Fast turn around Quench Heater tests

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On behalf of

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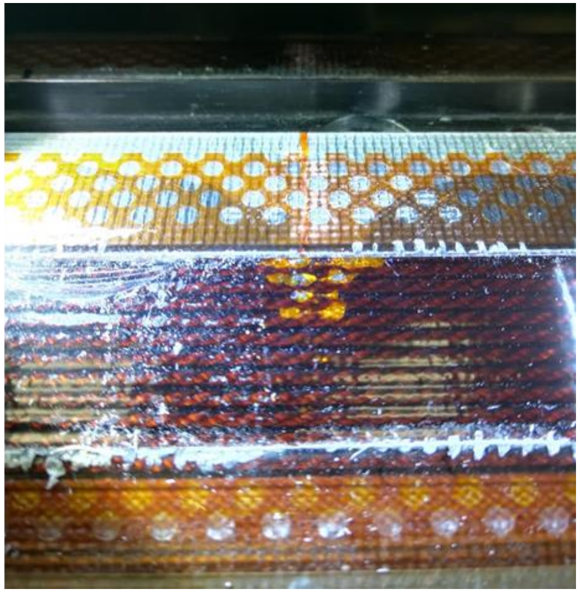
Outline

- Motivation
- MQXF electrical design
- First experiment: effect of thermal cycle on heater-coil insulation
- Second experiment: effect of heater firing on heater-coil insulation
- Third experiment: effect of quench on heater-coil insulation
  - Work in progress
- Conclusions

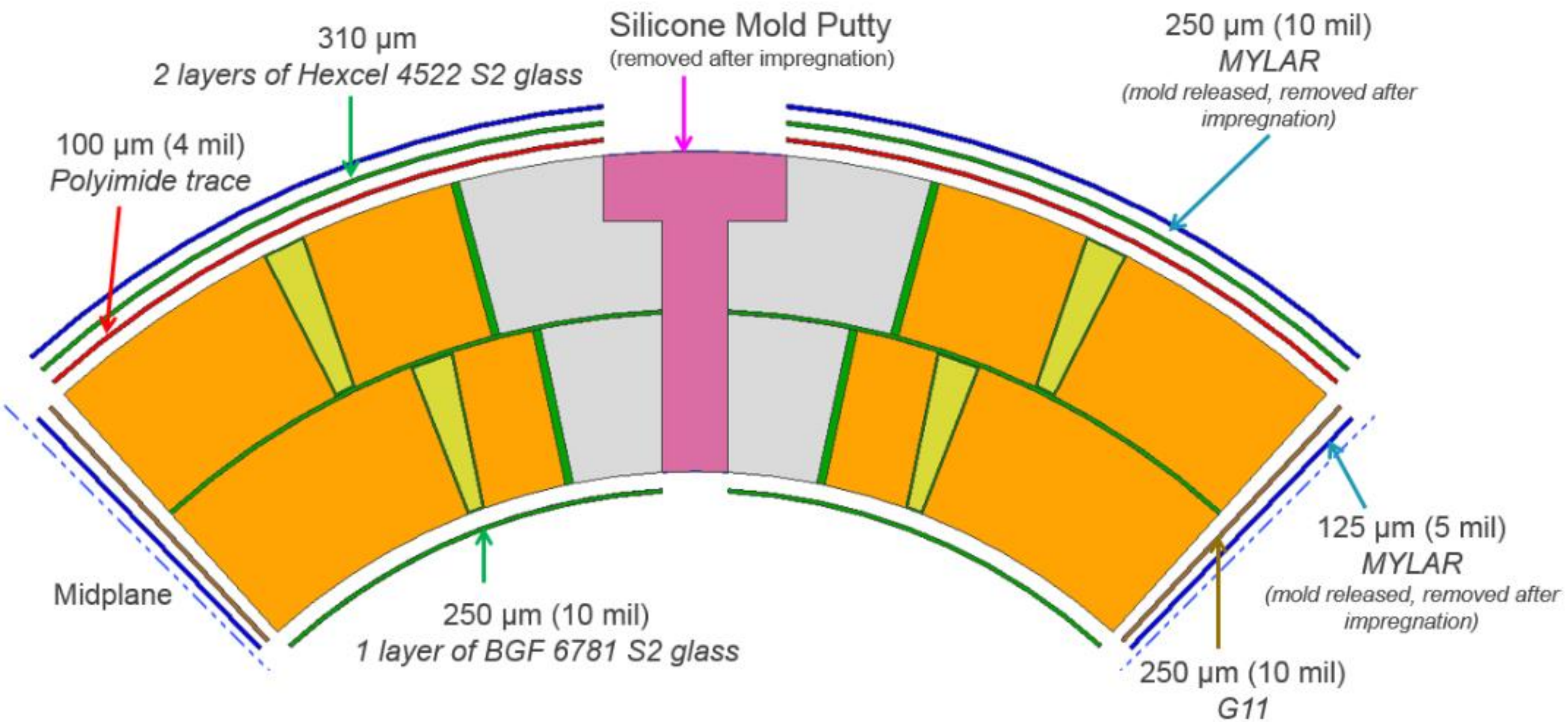
Motivation

- Autopsy of coils QXFP1 and QXFP5 showed evidence of thickness reduction of the heater-coil polyimide insulation after testing



