Quench performance 11T model magnets

Gerard Willering
CERN, TE-MSC-TF
23-09-2015

With contributions of Christian Loffler

Acknowledgement
All colleagues involved in preparing the magnet,
its instrumentation and testing.

The HiLumi LHC Design Study is included in the High Luminosity LHC project and is partly funded by the European Commission within the Framework Programme 7 Capacities Specific Programme, Grant Agreement 284404

Content

- Instrumentation
- Coil list
- Training overview of all coils
- Training per coil
- Holding current test results
- Ramp rate dependence and quench back
- Flux jumps
- Differences in mechanics between 101 and 102

Introduction

DS11 T tests so far at CERN

When	Name	Coils	Conductor	OL ground wrap	Powering limitations
Summer 2014	MBHSM101	105	RRP 108/127	100 µm glass	Reached 96 % of I_{ss} at 1.9 K
November 2014	MBHSP101	106 107	RRP 108/127 RRP 108/127	none 100 µm glass	Limitation in **coil 107**, only 4 quenches in 106, reached 82 % of $I_{ss.}$
June 2015	MBHSP102	106 108	RRP 108/127 RRP 132/169	None 100 µm glass	Reached 88 % of I_{ss}, but coil 106 detrained down to 81 %. No hard limitation up to 12 T.
August 2015	MBHSP103	109 111	RRP 132/169 RRP 132/169	100 µm glass 200 µm glass	
October 2015	MBHDP101	106-108 109-111	See above	See above	

11T Short Dipole – Outer Layer – Instrumentation
Voltage Tap Locations

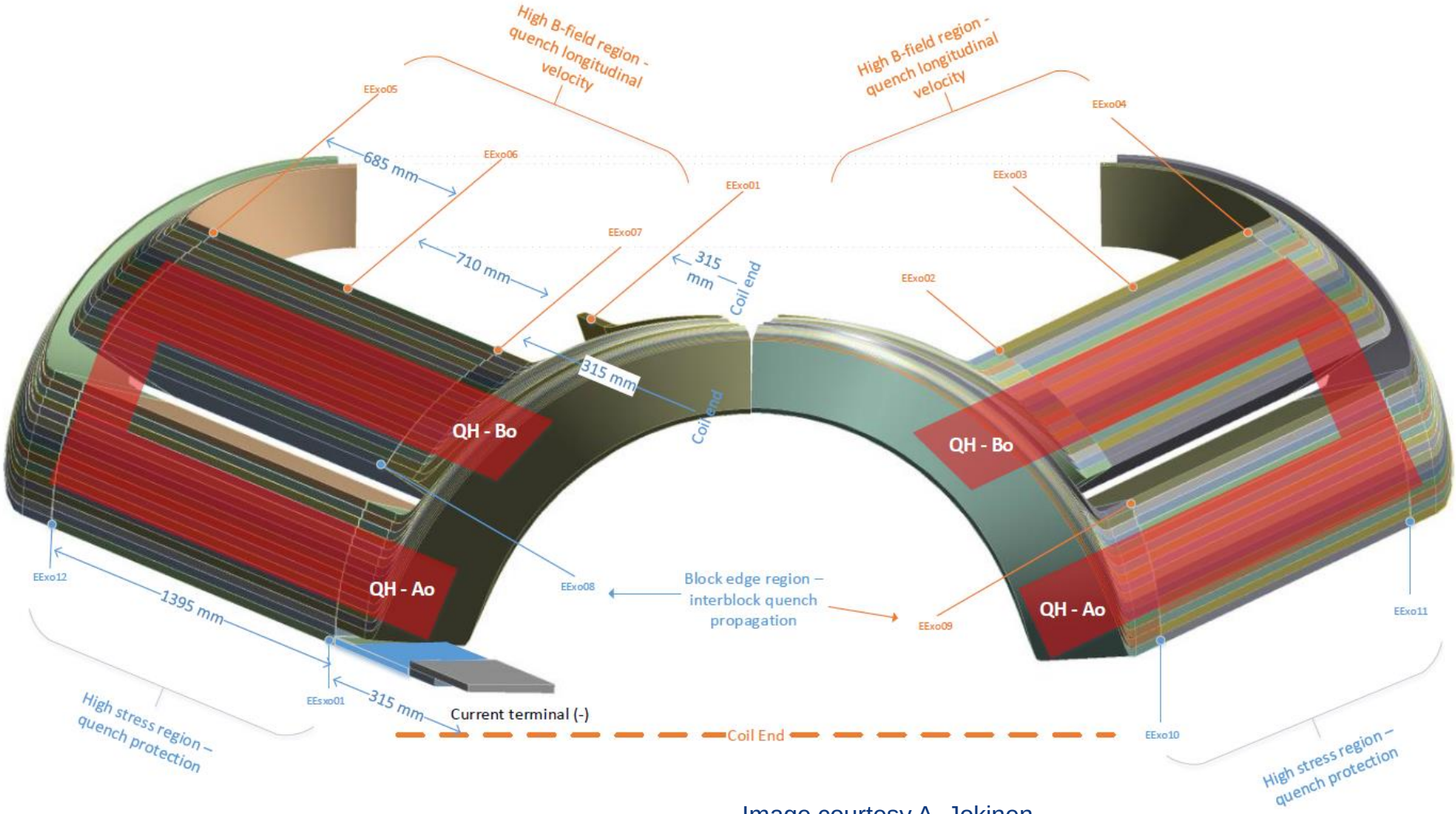


Image courtesy A. Jokinen

11T Short Dipole – Inner Layer – Instrumentation
Voltage Tap Locations

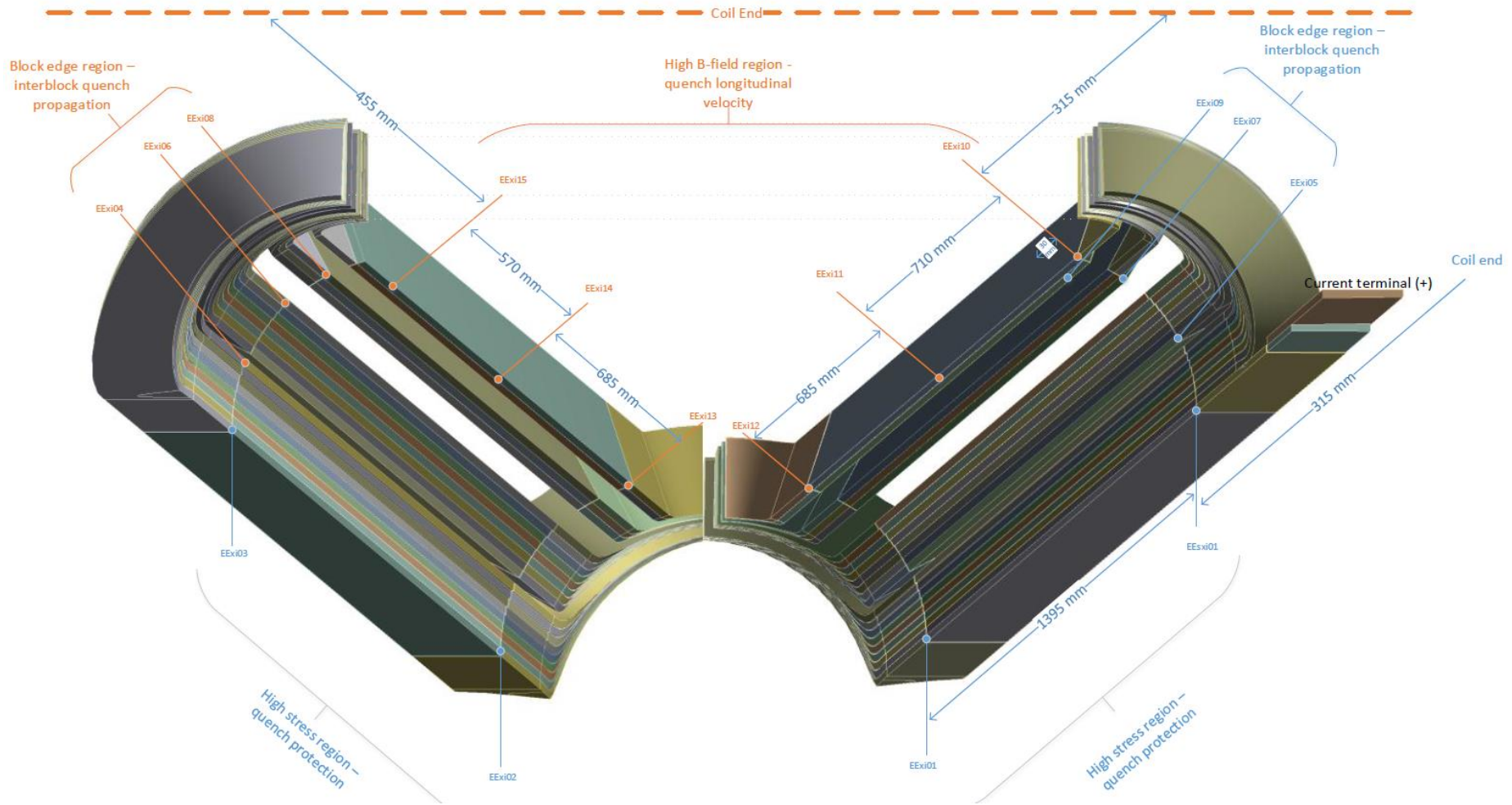
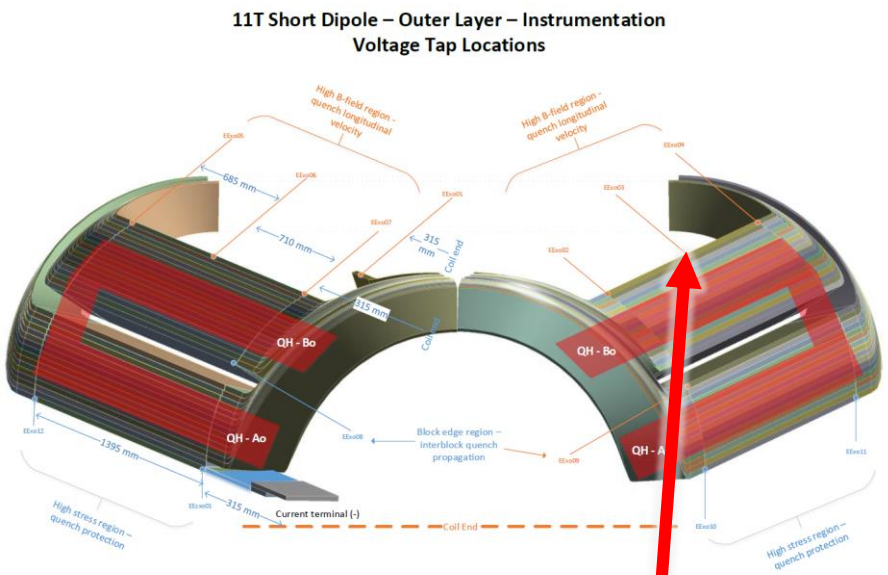
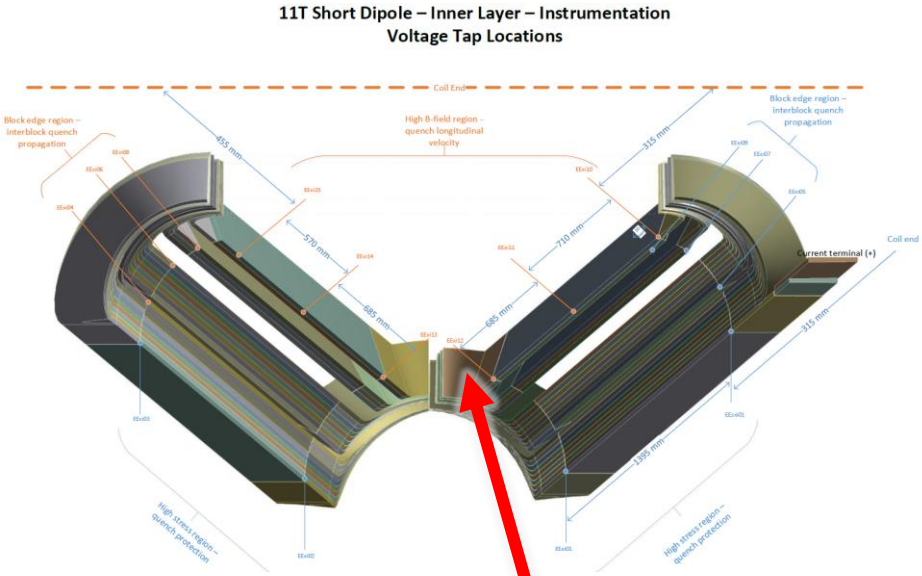


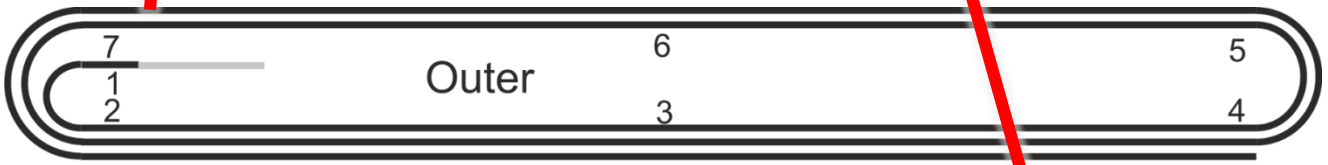
Image courtesy A. Jokinen

Coil instrumentation simplified view

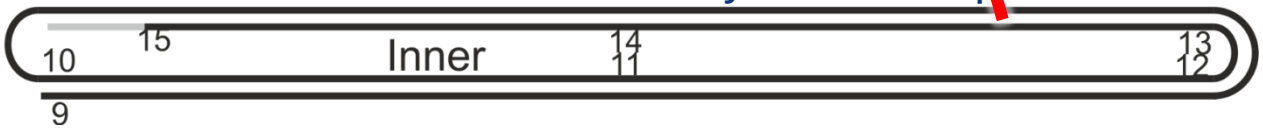




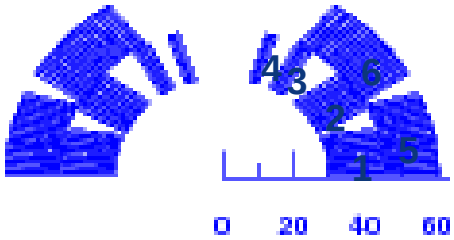
Pole turns of the outer layer with Vtap names



