MQXFB08: 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	148 151 149 150	526	584	614	596	605	614	+0%	-8%
2	148 150 149 151	532	590	621	603	599	621	+1%	-7%
3	148 149 150 151	540	594	627	600	603	627	+2%	-6%
4	148 149 151 150	541	595	629	596	608	629	+2%	-6%
5	148 151 150 149	525	583	610	635	560	635	+3%	-5%
6	148 150 151 149	530	590	618	636	560	636	+4%	-5%
7	151 148 150 149	555	618	642	632	557	642	+5%	-4%
8	150 148 151 149	557	619	643	634	557	643	+5%	-4%
9	151 148 149 150	558	620	645	593	602	645	+5%	-4%
10	150 148 149 151	558	620	646	600	596	646	+5%	-4%
11	150 151 148 149	564	624	647	633	560	647	+5%	-3%
12	150 151 149 148	563	622	651	572	633	651	+6%	-3%
13	151 150 148 149	566	627	653	633	559	653	+6%	-3%
14	151 150 149 148	568	628	657	571	633	657	+7%	-2%
15	150 149 148 151	577	633	664	599	603	664	+8%	-1%
16	151 149 148 150	577	633	664	592	608	664	+8%	-1%
17	151 149 150 148	576	632	664	569	636	664	+8%	-1%
18	150 149 151 148	578	633	665	571	636	665	+8%	-1%
19	149 148 150 151	603	665	686	595	596	686	+12%	+2%
20	149 148 151 150	603	666	688	590	602	688	+12%	+3%
21	149 151 148 150	611	672	691	589	605	691	+13%	+3%
22	149 151 150 148	608	668	691	566	633	691	+13%	+3%
23	149 150 148 151	614	674	698	596	599	698	+14%	+4%
24	149 150 151 148	615	675	700	568	633	700	+14%	+4%

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3

Coil sorting according to QH resistance

CASE ID	Electrical order			
	P1	P2	P3	P4
1	148	151	149	150
2	148	150	149	151
3	148	149	150	151
4	148	149	151	150
5	148	151	150	149
6	148	150	151	149
7	151	148	150	149
8	150	148	151	149
9	151	148	149	150
10	150	148	149	151
11	150	151	148	149
12	150	151	149	148
13	151	150	148	149
14	151	150	149	148
15	150	149	148	151
16	151	149	148	150
17	151	149	150	148
18	150	149	151	148
19	149	148	150	151
20	149	148	151	150
21	149	151	148	150
22	149	151	150	148
23	149	150	148	151
24	149	150	151	148
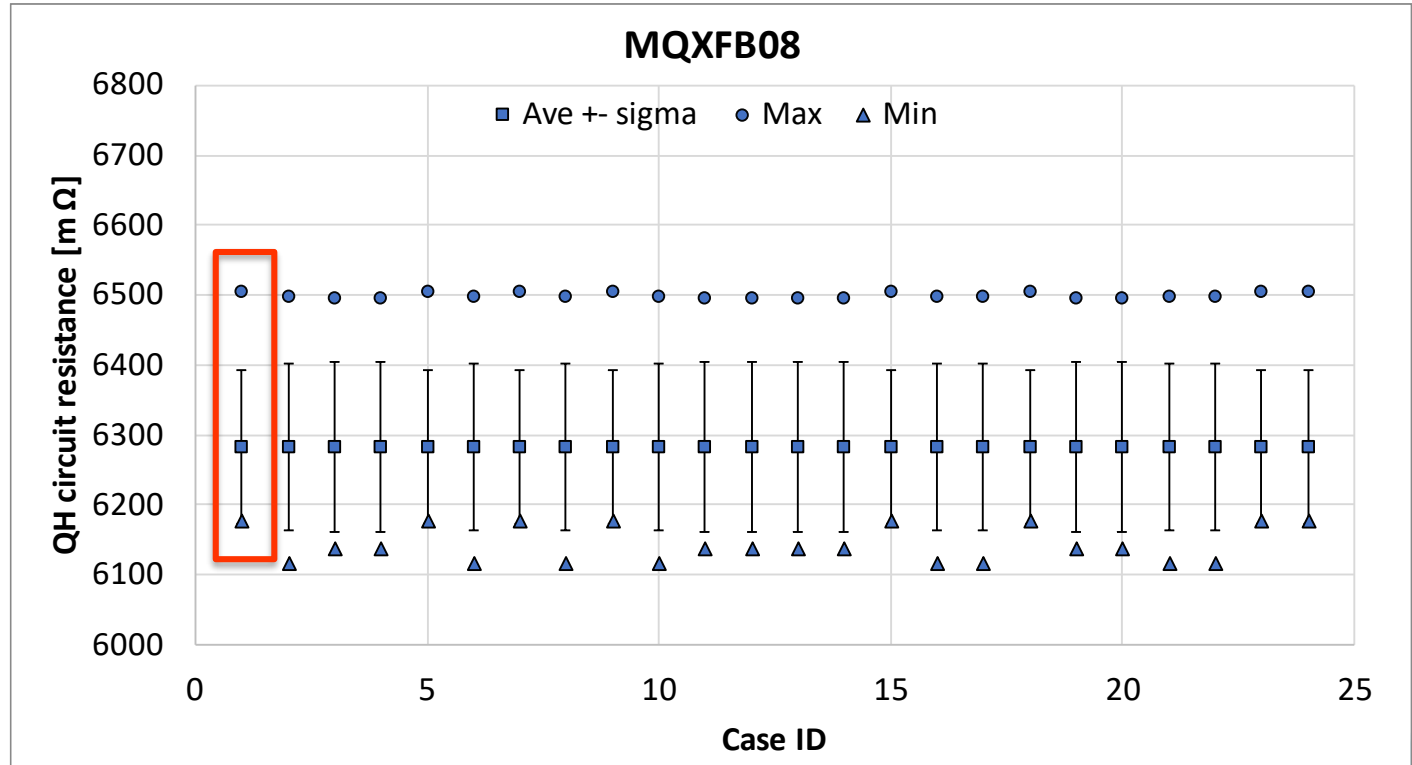
MQXFB08