- We want to reproduce the phenomenon, in order to identify the cause

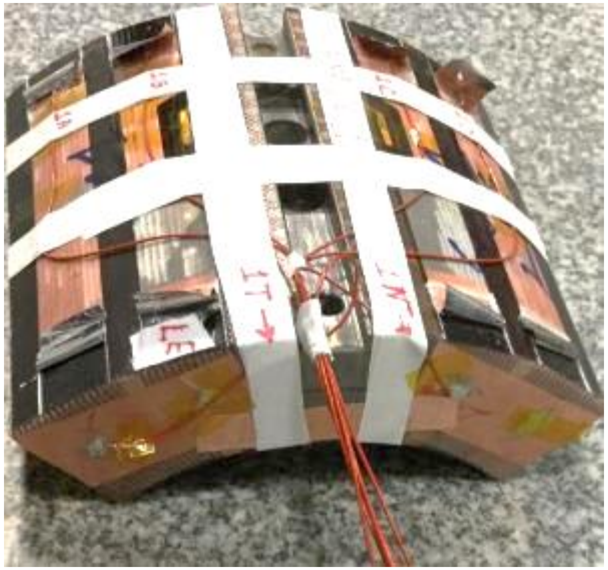
Electrical design



First experiment:
effect of thermal cycle on heater-coil insulation

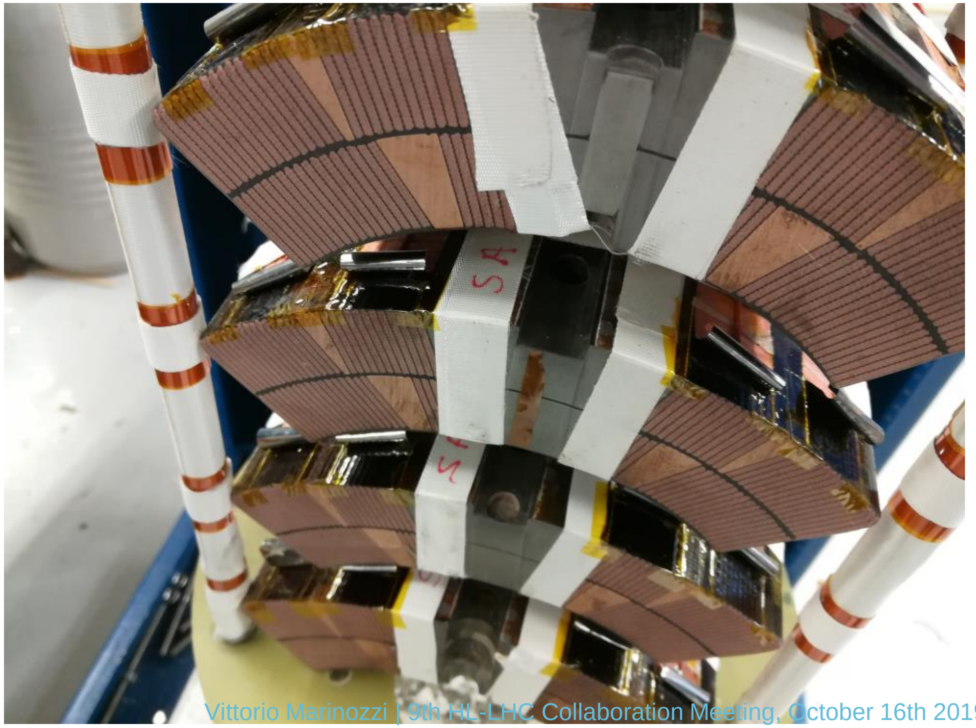
First experiment: effect of thermal cycle on heater-coil insulation (1)

- For this experiment, 5 samples of coil QXF108 have been prepared
  - QXF108 is a virgin MQXFA coil, not accepted for use in magnet due to a short coil-endshoe
- Samples consist of ~15 cm long sections of the coil
- Sample preparation
  - Quench heater peeled back from both edges of coil section
  - All turns wired together
  - Wires soldered to coil and each bus (4) for hipot test

