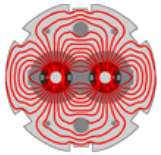


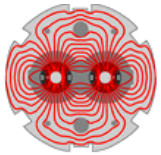
LARP

High Field Quadrupole Status - HQ

Shlomo Caspi

LBNL

LARP Collaboration Meeting – CM15
SLAC
November 1-3, 2010



LARP

Outline

- The HQ program and Target
- The HQ magnet
- Test results – HQ01 - a, b, c
- Conclusions and Plans

HQ Program & Targets

Program

- Part of the US LHC Accelerator Research Program (LARP)
- Develop Nb_3Sn quadrupole magnet for the LHC luminosity upgrade.

Magnet

- Extend Nb_3Sn magnet technology:
  - from 1 m long, 90 mm bore, 13T -> TQ
  - to 1 m long, 120 mm bore, 15T -> HQ + field quality
- HQ 80% program target:
  - 160 (T/m) at 4.4K
  - 175 (T/m) at 1.9K
  - Good memory – no retraining

Conductor

- Evaluate different strands (54/61 and 108/127 filaments).

LARP - Magnet R&D Program

LARP

1. Nb_3Sn Technology - TQ

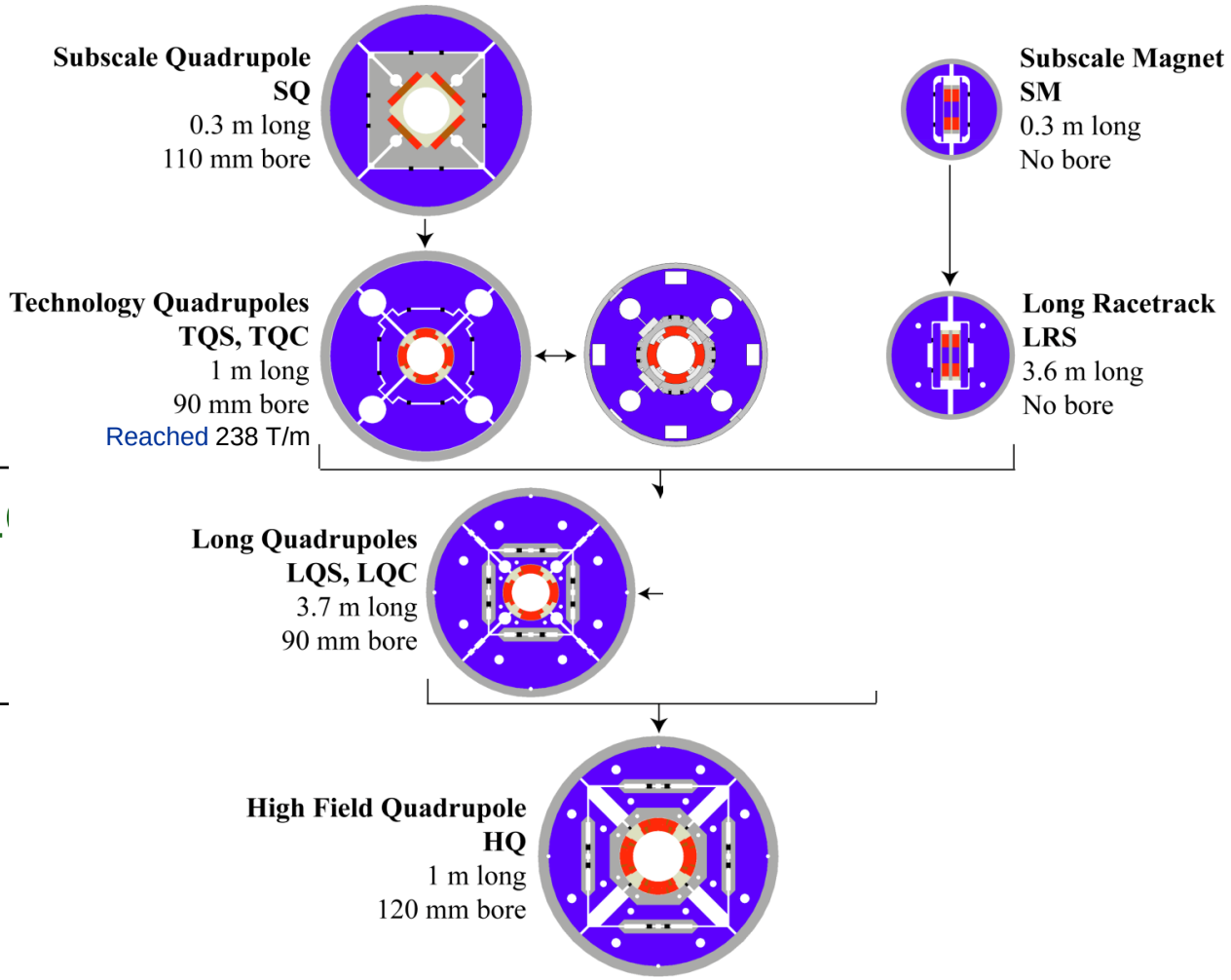
- *Conductor studies*
- *Coil fabrication*
- *Mechanical support*
- *Modeling tools*
- *Quench protection*

2. Length scale-up - L

- *Coil technology*
- *Quench protection*

3. Design optimization

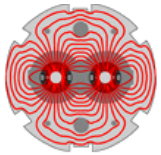
- *Larger aperture*
- *higher energy and forces*
- *Accelerator quality*



The HQ Collaboration Program

A collaboration between 3 US laboratories and CERN:

- BNL –
  - Tooling design - reaction, impregnation, shipping
  - Coil work - react, instrument and impregnate (50-50% BNL/ LBNL)
- FNAL –
  - Magnetic cross-section design
  - Design and fabrication of all islands, end spacers and shoes
  - HQ magnet test and single coils mirror test
- LBNL –
  - Coil winding, curing, reaction, instrumentation, impregnation.
  - Design, analysis and fabrication of structure
  - Magnet assembly and Test
  - Tooling design and fabrication
- CERN
  - Test



