LARP

Topical meeting on QXF quench protection – April 29, 2014

HQ02 High MIITs Studies

Preliminary *findings and next steps*

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with many contributions from:

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Presentation Outline

1. Magnet response for different conditions and protection settings
2. Hot spot temperature estimates for high MIITs quenches
3. Preliminary findings on the effects of high MIITs quenches
4. Lessons learned and next steps
5. Discussion

Background information on test results can be found at the following links

For HQ02b test (CERN):

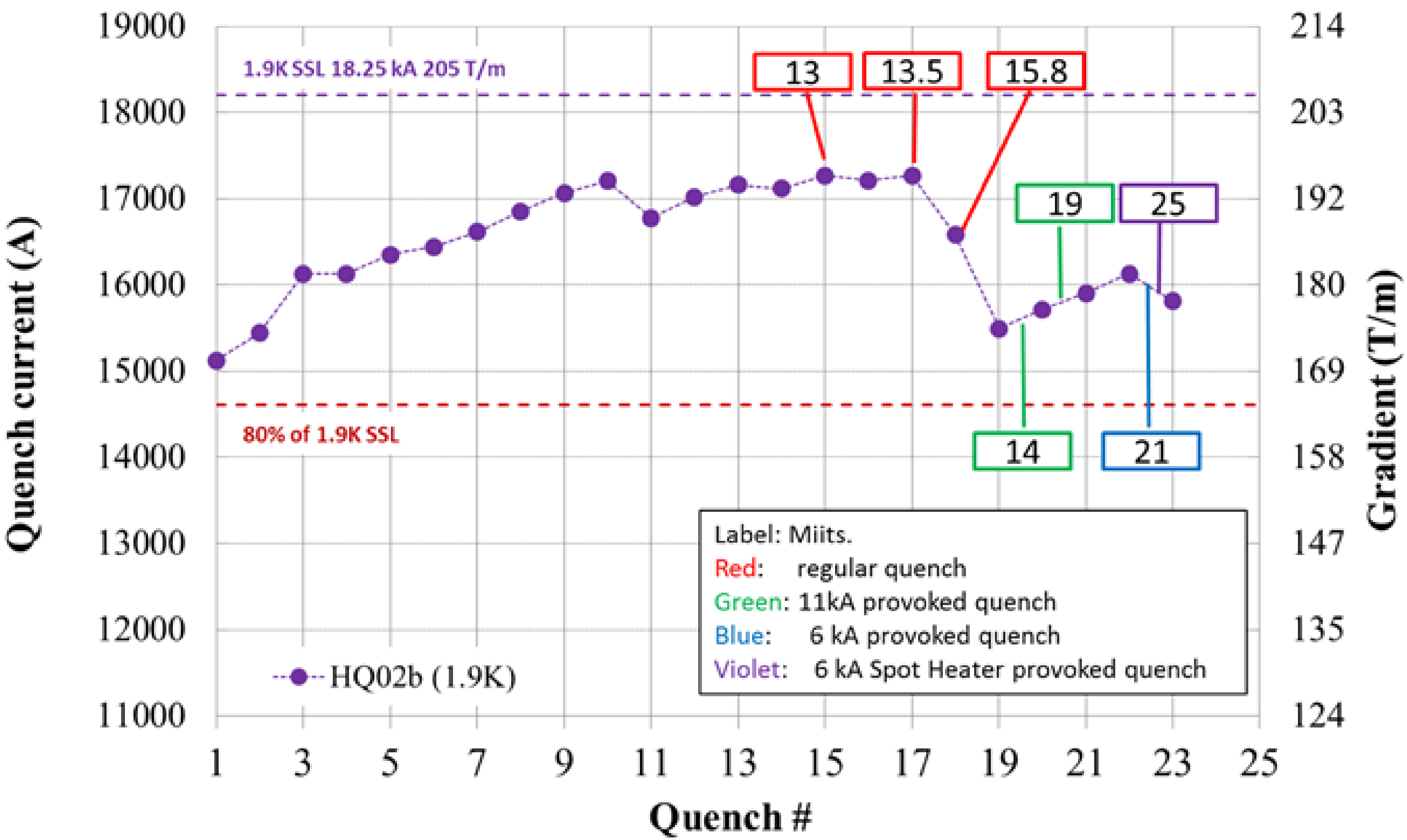
https://plone.uslarp.org/MagnetRD/ModelQuadrupoles/HQ/Meetings/2014/2014-04-24/

For HQ02a tests (FNAL):

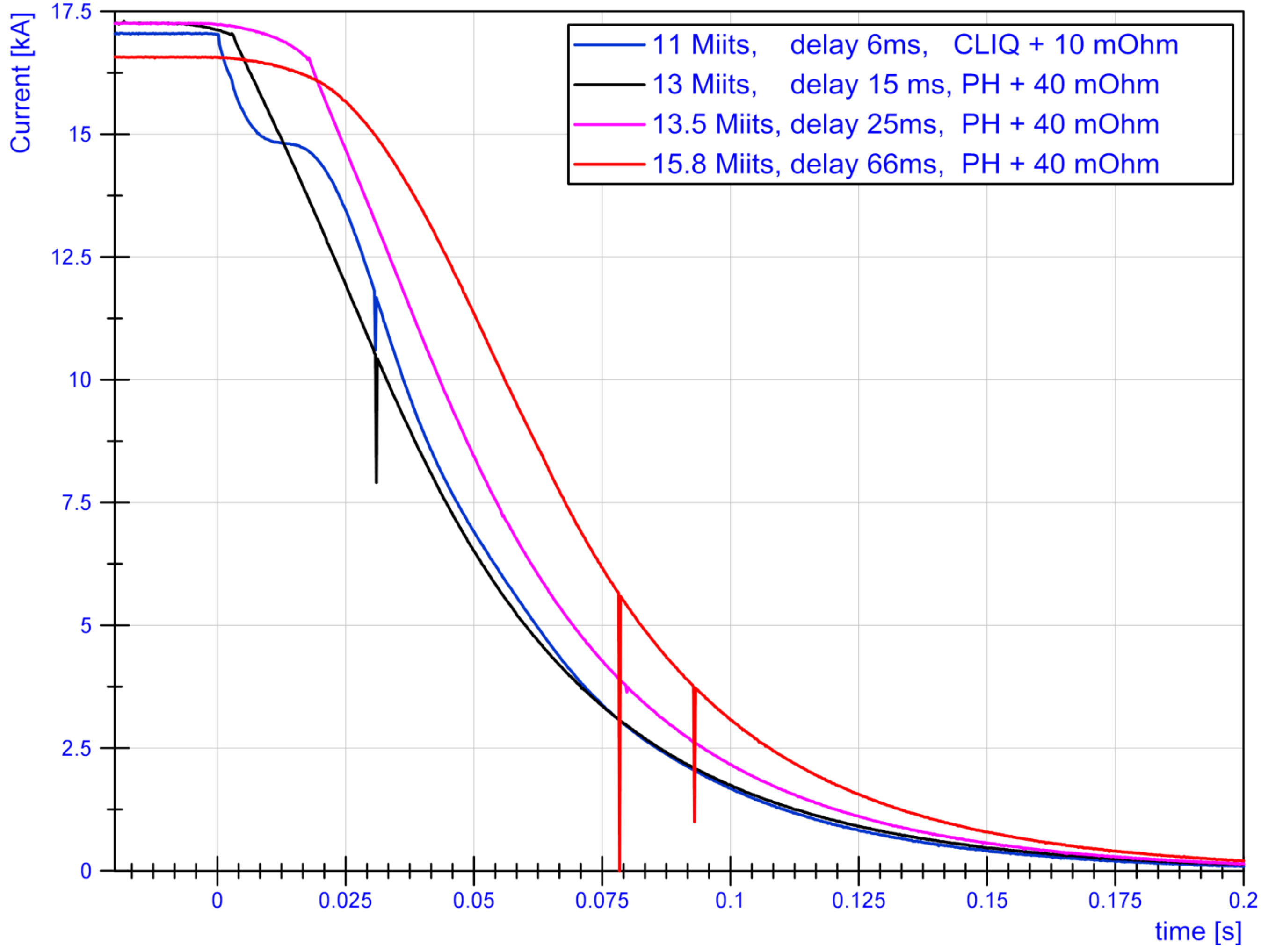
https://plone.uslarp.org/MagnetRD/ModelQuadrupoles/HQ/Meetings/2013/2013-06-28/