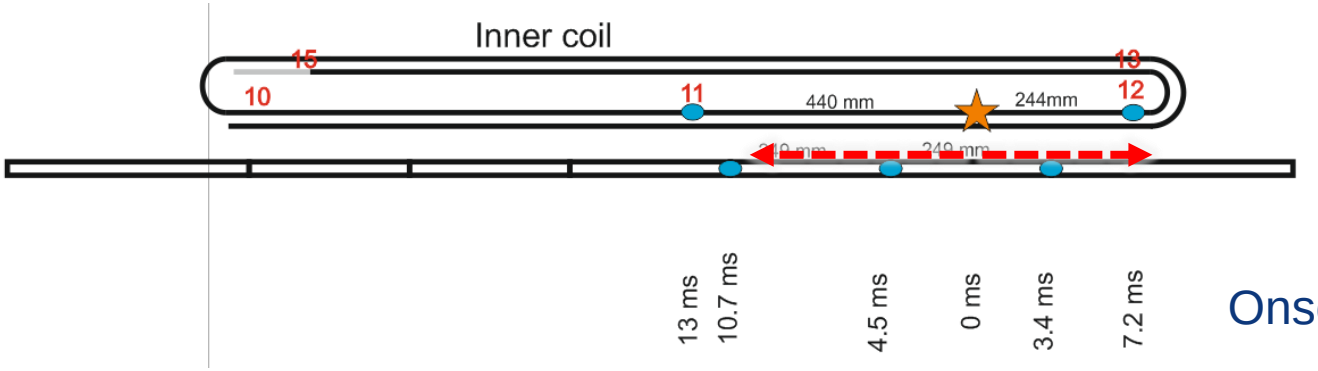
Pole turns of the inner layer with Vtap names



Conductor blocks



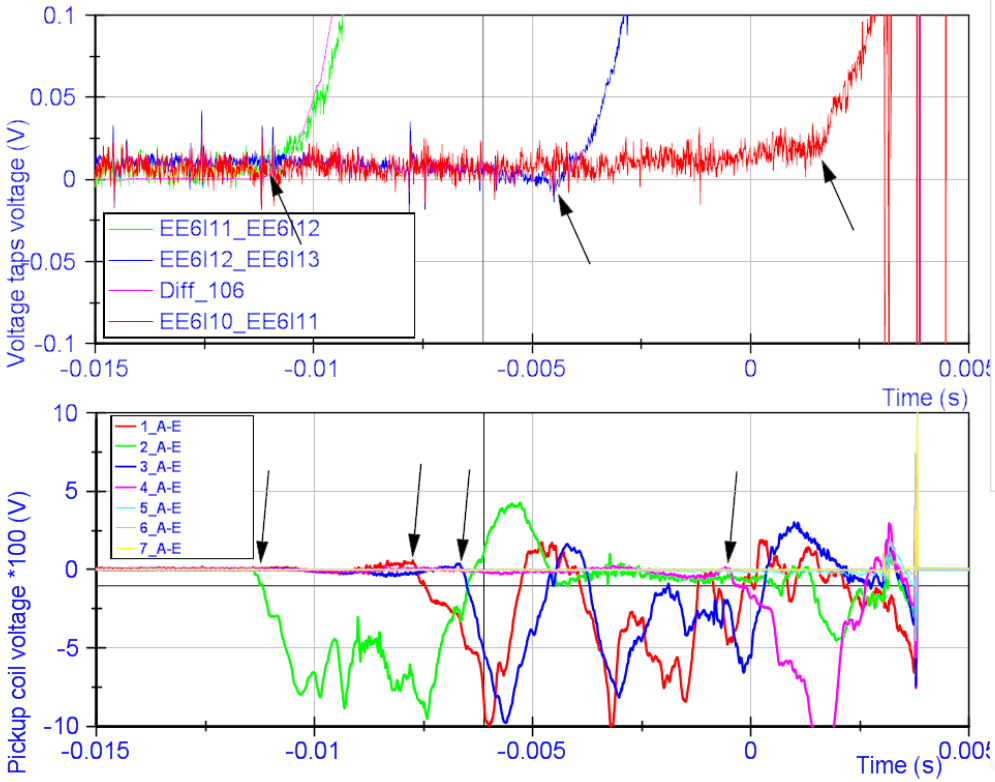
Quench localisation with pickup coils

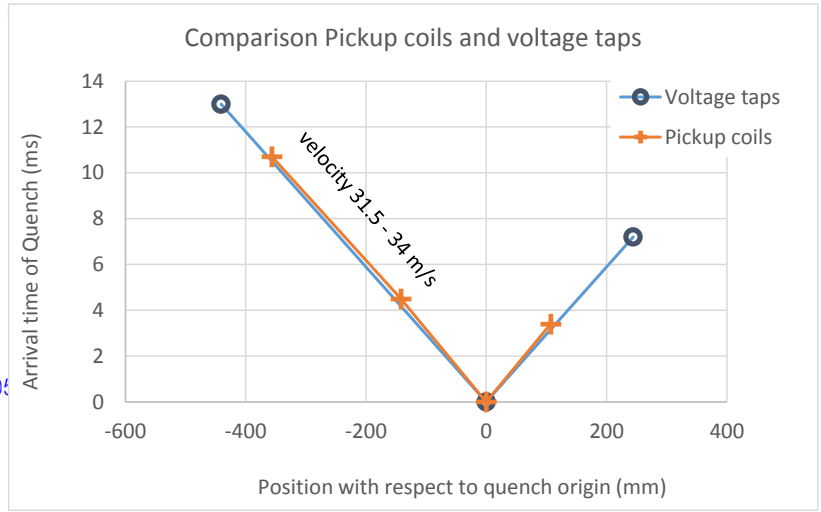


Voltage taps

MM shaft

Onset time of signal





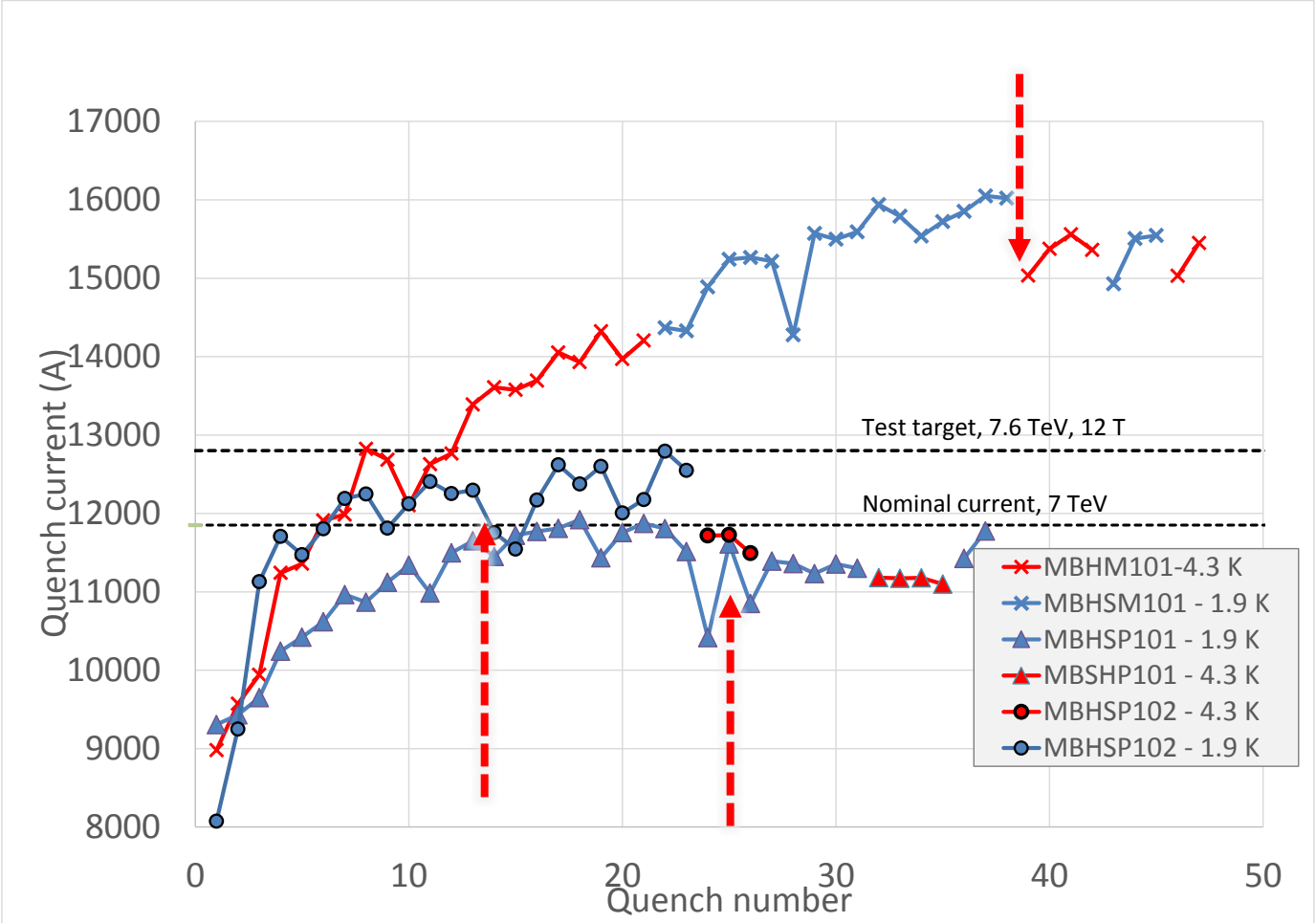
Very good agreement between the results for quench localisation.
Possibly more info can be extracted.

This will be a new standard measurement for the next series of tests.

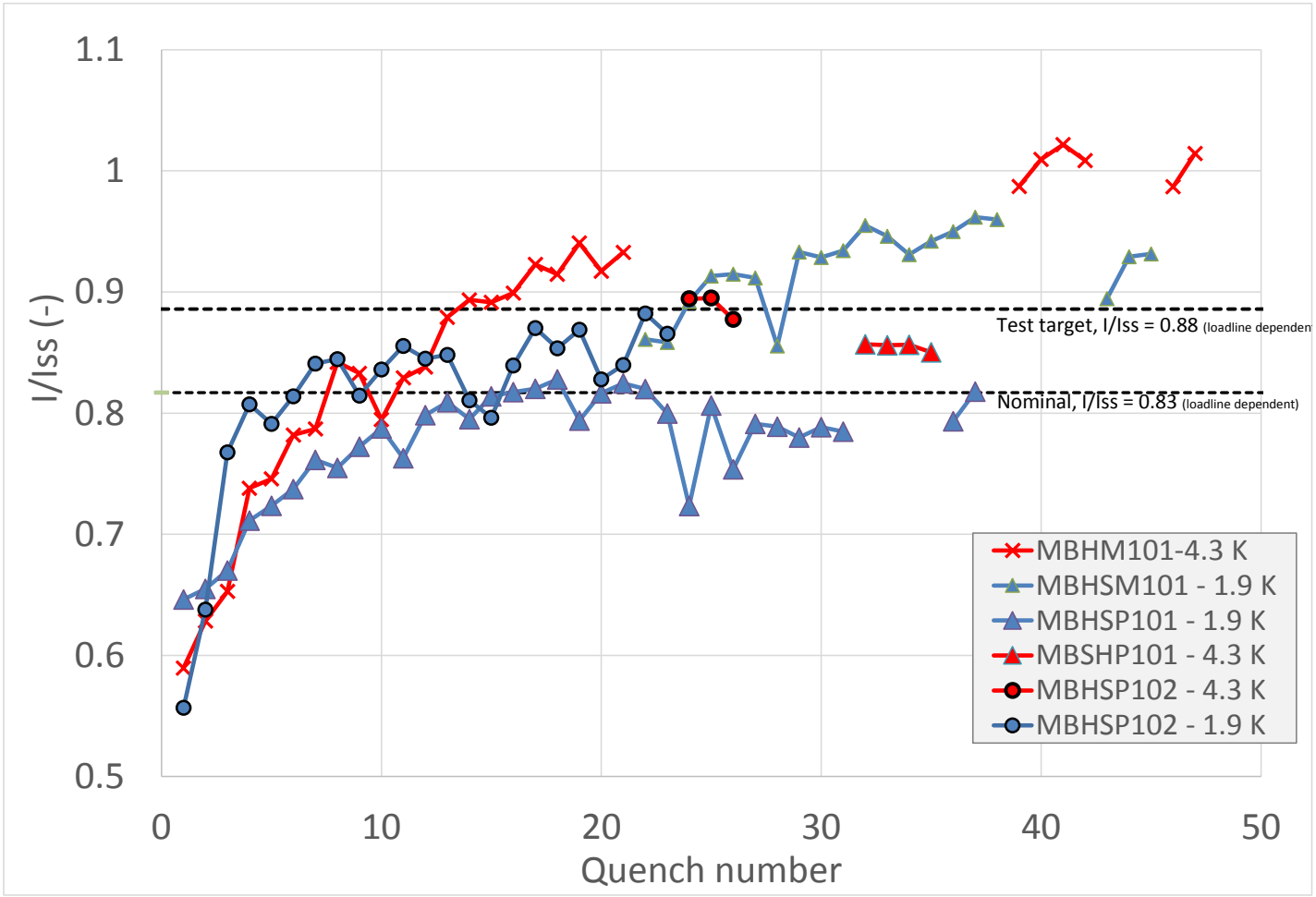
Training of the 3 models

Name	Coils	I_{ss} *
MBHSM101	105	16.7
MBHSP101	106 **107**	14.5 14.4
MBHSP102	**106** 108	14.5 14.8

I_{ss} calculated by Susana with Roxy with extracted strand data from Bernardo.