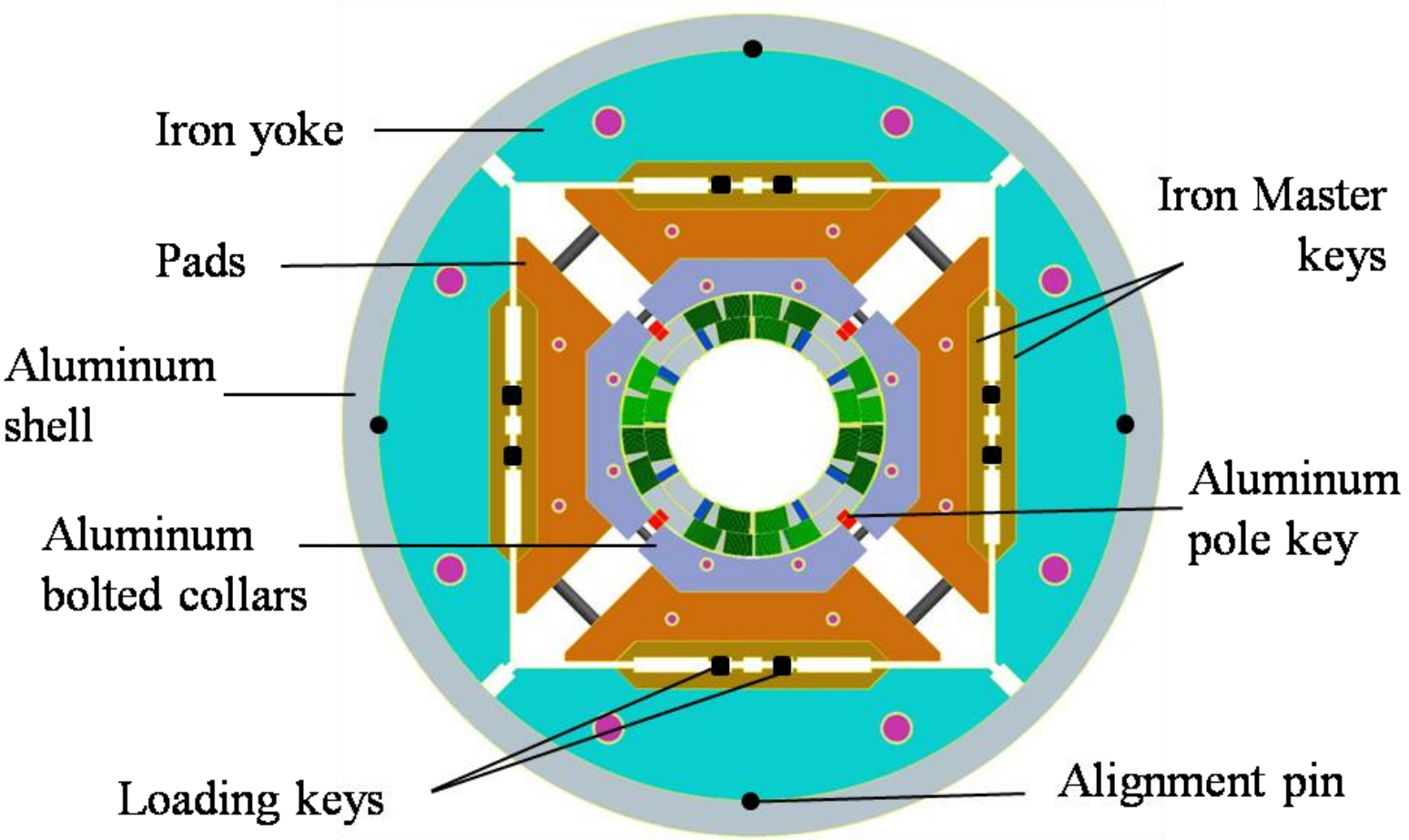
LARP

HQ Progress

2008	June	Presented conceptual designs for 114 and 134 mm bore
	July	Selection of 120 mm quadrupole aperture for Phase 1
	Sept.	Cable and coil cross-section geometry finalized
	Dec.	All coil fabrication tooling in procurement
2009	Mar.	All coil and structure components in procurement
	Apr.	Cables for ~10 coils fabricated (54/61 and 108/127)
	Sept.	Coil 1 completed and coil 2 wound
	Dec.	Coil 2 completed, coil 3-4 reacted, coil 5 wound
2010	Jan.	Structure pre-assembly completed
	Feb	Coil 1-4 completed
	Apr.	HQ01a test coils 1,2,3,4
	June	HQ01b test coils 1,4,5,6
	Oct.	HQ01c test coils 1,5,7,8

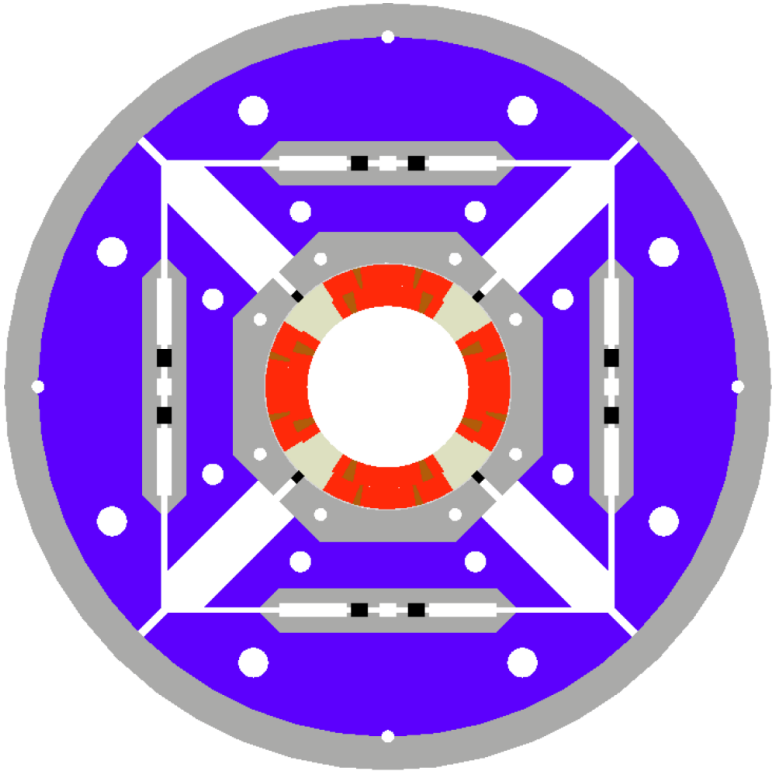
* By the end of 2010 five more coils should become available (up to #13)

LARP – HQ Cross-Section



HQ Parameters

Coil aperture	mm	120
Overall magnet diameter	mm	570
Jc 12T, 4.2 K, RRP 108/127	A/mm^2	3000
Maximum gradient 4.4 K/1.9 K	T/m	199/219
Maximum current 4.4 K/1.9 K	kA	17.7/19.5
Peak field 4.4 K/1.9 K	T	13.9/15.2
Jc 12T, 4.2 K	A/mm^2	3000
Max. stored energy 1.9 K	MJ/m	1.4
Max F_θ forces 1.9 K, IL/OL	MN/m	-1.92/-3.2
Maximum axial force per end	MN	1.4

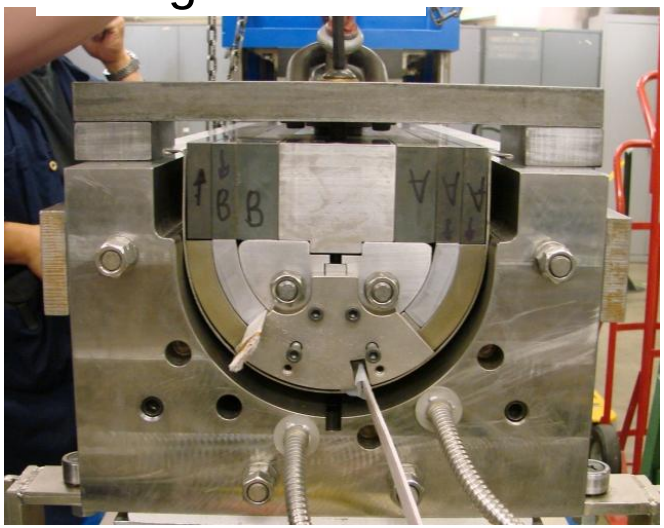


- **120mm bore, 0.8 mm strand, 15mm cable**
- **15T + alignment + field quality**
- **Keys & bladders & Al shell & Axial Al rods assembly**
- **Al collars + alignment keys**
- **Protection heaters layers 1 and 2**