https://plone.uslarp.org/MagnetRD/ModelQuadrupoles/HQ/Meetings/2013/2013/11/07/

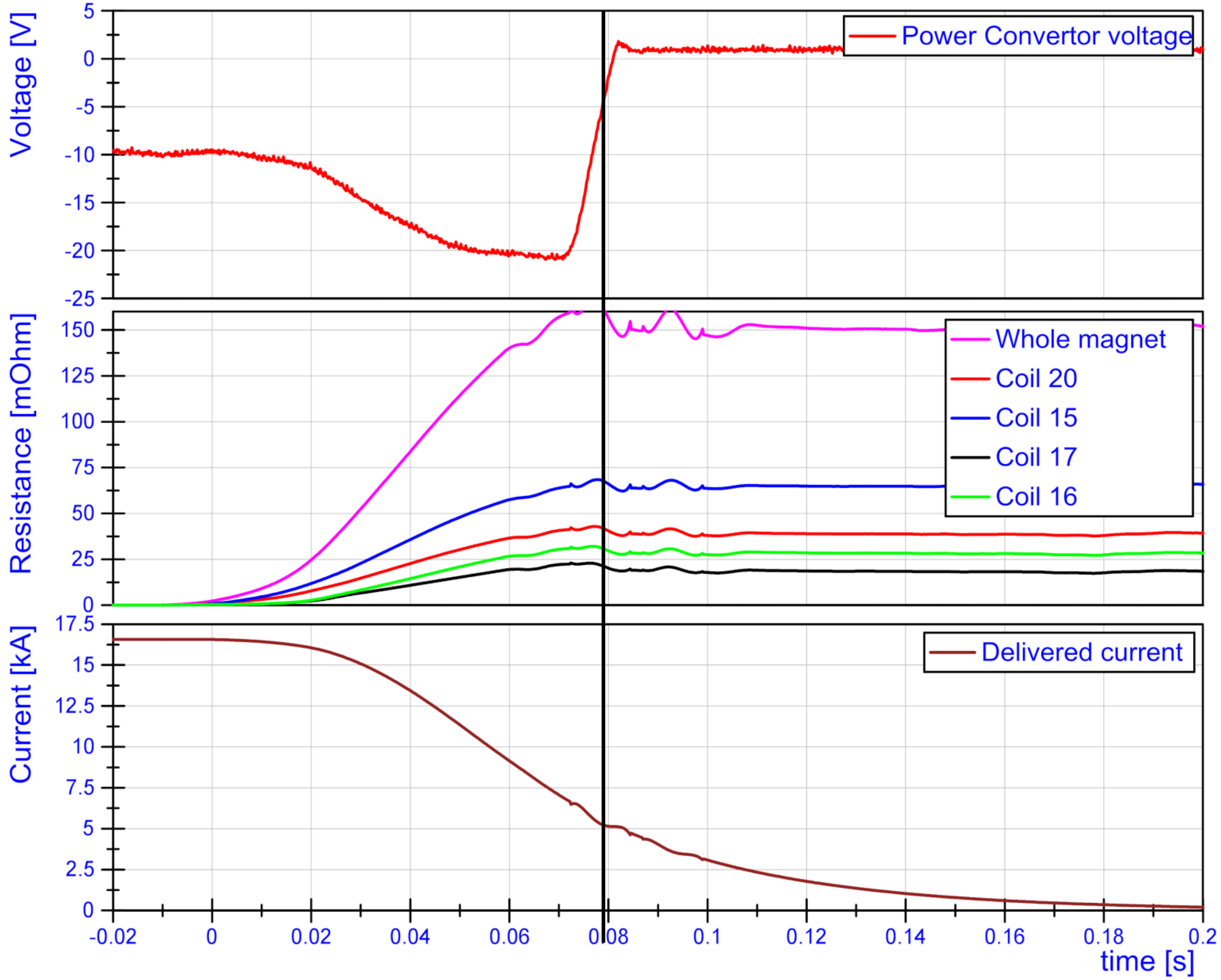
HQ02b Quench History