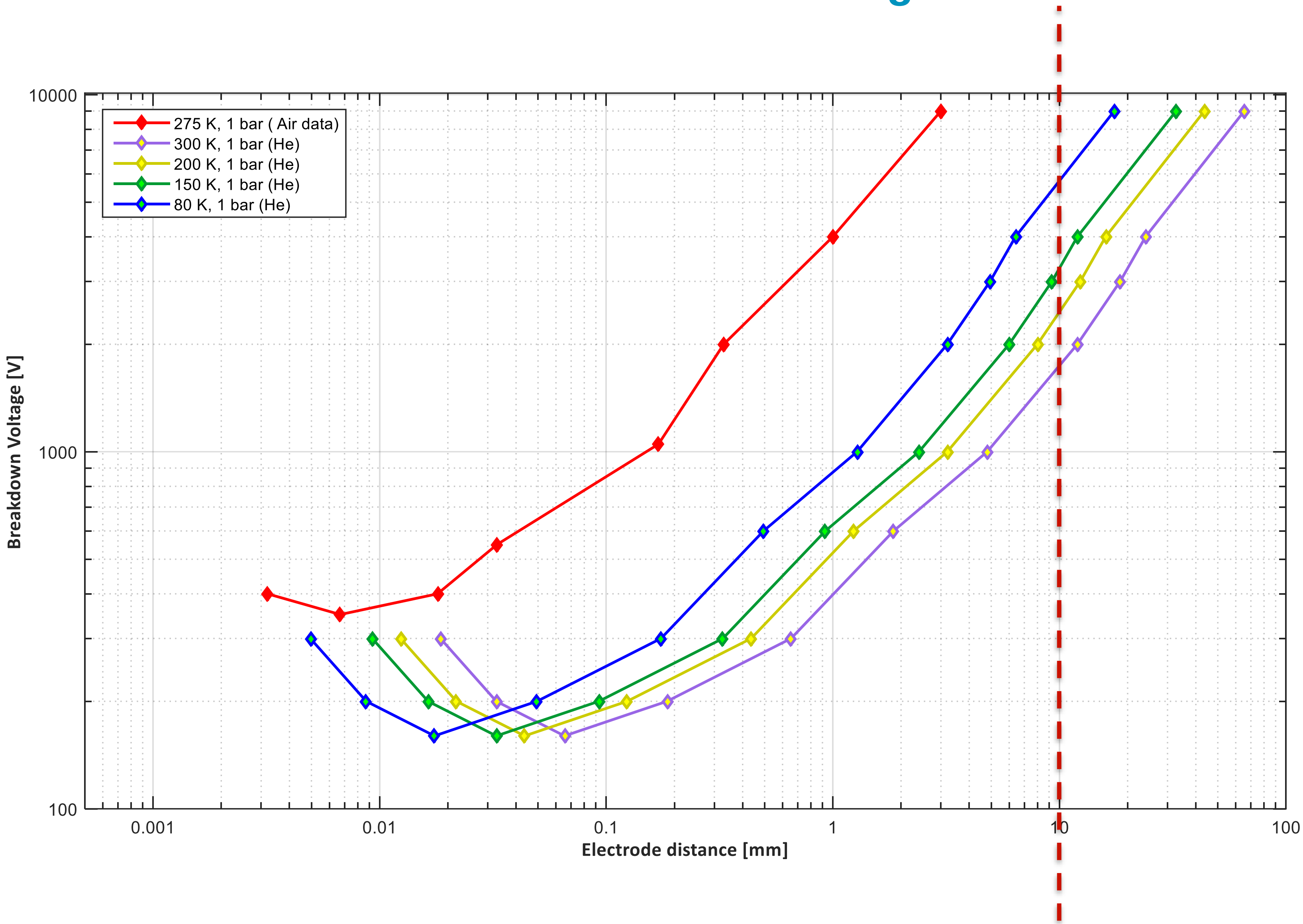


First experiment: effect of thermal cycle on heater-coil insulation (2)

- Test procedure:
  - Prepare MQXF coil samples
  - Verify electrical integrity of the samples before testing
    - 6 kV Coil-Heater Hipot test
  - Cool down in liquid helium the samples
  - Perform Coil-Heater Hipot tests at different temperatures
    - **4 kV** @ 4.2 K
    - **3.5 kV** @ 75 K
    - **2 kV** @ 150 K
    - **1 kV** @ 300 K



Helium breakdown voltage



1 cm = minimum heater-end distance

First experiment conclusion

- 10 of 20 heaters passed electrical checkouts before tests
  - Some heaters damaged during peeling off from edges
- 10 of 20 heaters passed all electrical tests from 4.2 K to room temperature
  - Visual inspection confirms that no sign of degradation are visible