Winding and Curing

Coil Winding

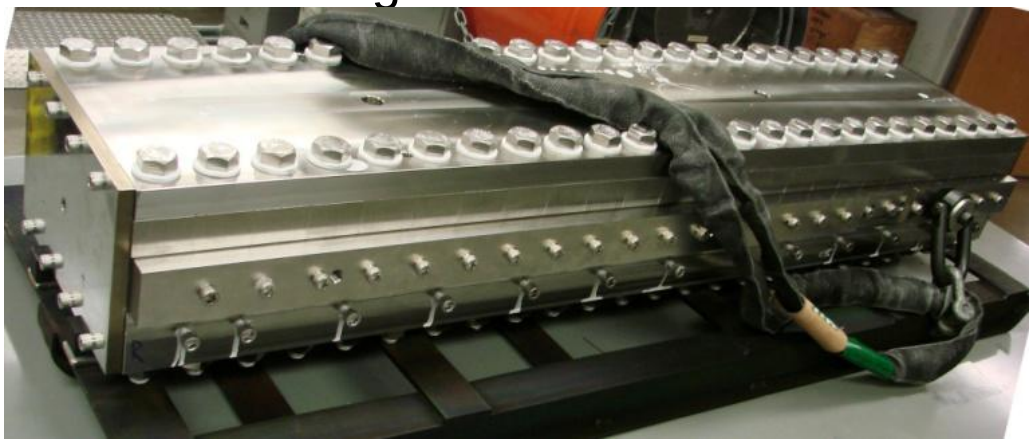
Curing



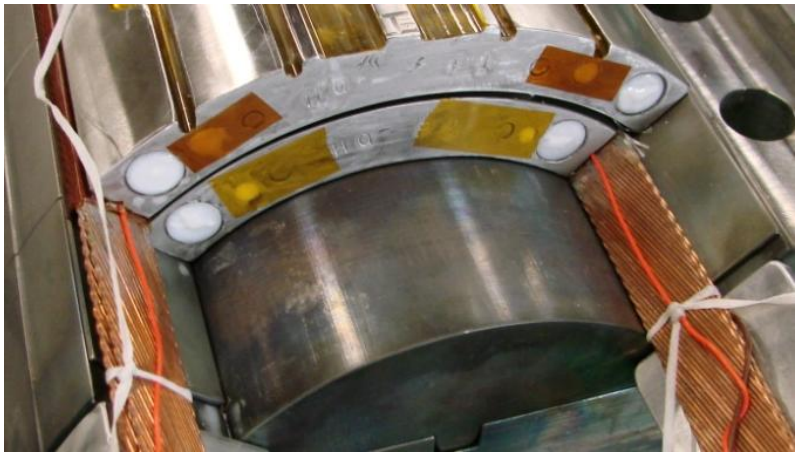
Cured Layer 1

Reaction, Instrumentation, Impregnation

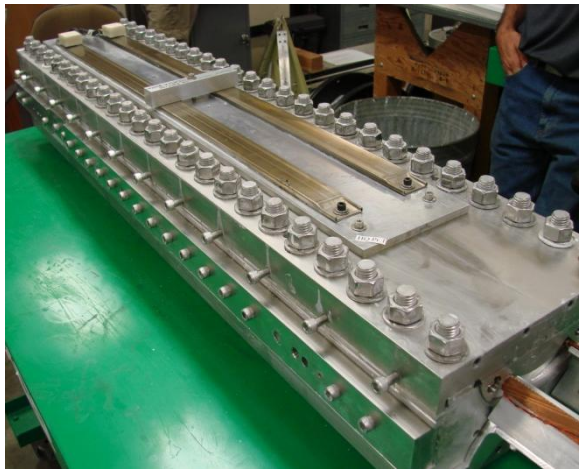
Reaction Tooling



- 72 hr at 210 C
- 48 hr at 400 C
- 48 hr at 665 C

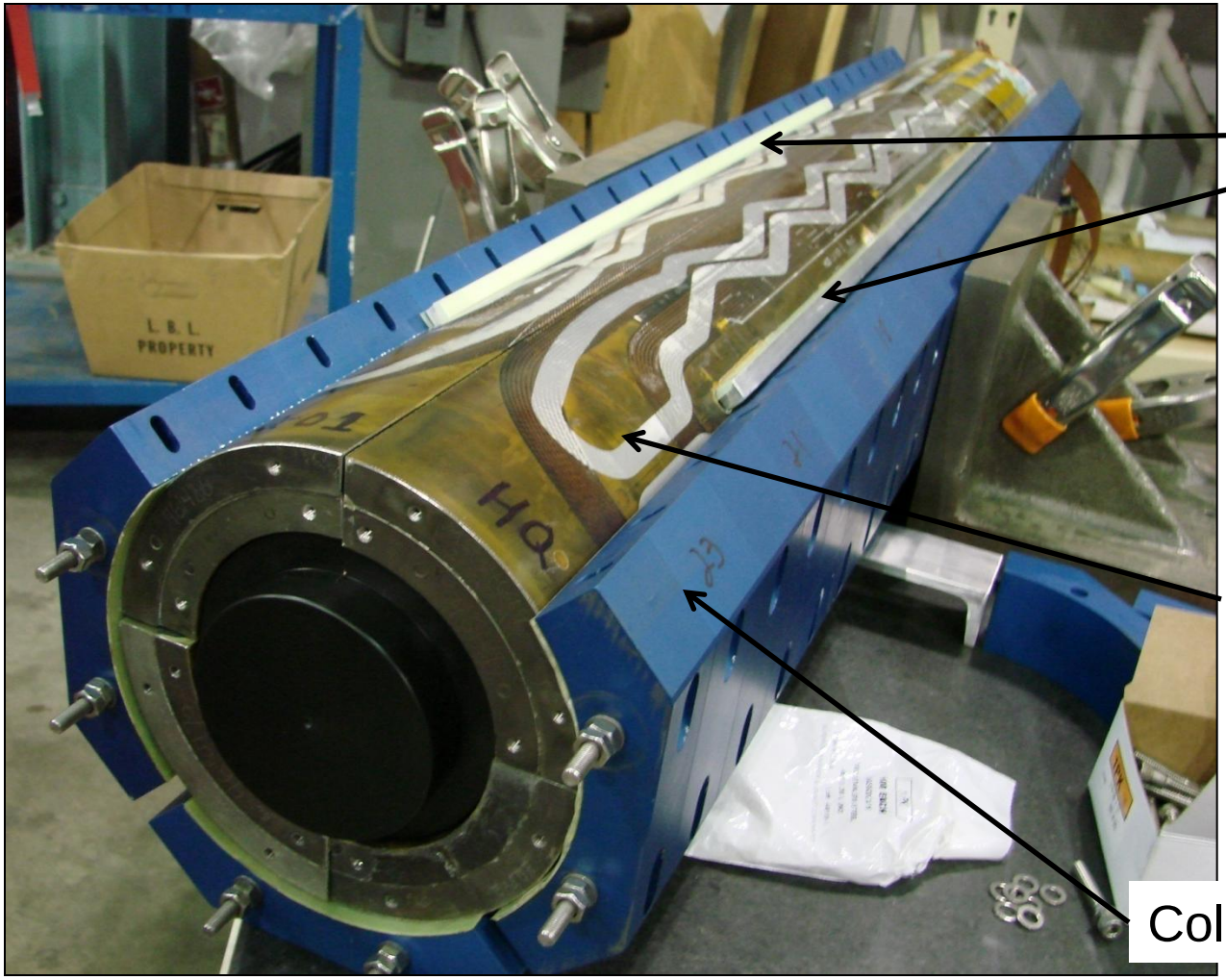


Post Reaction: NbTi Leads, VT, SG.