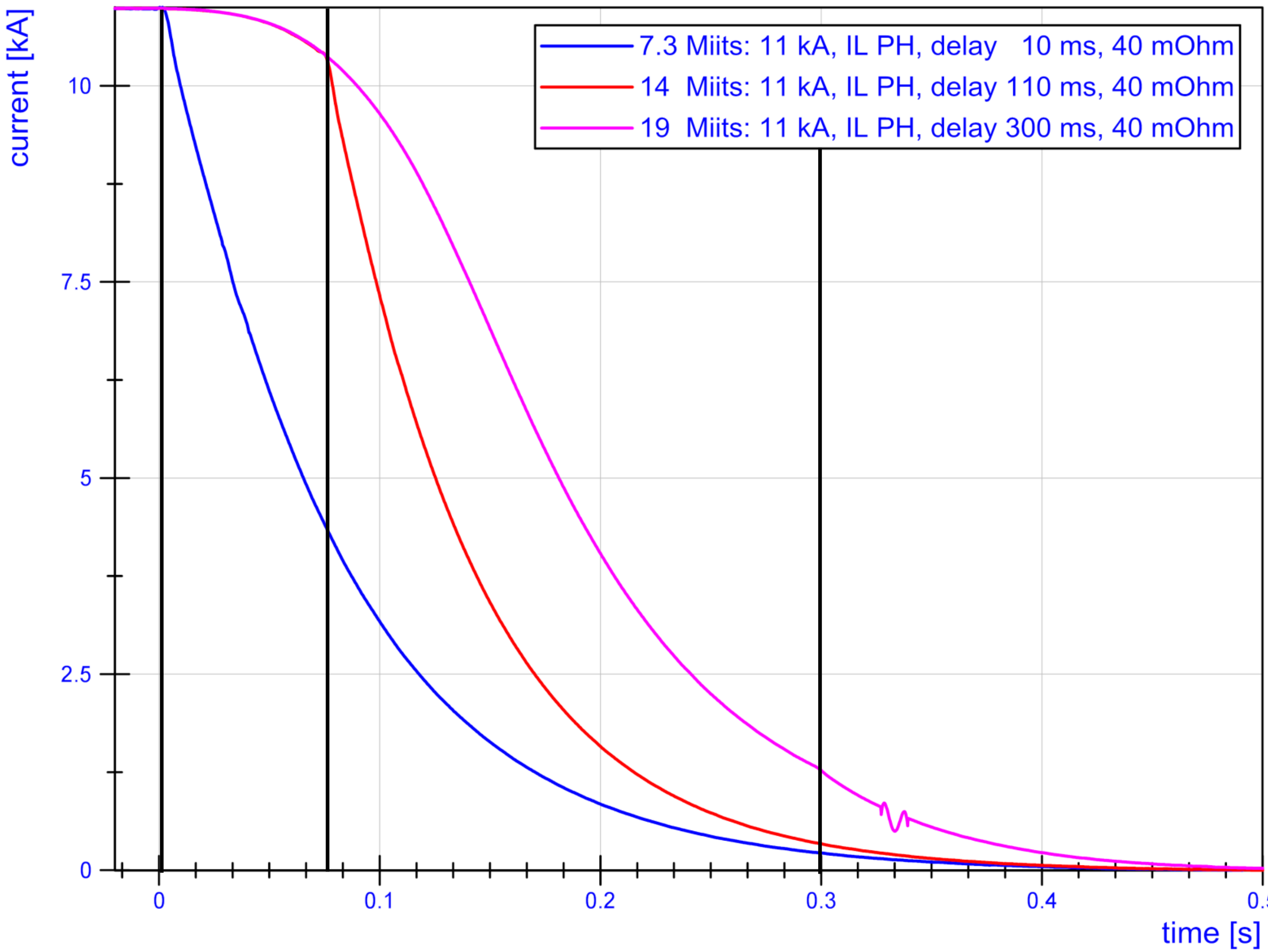
Plateau Quenches: current decay



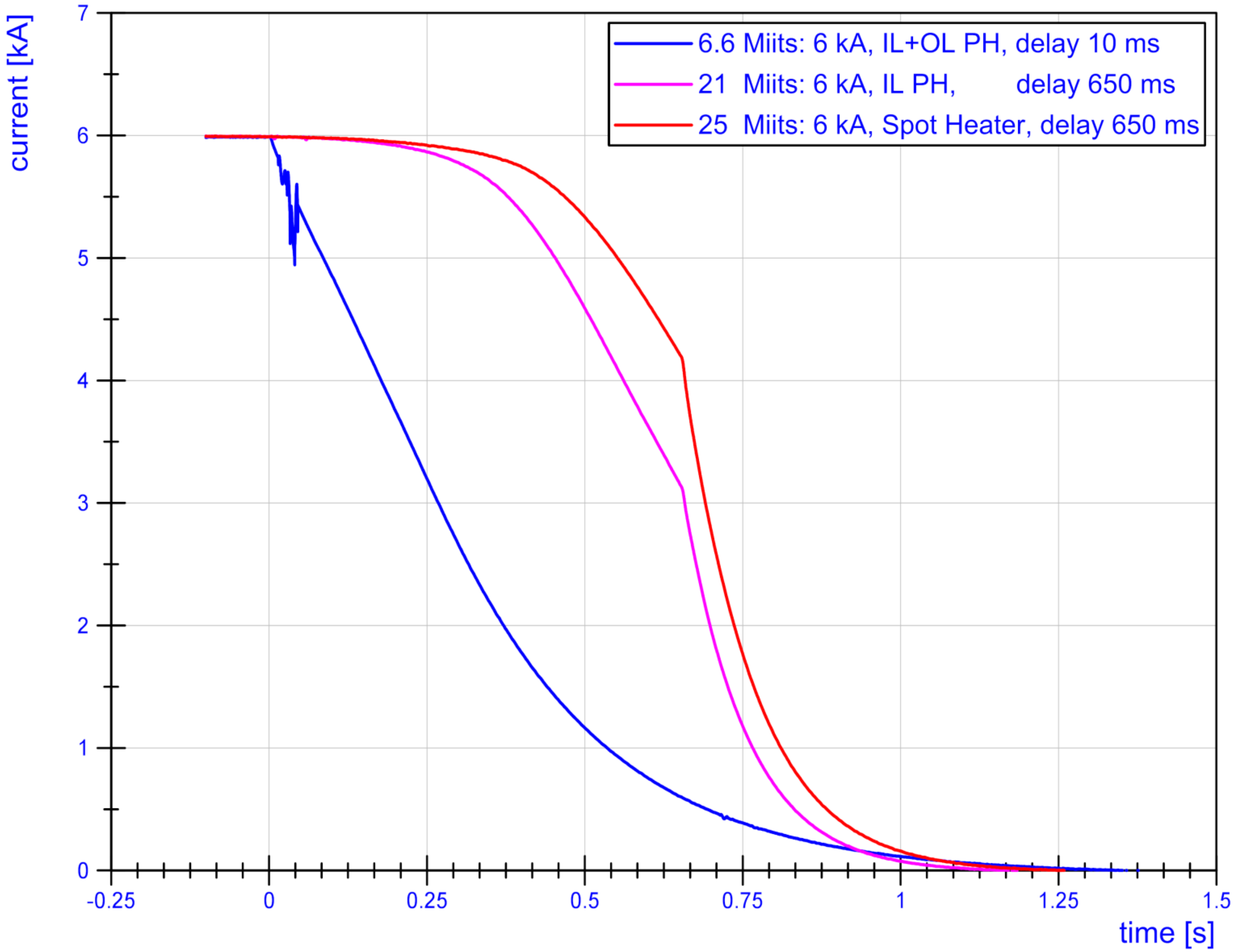
Plateau Quenches - Propagation



11kA provoked quenches (C16)



