MQXFB07: Coil ordering

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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.

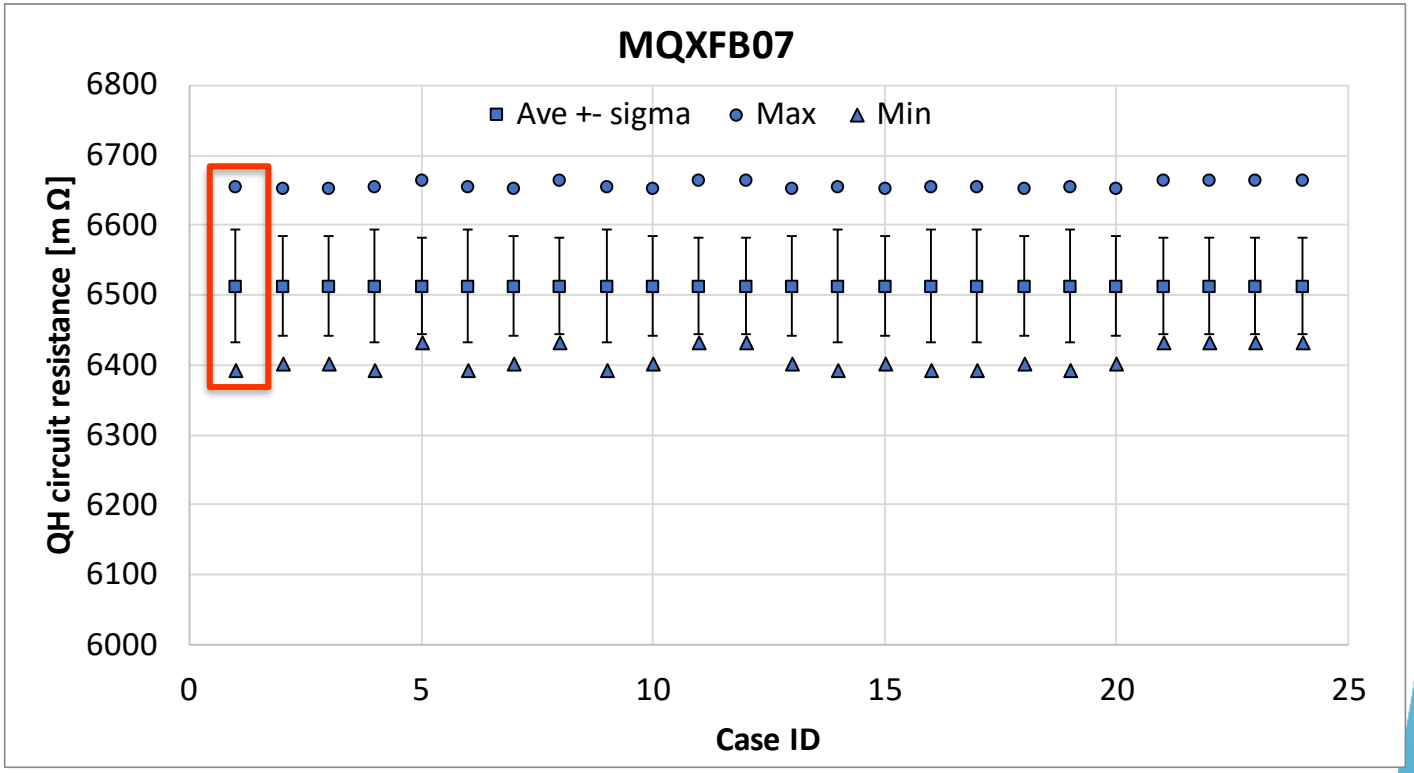
Maximum expected coil voltage defined by electrical design criteria (e.d.c.): 670 V at nominal current (see EDMS 1963398).
Configurations resulting in peak voltage to ground higher than this value are highlighted in red.