impregnation Tooling

Coils Assembly and Alignment

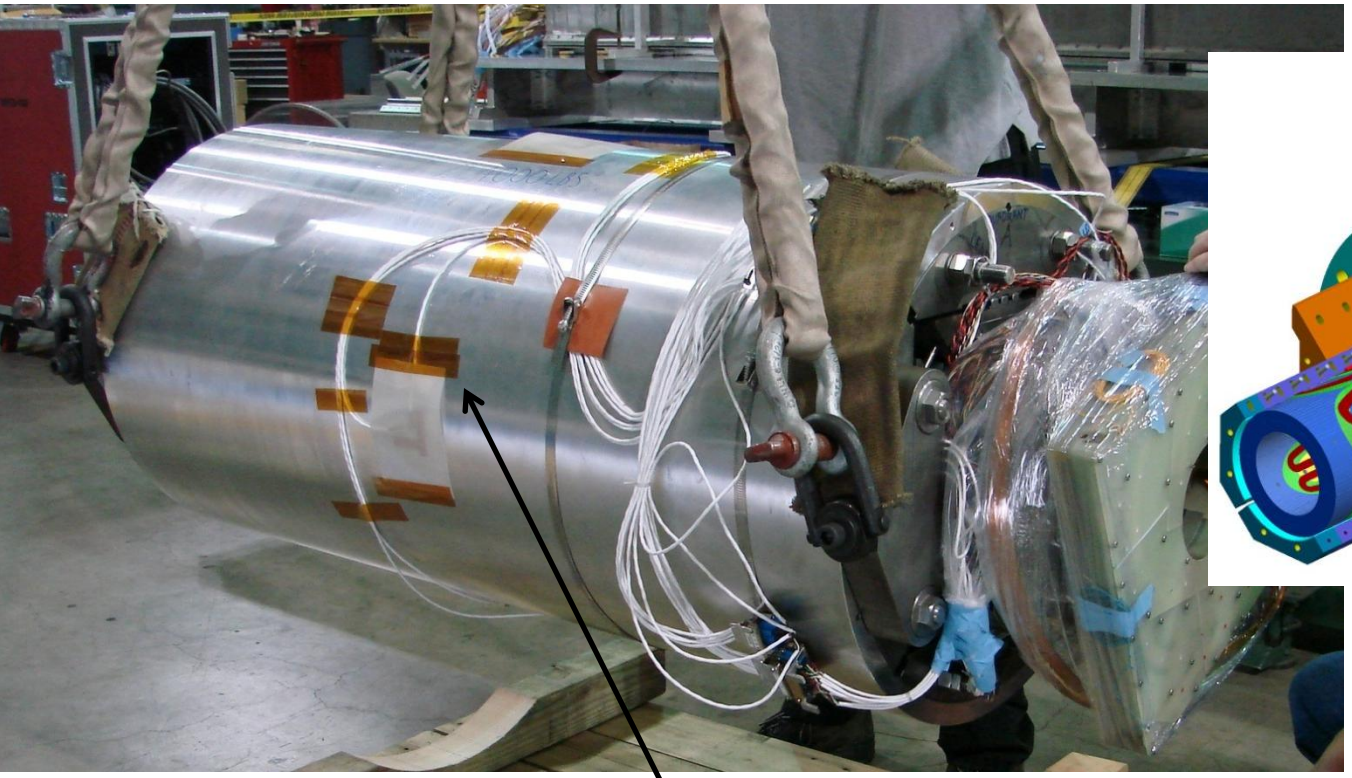


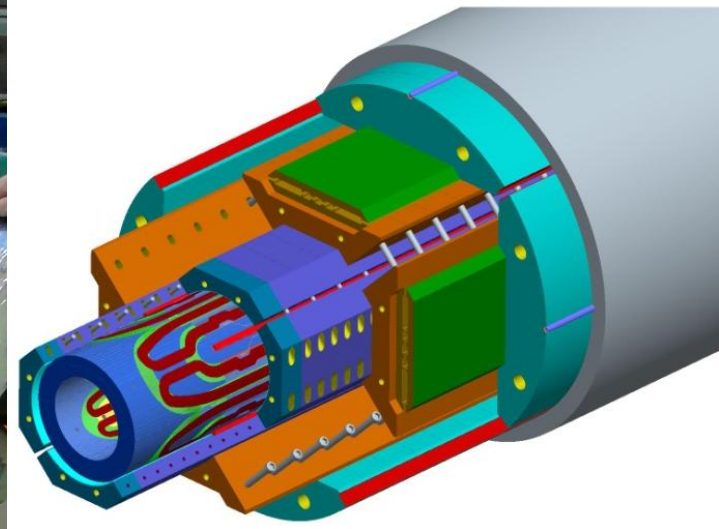
Alignment Keys

Coil & heater

Collars

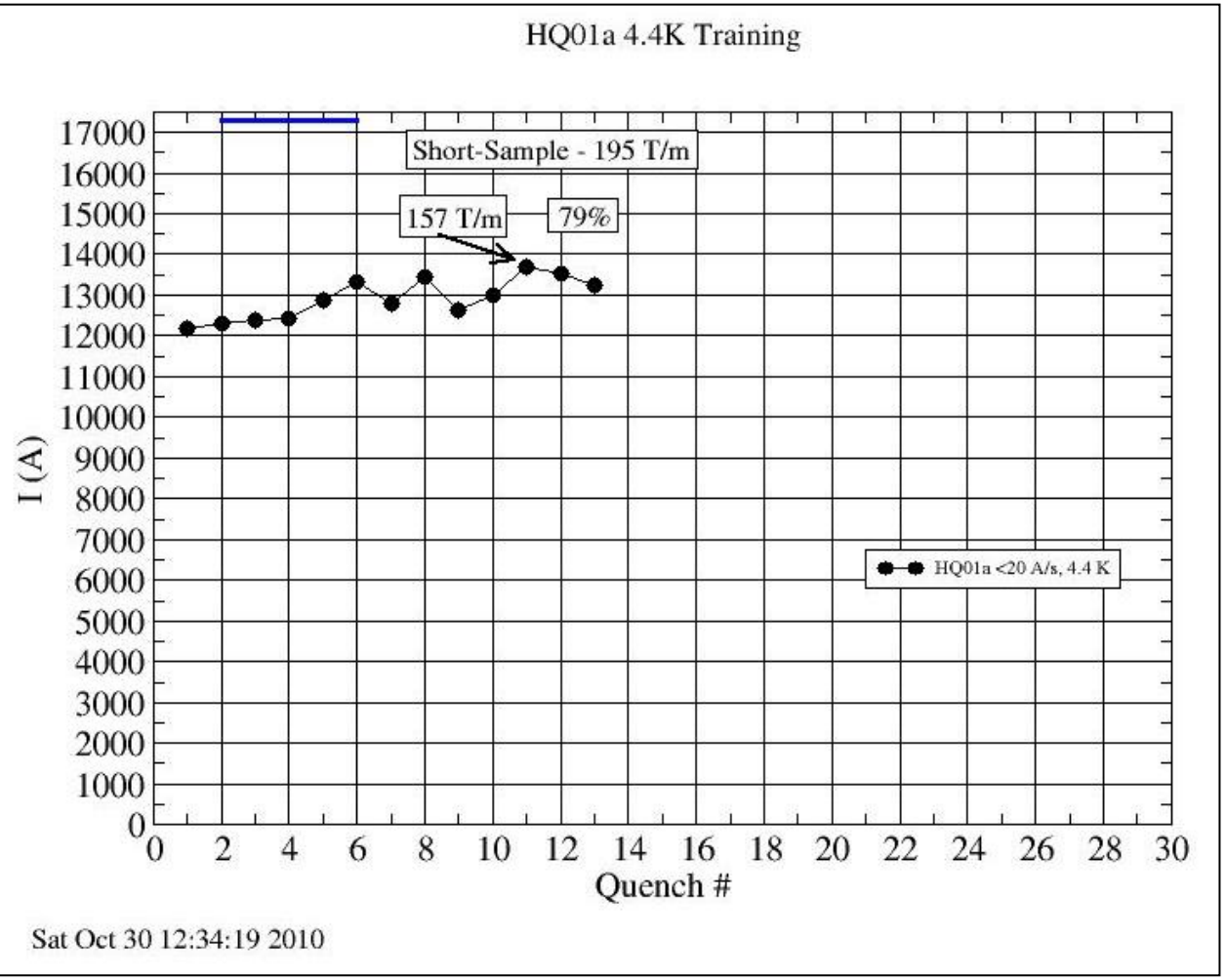
HQ01a – ready to test





Aluminum shell + strain-gages

Training Quenches – HQ01a

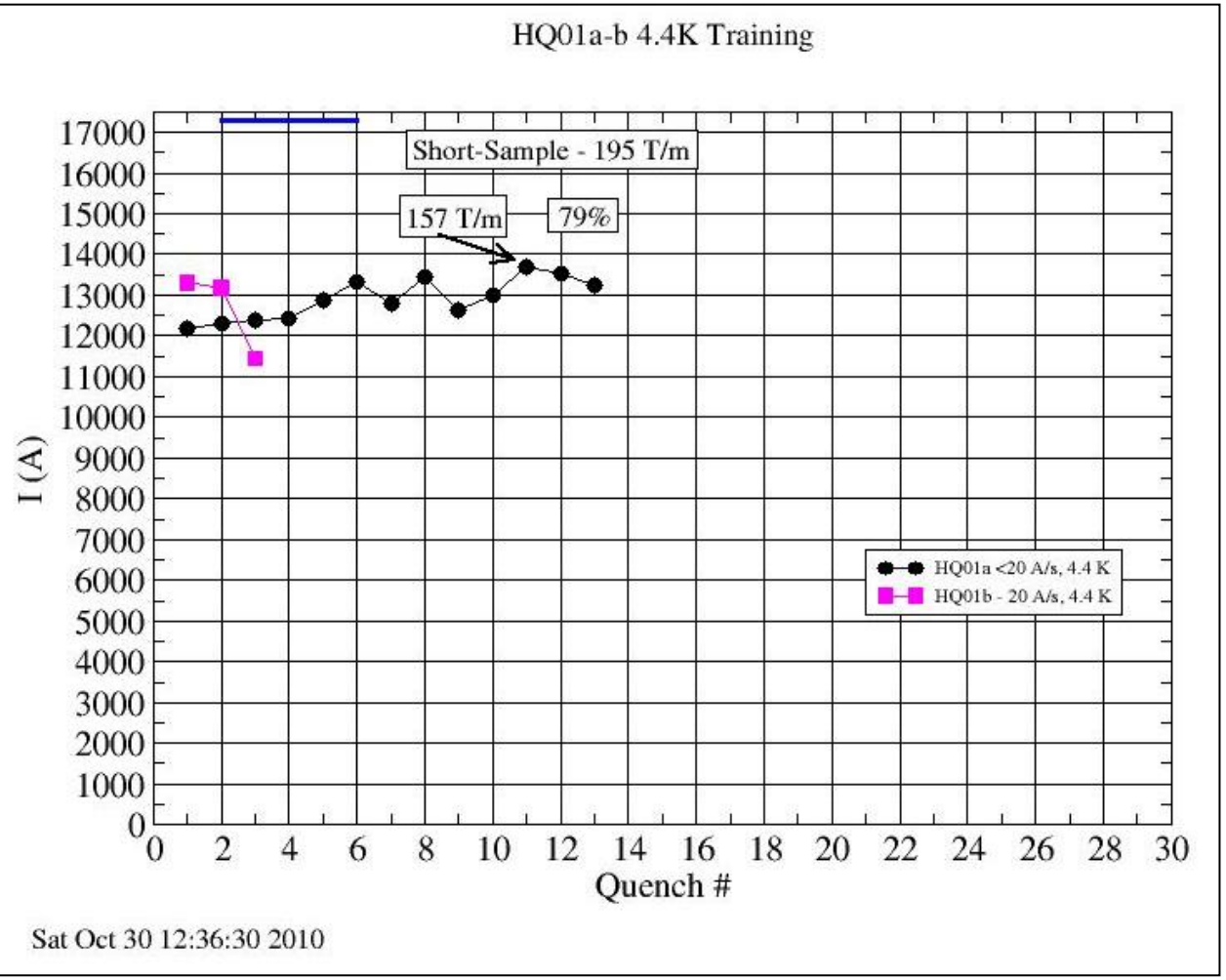


HQ01a

Q1 - 12183A (141T/m, 71% of ss)

Q11 - 13683A (157T/m, 79% of ss)