6 kA provoked quenches (C17)



HST calculation methods

- Three different semi-experimental approaches:

  - $R.I^2 = mc_p\ dT/dt$

    $\rightarrow T^n = T^{n-1} + \rho(T^{n-1}, B^{n-1}, RRR)\ .\ I^{2\ n-1}.\Delta t^{\ n-1} / (\ S_{cu}.S_t.VHC(T^{n-1})\ )$

  - $U.I = mc_p\ dT/dt$

    $\rightarrow T^n = T^{n-1} + U^{n-1}.\ I^{n-1}.\Delta t^{\ n-1} / (\ l.S_t.VHC(T^{n-1})\ )$

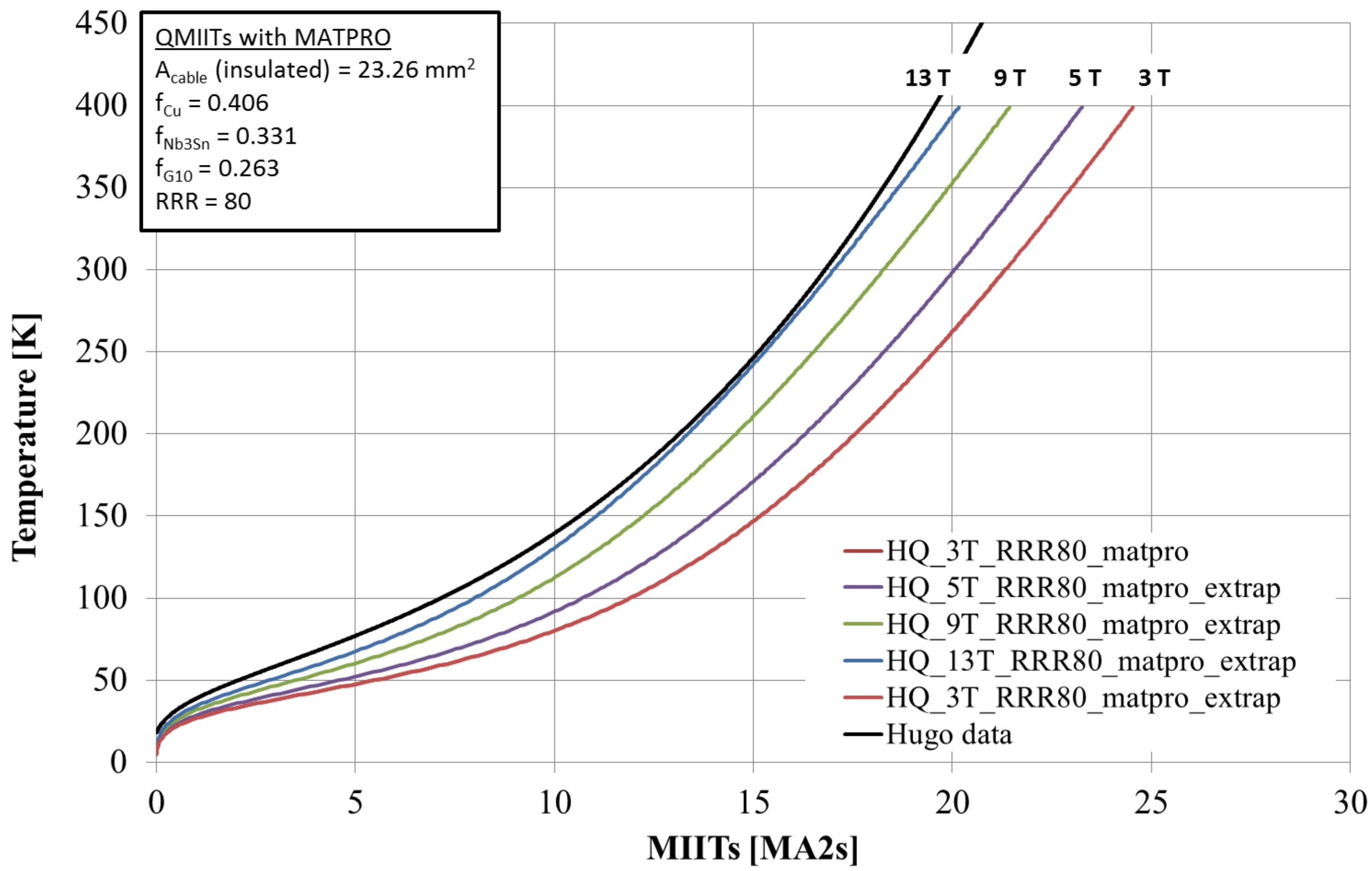
  - $U = R.I \rightarrow \rho_e = S.U / (\ I.l\ )$