	Electrical order	Case A	Case B	Case C	Case D	Case E	Worst-case	% wrt lowest	% wrt e.d.c.
1	146 147 138 145	531	586	617	629	573	629	+0%	-6%
2	138 147 146 145	546	602	634	629	573	634	+1%	-5%
3	146 145 147 138	530	584	619	577	634	634	+1%	-5%
4	146 147 145 138	533	586	619	575	635	635	+1%	-5%
5	138 146 147 145	525	581	606	638	567	638	+1%	-5%
6	138 145 146 147	543	600	630	638	565	638	+2%	-5%
7	146 145 138 147	528	584	614	639	565	639	+2%	-5%
8	146 138 147 145	525	572	592	639	569	639	+2%	-5%
9	138 145 147 146	546	601	635	569	645	645	+3%	-4%
10	138 147 145 146	549	602	635	567	645	645	+3%	-4%
11	138 146 145 147	525	581	604	646	560	646	+3%	-4%
12	146 138 145 147	525	573	591	647	561	647	+3%	-3%
13	145 146 138 147	590	655	674	635	560	674	+7%	+1%
14	145 138 146 147	593	658	677	636	561	677	+8%	+1%
15	145 146 147 138	593	656	679	574	628	679	+8%	+1%
16	147 146 138 145	598	662	681	625	567	681	+8%	+2%
17	145 138 147 146	596	658	682	566	640	682	+8%	+2%
18	147 138 146 145	601	665	684	626	569	684	+9%	+2%
19	147 146 145 138	600	663	685	571	628	685	+9%	+2%
20	147 138 145 146	603	665	688	564	640	688	+9%	+3%
21	145 147 146 138	621	676	707	564	634	707	+12%	+6%
22	145 147 138 146	621	676	707	556	645	707	+12%	+6%
23	147 145 146 138	626	682	711	564	634	711	+13%	+6%
24	147 145 138 146	626	682	711	556	645	711	+13%	+6%

Generated by E. Ravaioli, TE-MPE-PE

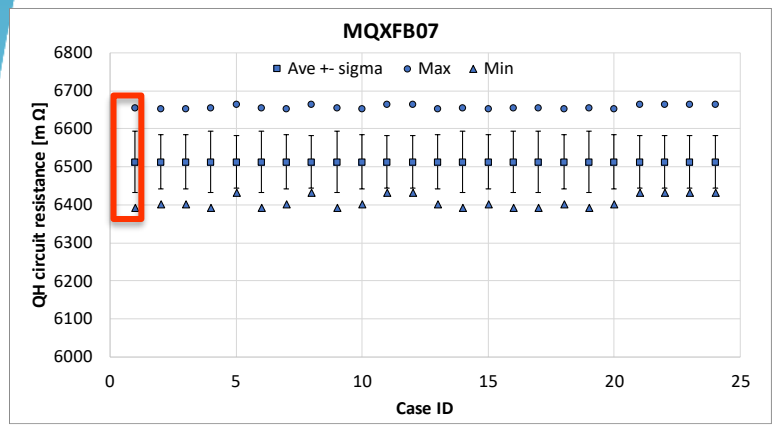
Coil sorting according to QH resistance

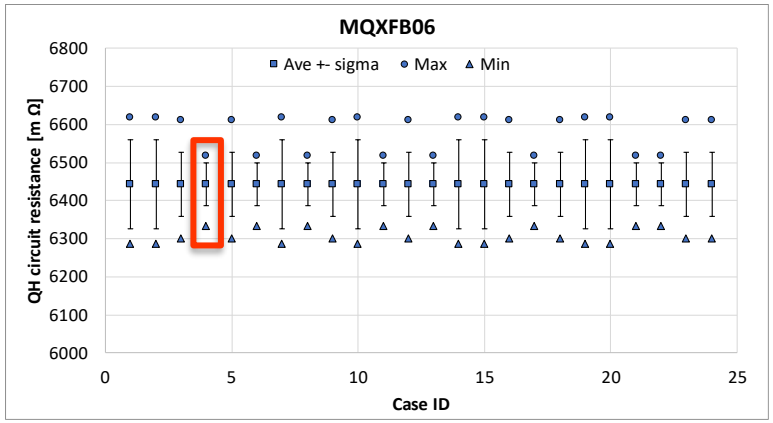
	Electrical order			
CASE ID	P1	P2	P3	P4
1	146	147	138	145
2	138	147	146	145
3	146	145	147	138
4	146	147	145	138
5	138	146	147	145
6	138	145	146	147
7	146	145	138	147
8	146	138	147	145
9	138	145	147	146
10	138	147	145	146
11	138	146	145	147
12	146	138	145	147
13	145	146	138	147
14	145	138	146	147
15	145	146	147	138
16	147	146	138	145
17	145	138	147	146
18	147	138	146	145
19	147	146	145	138
20	147	138	145	146
21	145	147	146	138
22	145	147	138	146
23	147	145	146	138
24	147	145	138	146