Training Quenches – HQ01a+b



HQ01a

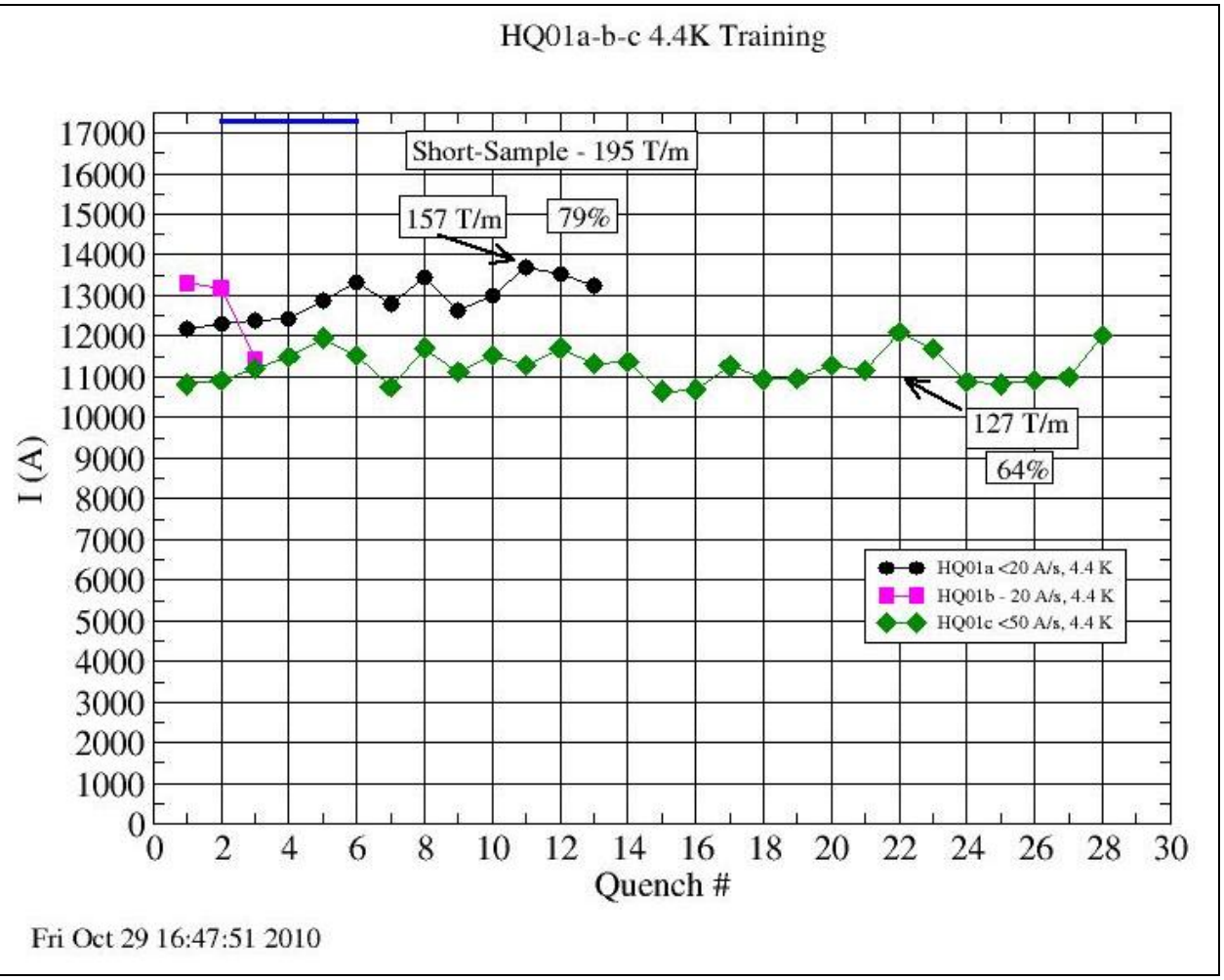
Q1 - 12183A (141T/m, 71% of ss)

Q11 - 13683A (157T/m, 79% of ss)

HQ01b

Q1 - 13308A (153T/m, 77% of ss)

Training Quenches– HQ01a+b+c

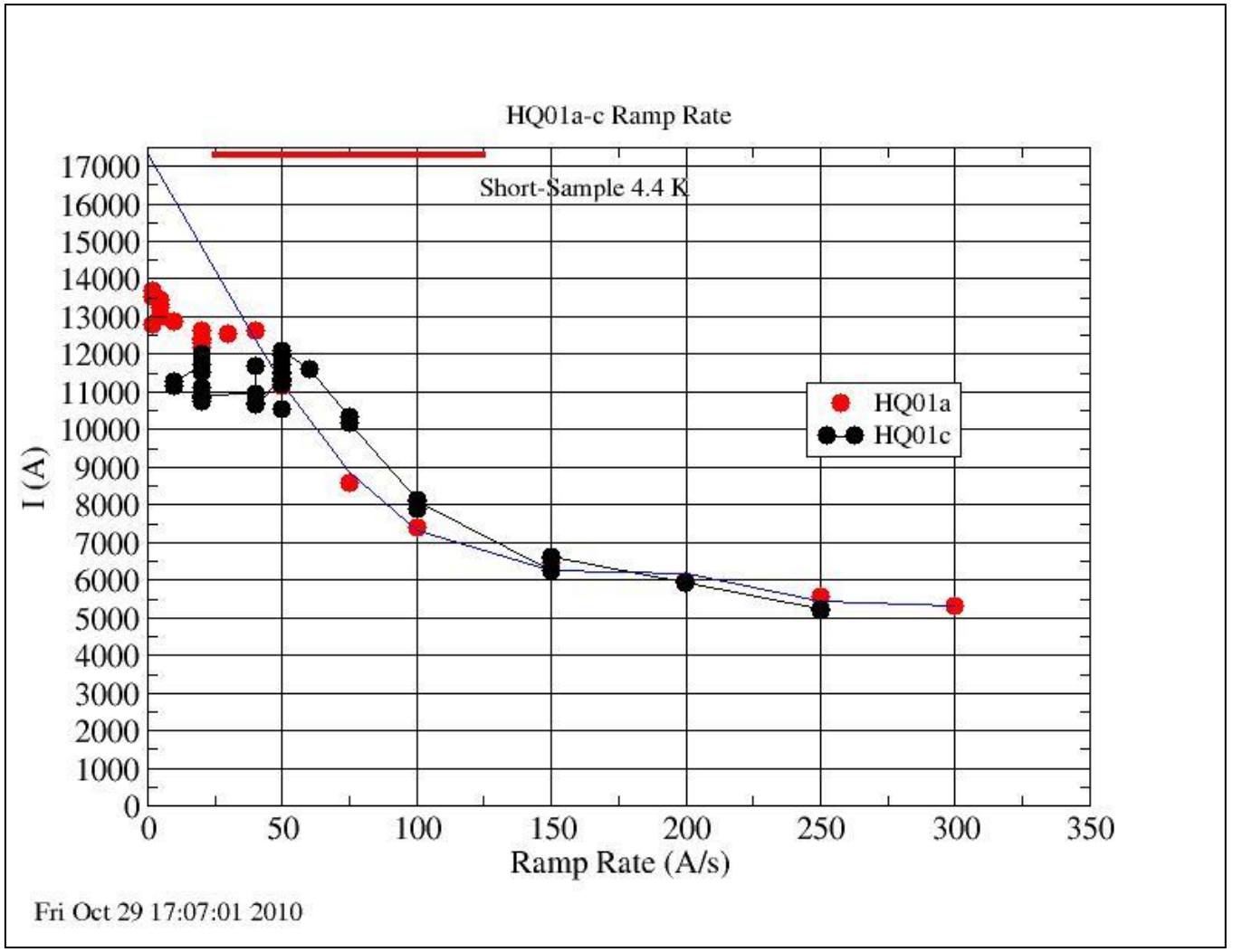


HQ01a
Q1 - 12183A (141T/m, 71% of ss)
Q11 - 13683A (157T/m, 79% of ss)

HQ01b
Q1 - 13308A (153T/m, 77% of ss)