    $\rightarrow T^n = f(\rho^n, B^n, RRR)$

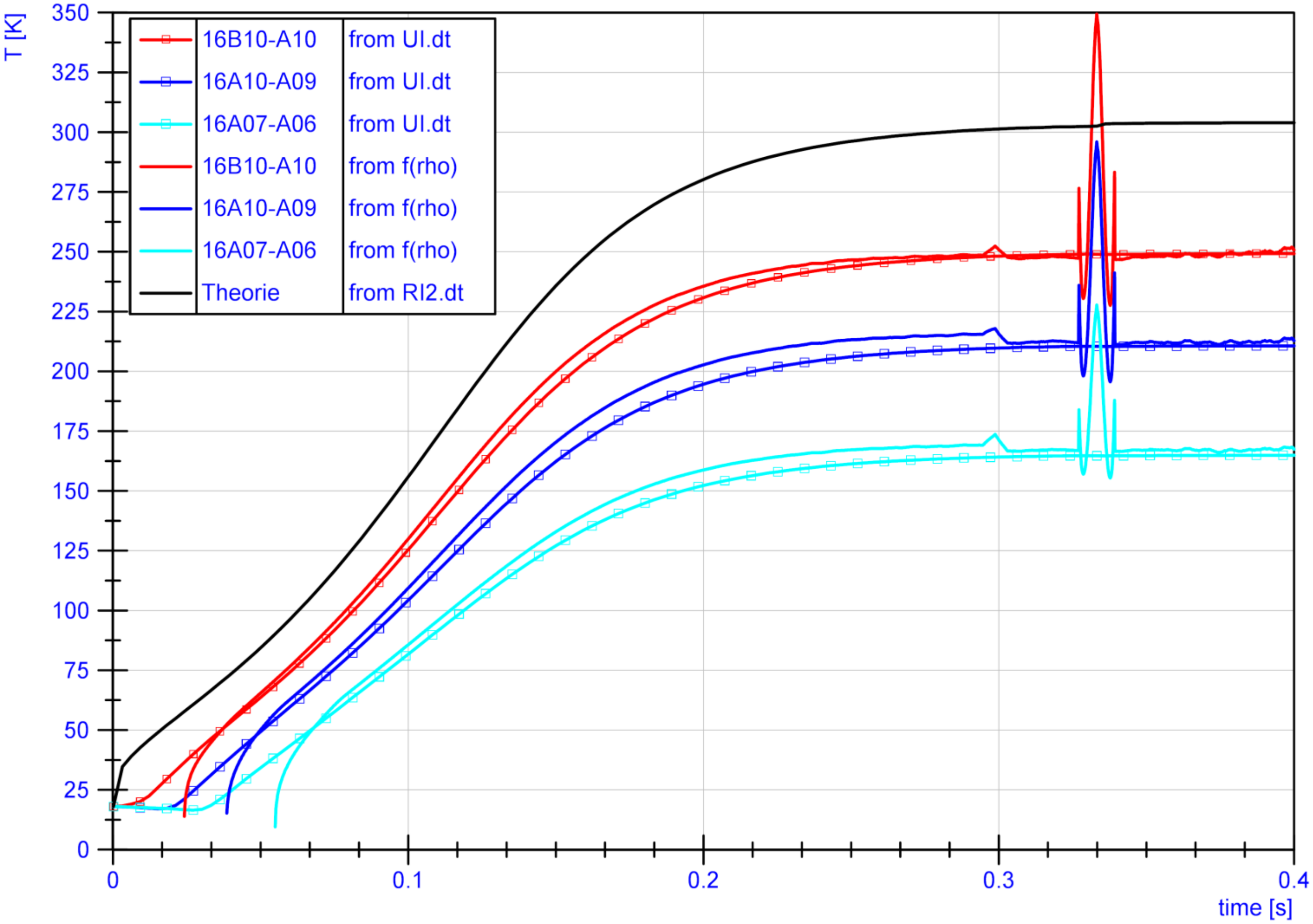
Number of strands	Strand diameter	Copper non-copper ratio	Cable width	Bare Cable Thickness	Insulation thickness
Ns	Ds	Cu/nCu	w_c	t_c	t_i
-	mm	-	mm	mm	mm
35	0.778	1.227	14.77	1.3756	0.09