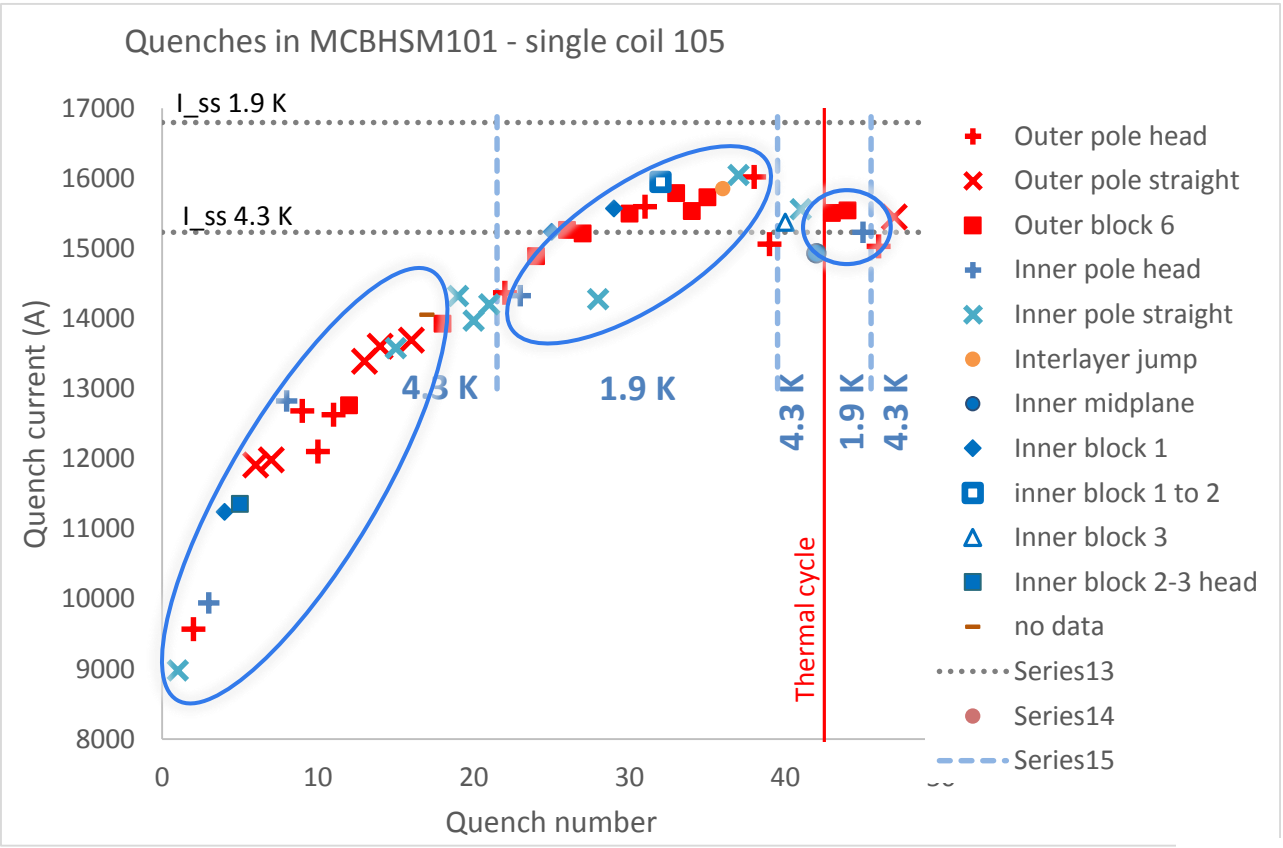


Training of the 3 models



Training of MBHSP102 biased since coil 106 was already trained before.

Training in the single coil HCMBHSM101- coil 105

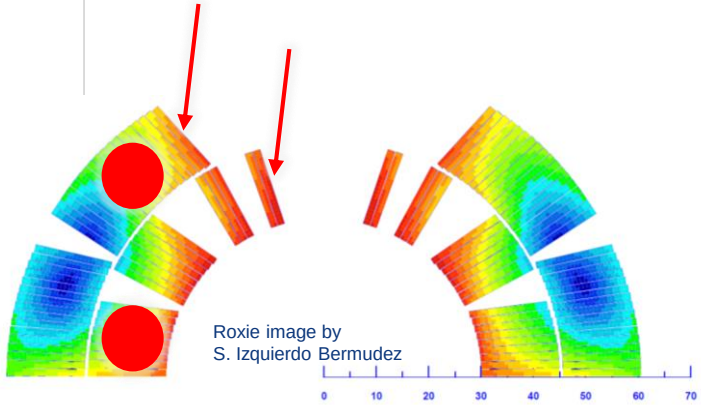


Initial training 4.3 K
mainly around the pole

Initial training 1.9 K mainly on outer block 6

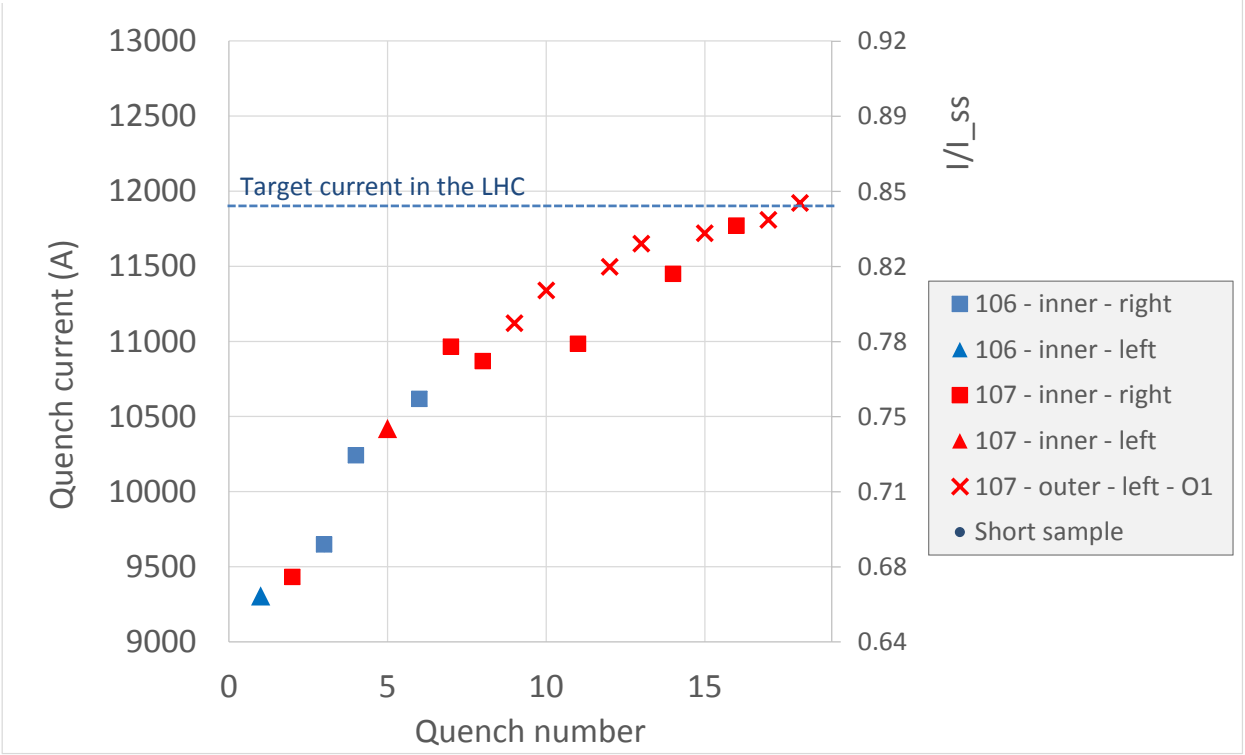
Slight detraining after the thermal cycle for 1.9 K, not for 4.3 K.

The training is rather random without real ‘weak spots’.



Training in the single coil MBHSP101- coil 106-107

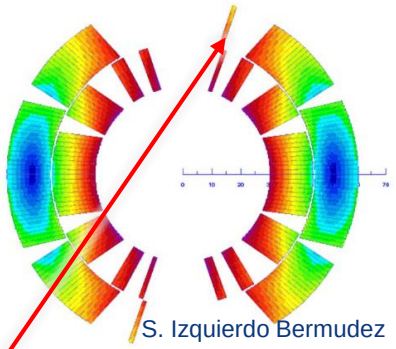
Initial training in the single aperture at 1.9 kA

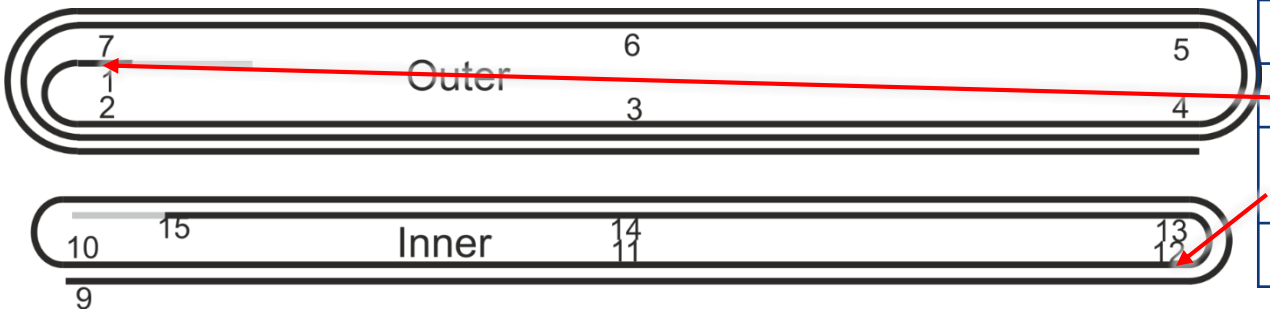


4 quenches initiated in coil 106, no more quenches from 10.6 to 11.9 kA!!

Initial training looks OK for coil 107 except for 2 specific spots.

Target of 11.85 kA is reached.

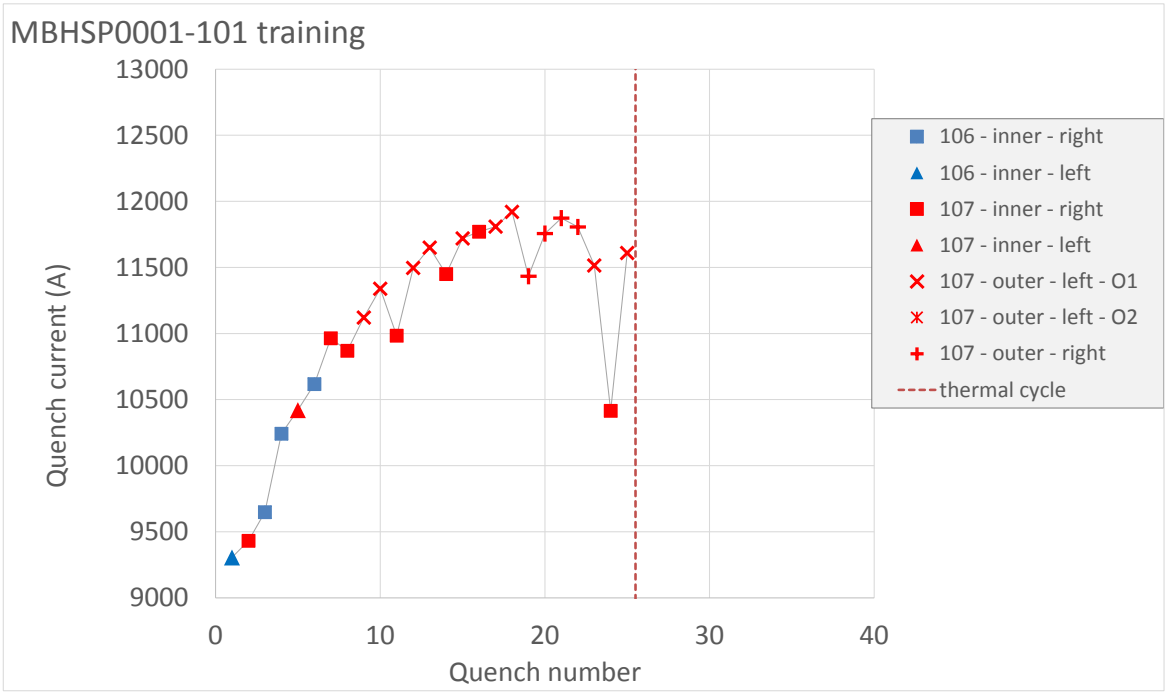




Initial training

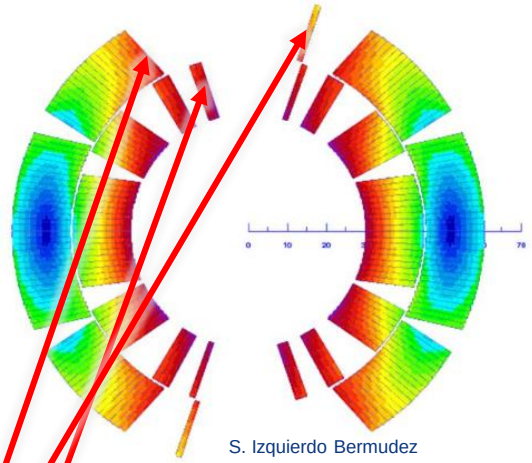
Location	# quenches
Coil 106	4
Coil 107 at O1	7
Coil 107 inner layer around key end	6
Coil 107 around I12	1

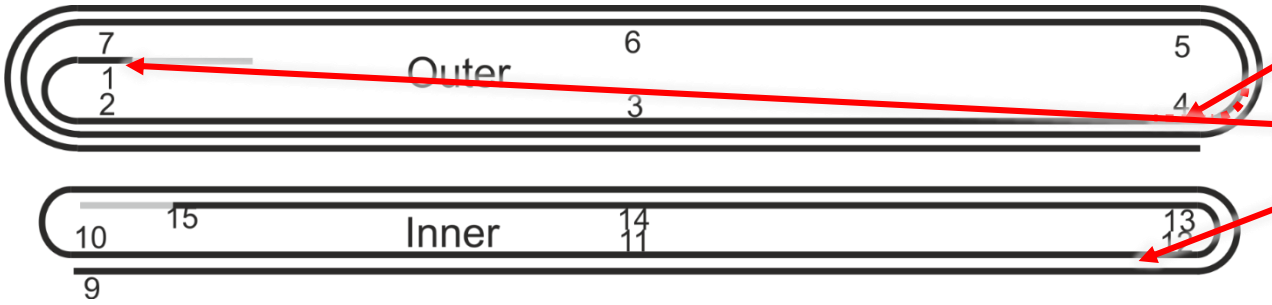
Detraining or possible degradation in the single aperture at 1.9 K