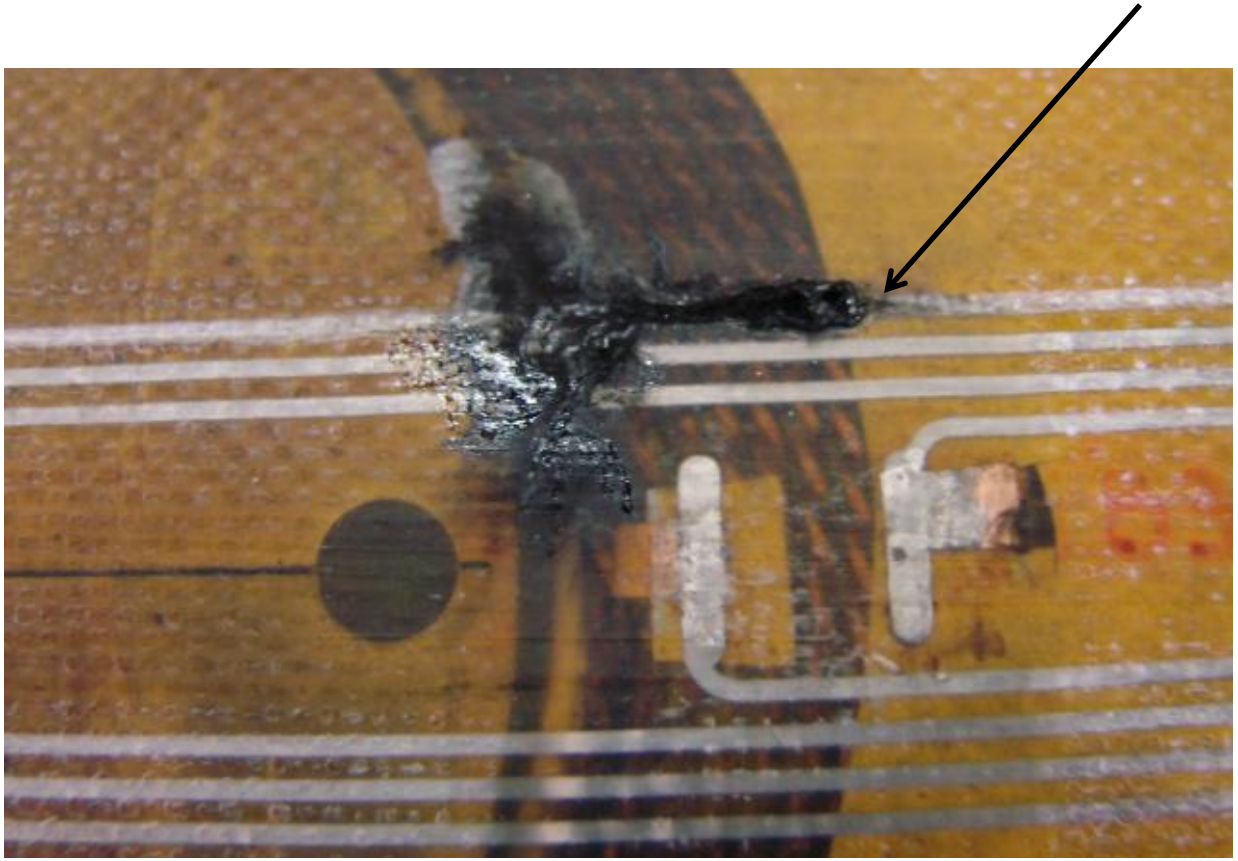
HQ01c
Q1 - 10800A (127T/m, 64% of ss)
Q5 - 11953A (138T/m, 70% of ss)

Ramp Rate Quenches



HQ01a Test – Coil #2

- Visual high voltage damage seen on outer layer end turns

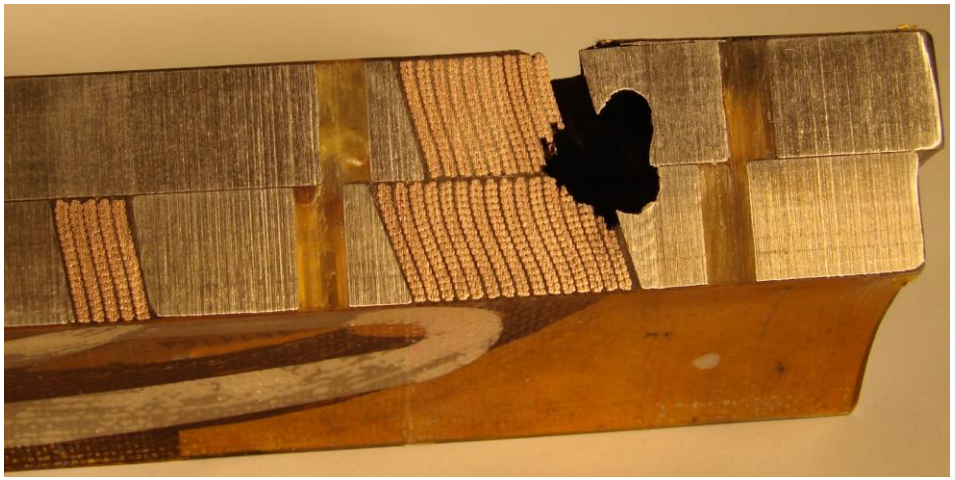


HQ01b Test – Coil #6

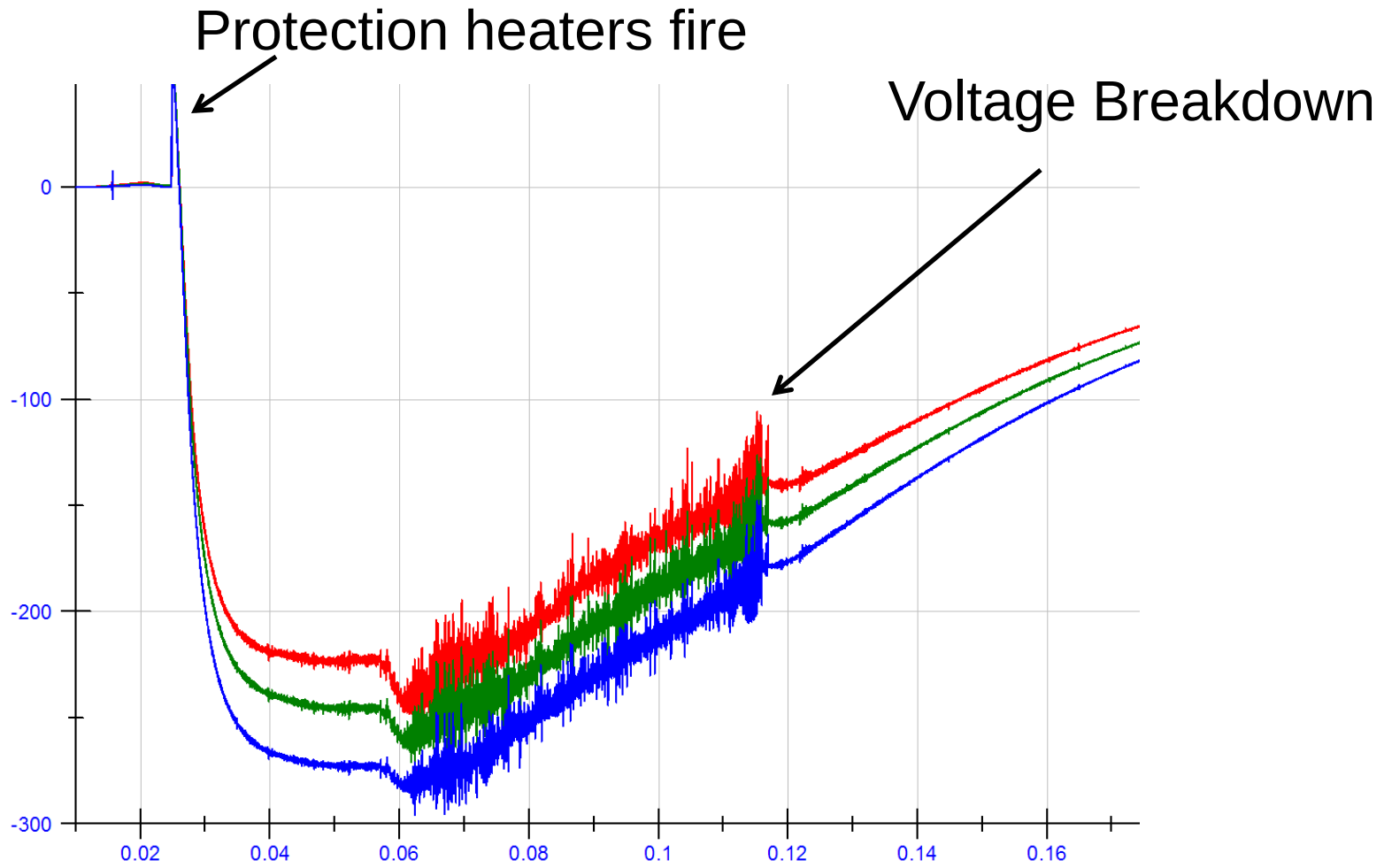
- Voltage breakdown at the return-end of coil #6 between coils and end-shoe.
- This location exhibits the highest voltage difference within a coil as well as high risk location when both layers and both shoes meet at one spot.