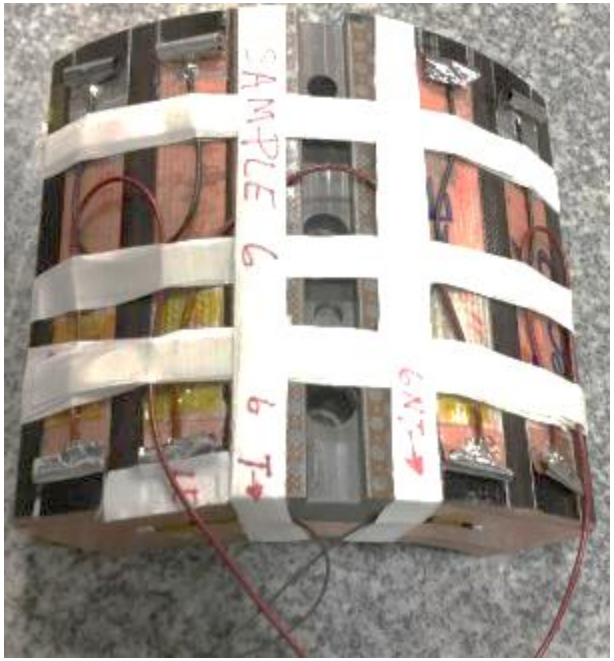
- **Conclusion: in this experiment, thermal cycle had no effect on heater-coil insulation**

Second experiment:
effect of heater firing on heater-coil insulation

Second experiment: effect of heater firing on heater-coil insulation (1)

- Goal is to fire the heaters on similar samples, in order to look at the effect on the heater-coil insulation

- Two coil QXF108 samples have been preferred as before, but with 4 heaters strips put in series



Capacitor bank to fire heaters

- In order to fire the heaters, a dedicated capacitor bank has been built:
  - Twelve 75 V, 27 mF capacitors in parallel
  - Able to reproduce the peak power density which occurs in long coils (236 W/cm^2), with the correct discharge time (32 ms)

- Capacitor bank has to be discharged on 4 heater strips put in series

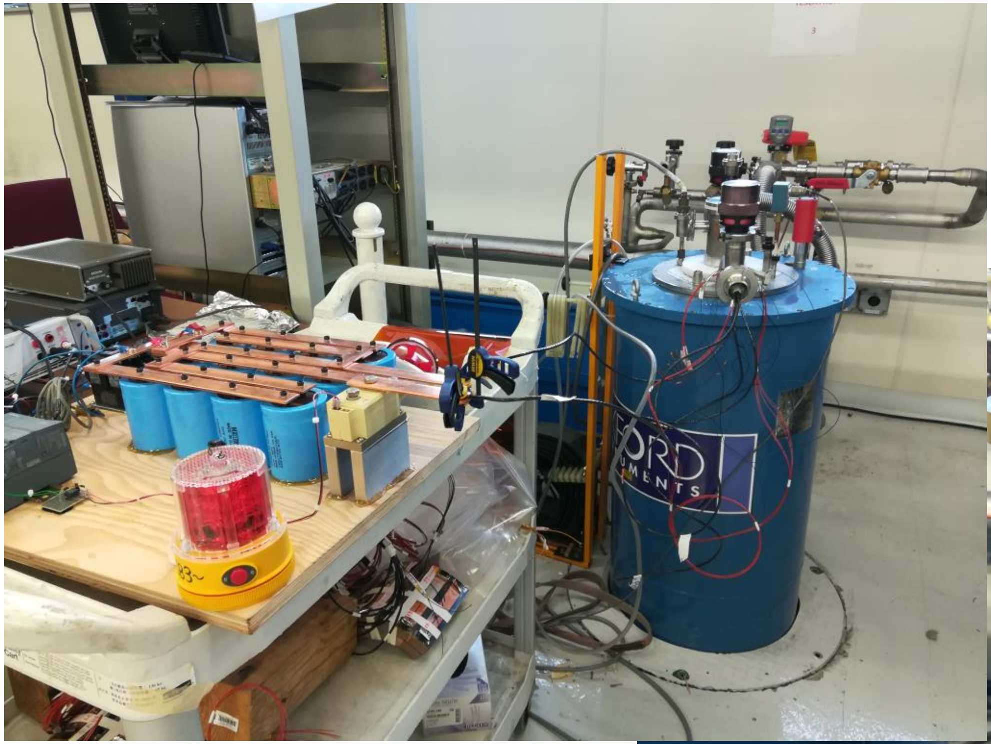
Second experiment: effect of heater firing on heater-coil insulation (2)