MR	RRR	
Ωm/T	-	
0.005	140	C17
	80	C16

HQ Calculations



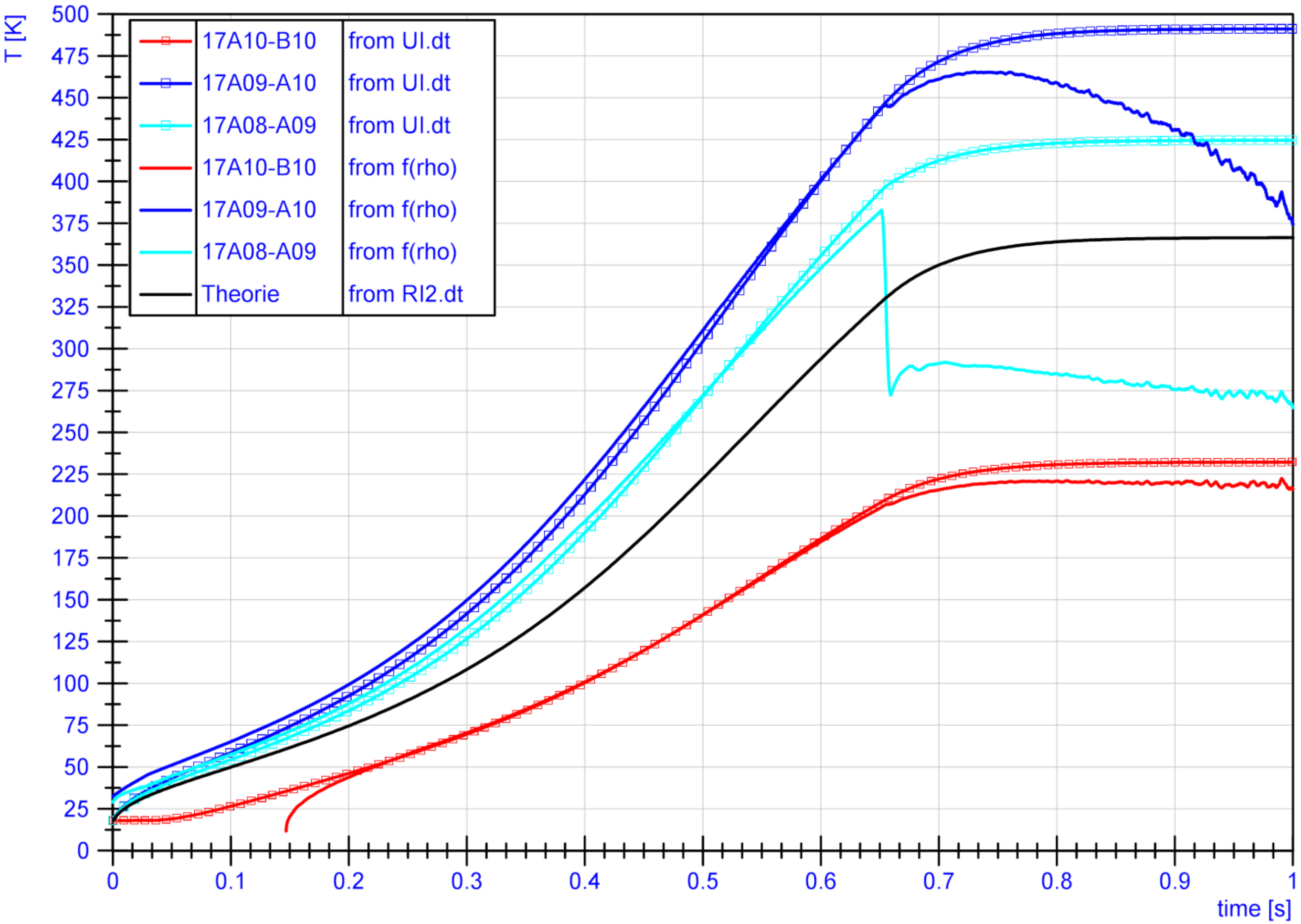
Hot Spot Temperature Estimates



19 Miits case
Coil 16
RRR=80

T_{th} = 300 K
T_{exp} = 250 K

Hot Spot Temperature Estimates



25 Miits case

Coil 17

RRR=140

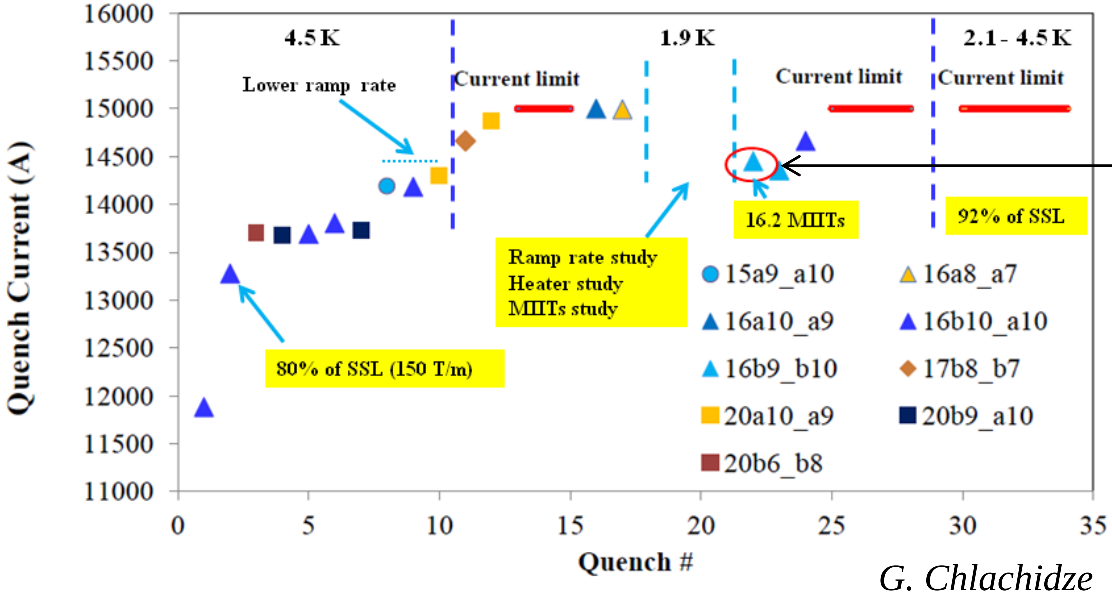
T_{th} = 360 K

T_{exp} = 480 K

Summary of HQ02b High MIITs Study

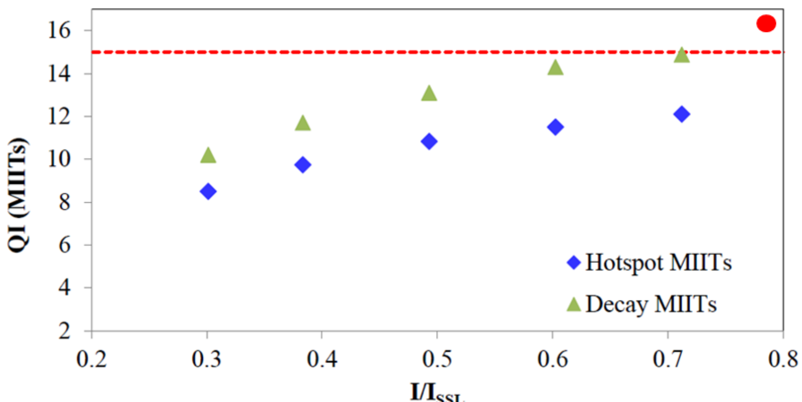
Date	QH #	Type	T (K)	Current (kA)	First location	Miits	Protection settings
Wed 4/2		Verification 4.2K	4.2	15.826	C17, A10B10		Standard (6ms, IL+OL+40mOhm)
Th 4/10	12	Training/plateau	1.9	17.024	C20, A7A8	11.2	Standard
Th 4/10	13	Training/plateau	1.9	17.162	C20, A7A8	11.2	Standard
Th 4/10	14	Training/plateau	1.9	17.12	C20, A7A8	11.6 (target 13)	Safety trigger bef. target 11 ms
Fr 4/11	15	Natural - high miits	1.9	17.27	C20, A7A8	**13** (target 15)	Splice trigger bef. target 18 ms
Fr 4/11		Ver. ramp 16.4kA, no quench	1.9	16.4	No quench		
Fr 4/11	16	Natural - high miits	1.9	17.212	C20, A7A6 --> A6A5	**12.7** (target 15)	14.4 ms trigger bef. target 18
Mon 4/14		Ver. ramp 16.4kA, no quench	1.9	16.4	No quench		
Mon 4/14	17	Natural - high miits	1.9	17.27	C20, A7-A6-> A6A5	**13.5** (target 16)	25 ms delay (HT+EXT)
Mon 4/14	18	Natural - high miits	1.9	16.58	C20, A8A7 --> A7A6	**15.8** (target 16)	66 ms delay (HT+EXT)
Tue 4/15	19	Verification/retraining	1.9	15.49	C20, A8A7 --> A7A6		Standard
Tue 4/15		Provoked - ILH coil 16	1.9	11	C16	**14**	110 ms delay (HT+EXT)
Tue 4/15	20	Verification/retraining	1.9	15.71	C20, A8A7 --> A7A6		Standard
Wed 4/16		Provoked - ILH coil 16	1.9	11	C16	**19**	300 ms delay (HT+EXT)
Wed 4/16	21	Verification/retraining	1.9	15.904	C20		Standard
Wed 4/16		Attempts with ILH coil 16	1.9	3 & 4	No quench		
Wed 4/16	22	Verification/retraining	1.9	16.13	C20, A8A7 --> A7A6		Standard
Th 4/17		Attempt - ILH coil 16	1.9	6	No quench		
Th 4/17		Provoked - ILH coil 17	1.9	6	C17	**21**	600 ms
Th 4/17		Provoked - SH coil 17	1.9	6	C17	**25**	650 ms
Th 4/17	23	Verification	1.9	15.809	C17, A9A10		Standard
Th 4/17		Verification 4.3K	4.3	15.382	C17, A9A10		Standard

