MQXF Quench Protection

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Outline

- Status at MT23 (First complete analysis)
- Recent progress
- Plans

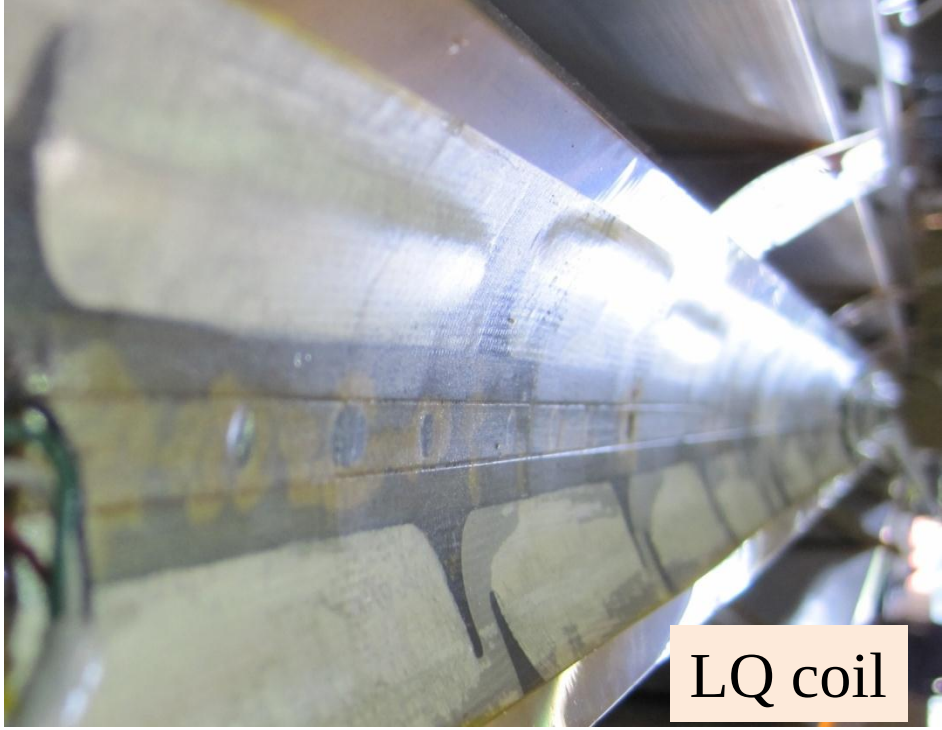
Status at MT23

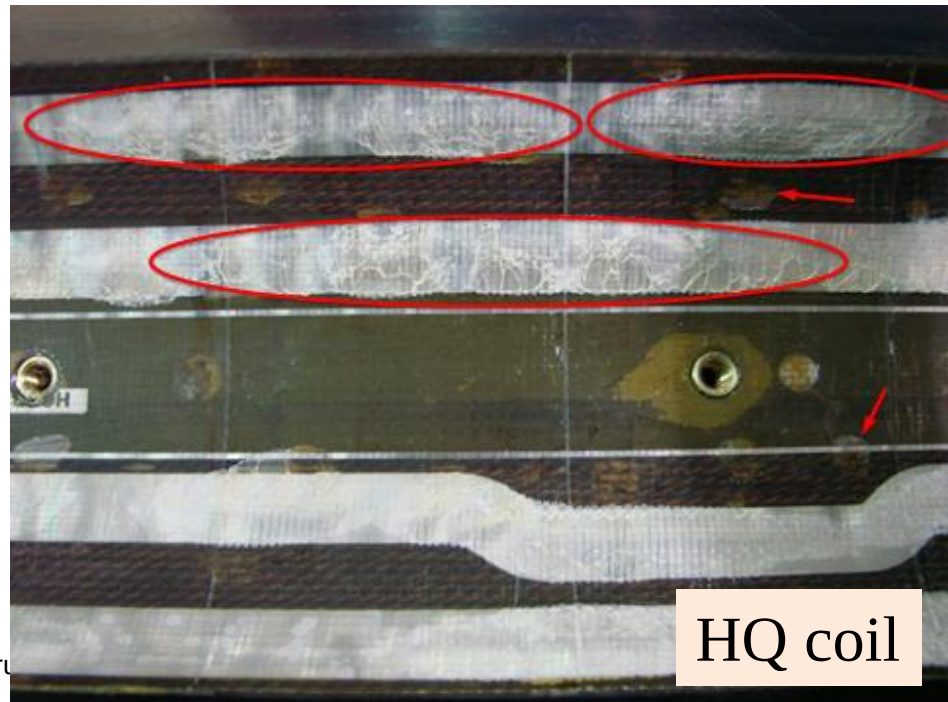
- Simulations performed with QLASA and ROXIE using MATPRO material property database
  - Using preliminary MQXF requirements
  - Assuming heaters only on the outer layer
  - With conservative assumptions:
    - Layer-layer propagation
    - Impact of bronze in strands
    - No dynamic effects

