RMM1d cold powering test results
CRMHRMM_M001-CR000014

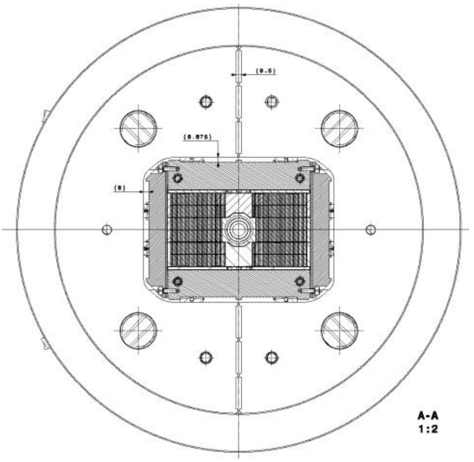
Gerard Willering

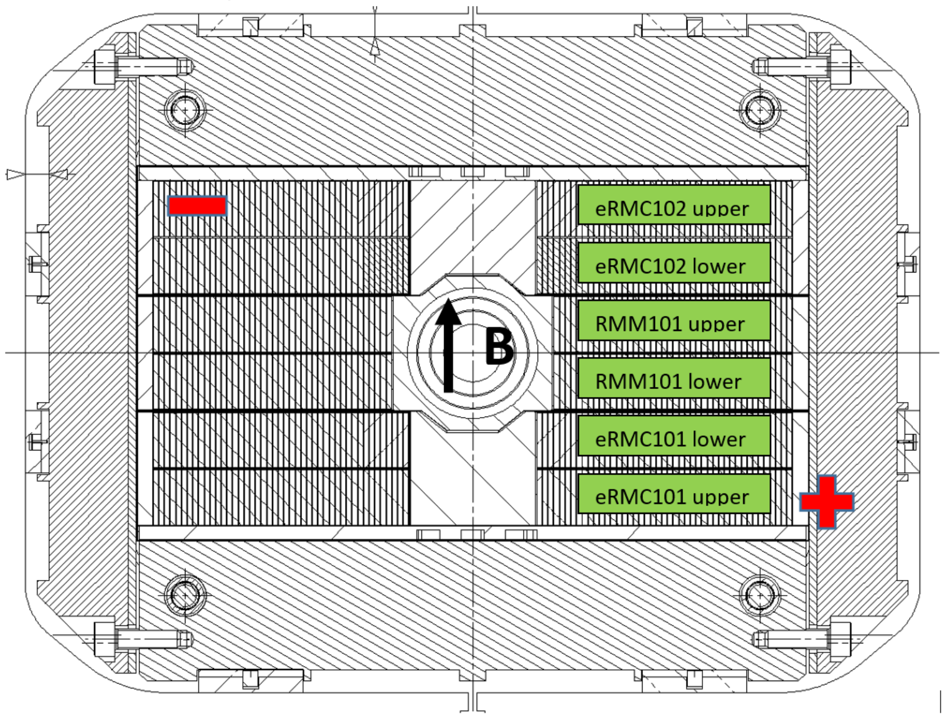
For TE-MSC-TM:
Gerard Willering, Carlo Petrone, Mariano Pentella, Franco Mangiarotti, Jerome Feuvrier, Jean-Luc Guyon, Michael Boczan et al.

With For RMM project:
Juan Carlos Perez, Jose Ferradas, et al.

13 November 2024 – HFM Forum discussion

Introduction





RMM1d uses the same coils the same magnet as RMM1a, b and c, with some mechanical adaptations (rods, shims, ..)

3 double flat racetrack coils. No bore, but a central cavity is used to measure field.