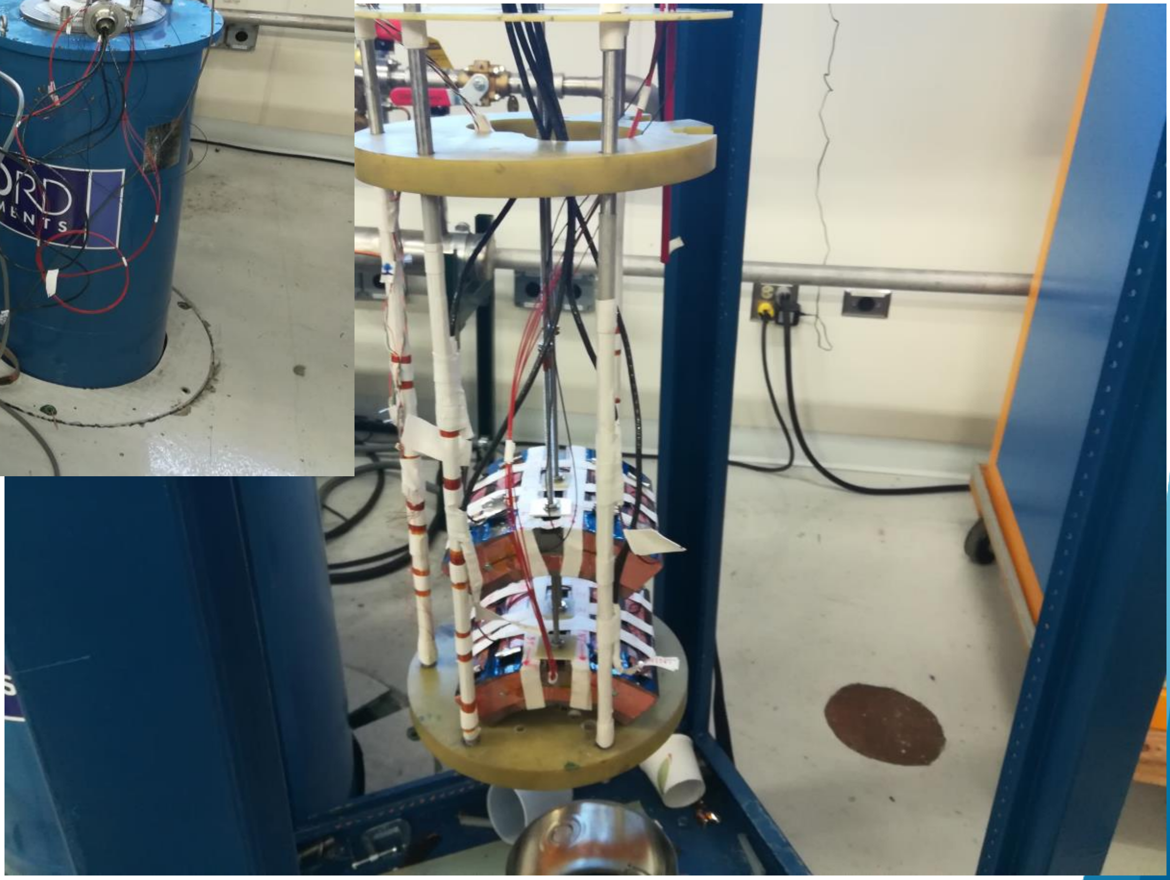
- 2 samples (sample 3 and sample 6) have been cooled down, after **all** heater traces passed 6 kV Hipot at room temperature

- At 4.2 K, heaters have been fired **20 times** on sample 3, only **6 times** on other sample 6
  - It showed high resistance (~10 MOhm) after 6^{th} firing, making impossible to continue the experiment

- Performed heater-coil-Hipot to:
  - **4 kV** @ 4.2 K (before and after firing)
  - **3.5 kV** @ 75 K
  - **2 kV** @ 150 K
  - **1 kV** @ 300 K

Pictures





Second experiment results (1)