➔ Hot spot temp. ~ 350 K
  - Without margin and redundancy
  - Close to epoxy glass transition temperature
    - ~max acceptable temp. if there is no earlier detraining

"Bubbles" Issue

- "Bubbles" on coils inner surface
  - Coil-insulation separation
  - Heater-coil separation
- Seen in TQ, LQ, HQ coils only non inner layer
  - TQ coils showed small "bubbles" (no heaters on IL)
  - HQ coils showed small "bubbles" and cracks along heaters
  - LQ coils had long "bubbles"



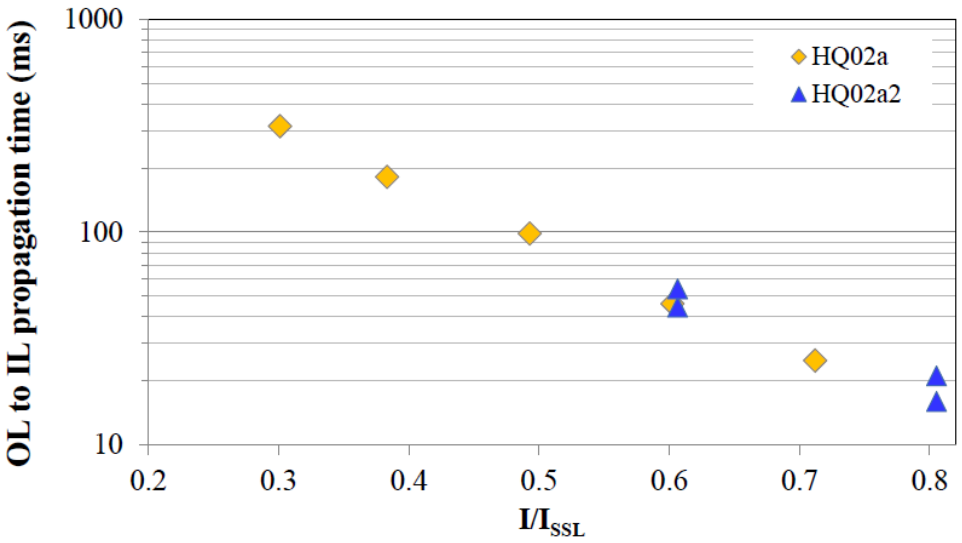


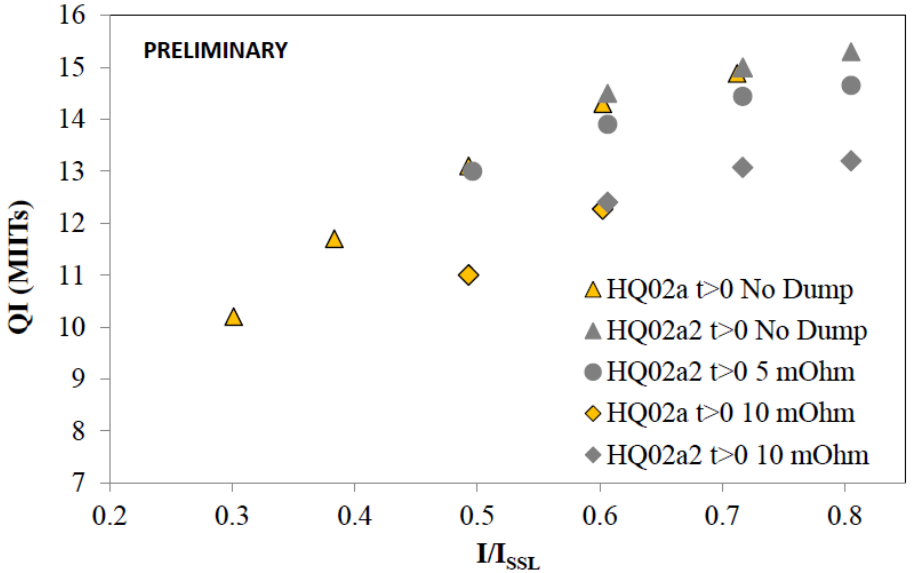
Progress so far

- Demonstrated beneficial effect of bronze
  - ➔ Hot spot temperature lower by ~ 30K
- Compared property databases
  - ➔ MATPRO is most conservative
- Performed QP tests on HQ
  - – Next slides
- Compared HQ test data with simulations (using MT23 assumptions)
  - – Next slides

Feedback from HQ02 test

- Measurement of quench propagation from Outer Layer to Inner Layer
- Measurement of Quench Integral with different dump resistors
  - simulating MQXF conditions





Simulations vs. Measurements

- Under the assumptions used for MQXF, the heaters-induced quench simulations are **conservative**.
- At the current of interest (0.8 of SSL), the MIITs are **overestimated by about 13 %** (~ 65 K)
- Margin is due to:
  - dI/dt effects
  - conservative assumptions in modeling of heaters and propagation OL to IL

Current/SSL	0.8	0.7	0.6	0.5	0.4
MIITs difference % (no dump case)	14.5	13.2	9.6	10.7	8.1
MIITs difference % (3 mΩ dump case)	13.4	11.1	6.4	5.3	0.9