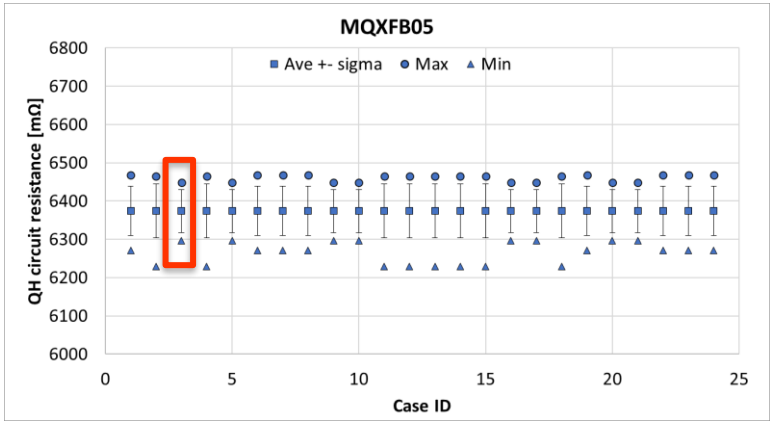


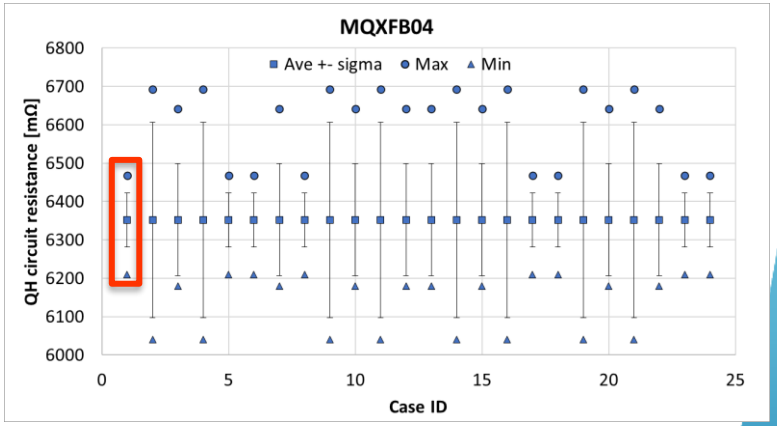
MQXFB07, B06, B05 and B04

- QH production is becoming more and more reproducible!