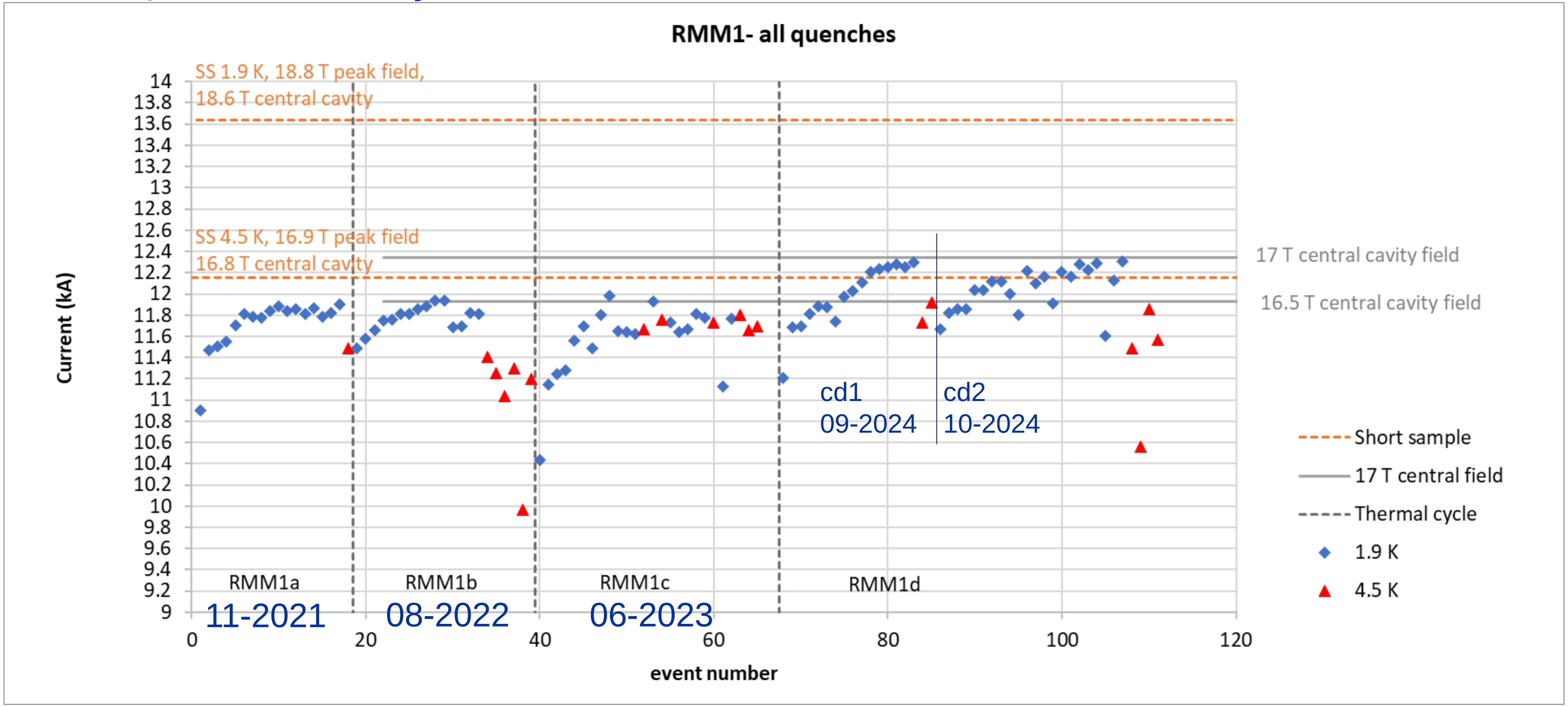
The two eRMC coils were also part of the eRMC magnet.

Test result discussion RMM1a: https://indico.cern.ch/event/1106639/
Test report RMM1a: 2685493