MQXFB08, B07, B06, B05 and B04
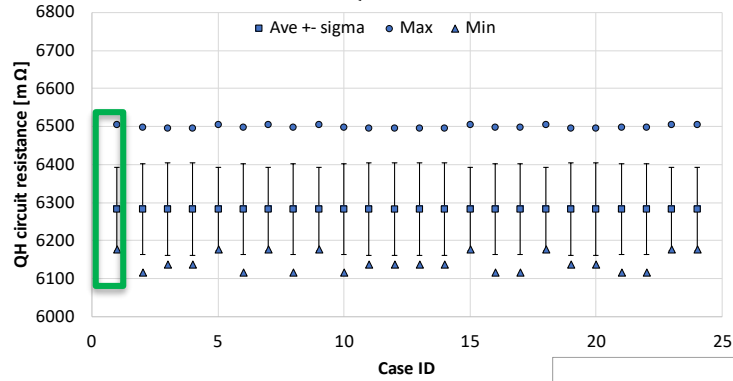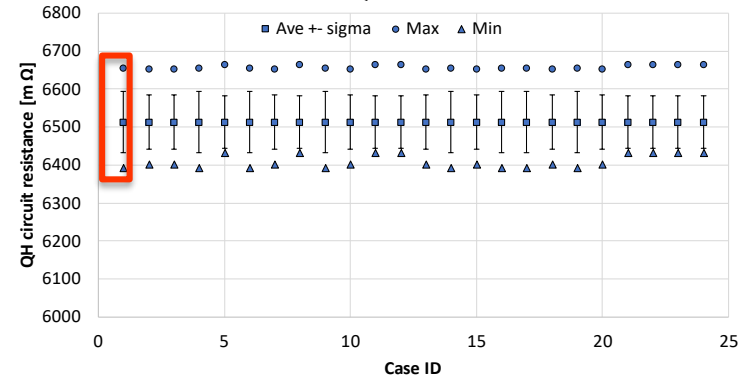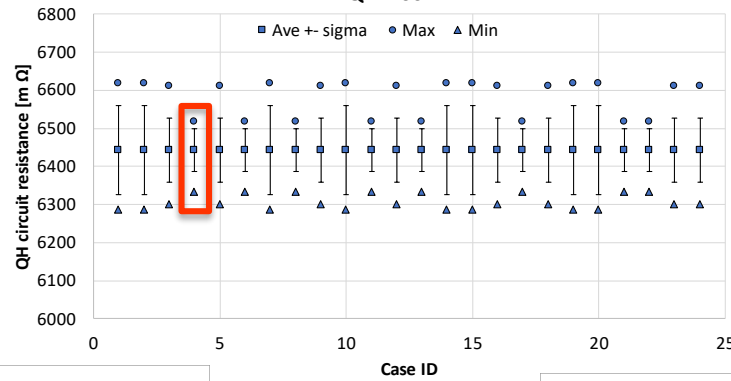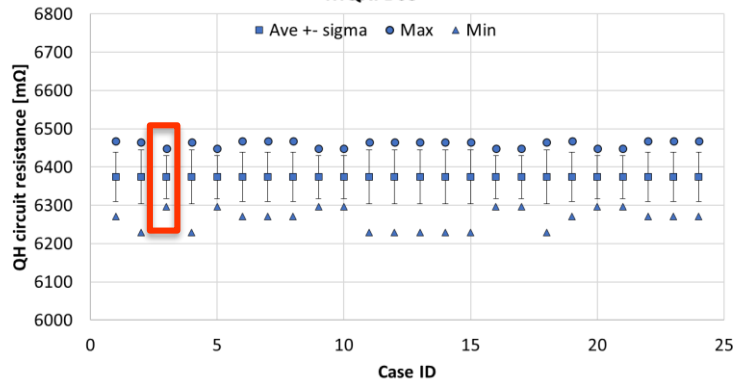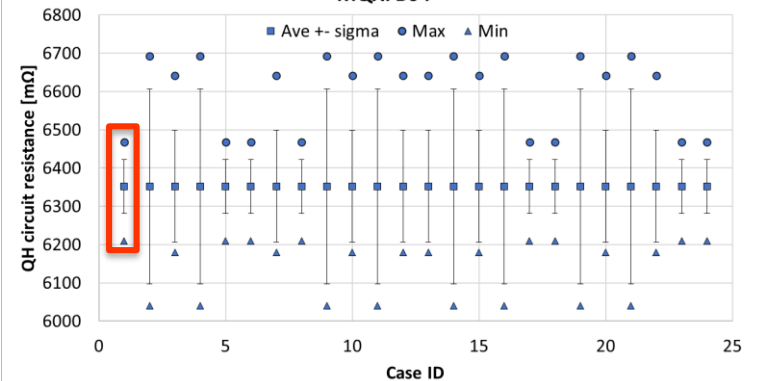
Conclusion