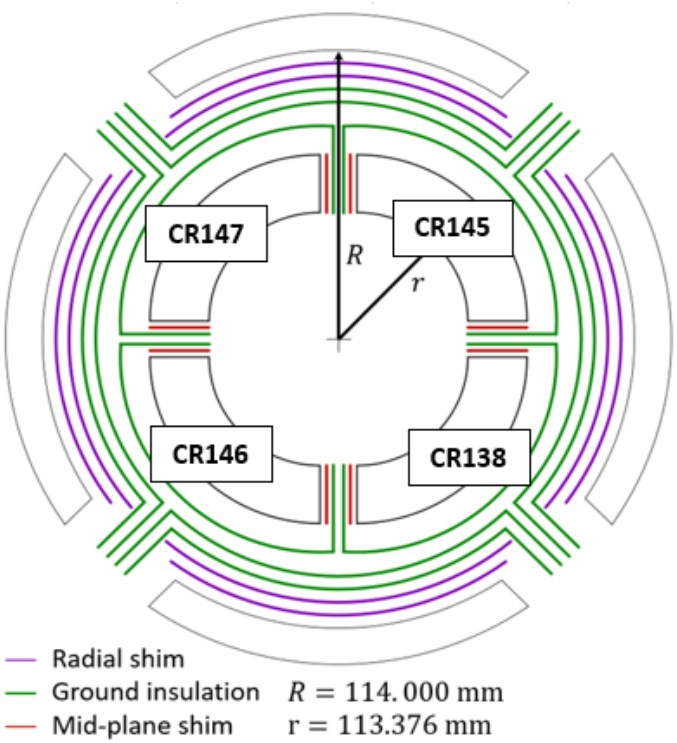






Conclusion

- Here is presented the coils ordering for MQXFB07

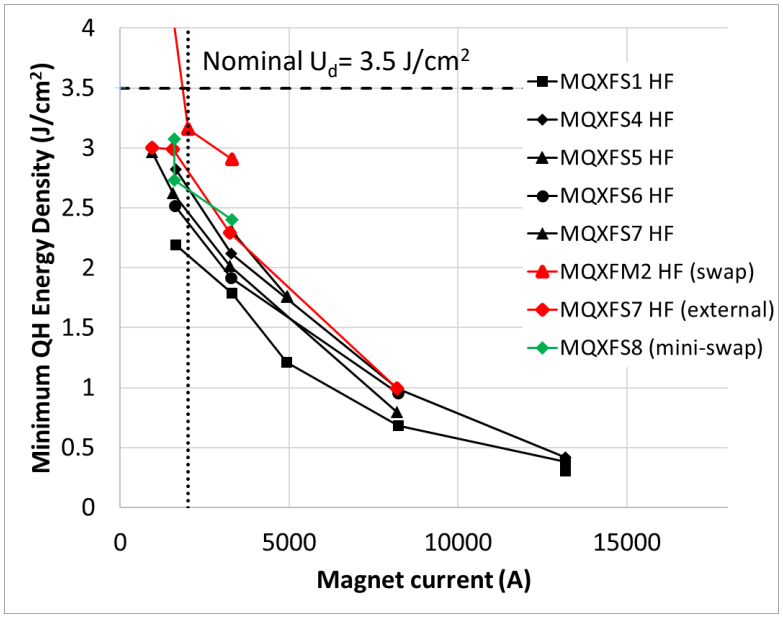


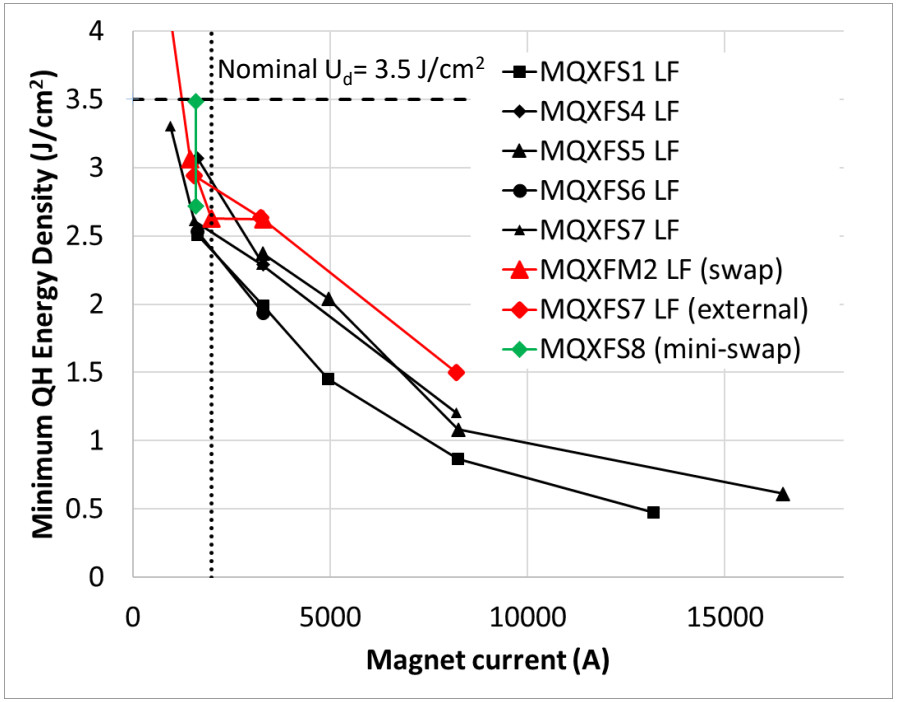
References

- 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

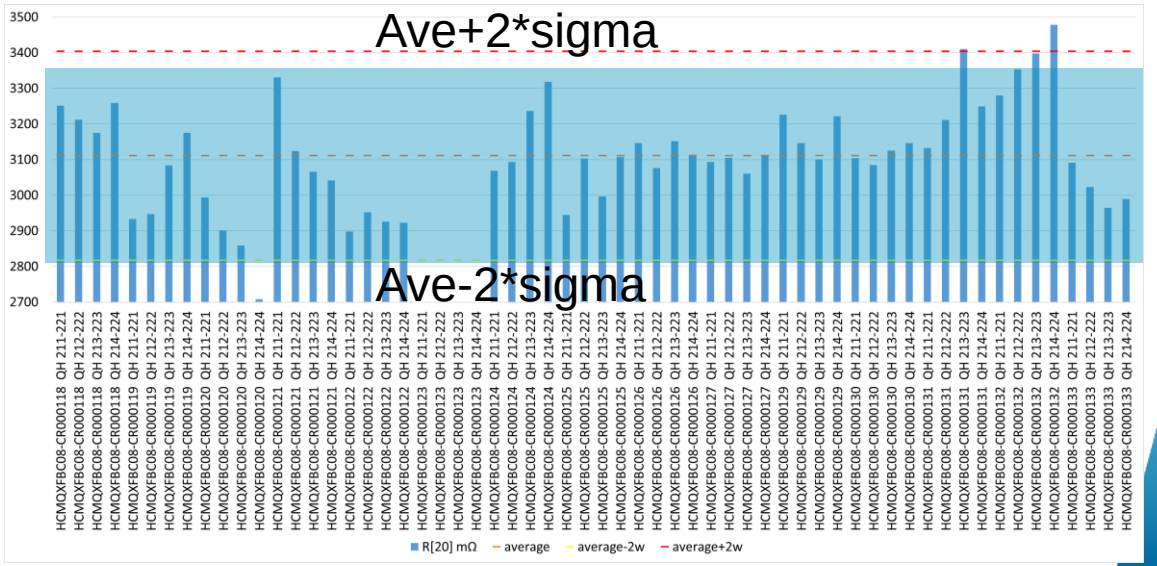
- The target was 3.1 ± 0.26 (2.84-3.36 ohms, i.e., ± 8 %)
- With few exceptions, we are within the target
- In case we are slightly out of the tolerance in the individual strips, the expected heater circuit resistance after assembly