The detraining and quenches around voltage tap O4 are remarkable in quench 19 to 22

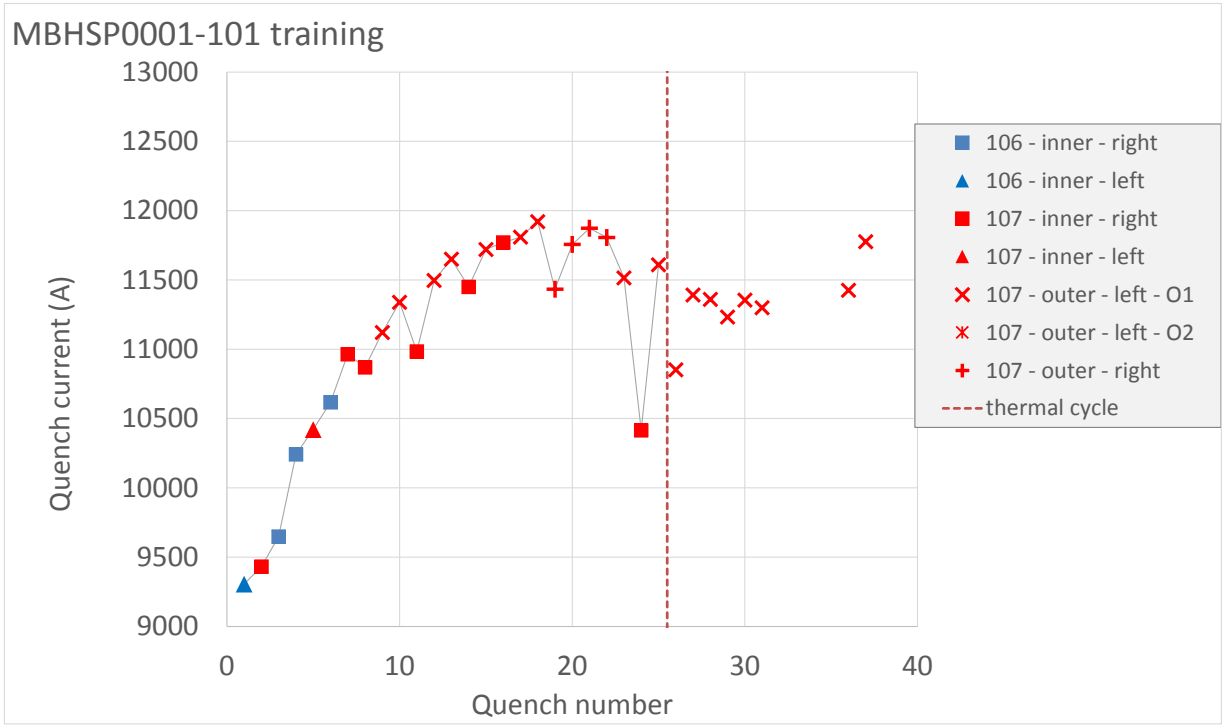
A strong detraining quench followed in quench 24.





Quench 19 to 22	Outer layer, close to Vtap O4
Quench 23, 25	At Vtap O1
Detraining 24 (50 A/s)	Close to Vtap I12

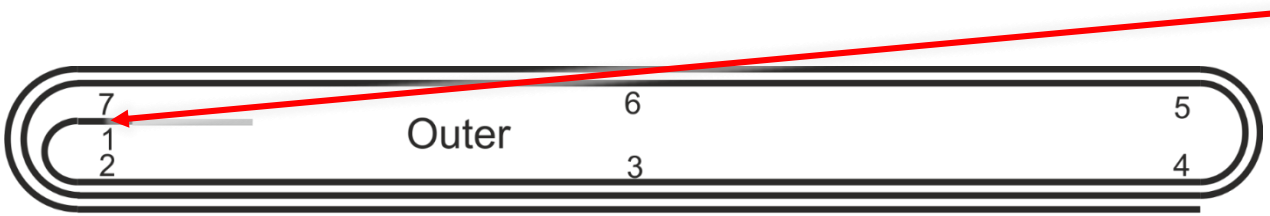
After thermal cycle at 1.9 K

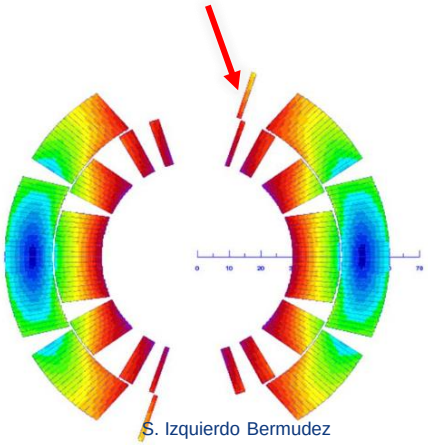


Quench 26 to 31 at 1.9 K show a rather limited quench current, always quenching in the same location.

Apparently the coil was degraded after thermal cycle for 6 quenches, but after the tests at 4.3 K the quench level increased to 11.76 kA.

All quenches from quench 25 at 1.9 K in O1





S. Izquierdo Bermudez

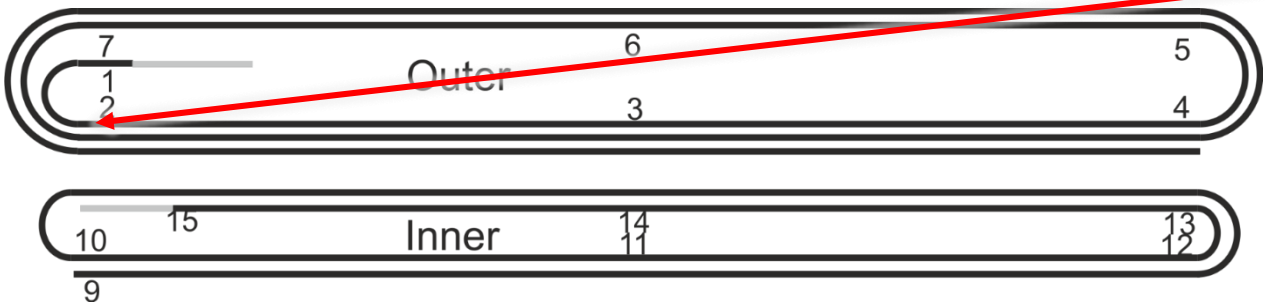
4.3 K powering

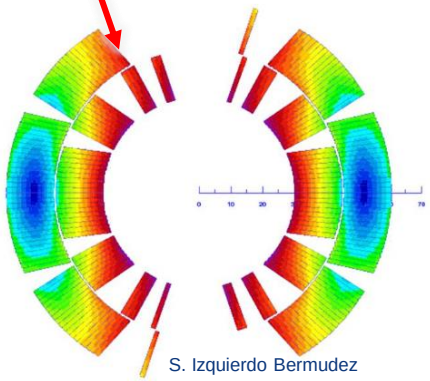
The lower quench current at 4.3 K at 0.85*I_{ss} is not expected.

At 10 A/s 3 quenches at 11177 ± 4 A with identical quench location and pattern.

The quench at 50 A/s occurred at 11095 A with similar quench pattern.

Quench location is at voltage tap O2





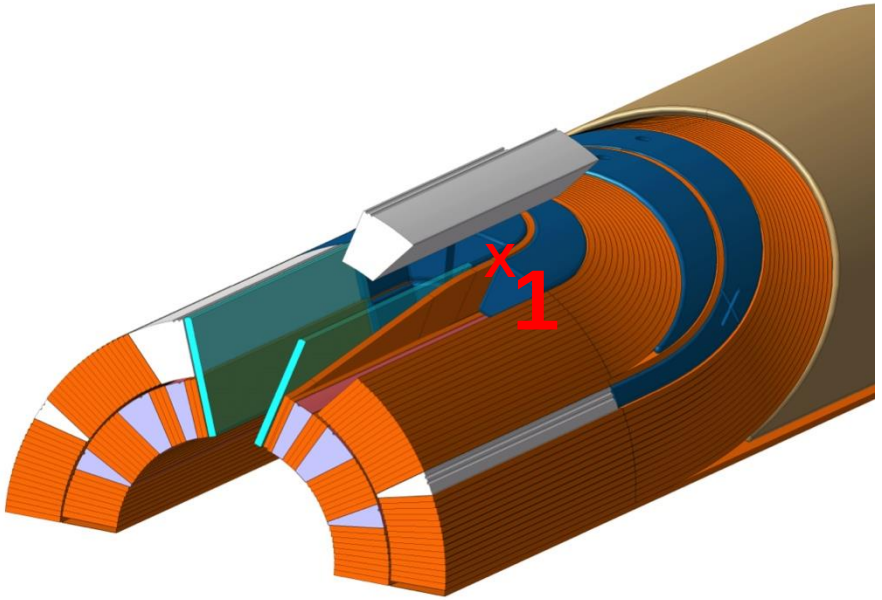
S. Izquierdo Bermudez

Summary of weak locations in coil 107

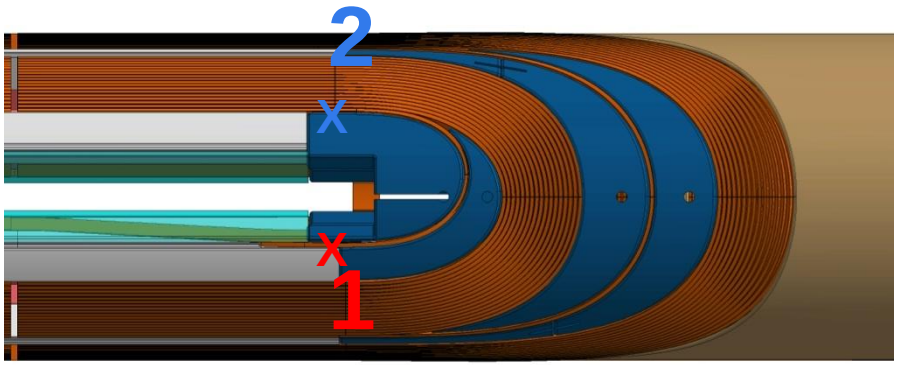
1. At voltage tap O1, just out of the layer jump.
   7 quenches during initial training
   Limiting point later on at 1.9 K

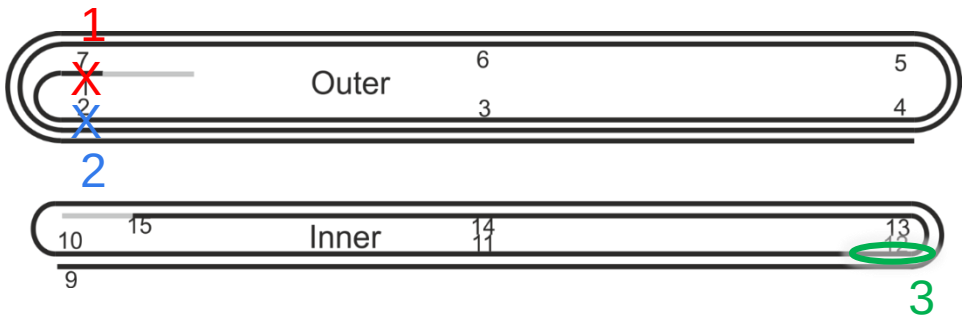
2. At voltage tap O2, opposite of O1.
   Limiting point at 4.3 K