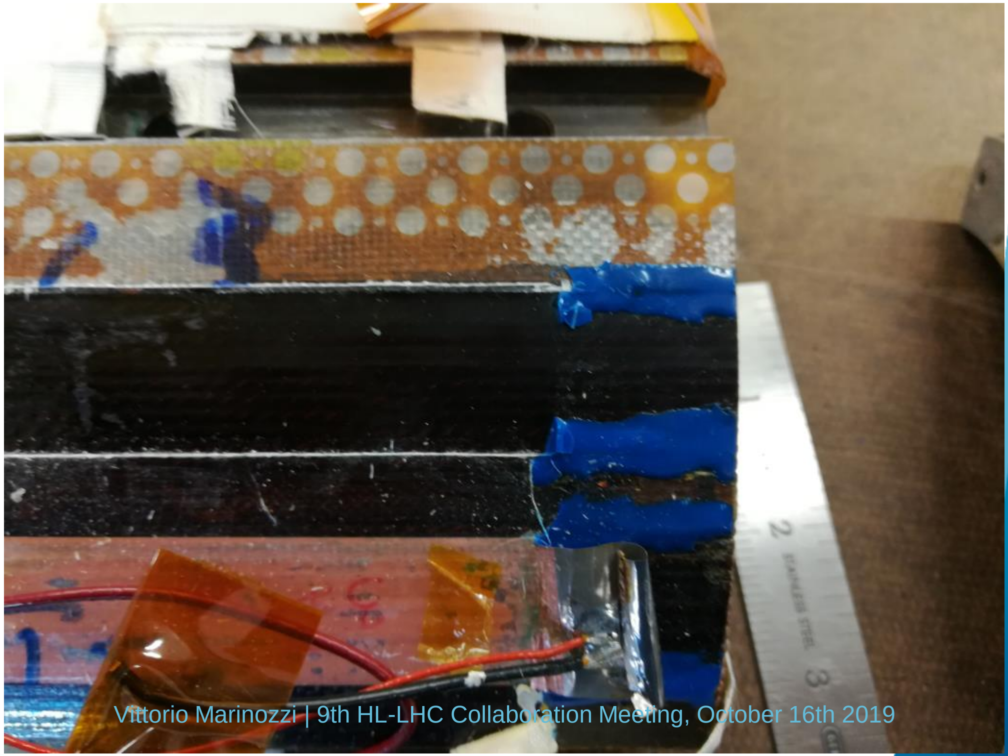
- Both samples passed 4 kV at 4.2 K
- At 75 K:
  - Sample 3 **failed at 2 kV**, compatible with a path of **~ 3 mm**
  - Sample 6 **failed at 3 KV,** compatible with a path of **~ 5 mm**
- At 150 K
  - Sample 3 **failed at 1.67 kV**, compatible with a path of **~ 4 mm**
  - Sample 6 recovered, and **passed** 2.5 kV test

Second experiment results (2)

- After testing, heater traces have been hipotted up to 4 kV individually, to check the limiting ones
  - Test was limited by the ends of the traces, where sparkles were visible where the strips had been cut

- After completely peeling off the heaters, no sign of bubbles can be found on both samples

- **Conclusion: In this experiment, heater firing seems not to degrade electrical insulation**



Third experiment:

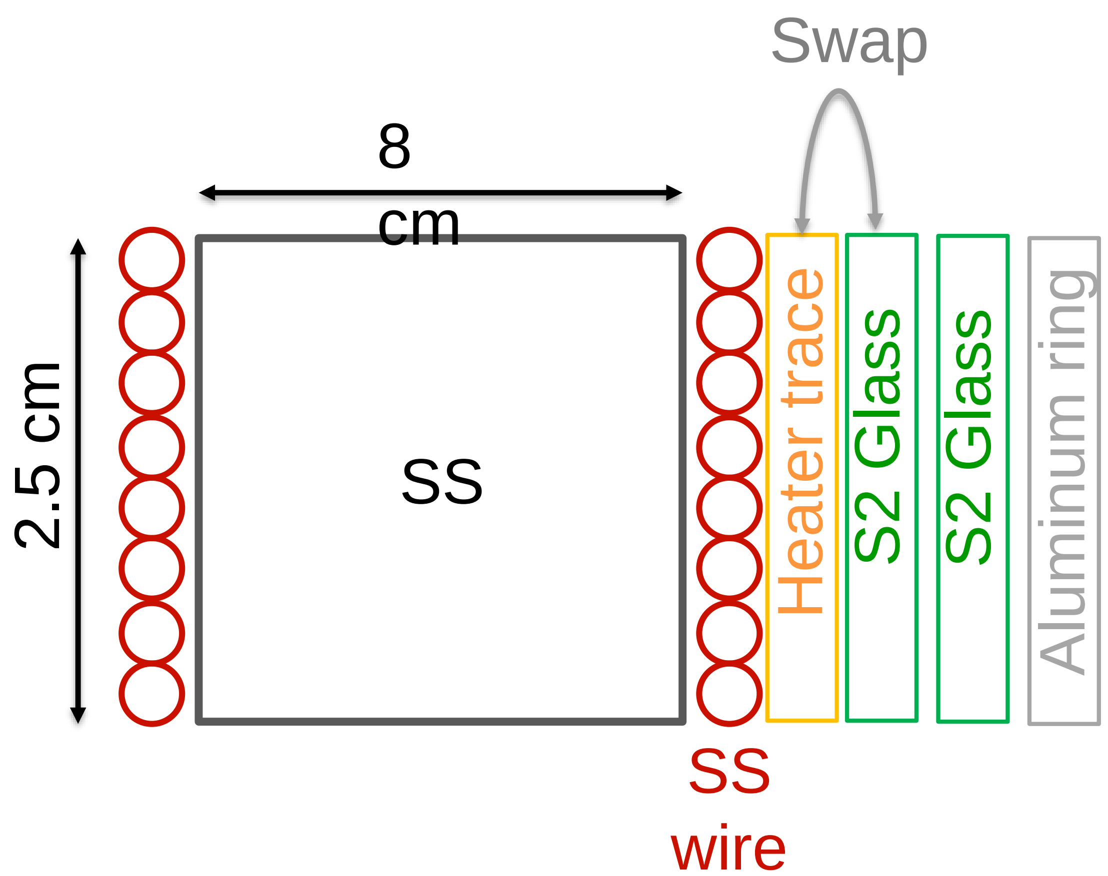
effect of quench on heater-coil insulation