Test program RMM1b: EDMS 2771286
Test report RMM1b: EDMS 2782316

Test result discussion eRMC https://indico.cern.ch/event/890619/

RMM Quench History

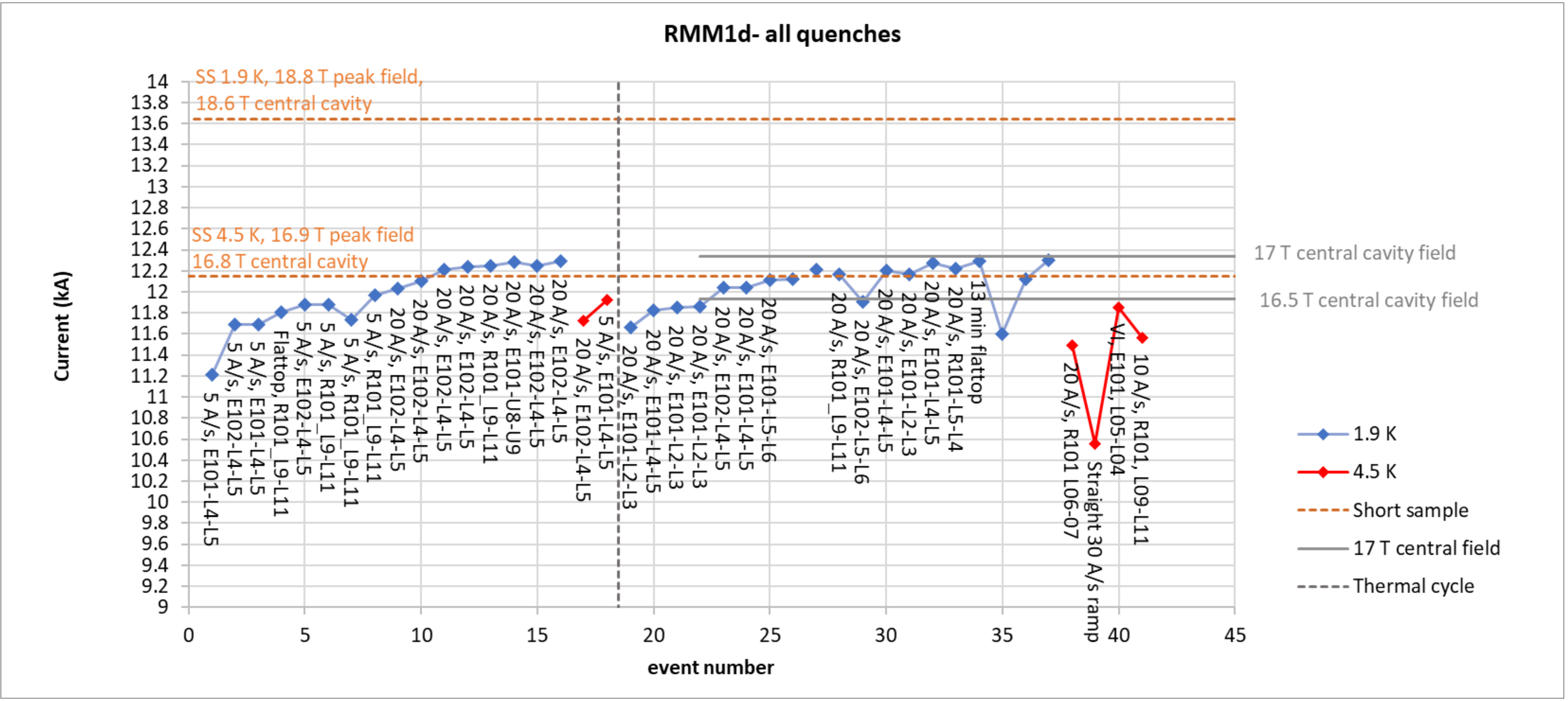


Focus on the RMM1d test:

Reaching **record field** of 16.94 T central cavity field at 1.9 K and above 17 T peak field on the conductor.

Reaching 16.5 T central cavity field and 98 % of Iss at 4.5 K.

RMM1d Quench history

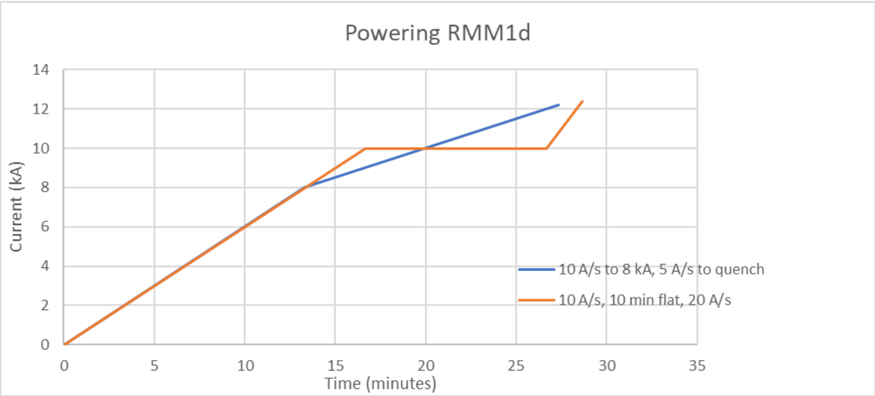


Content of the next slides:

1. Conductor performance at 1.9 K
2. Conductor performance at 4.5 K
3. Training performance at 1.9 K

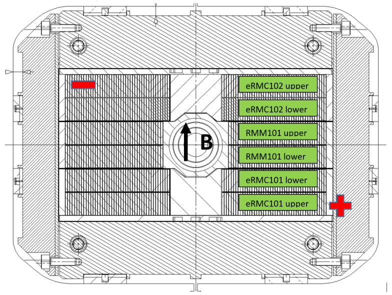
RMM1d Conductor performance limit at 1.9 K

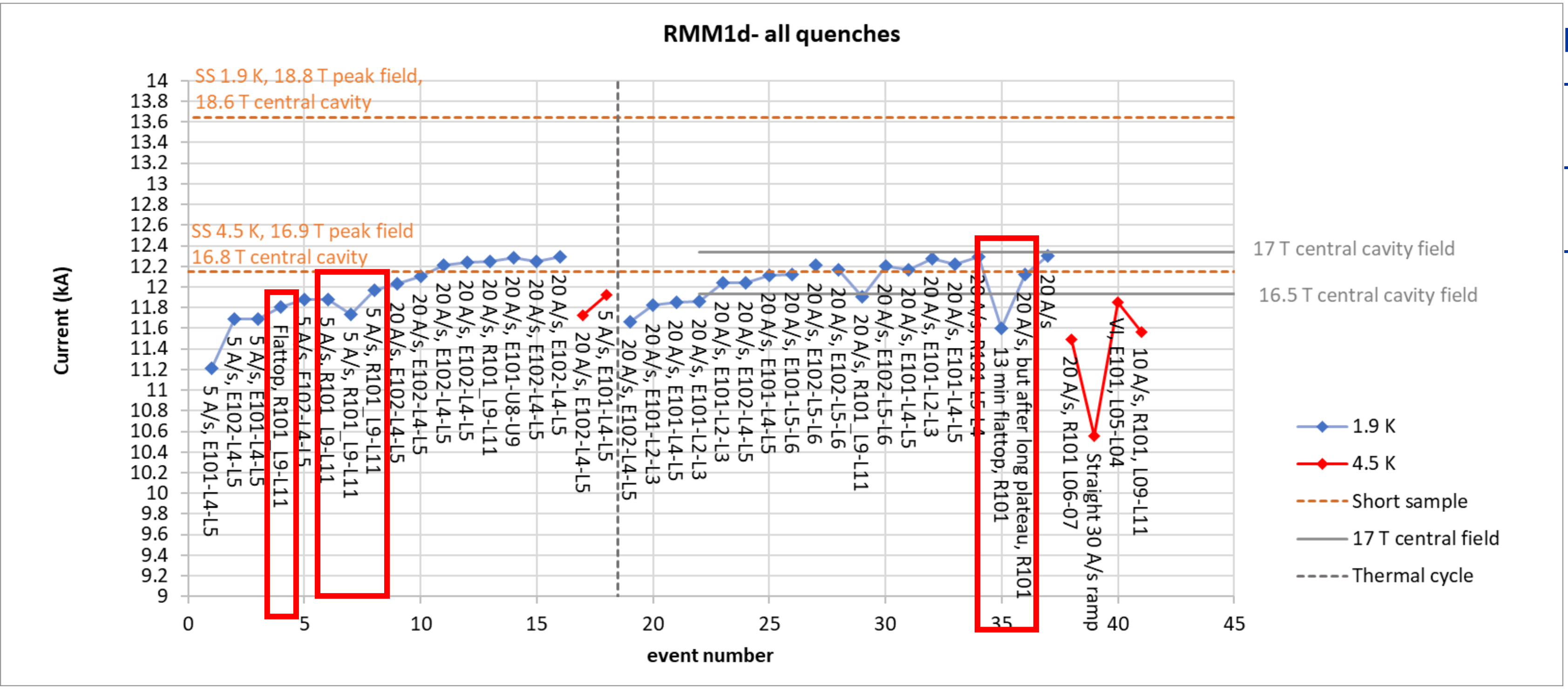
RMM1d Conductor limit at 1.9 K



Powering cycles

- At the start of the training the used cycle was ramp to 8 kA at 10 A/s, followed by 5 A/s to quench. Without helium cooling channels in the coils or structure, slow ramp is needed to allow dissipation of losses.