3. Around voltage tap I12, close to the pole head with 6 training quenches and detraining.

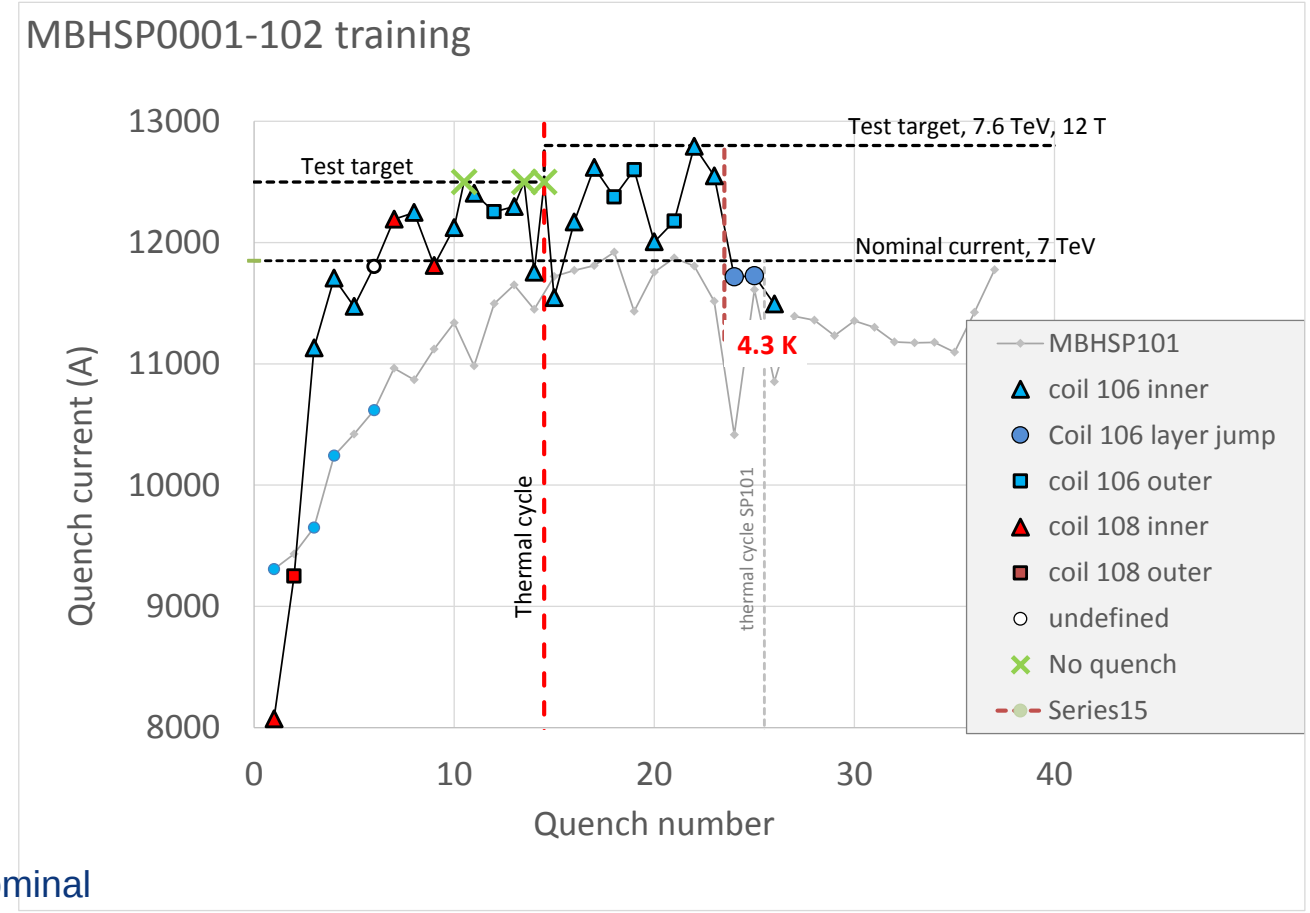


Images courtesy N.Peray and D. Smekens



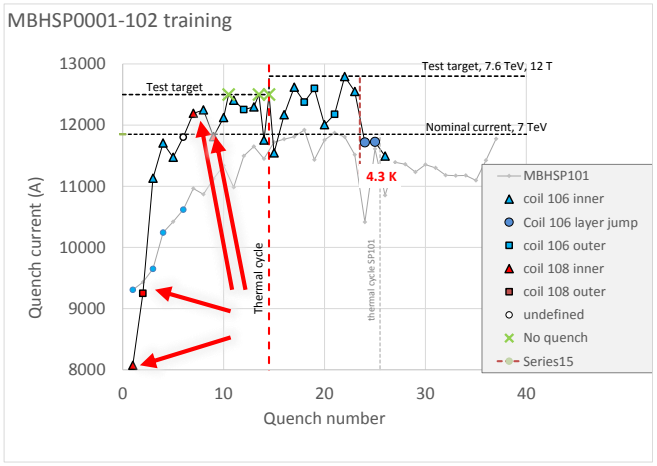


Training



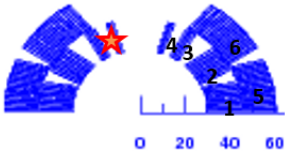
- **6 quenches** to nominal
- 10 quenches to initial target of 12.5 kA
- Only 3 or 4 re-training quenches for coil 106 after de-collaring and re-collaring
- Coil 108 only showed 4 or 5 (de)-training up to 12.3 kA, it never quenched again up to 12.8 kA.
- Memory after thermal cycle is good, with one quench just below nominal.
- Target of 12.8 kA (12 T) reached in the second cool down.

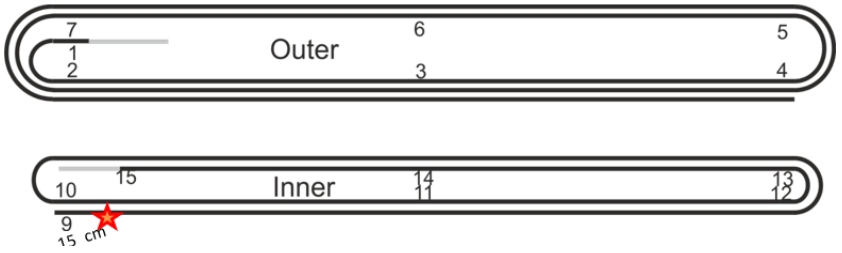
Training coil 108

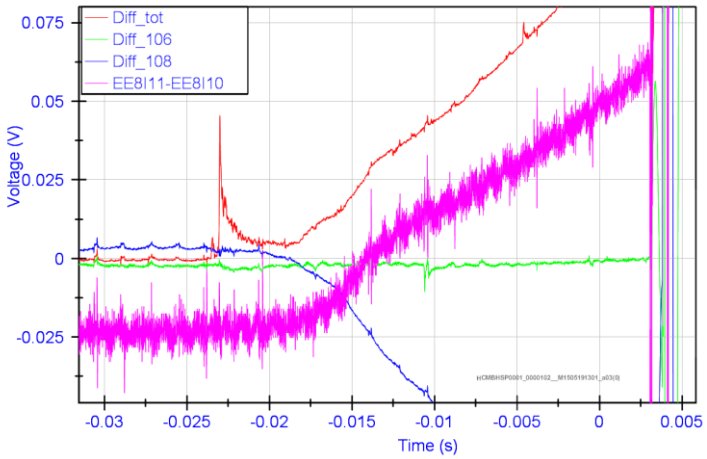


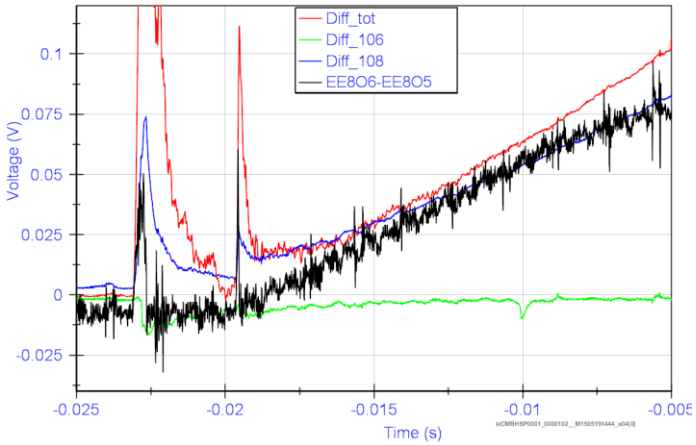
4 quenches in coil 108:
Quench 1, 2, 7, 9

9



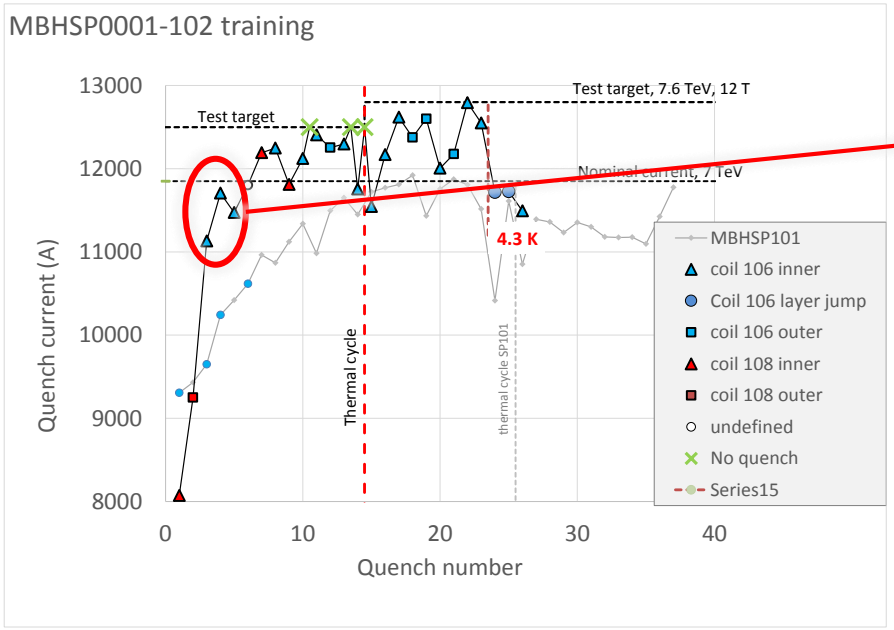


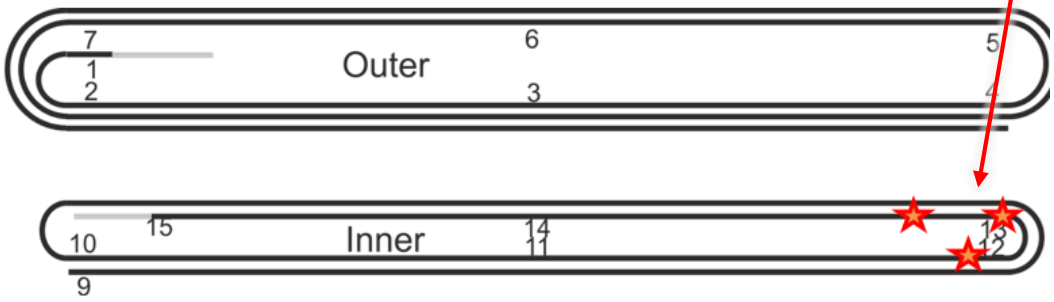




Large precursors in the two low-current quenches (8 and 9.2 kA)
4 different quench locations.

Training coil 106 – First 3 quenches

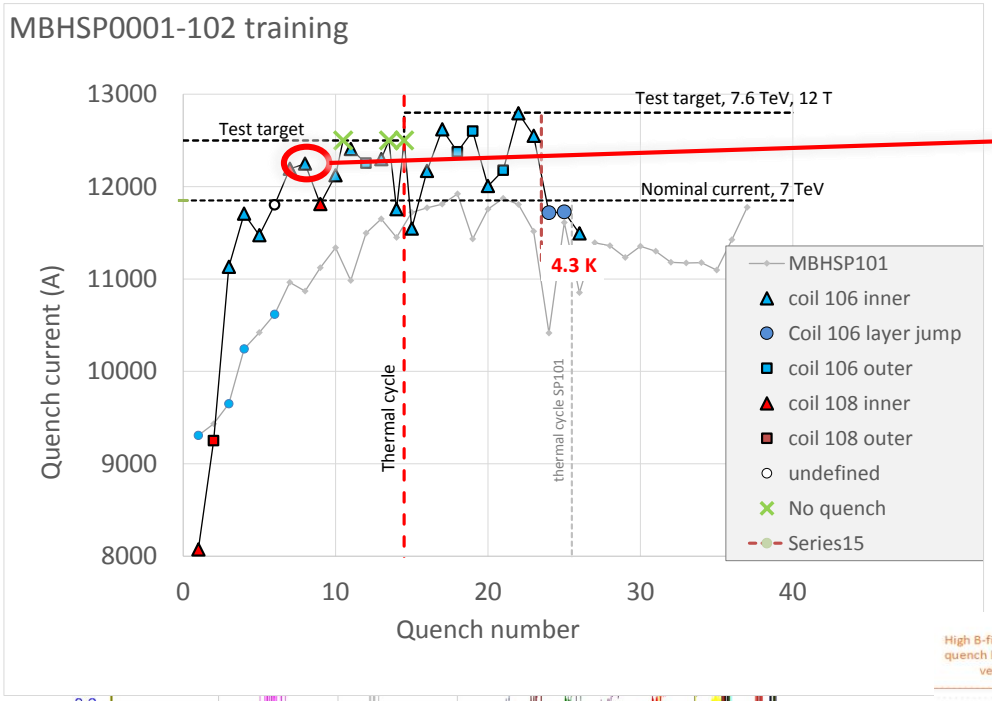




Quenches close to the head of the inner layer, high-field turn.

Confirms the quench location of the training of coil 106 in MBHSP101.

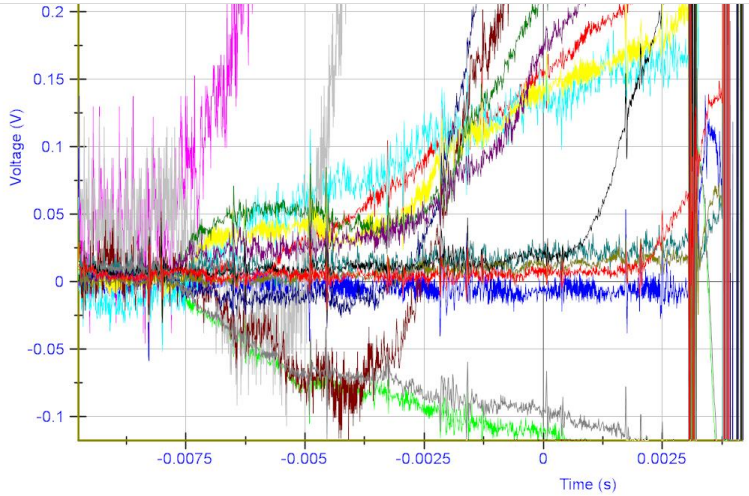
Training coil 106 – quench 8

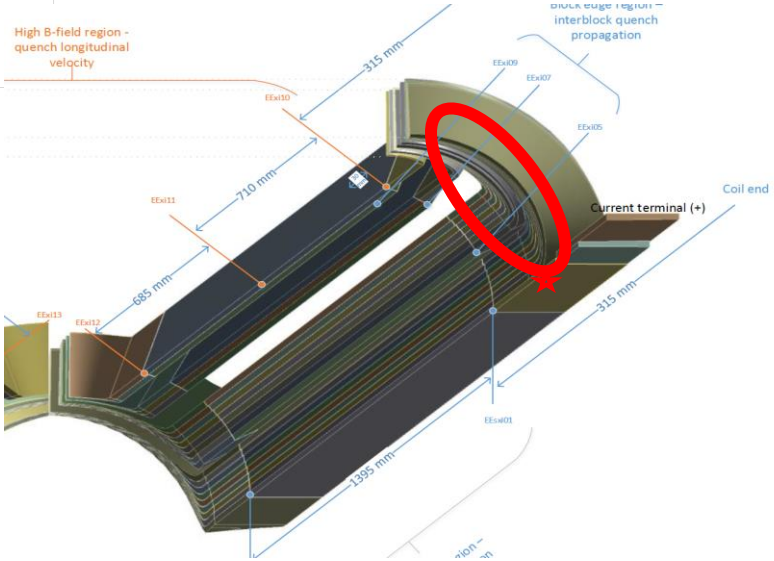


Quench 8 was a “massive” quench: In coil 106 the whole cross-section of the inner layer quenched within 1 ms at the coil head.