(Work in progress)

Third experiment: effect of quench on heater-coil insulation

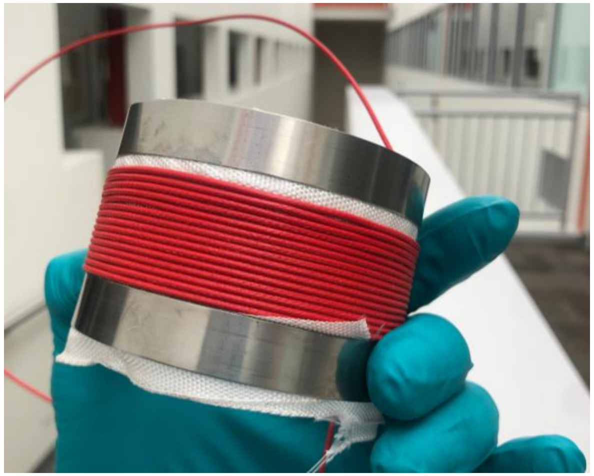
- Fast turn around experiments with coil/magnet quenches are very difficult to perform
  - Lots of time and resources needed
- We are building Ni-Cr (stainless-steel-like) coils to "simulate" quench
  - Coils are built using same procedures as MQXF coils
    - Reaction, impregnation, same materials
  - During test, then they are heated up from 4 K to 200 K in the same time as MQXF magnet during a quench by a current discharge
  - We will allow impregnation voids using different techniques, to create areas that will be filled by helium during testing