- This ramp lead to premature and consistent quenching at R101 lower layer, low field region, including holding current (flattop) quenches.
- A new ‘standard’ was adopted: ramp to 10 kA at 10A/s, followed by a plateau of 10 minutes, then ramp at 20 A/s.





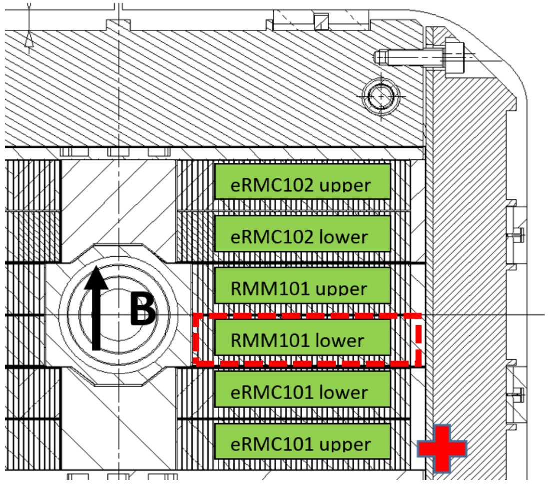
Holding current quench and low current quench:

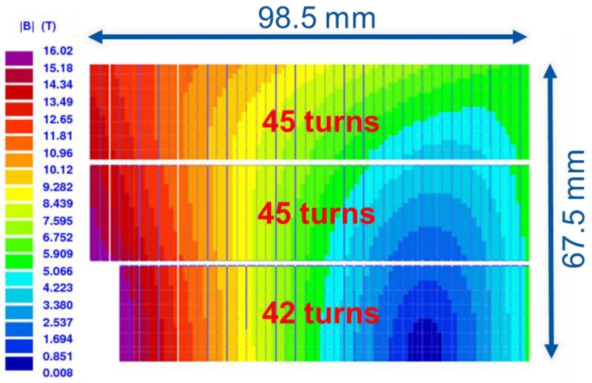
- 5 A/s ramp quench starts at around 11.9 kA. **Also in RMM1c.**
- Holding quench at initial target current of 11.81 kA was 5 to 7 minutes. **Already seen in RMM1b test.**
- New cycle avoids this limitation at least up to 12.3 kA.