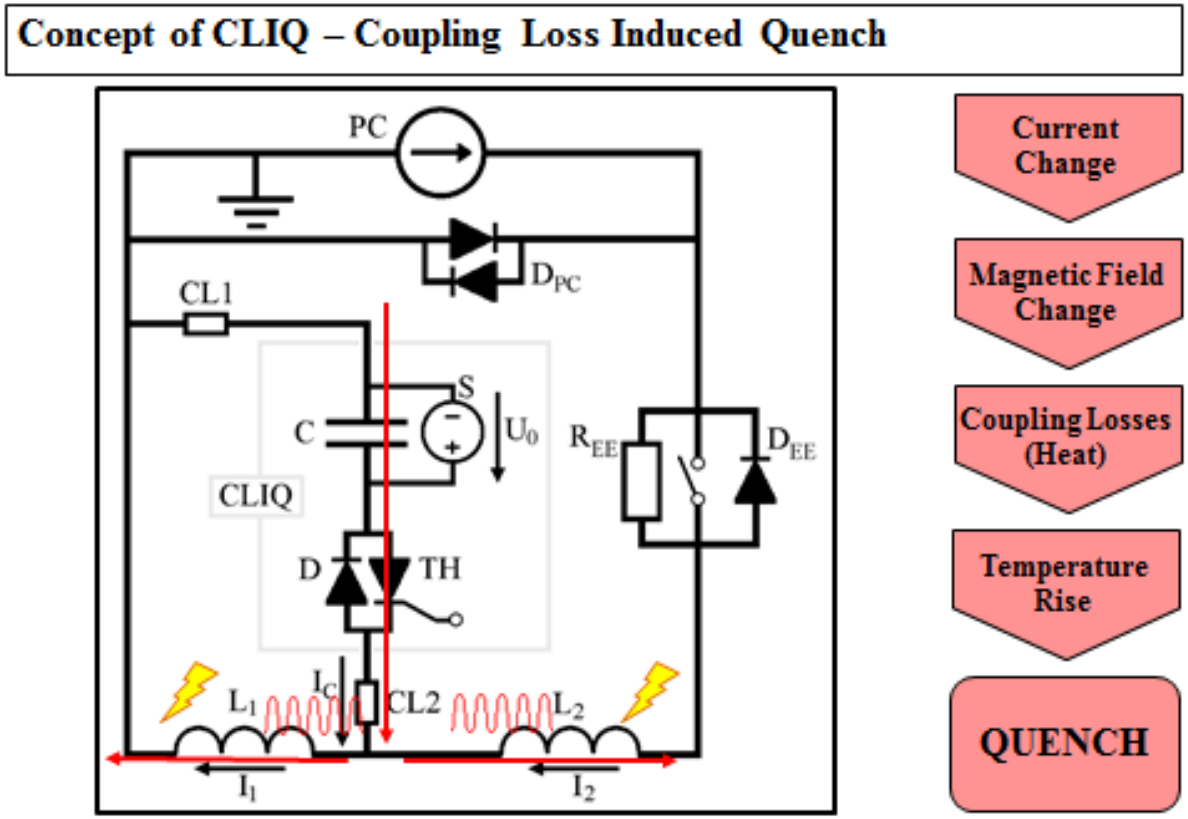
Most significant case for MQXF

Plans

- The recent improvements may not be sufficient to provide redundancy and margin
  - This is a risk, therefore:
- We are addressing it by:
  - Optimization of heater design and materials
  - Development of heaters for Inner Layer w/o bubbles
  - Exploring the use of CLIQ
    - Coupling Loss Induced Quench