- Here is presented the coils ordering for MQXFB08

Legend:
- Radial shim
- Ground insulation $R = 114.000$ mm
- Mid-plane shim $r = 113.376$ mm
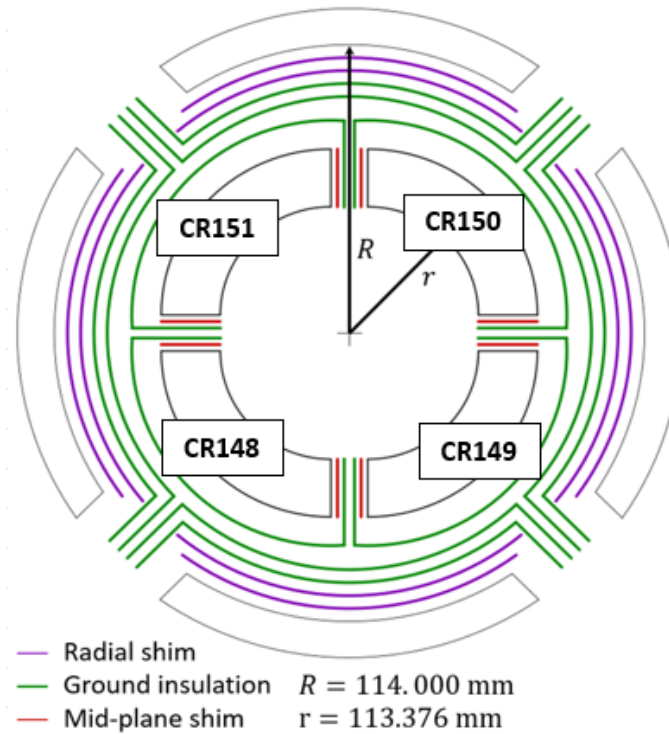
References

