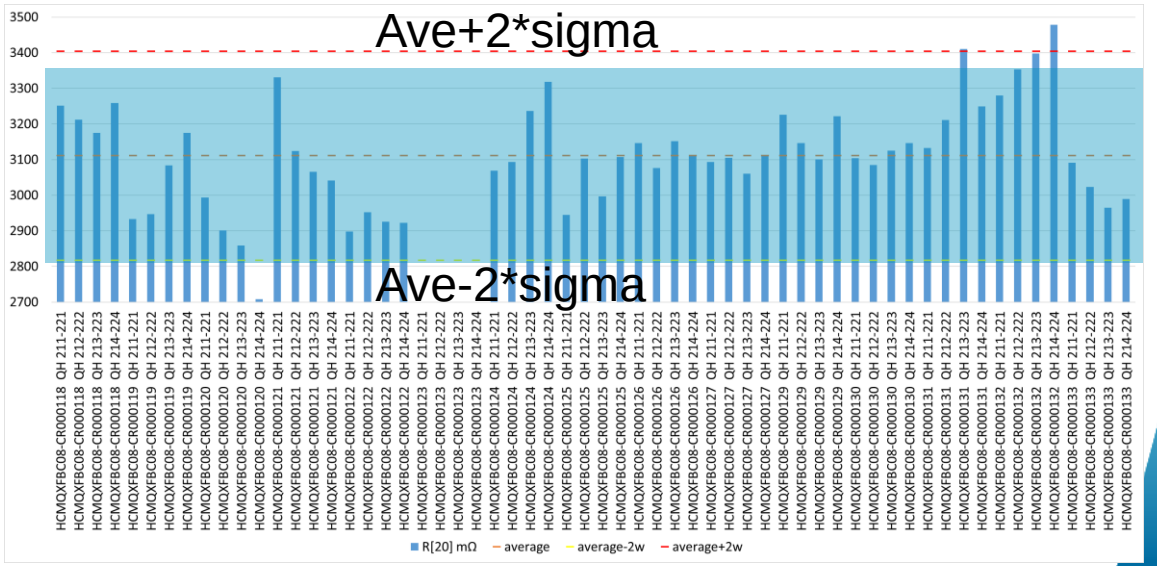
- The target was 3.1 ± 0.26 (2.84-3.36 ohms, i.e., ± 8 %)
- With few exceptions, we are within the target
- In case we are slightly out of the tolerance in the individual strips, the expected heater circuit resistance after assembly is checked and if possible, the coil can be placed in the optimal position to compensate for deviations
  - The driving parameter is the peak voltage to ground based on conductor properties, but in general several configurations are able to fulfill requirements
  - So far, this optimization was not needed.

Average of R[20] mΩ	Column Labels				
Row Labels	QH 211-221	QH 212-222	QH 213-223	QH 214-224	Grand Total
High field quench heater - Left		3095.176874			3095.176874
High field quench heater - Right			3110.955652		3110.955652
Low field quench heater - Left	3106.567586				3106.567586
Low field quench heater - Right				3131.417987	3131.417987
Grand Total	**3106.567586**	**3095.176874**	**3110.955652**	**3131.417987**	**3111.029525**

Ref. Coil	(All)

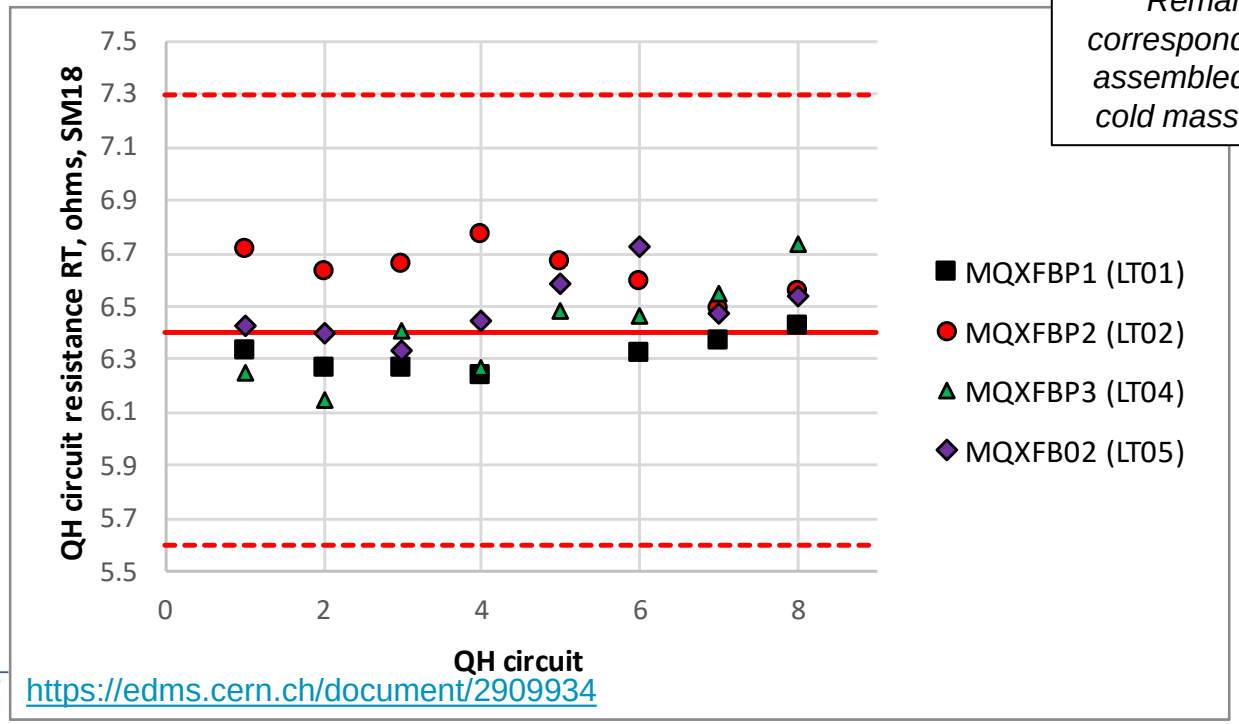
StdDevp of R[20] mΩ	Column Labels				
Row Labels	QH 211-221	QH 212-222	QH 213-223	QH 214-224	Grand Total
High field quench heater - Left		114.1950159			114.1950159
High field quench heater - Right			153.8398056		153.8398056
Low field quench heater - Left	128.9490125				128.9490125
Low field quench heater - Right				179.045659	179.045659
Grand Total	**128.9490125**	**114.1950159**	**153.8398056**	**179.045659**	**146.6963646**