  - Test max acceptable temperature (HQ02b)
- Longer magnets with lower gradient are the back up solution (with several drawbacks)

CLIQ

- Developed at CERN for 120mm NbTi quads
- May be an option for MQXF

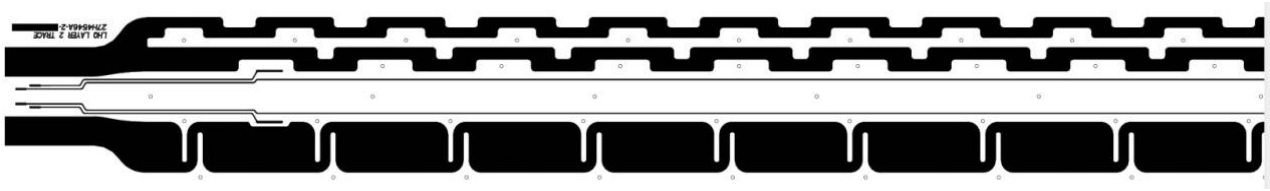


Note: most effective on inner layer

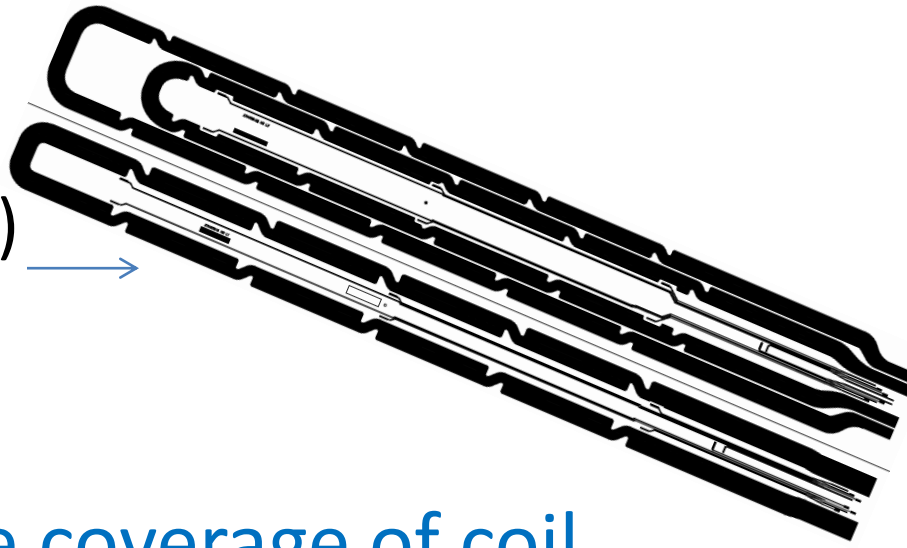
➔ Complementary to heaters on outer layer