High MIITs information from HQ02a



G. Chlachidze

16.2 MIITs
(80 ms dump delay)
Coil 16
Segment b9b10
(OL pole)



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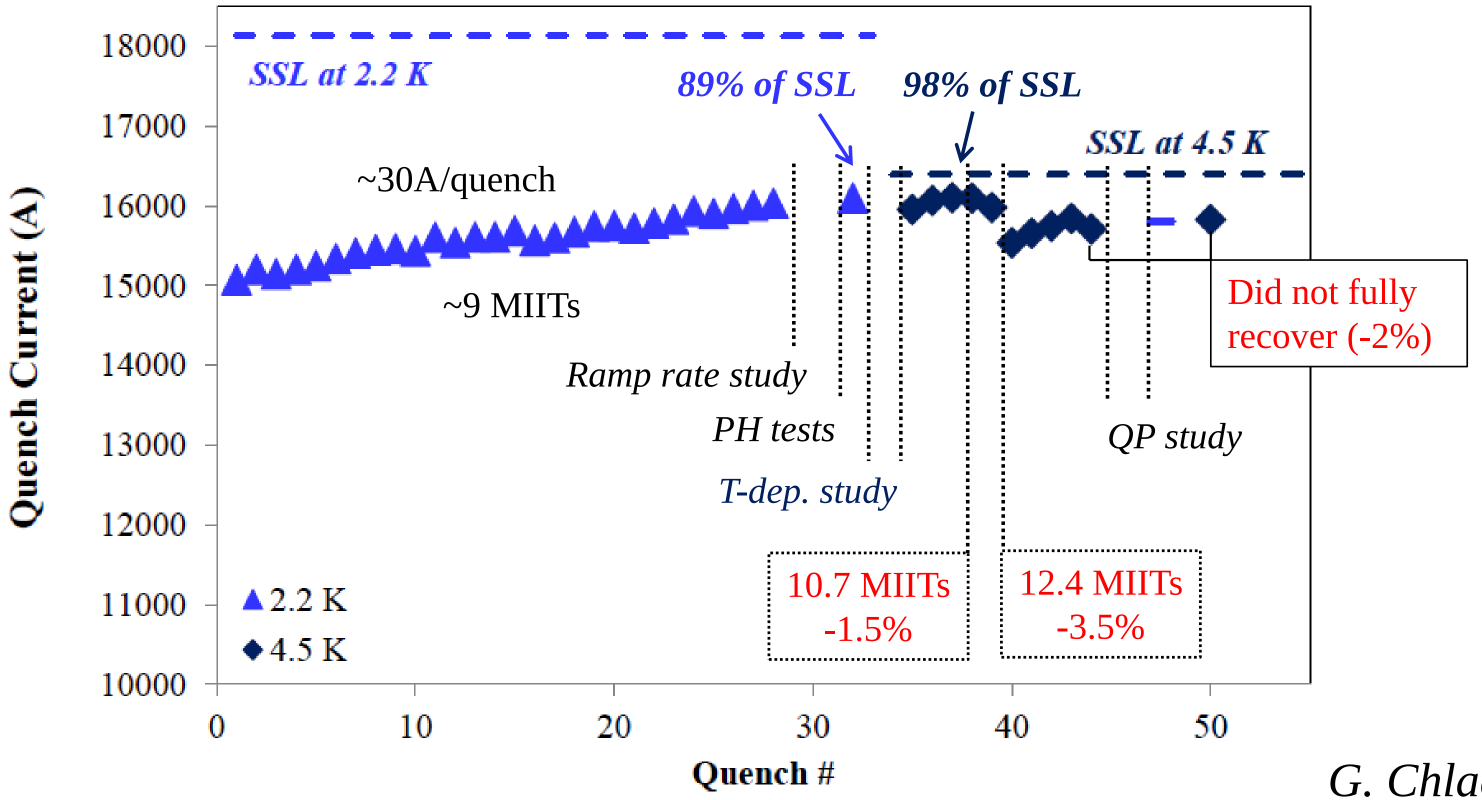
- QI study using provoked quenches protected with OL heaters and no dump
- Generally keeping hot spot MIITs below 12
- One natural quench in coil 16 resulted in 16.2 MIITs (*despite incorporating 60 mΩ dump with 80 ms delay*)

High MIITs information from HQ02a-2

- Detraining (3.5%) and slow retraining following 12.4 MIITs quench
  - *Decision to postpone high MIITs studies after pre-load increase*
- Did not fully retrain/recover max quench level (98% @ 4.5K)
  - *Not clear if detraining or degradation, and cause*



G. Chlachidze

Comments on Detraining vs. MIITs

- Effect observed in HQ02a, HQ02a2 and HQ02b
- Affects mechanically weak areas where training quenches occur
  - Looks like a temporary loss of training memory, without any permanent effect
  - Areas with better mechanical support are not affected at same/higher MIITs level
- Areas that are affected at lower pre-load becomes less sensitive with increased pre-load
  - Comparison between HQ02a2 and HQ02b
- Not a fundamental issue or a focus of the high MIITs study, but it negatively affects the high MIITs study due to time required for retraining (in order to recover baseline quench level or assess permanent degradation)
- Still an interesting effect from the mechanical standpoint
  - May be a factor in slowing down training or reaching a plateau

Comments on Degradation vs. MIITs

At the MIITs level that we were able to probe in HQ02, only minor or no permanent degradation was observed:

- No effect from **16.2 MIITs** spontaneous quench in HQ02a (C16 OL pole) during quench integral studies: magnet reached 98% of SSL at 4.5K after 2.2K training in HQ02a2
- A **12.5 MIITs** quench (4.5K, 16kA) *may* have caused a **2% degradation** in HQ02a2 (from 98% SSL to 96%...) *but* characterization was not complete and cause may be different from MIITs.
- No indication of permanent degradation from **13.5/15.8 MIITs** spontaneous quenches at 17.3/16.6kA (1.9K) in HQ02b (but: incomplete assessment, no full retraining or 4.5K verification)
- No indication of any effect from **19 MIITs** provoked quench in coil 16 (but: incomplete assessment, no full retraining or 4.5K verification)
- A **25 MIITs** spot heater provoked quench at 6kA (C17 pole) in HQ02b caused significant detraining (>8%) and *may* have caused a **2% degradation** from 96% SSL to 94% (but: additional retraining would have been needed before verification quench at 4.3K)

Some lessons learned and Next Steps

- Capability of reaching High MIITs is limited by rapid quench propagation, leading coil resistance growth and fast current decay, despite attempts to actively maintain current levels (worse than "no protection" conditions)
  - Applies to low/intermediate/high current & field
  - Data on long term quench evolution is a key by-product of high MIITs study
  - Needs to be adequately reflected in quench protection design/simulations
- Proper high MIITs study requires significant testing effort due to long recovery times and need to retrain (can be mitigated w/higher pre-load)

Future goals:

- Further increase MIITS. Should be addressed both on the magnet side (e.g. promising results from SH) and the facility side
- Perform better characterization to fully profit from design/fabrication investment
  - More time for retraining (quite reasonable in HQ02b: perhaps 2-3 days of retraining sufficient to find plateau at each level)
  - Regularly perform control quenches at 4.5K after retraining at each step
  - Full characterization should include ramp rate, temperature dependence