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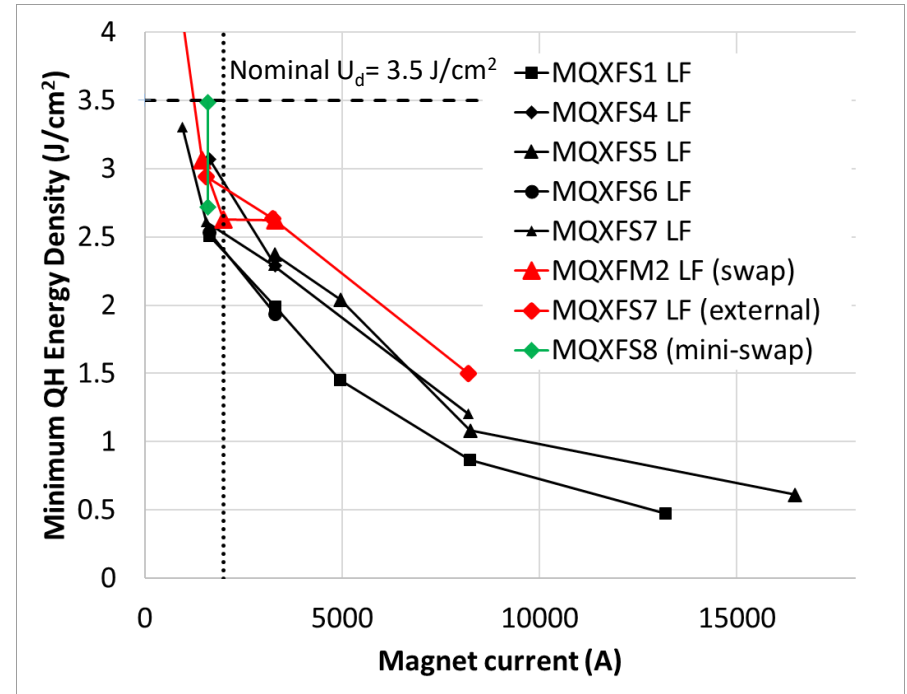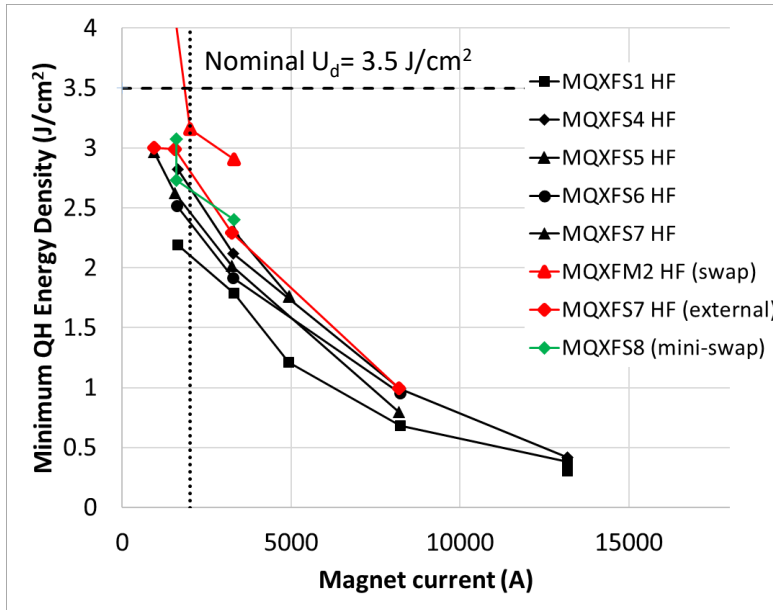
Minimum Energy Density = 2.5 – 2.7 J/cm^2 (to initiate a quench at 2 kA)

Final QH configuration:

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

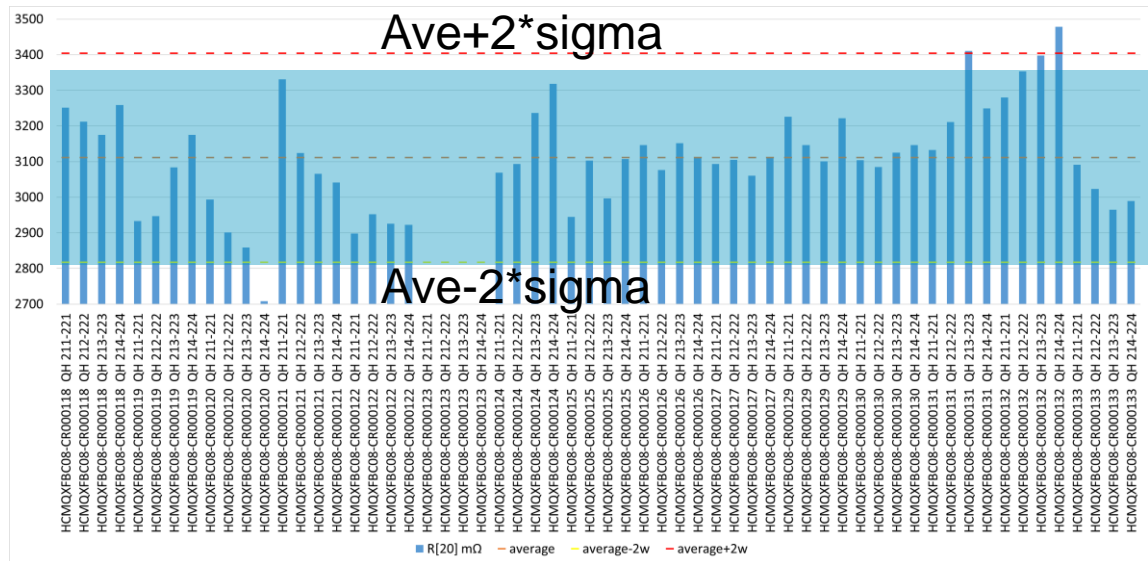MQXFA impregnated heaters in direct contact with the coil (S1-S6)