To be tested on HQ02b

Heater development



- Pattern optimization
  - LHQ coil test
  - HQ03 (MQXF style heaters)
- Material optimization
  - Reduce heater delay time
- Minimization of polyimide coverage of coil inner surface using copper plated heaters
  - Better heat extraction
  - Avoid bubbles



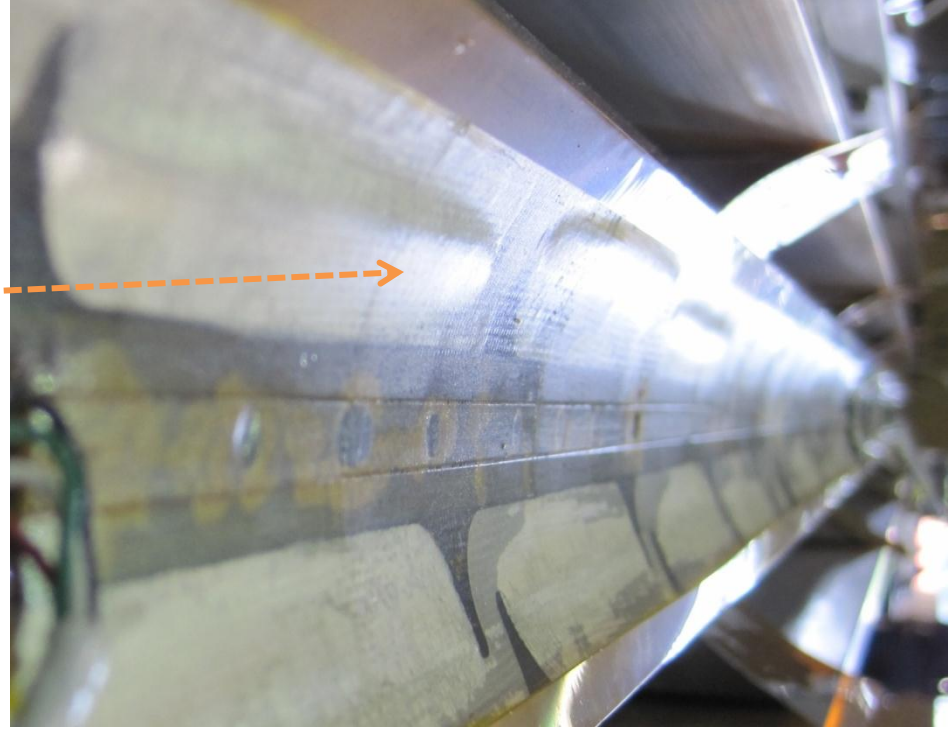
Conclusion

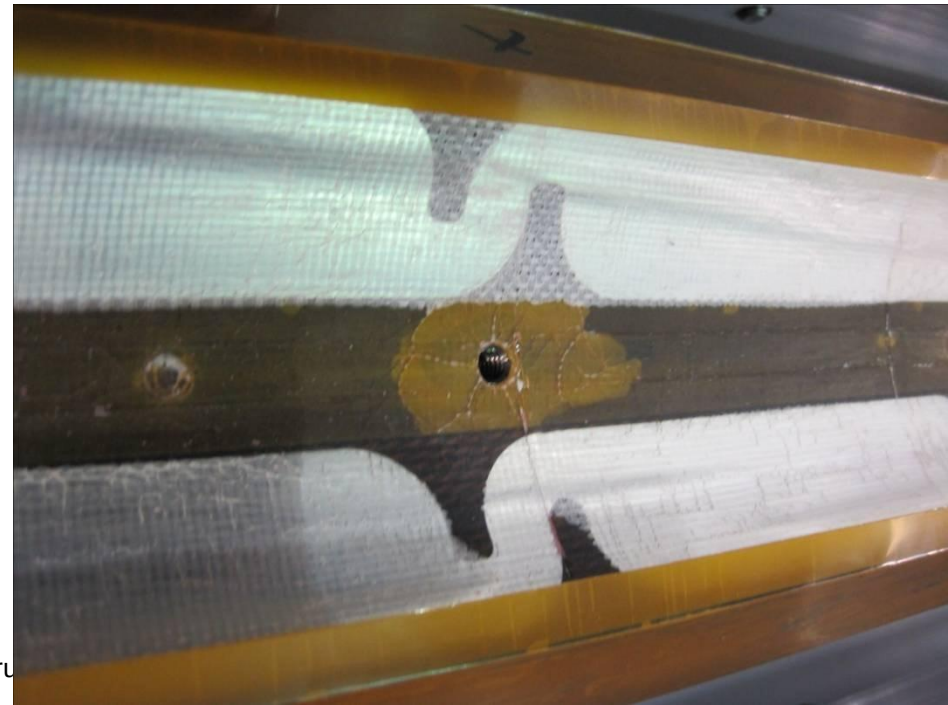
- Quench Protection is the only part of the design that still needs some R&D
- We are aware of this risk and are addressing it intensively developing alternative solutions in collaboration with CERN
- A workshop is planned after HQ02b test to assess QP and finalize MQXF lengths
  - Temptative time: end of April

Back up Slides

Coils after Test