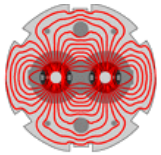
Top view

Side view



Voltage Activity During a Quench





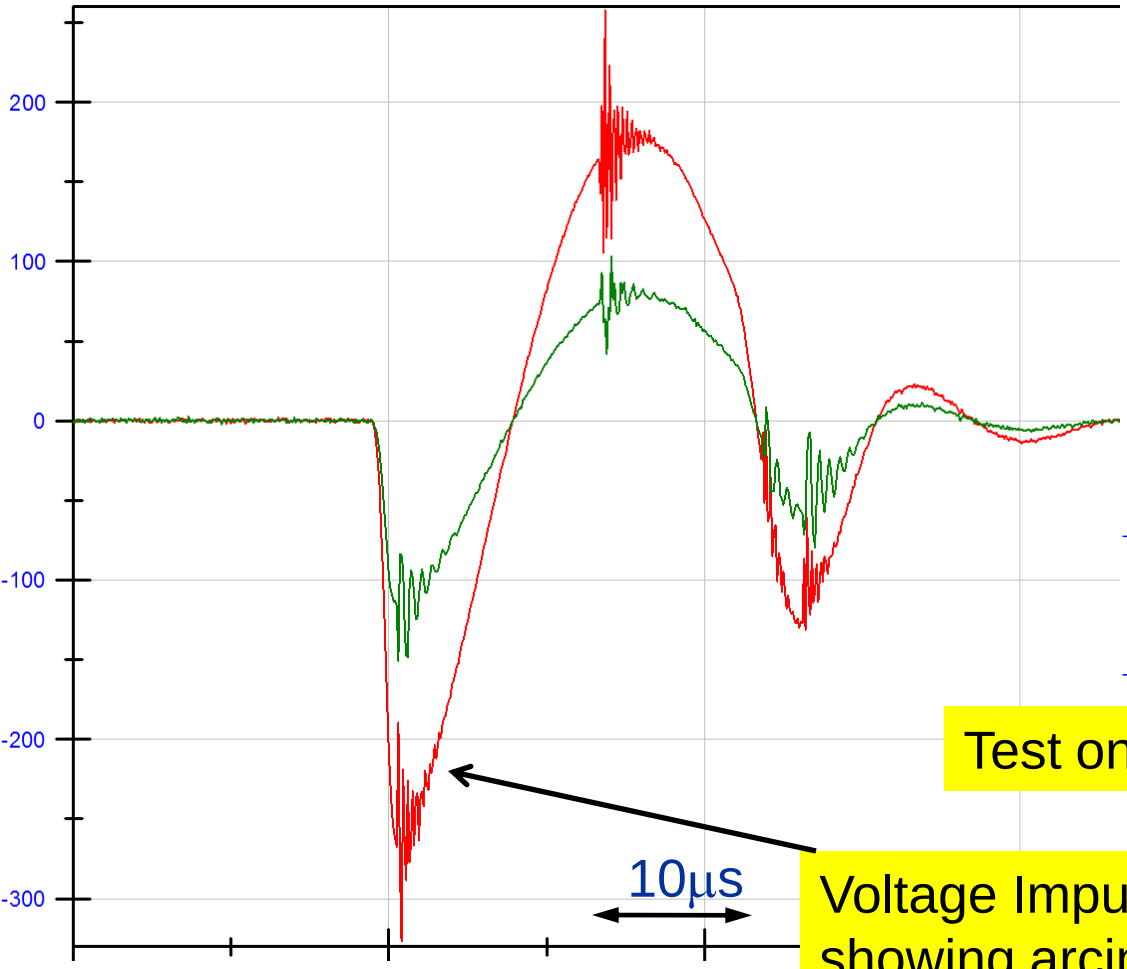
Impulse Tests on HQ Coils

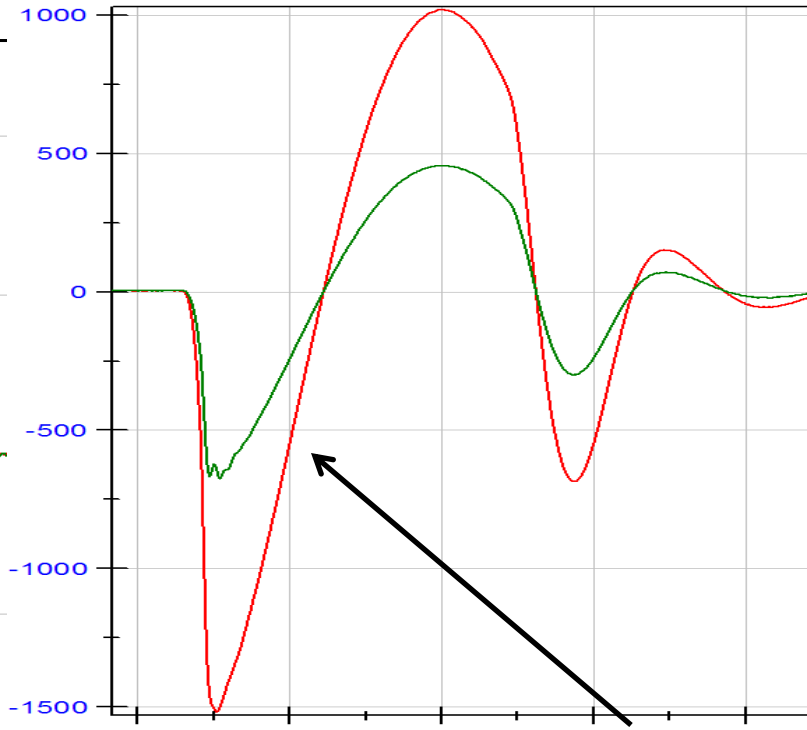
- Coils #1,2,3,4,5,7 went through an impulse test (#6 was cut)
- Coils #1,3,5,7,8 passed
- Coil #2,4 failed

<u>Coils for HQ01c test</u>

- Use coils #1,5,7,8.
- The test is to confirm detection of inter-coil high voltage risks