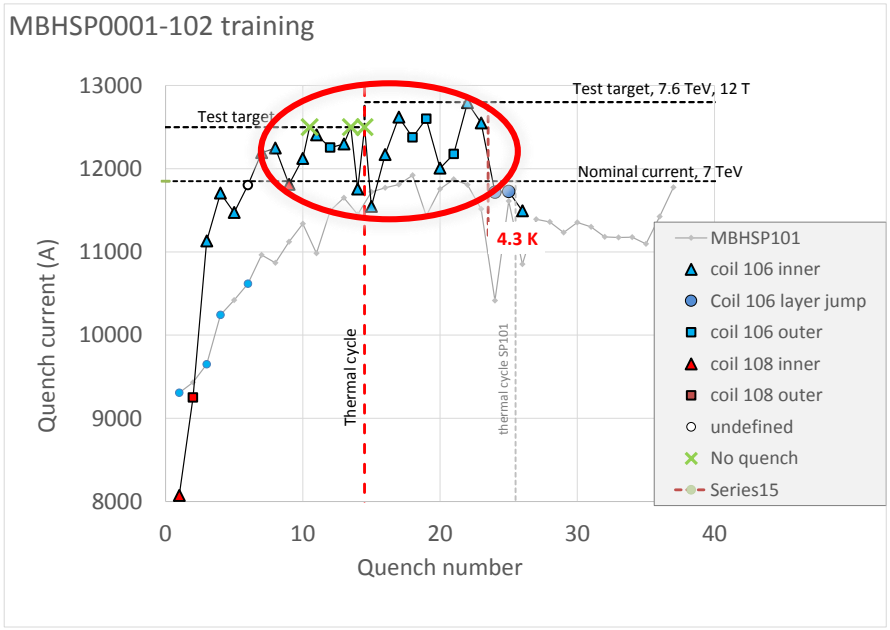
This was followed by a detraining in coil 108…

No special signals were seen in mechanical measurements.



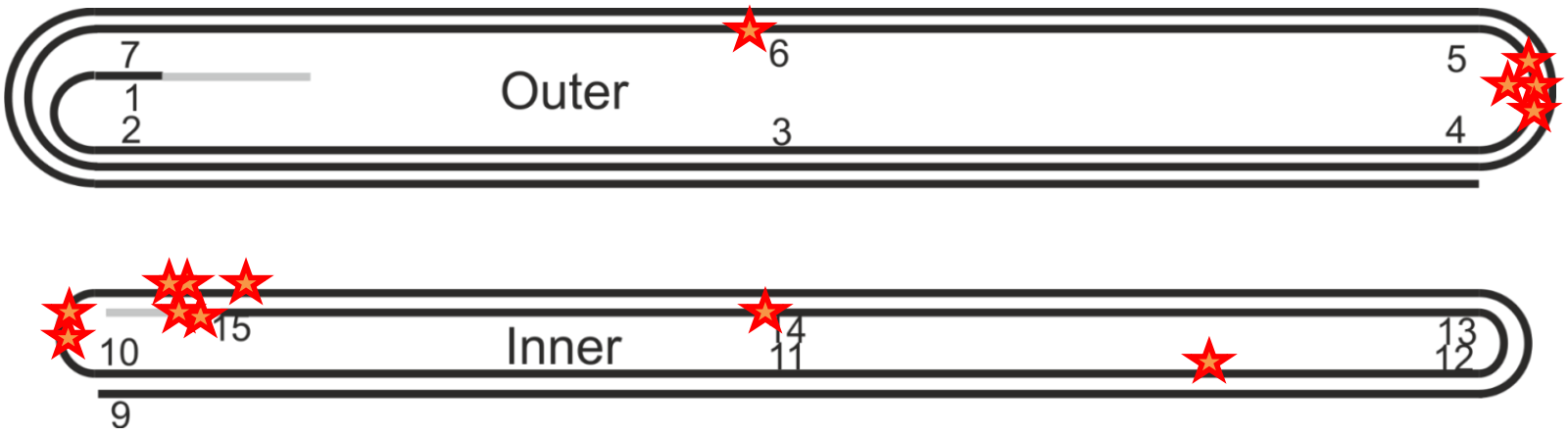


Training coil 106 – Further training and detraining at 1.9 K

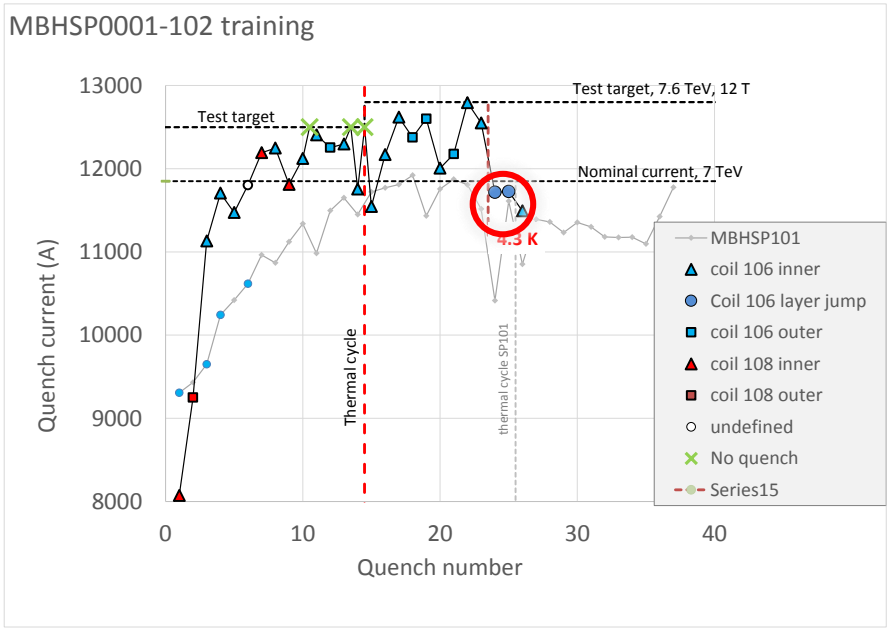


Quench location overview coil 106

Different training location than the first 3 training quenches and the training in MBHSP101.

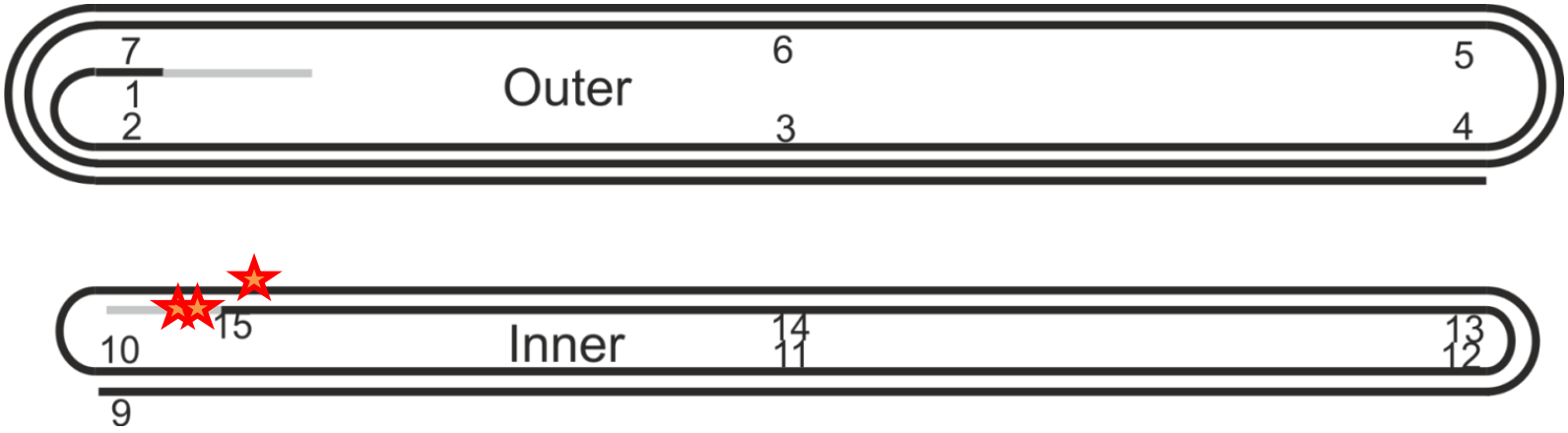


Training coil 106 – Powering at 4.3 K



At 4.3 K two identical quenches at identical temperatures. Seems to be the limiting point of the coil, but difficult to conclude on 2 quenches.

Detraining to 11.5 kA in the same region. Very similar quench pattern as the 1.9 K (de)training quenches.



Resistance and RRR

Coil	Conductor	R_{Troom} (mΩ)	RRR
105	RRP 108/127	422	95
106	RRP 108/127	423	65
107	RRP 108/127	422	75
108	RRP 132/169	407	165
109	RRP 132/169	400	??
111	RRP 132/169	401	??

Data from electrical measurements in B927 at T_{room}, confirmed by measurements in SM18
Resistance from EESxOI to EESxOO, normalized to 293 K

Resistance at room temperature for 108/127 cables is 5 to 6 % higher.
RRR is much higher for coil 108 then 105, 106 and 107.

Can low RRR be directly related to the training in the coils?

Holding current tests

MBHSM101

40 minutes at 15 kA: no quench

MBHSP101

30 minutes at 11.3 kA followed by 30 minutes at 11.5 kA: no quench

MBHSP102

10 hours 11.85 kA: no quench

2.5 hour 12.3 kA: no quench

Not a single quench during flattop observed in any of the coils during any test at any current.

Ramp rate dependence of quench current

MBHSM101

Same quench current at 10 and 50 A/s

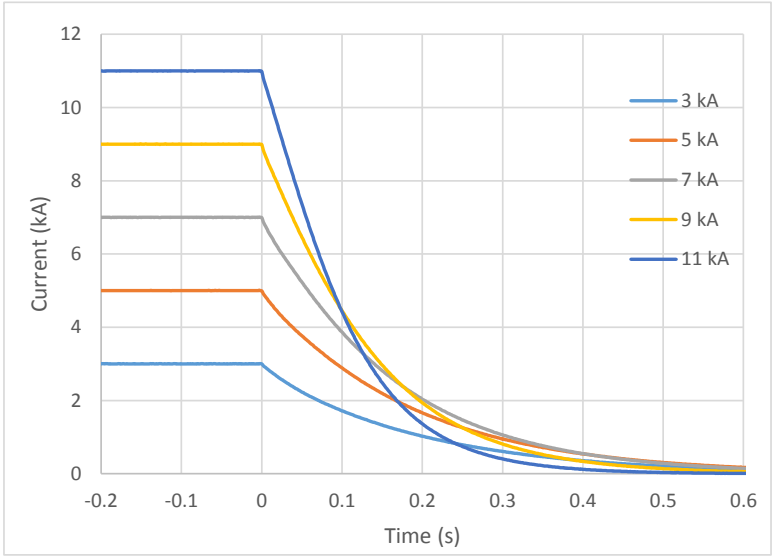
MBHSP101

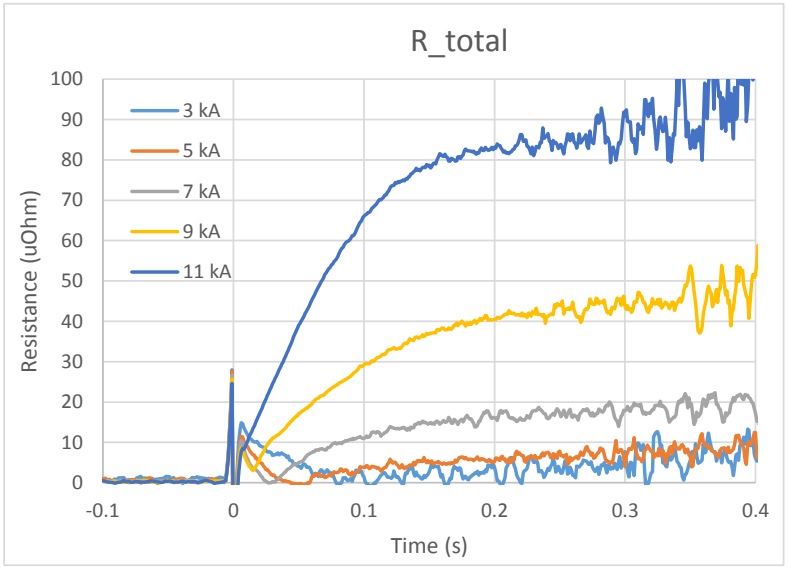
Erratic quench behaviour. No RR studies performed.
No quench at 80 A/s up to 11.25 kA.