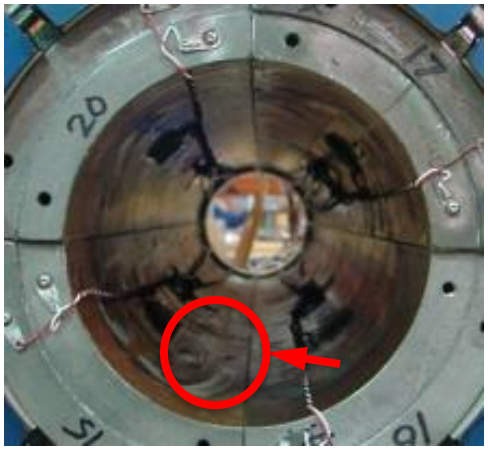
- Some “bubbles” on coils inner layer
  - Coil-insulation separation
- Possible causes:
  - Superfluid helium and heat during quench
    - Seen in TQ coils
  - Heat from heaters on inner layer
    - Only in LQ coils
- Plans:
  - Strengthen insulation or
  - Change heater location or
  - Add support on coil ID



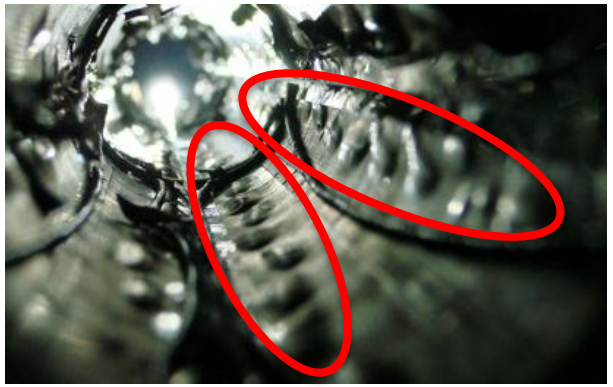


Coil Processing: Impregnation

- Instrumentation traces
  - Do laminated polyimide trace materials pose problems for impregnation?
  - Trace behavior (bubbles) on inside bore after testing cycle have continued



Inside bore of HQ02a during assembly (Coil 15 was previously tested in HQ mirror)



Bubbles on inside bore of LQS03 after magnet test