Impulse Tests on HQ Coils

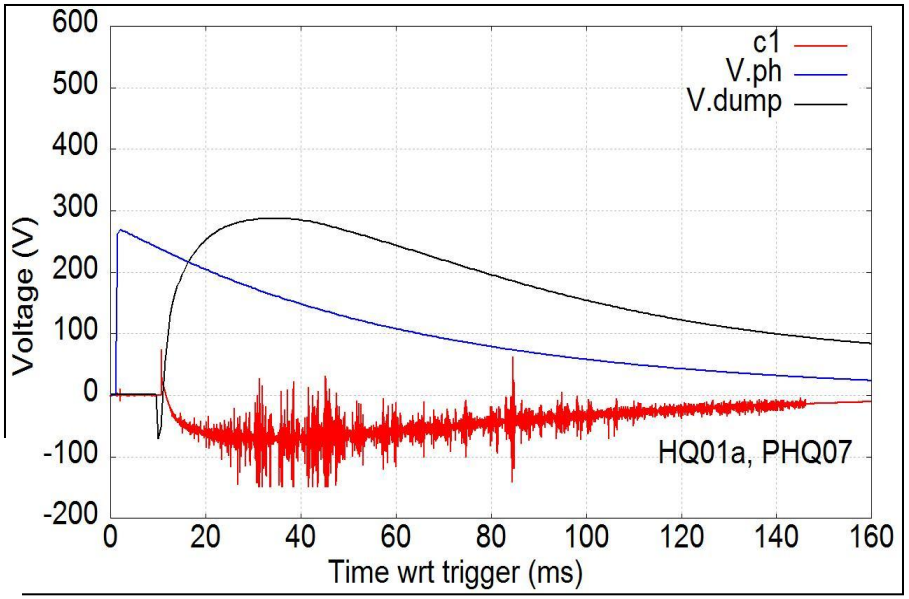


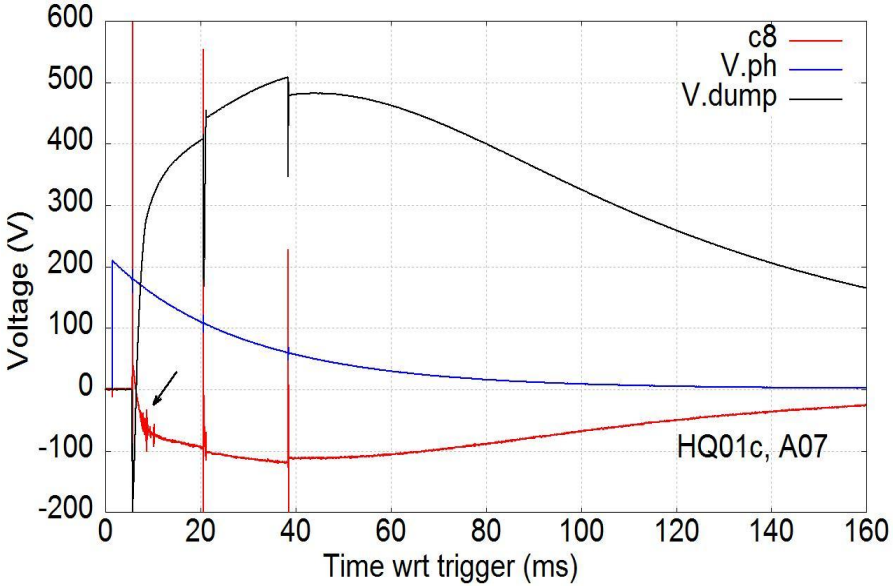


Test on coil showing no arcing activity

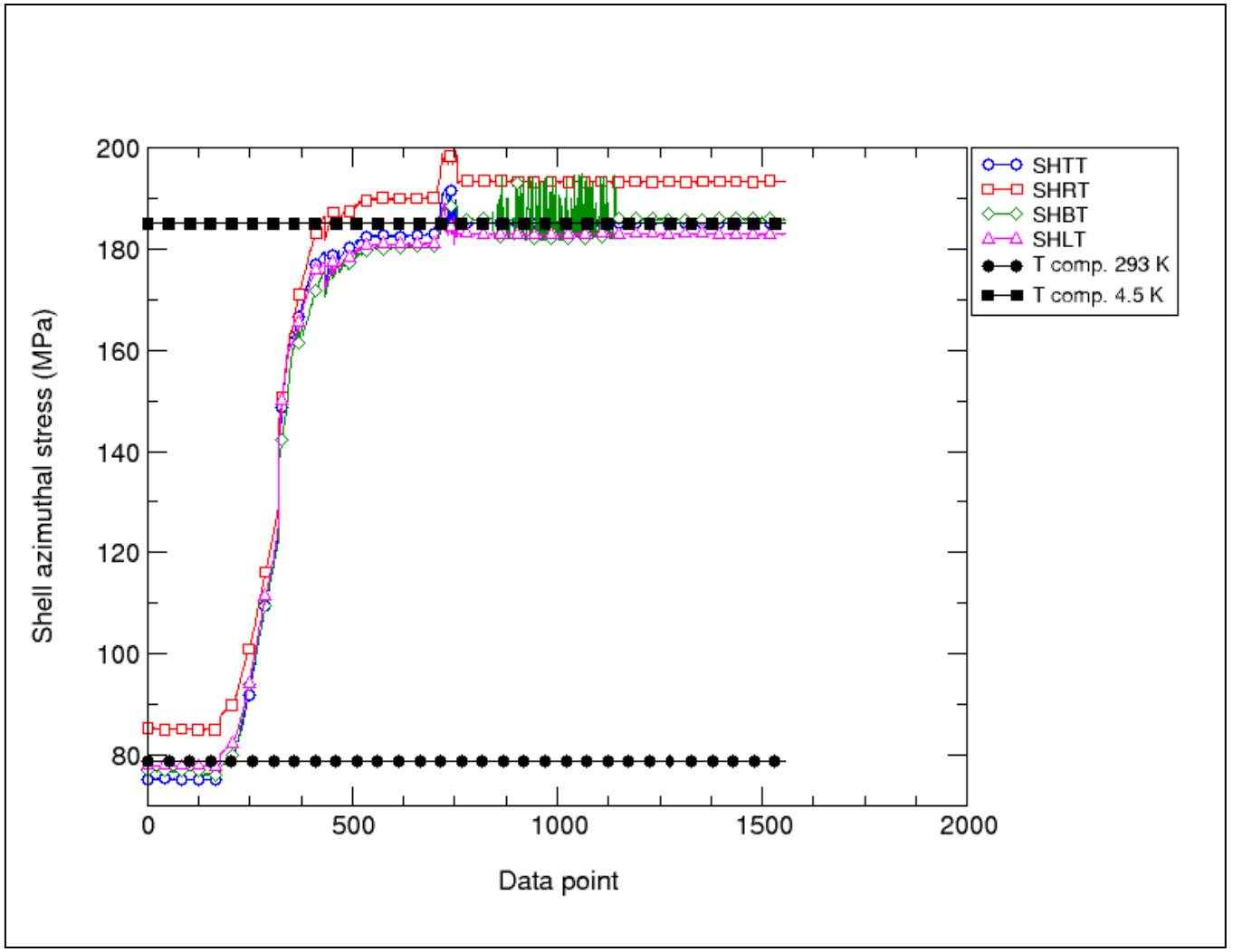
Voltage Impulse test on a damaged coil showing arcing activity

Noise assessment
HQ01c vs. HQ01a



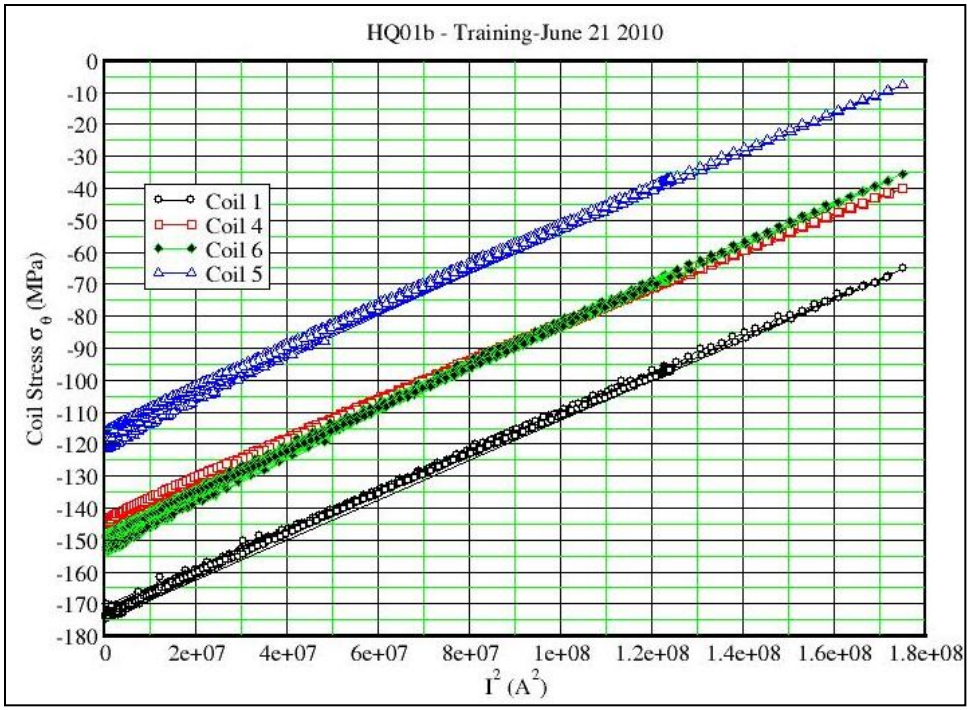


HQ01c – Shell Cool-down Stress



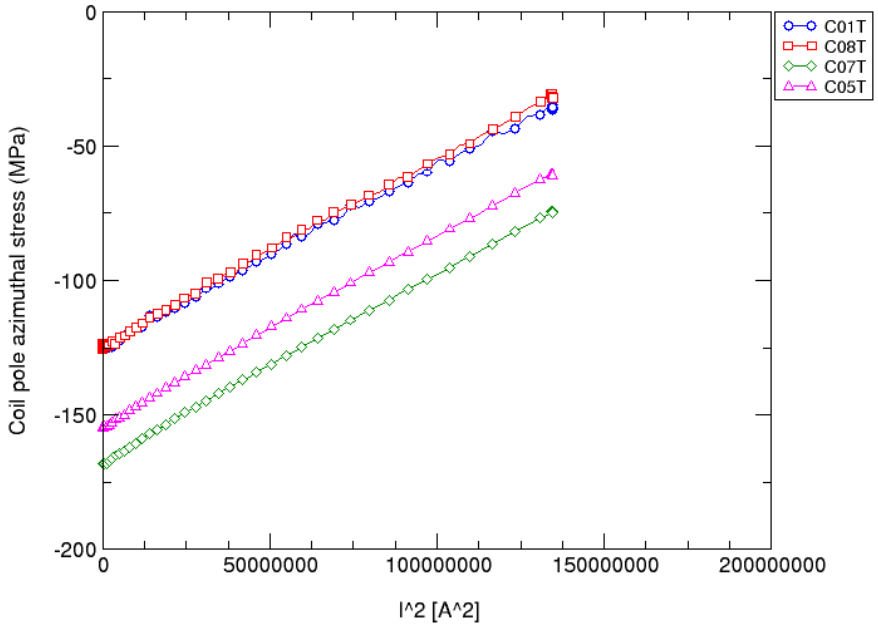
HQ01b-c – Pole Stress During Ramp

LARP

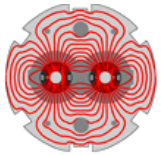


HQ01b

HQ01c

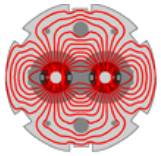


Linear behavior of coils azimuthal stress with current square



Summary

- A 120 mm bore, Nb_3Sn quadrupole is under construction and testing expecting to reach ~215 T/m at 1.9 K
- The 3 tests (HQ01a/b/c)
- Plateau at 70%-79% of short-sample (highest 157T/m).
- Voltage breakdown activities observed- HQ01a/b.
- No voltage breakdown activities observed in HQ01c
- Need to improve QA and re-evaluate risks –
  - Revise high-pot procedures
  - Increase layer-to-layer and coils-to-shoes insulation
  - Add voltage impulse tests
  - Revise protection heaters design
  - Revise coil cross-section and coil-end designs



LARP

Tuesday's Topics for Discussion …

Meetings and Discussions

- MS-A1A: HQ Coil, present design
  Conveners: Helene FELICE (LBNL)
  (Kavli 3rd floor: 09:00 - 10:30) Are the HQ collars too-thick? HQ was designed before the 200MPa TQS03 test took place.
- MS-A2A: HQ coil, new design
  Conveners: Helene FELICE (LBNL)
  (Kavli 3rd floor: 10:50 - 12:20) Is it time for a new structure?
- MS-A1B: HQ structure
  Conveners: Paolo Ferracin (LBNL)
  (Yellow room: 09:00 - 10:30)
- MS-A2B: Magnet testing
  Conveners: Guram Chlachidze (FNAL/TD/MSD)
  (Yellow room: 10:50 - 12:20)