MBHSP102

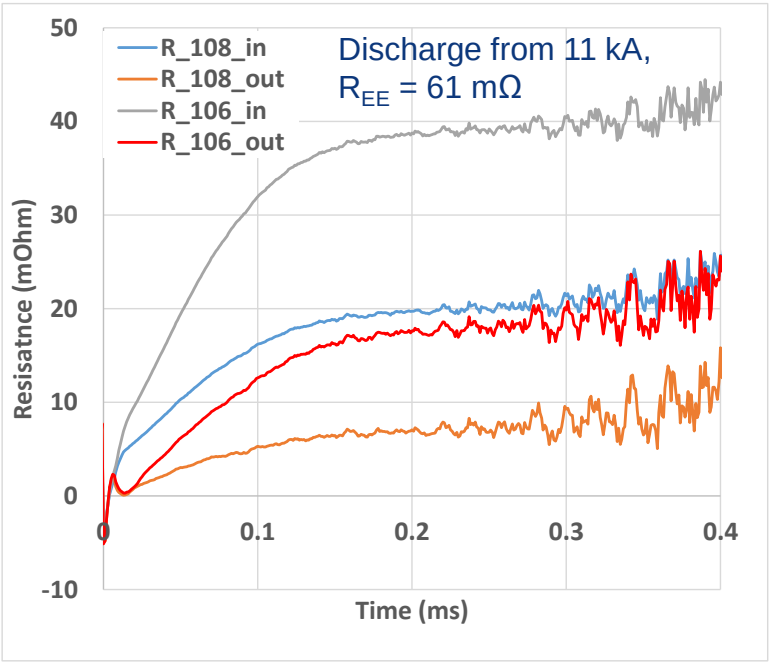
200 A/s: No quench to 11.85 kA
300 A/s: Quench at 10.8 kA

Quench back - Energy extraction tests – MBHSP102



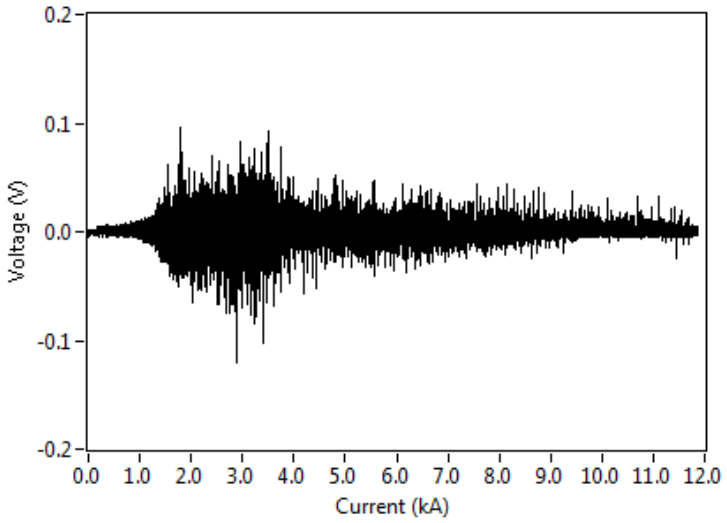


EE switch opened, no QH firing.
All resistance in the coil due to quench back.

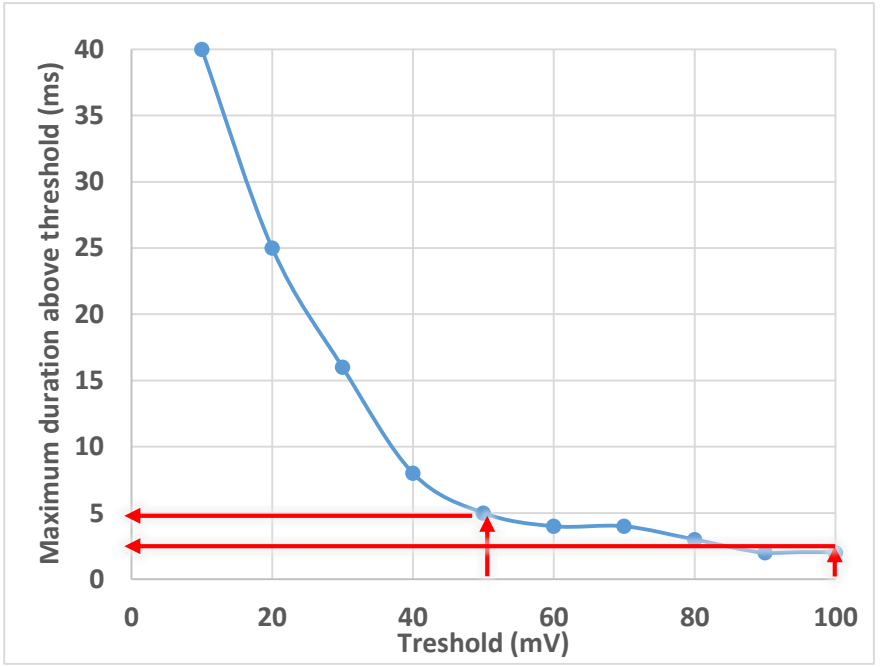


Coil 106 and 108 have about the same start time of quench back, but resistance growth in coil 106 is much faster.

Flux jumps MBHSP102



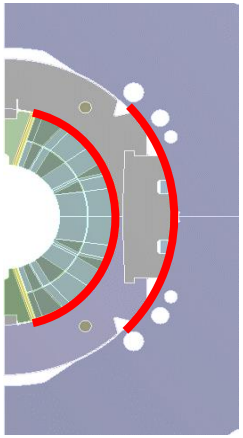
Maximum peak -120 mV.
Measurement frequency 5 kHz



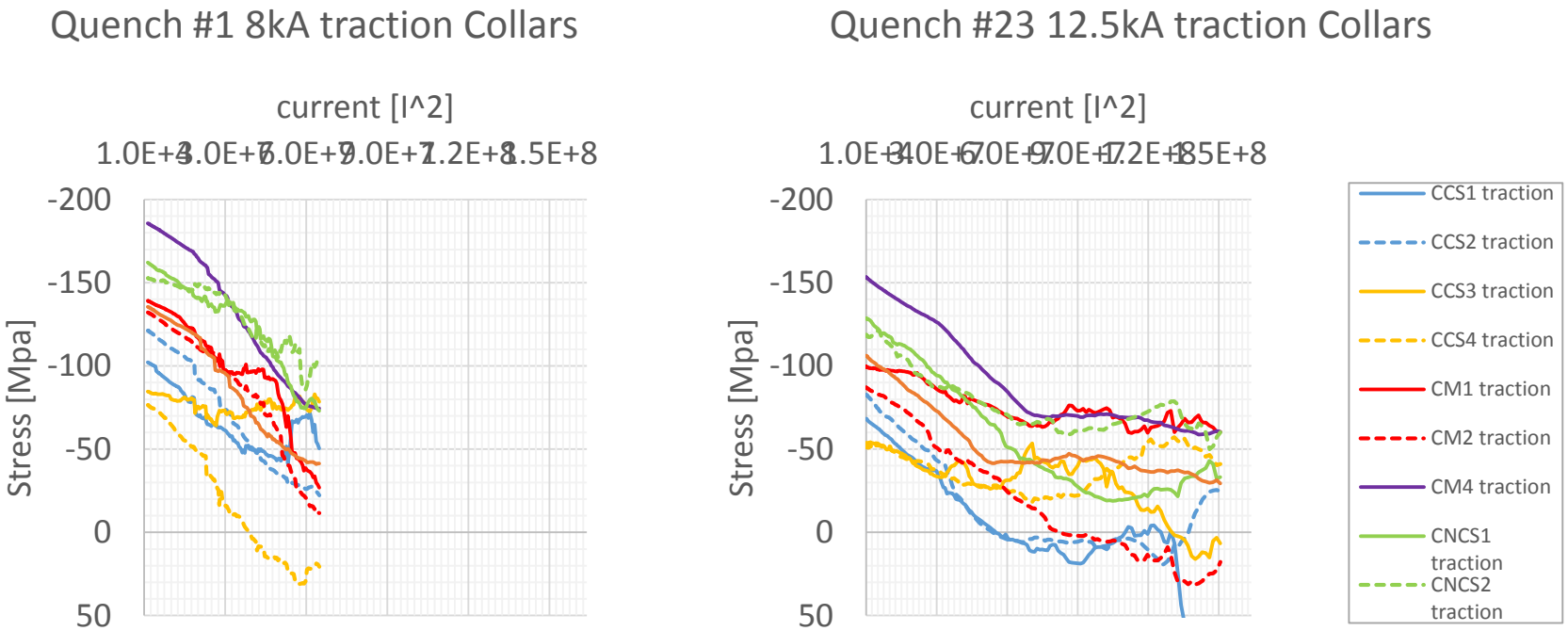
With a threshold of 50 mV, minimum validation time is needed of 5 ms if a single threshold and evaluation is taken for the full range.

Preloading difference of MBHSP102 to MBHSP101

- Added 50µm radial shim collar to coil
- Added 50µm radial shim collar to yoke
- Change in the layout of the transition region
  - Length of last loading pole increased (85-240mm)
  - Top Kapton-shim on loading pole replaced by steel-shim
- No unplanned 0.25mm midplane shim
- Coil geometry is similar to 101

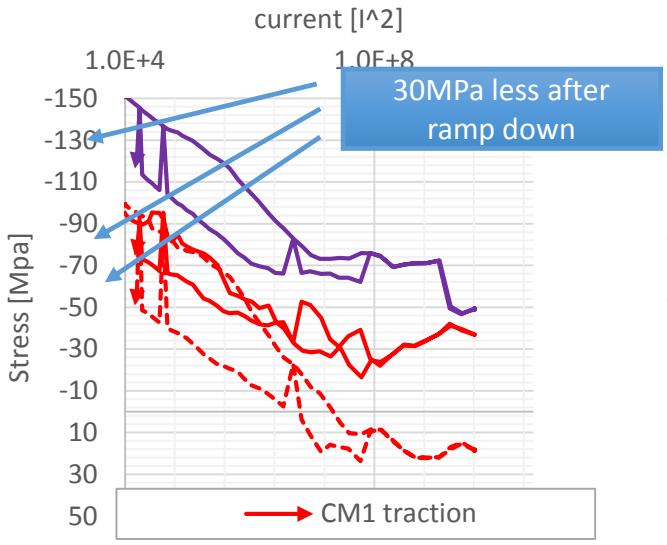


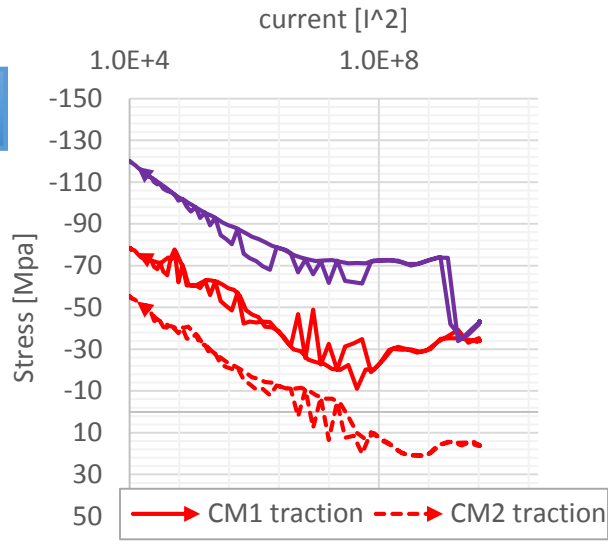
Mech. Behavior in radial direction of MBHSP102



Change of mechanical behaviour during the test campaign. Continues powering causes some sort of settling in the system.

Influence quench vs. no quench in MBHSP102
magnetic measurements to 11.8kA





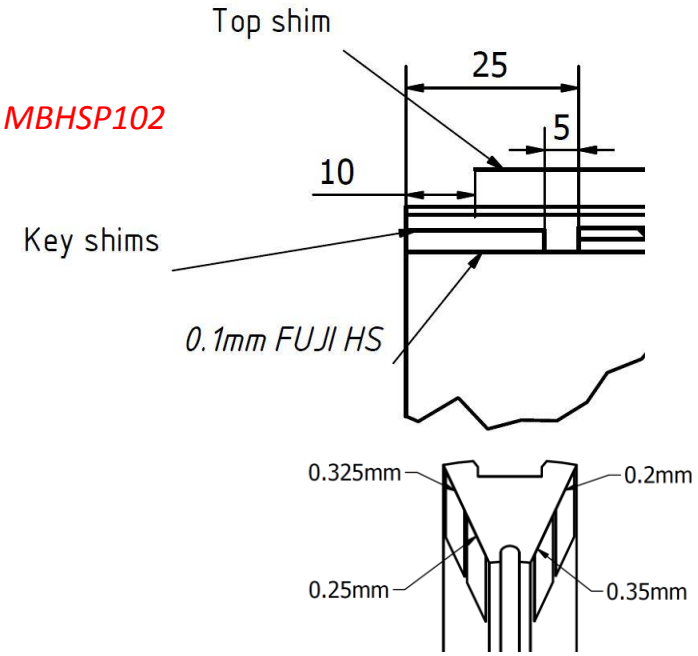
1st ramp after a training quench

2nd ramp after the 1st ramp of the MM

Changes for MBHSP103

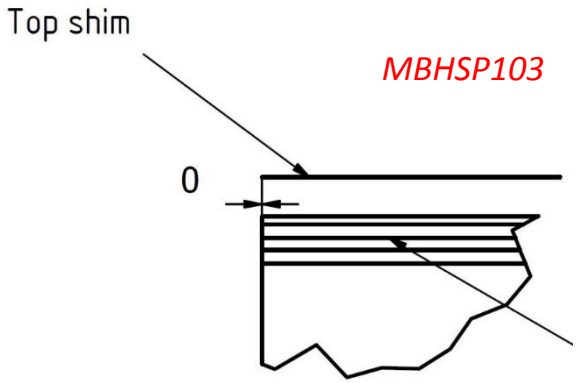
Top shim = 50µm
2 x reduction every
20-30mm

MBHSP102



Each key leg individually shimmed

MBHSP103



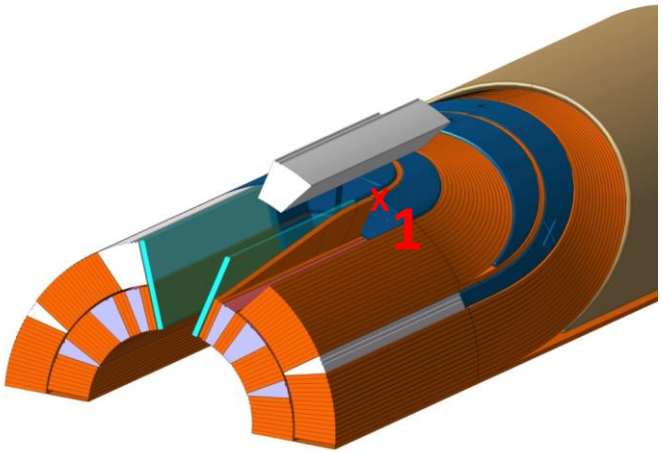
Only adaption in the transition region with the top shim