Coil design



Swap
8
cm
2.5 cm
SS
Heater trace
S2 Glass
S2 Glass
Aluminum ring
SS
wire

Pictures



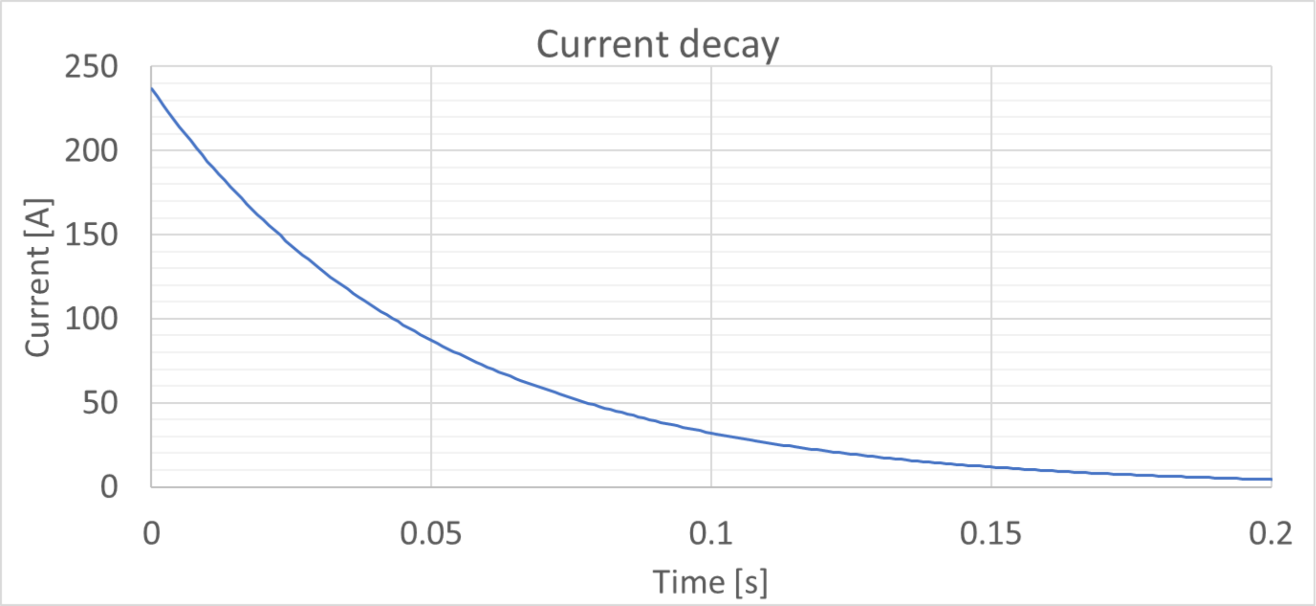
Coil parameters

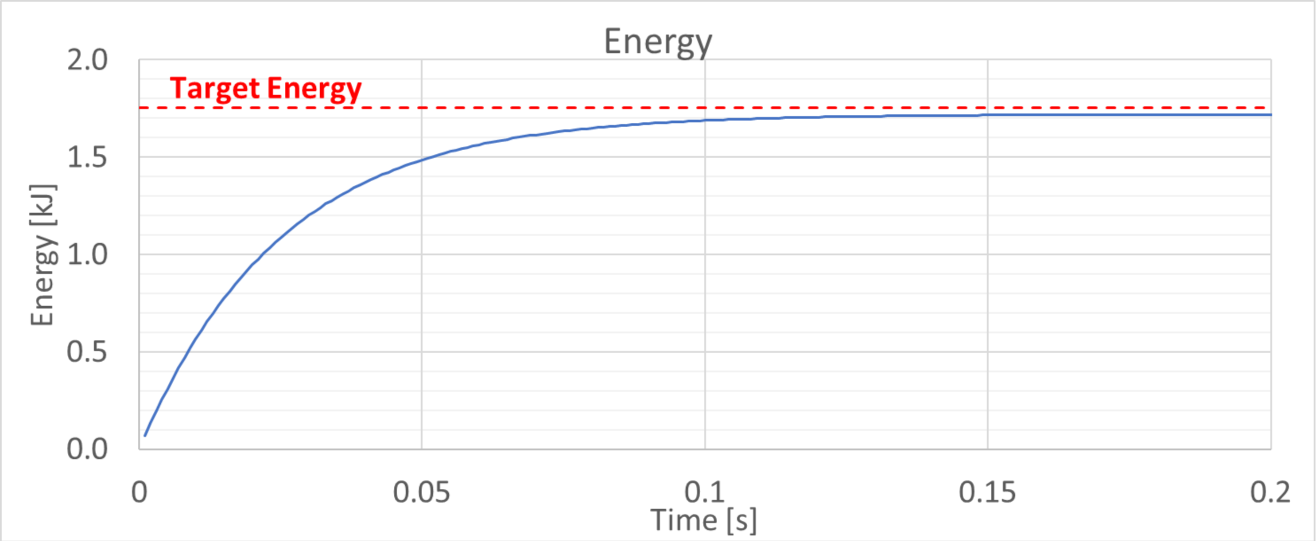
Wire diameter	1.3 mm
Insulation material	S2 glass
Insulation thickness	0.15 mm
Wire length	3 m
Number of turns	15
Inductance	37.5 μH
Conductor Weight	34 g
Energy from 2 K to 200 K	1.75 kJ
Warm Resistance	1.6 Ω
Resistance @ 4.2 K	1.1 Ω

Test plan

- Cool down the coils at 4.2 K
- Discharge CLIQ (40 mF, 300 V, 1.8 kJ) on one coil several times
  - This will cause a temperature rise to 200 K in ~ 100 ms
  - Tau ~ 50 ms
  - No current oscillations are expected due to really low inductance (130 Hz oscillation)
- Perform electrical checkouts to verify integrity of the insulation, using MQXF electrical QC criteria
- Perform an autopsy of the coils to look for bubbles in the insulation
- Target of first experiment is reproduce the bubbles
  - If successful, we will make the swap and repeat the experiment to see if this solves the bubbles issue

Plots


Current decay
Current [A]
250
200
150
100
50
0
0
0.05
0.1
0.15
0.2
Time [s]


Energy
Target Energy
Energy [kJ]
2.0
1.5
1.0
0.5
0.0
0
0.05
0.1
0.15
0.2
Time [s]

Conclusions

- Some fast turn-around experiments have been performed to try to identify and reproduce the mechanism of thickness reduction of the MQXF heater-coil polyimide insulation
- First experiment on QXF108 samples showed that a thermal cycle cannot reproduce the issue
- Second experiment on QXF108 samples showed that firing the heaters cannot reproduce the issue

- A third experiment is ongoing, aiming at reproducing the effect of quench on the insulation
  - A small Ni-Cr coil will be heat up from 4 K to 200 K in 100 ms by a CLIQ discharge, in order to simulate a quench.
  - Effect of the test on the insulation will be verified by high voltage testing, and by visual inspection and coil autopsy
  - If reproduction of thickness reduction of the polyimide will be successful, we will repeat the experiment performing the swap, to check if it can solve the issue