Limites	min	max
QHs	2817.636796	3404.422254



Quench heater circuit resistance, tolerance range at warm, SM18

- SM18 ranges follow 180 tolerances for electrical QA, i.e., 5.6 – 7.3 ohms (i.e, +- 13 %)
  - Previous target 6-6.8 ohms (i.e, +- 6 %)
  - For reference, LHC dipoles was 22 ohms +- 4.5 ohms (i.e, +- 20 %)
- The maximum difference between warm before test and warm after test shall be < 0.05 ohms (as LHC dipoles)

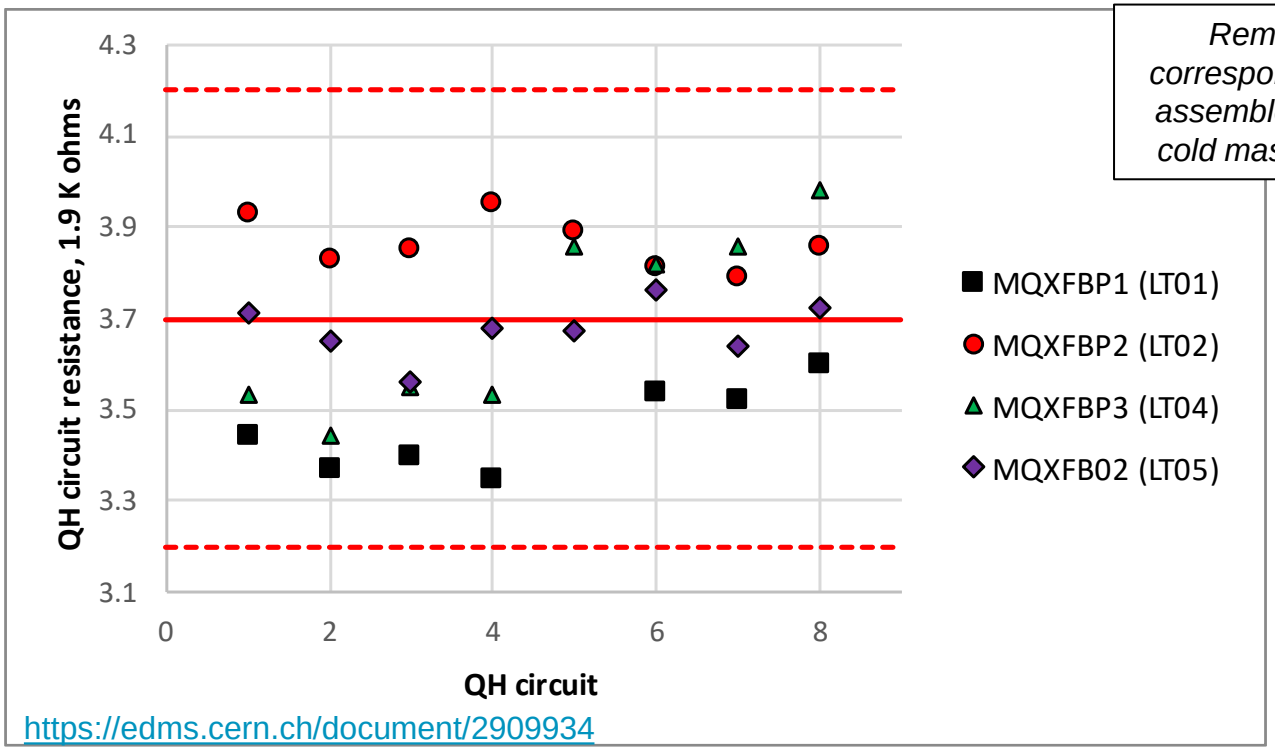


Remark: all data corresponds to magnets assembled in temporary cold mass configuration

https://edms.cern.ch/document/2909934

Quench heater circuit resistance, tolerance range at cold, SM18

- At cold, we keep the same spread that at warm, i.e., 13 %
  - Target is 3.7 +- 0.5 ohms (i.e., 3.2 to 4.2 ohms, before it was 3.5-3.9 ohms)
    - The resistance of at least 4 circuits shall be larger than 3.4 ohms to assure sufficient margin to initiate a quench at low current
  - For reference, LHC dipoles was 12.5 ohms +- 3 ohms (i.e, +- 24 %)



Remark: all data corresponds to magnets assembled in temporary cold mass configuration

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Cold vs warm

- Remark: after MQXFBMT4 test, enough information to decouple the RRR from quench heaters and wiring, to maybe find a better correlation in terms of RRR