Summary of weak locations in coil 107

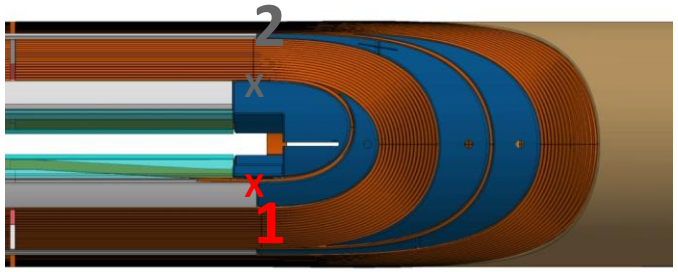
1. At voltage tap O1, just out of the layer jump.
   7 quenches during initial training
   Limiting point later on at 1.9 K

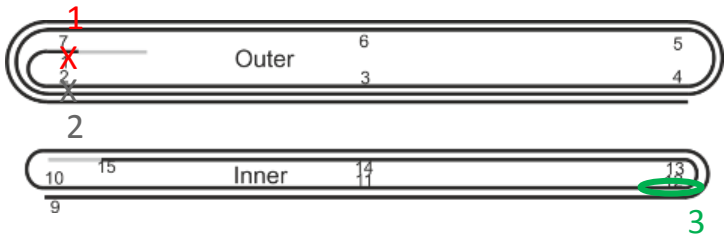
2. At voltage tap O2, opposite of O1.
   Limiting point at 4.3 K

3. Around voltage tap I12, close to the pole head with 6 training quenches and detraining.



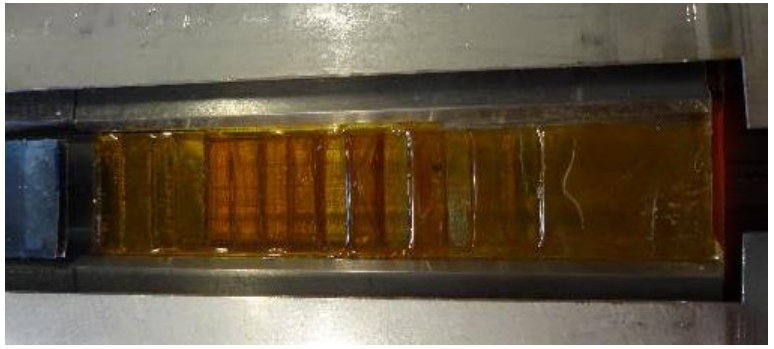
Images courtesy N.Peray and D. Smekens

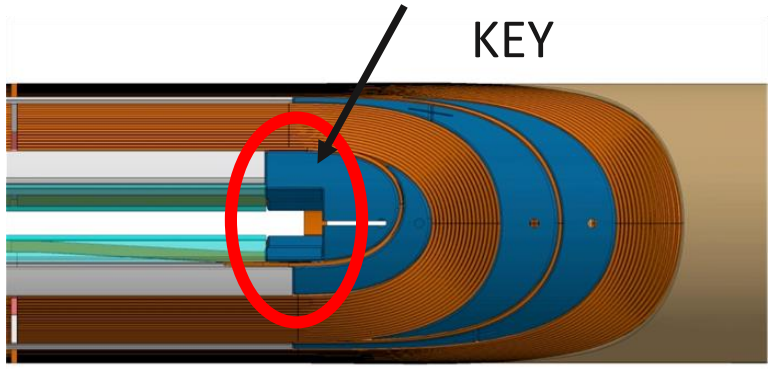




Summary for MBHSP101

- Most of the quenches are in the key region
- Shimming of the keys has not been strong enough





Discussion topics

- Training quenches
  - Mechanical origin? Do we

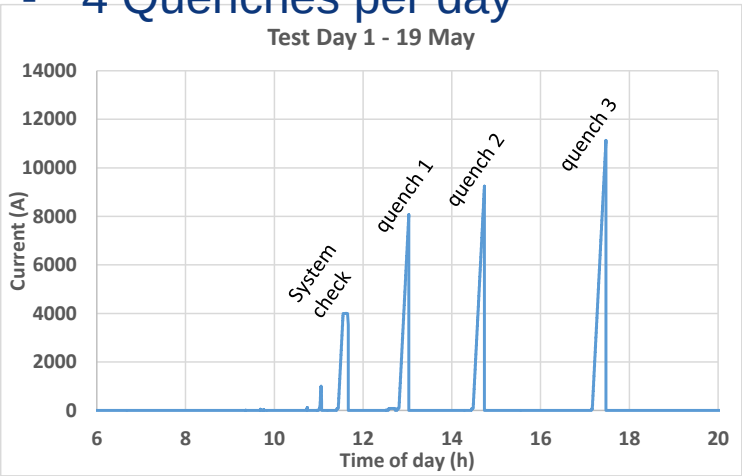
- What triggers the erratic and detraining quenches ?
  - 108/127 coils with low RRR very sensitive to small perturbations??
  - Mechanical origin??

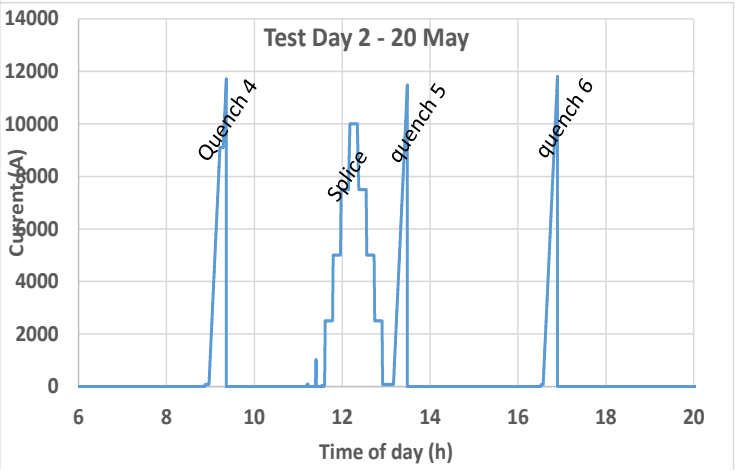
- Do we think detraining comes from local or more global movement and can higher RRR cure this (coil 108 only quenched 4 times up to 12.8 kA).

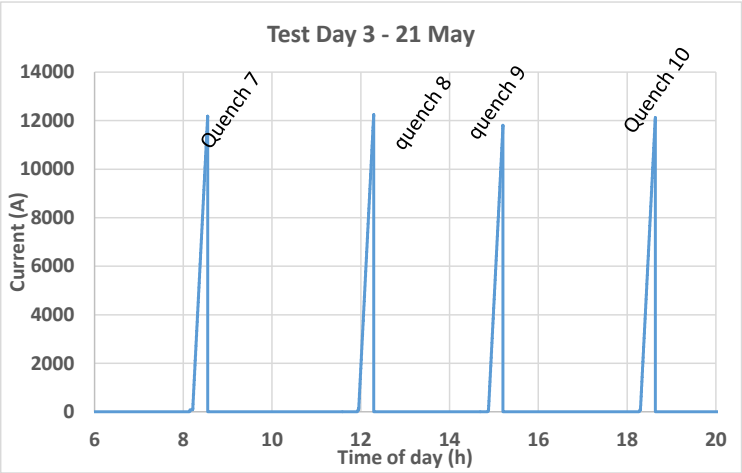
Backup slides

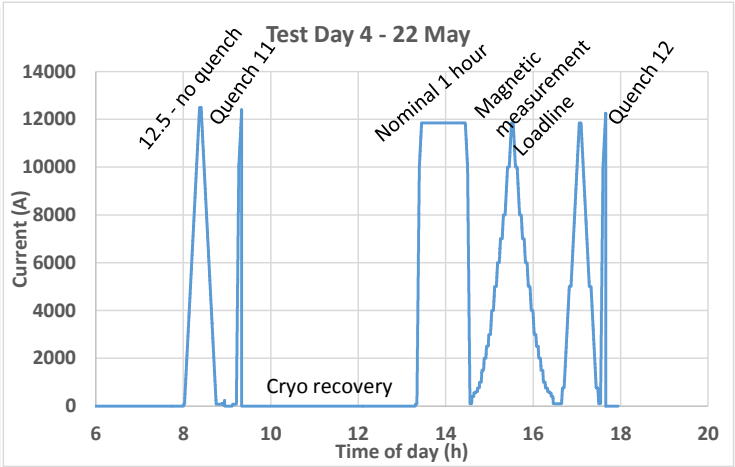
Training program

- Training at 1.9 K, 10 A/s
- Target current 12.5 kA
- Training not interfered with other tests, only splice measurement.
- 4 Quenches per day





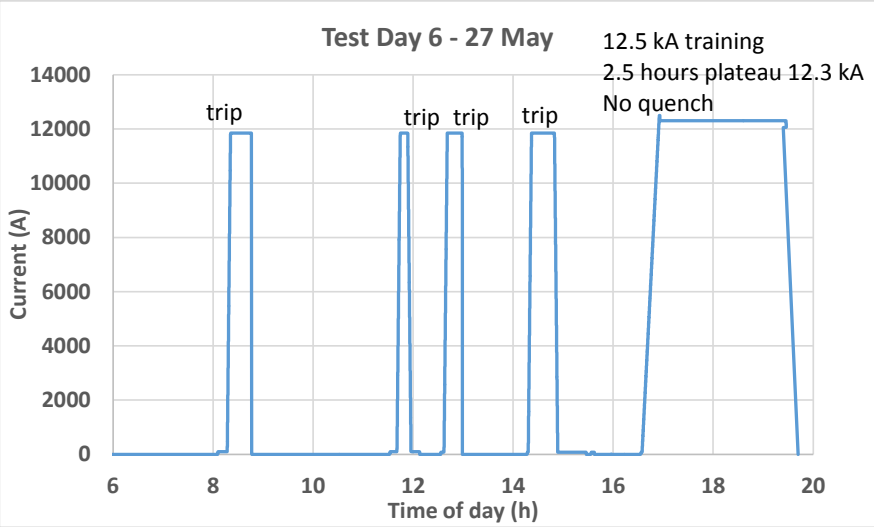


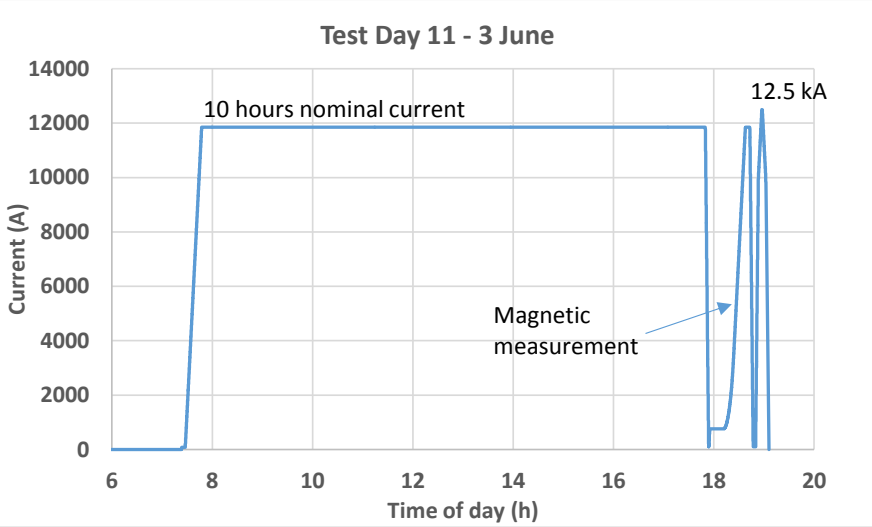


Stability test/holding current test

2.5 hours at 12.3 kA, no quench.

10 hours at nominal current, followed by a magnetic measurement cycle and a ramp to 12.5 kA without quench.

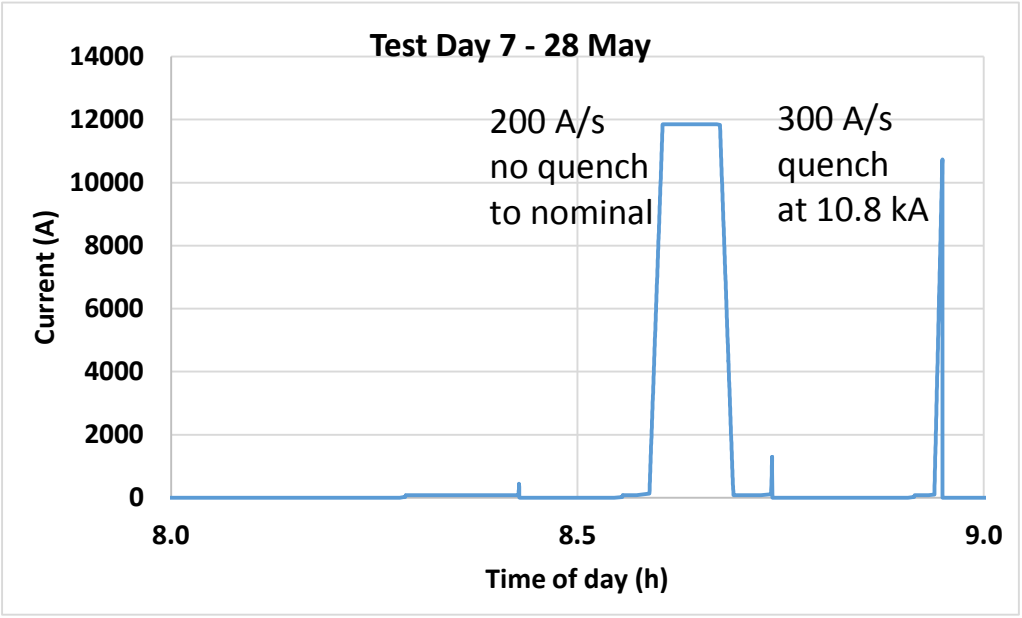




Note the length of the test days from 8h to 20h

No sign of any instability

Ramp rate dependence



- No quench at 200 A/s up to nominal current.
- Quench at 300 A/s at 10.8 kA.

- No further ramp rate dependence tests are done, considering:
  - quench back results
  - High ramp rate without quench
  - Limited test time

Magnetic measurements

3 flavours of magnetic measurements,
See presentation of Lucio next week for results