Acknowledgment

Large collaborative effort on HQ02 Design, Fabrication and Test involving teams at BNL, FNAL, LBNL & CERN

Giorgio Ambrosio, Mike Anerella, Marta Bajko, Franck Borgnolutti, Rodger Bossert, Dan Cheng, Guram Chlachidze, Vincent Desbiolles, Dan Dietderich, DiMarco, Helene Felice, Paolo Ferracin, Jerome Feuvrier, Arup Ghosh, Christian Giloux, Arno Godeke, Maxim Martchevskii, Emmanuele Ravaioli, Tiina Salmi, Jesse Schmalzle, Michael Tartaglia, Ezio Todesco, George Velev, Peter Wanderer, Xiaorong Wang, Gerard Willering, Miao Yu

Discussion points

Assessment of HQ results:

- Better understand/reconcile temperature vs. MIITS
- Measurement of long term evolution vs models
- Is high MIITs at low field representative of other conditions

Plans for future testing:

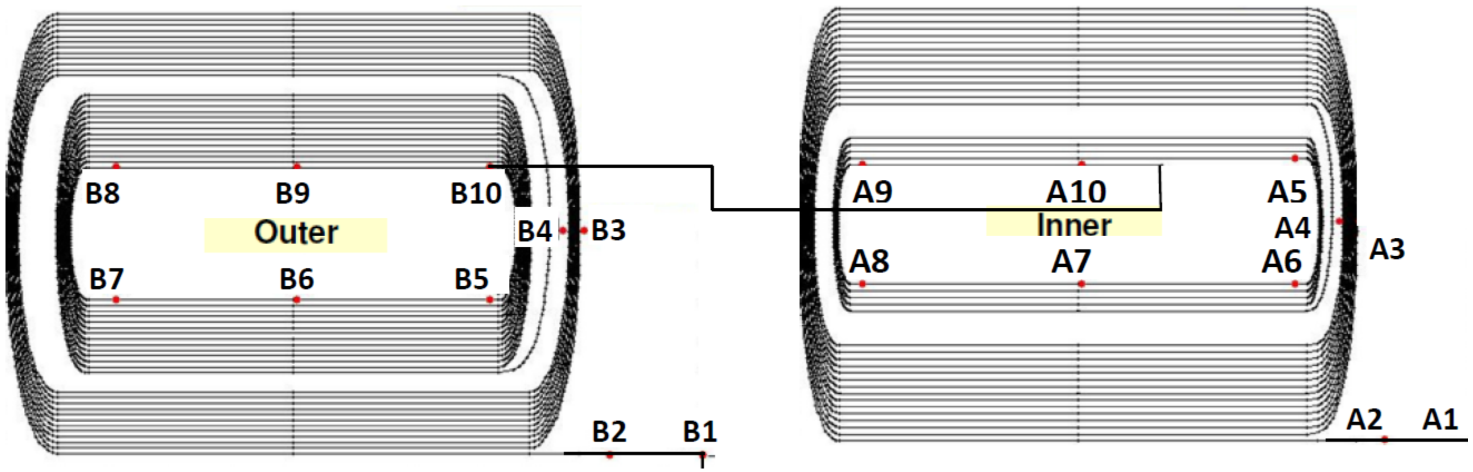
- Options for better characterization, higher MIITS
- Spot heater, facility changes
- Timeline of tests vs needs of QXF

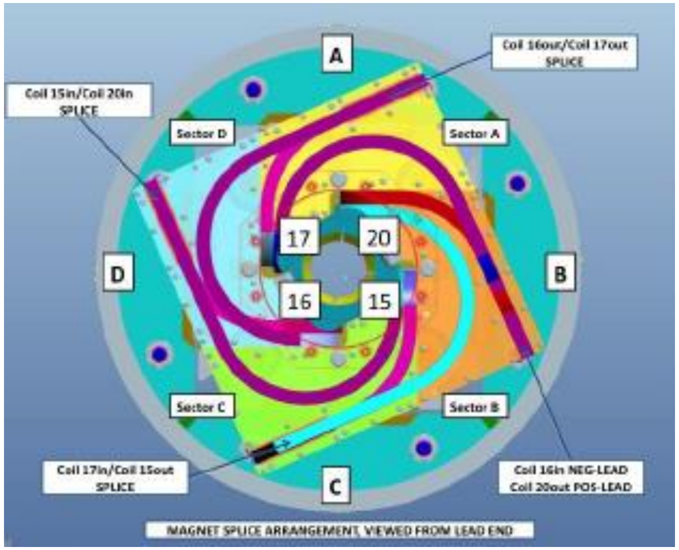
Relevance to QXF:

- Incorporate quench evolution information in QP design
- Relevance of HQ to short QXF, effect of core design, cable, etc.
- Applicability to long magnets

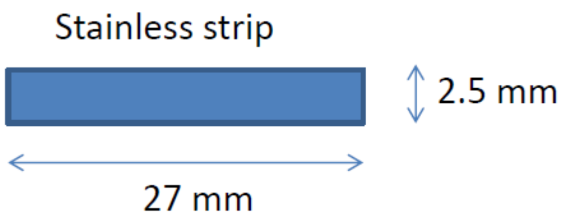
Backup Slides

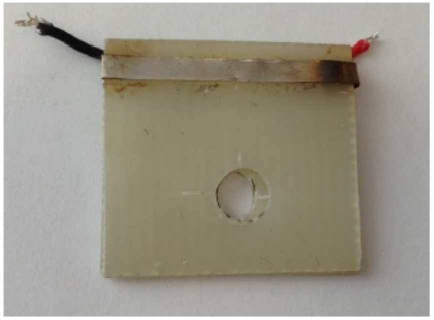
Coil and v-tap configuration





HQ Spot heater information (Maxim)





Thickness: 75 micron

Resistance (RT) = **0.316 Ω**

3 A current = > 4.2 W/cm^2
4 A current => 7.5 W/cm^2
5 A current => 11.7 W /cm^2

- The bare heater strip can sustain 3 A indefinitely or 5 A for 3 s at room temperature.
- Heater strip pressed against a plastic tube holds 5 A for 5 s without sign of burning
- Burnout is likely to occur near the bended ends

Tiina's simulations for the "regular" HQ heater give ~15 ms heater delay for 10 W/cm^2 and ~24 ms for 5 W/cm^2 (at 80% SSL)

Recommendation:
Start with 5 A peak current and ~75 ms time constant , then gradually increase the time constant up to ~200 ms. If still no quench, then increase the current in small (~0.5 A) steps.

6kA spot heater quench obtained using 6 A, 1 s pulse