QH resistance – individual strips

- The target was 3.1 ± 0.26 (2.84-3.36 ohms, i.e., $\pm 8\%$)
- 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

Ave+2*sigma

Ave-2*sigma

- 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
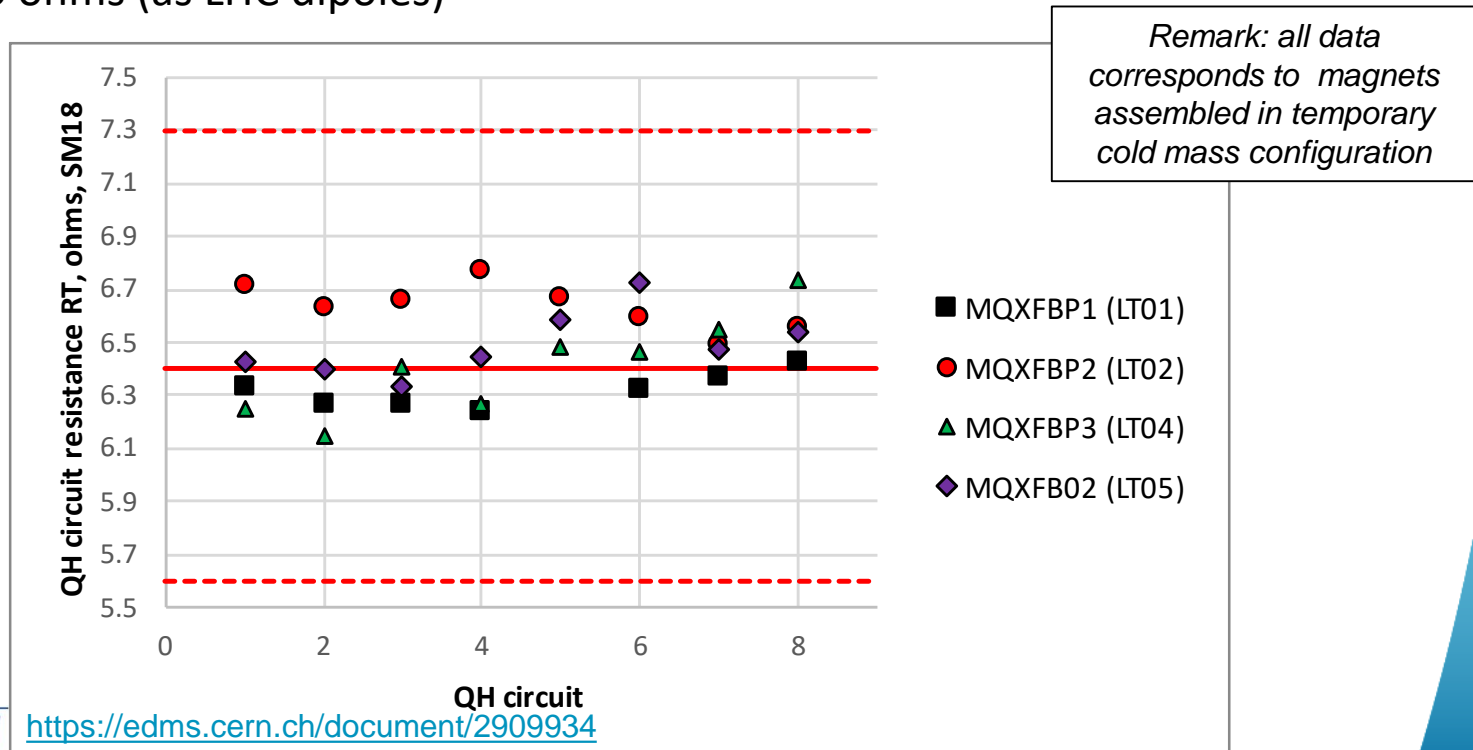
Quench heater circuit resistance, tolerance range at cold, SM18