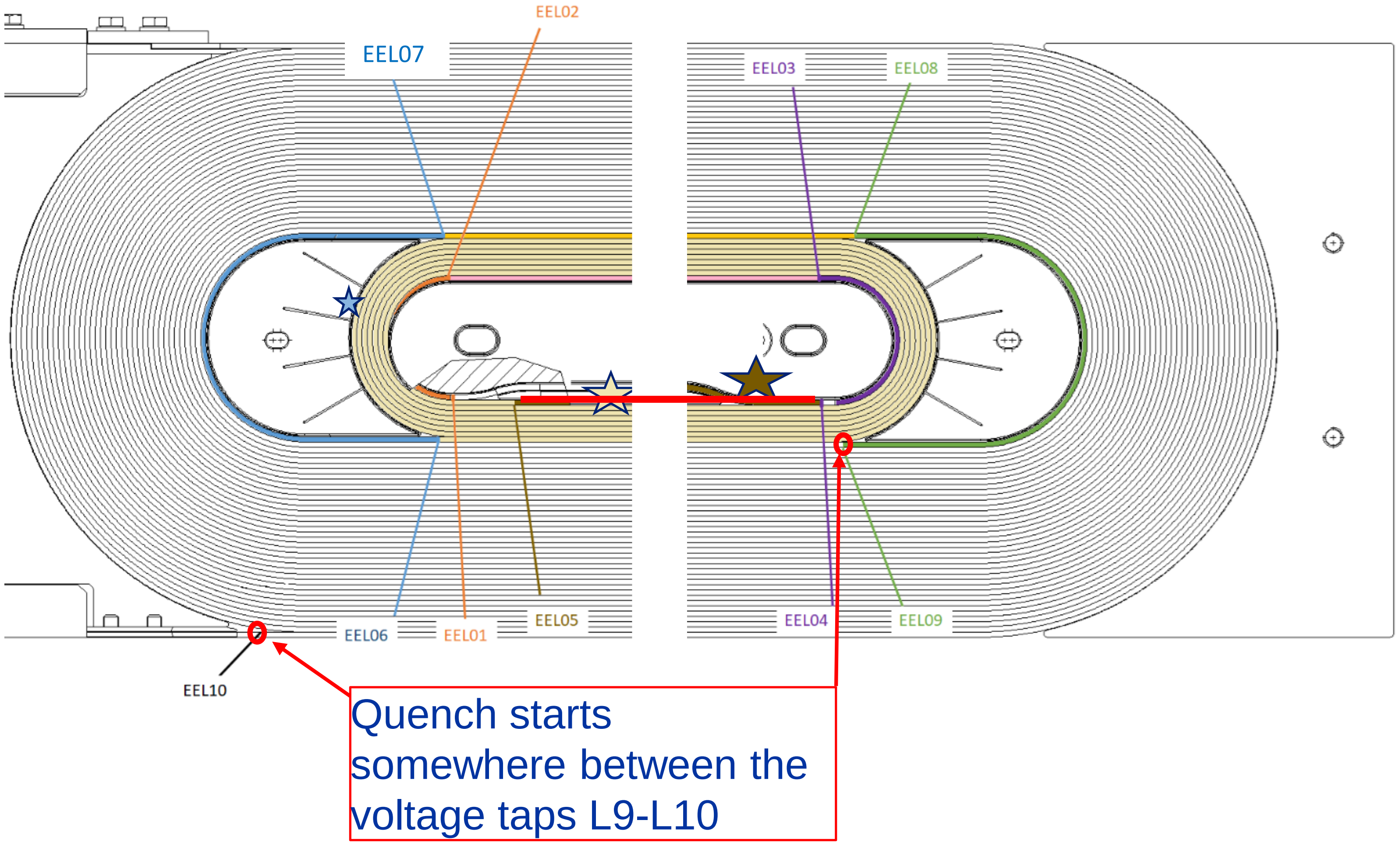
Current (kA)	Flattop time
12.1 kA	8.5 seconds
12.0 kA	11.3 min
11.8 kA	48 min
11.81 kA (different precycle)	5 min 7 min

RMM1d Conductor limitation at 1.9 K

Consistent quenching without precursor in a location in R101 L9-L10.