is checked and if possible, the coil can be placed in the optimal position 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)

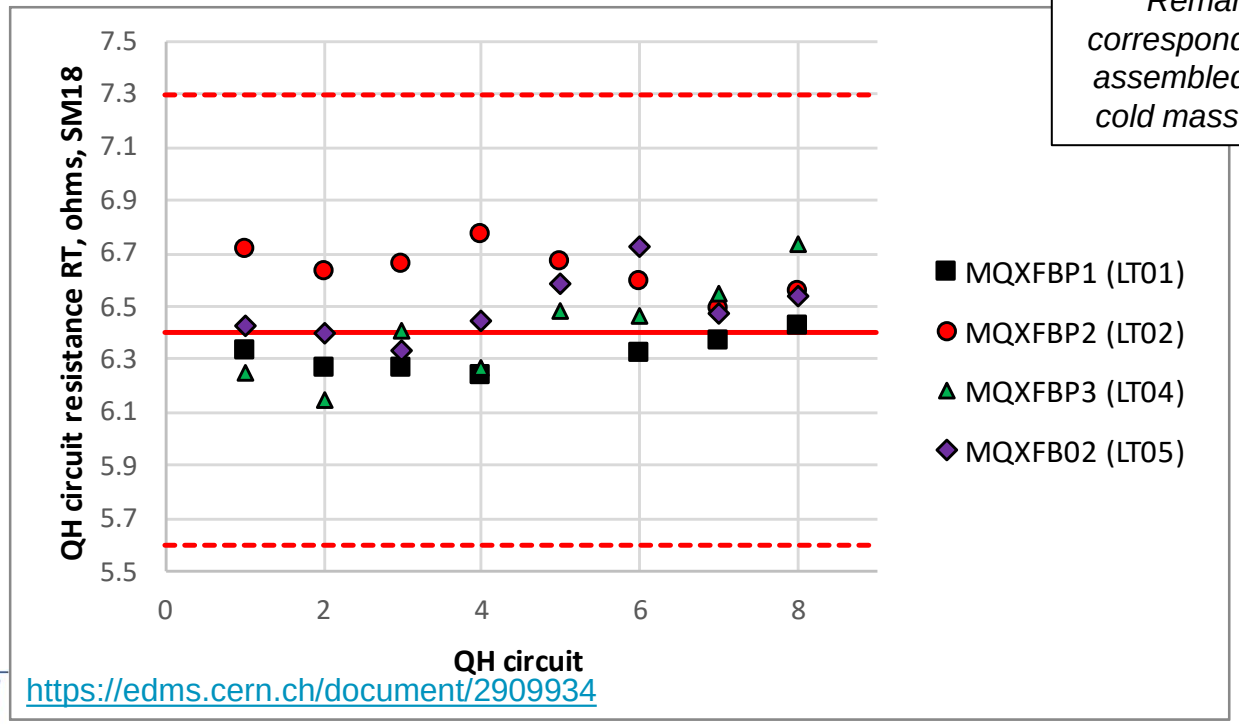
StdDevp of R[20] mΩ	Column Labels				
Row Labels	QH 211-221	QH 212-222	QH 213-223	QH 214-224	Grand Total
High field quench heater - Left		114.1950159			114.1950159
High field quench heater - Right			153.8398056		153.8398056
Low field quench heater - Left	128.9490125				128.9490125
Low field quench heater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