- 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

- MQXFBP1 (LT01)
- MQXFBP2 (LT02)
- MQXFBP3 (LT04)
- MQXFB02 (LT05)

https://edms.cern.ch/document/2909934
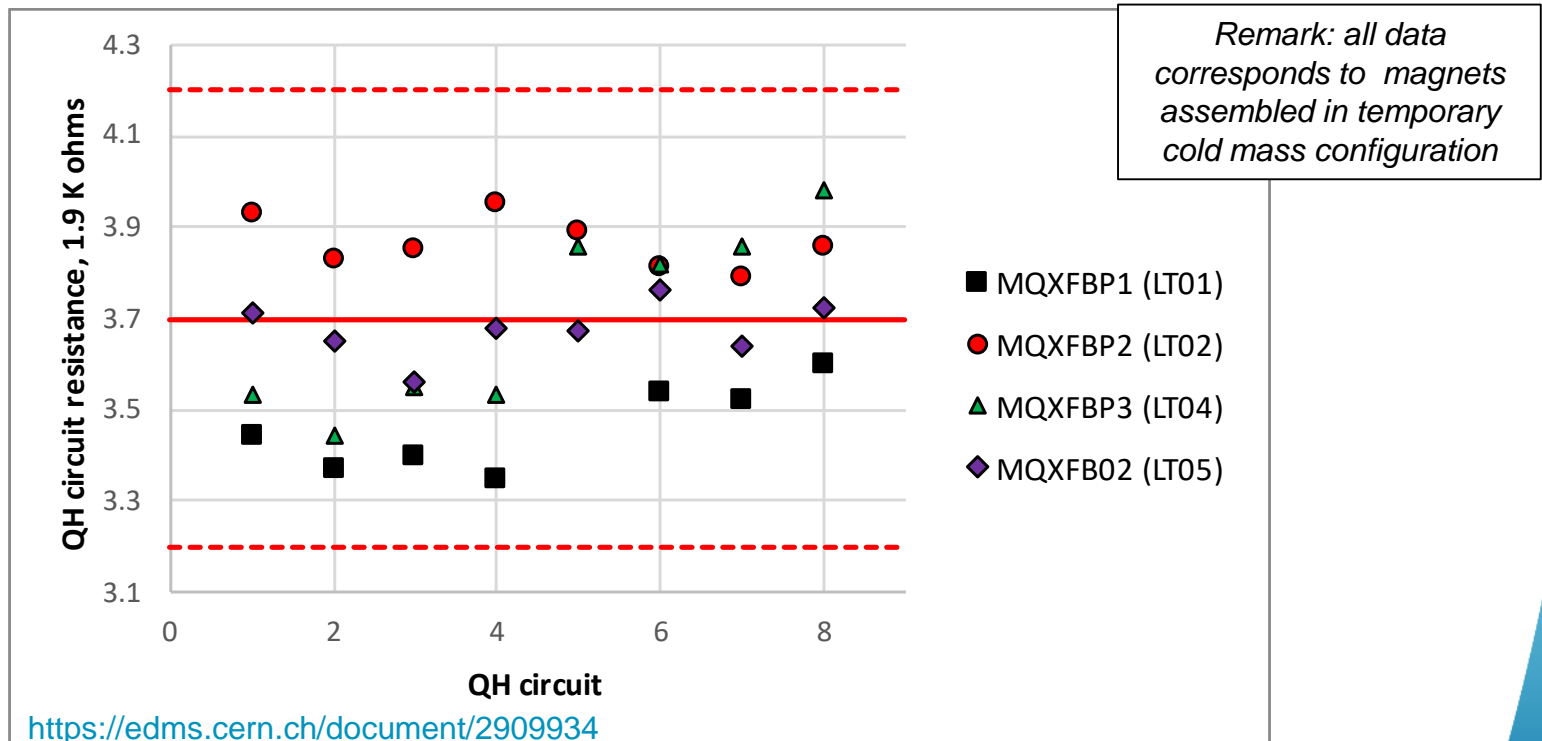
Cold vs warm

- 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