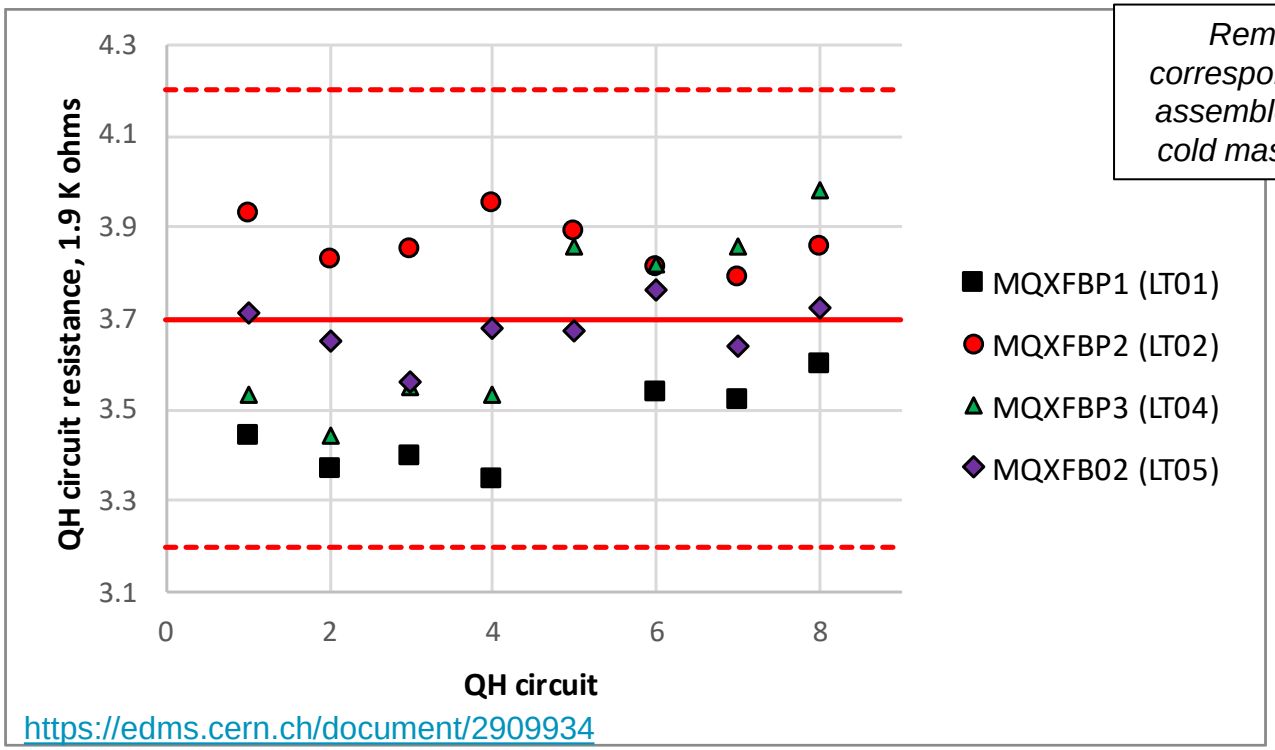


Remark: all data corresponds to magnets assembled in temporary cold mass configuration

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