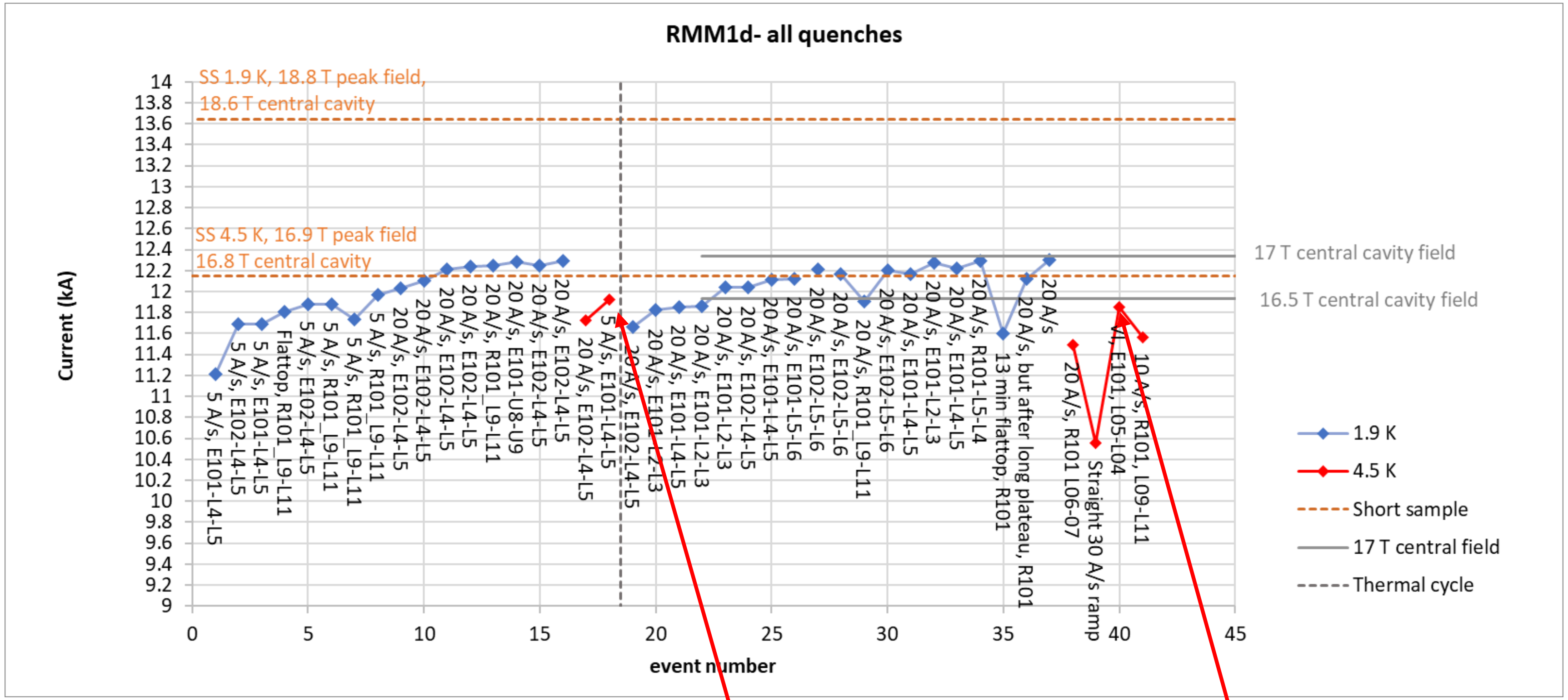


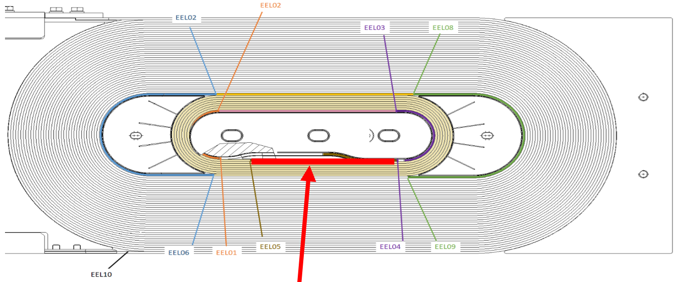


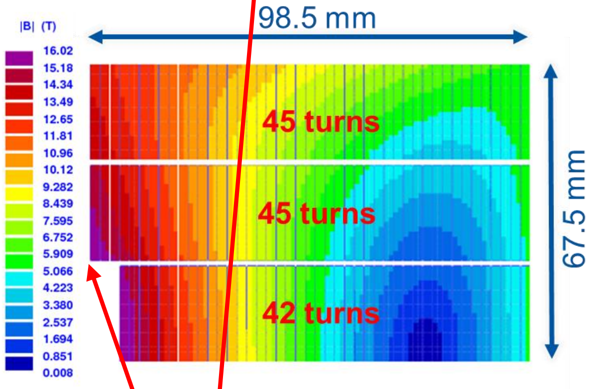


RMM1d Conductor performance limit at 4.5 K

RMM1d Conductor limitation at 4.5 K







At 4.5 K

Cool down 1: reaching 11.92 kA (98.1 % from short sample)

Cool down 2: reaching 11.86 kA (98.0 % from short sample)

Highest current reached in the slowest cycle (V-I cycle).

No sign of voltage build up in the V-I measurements.

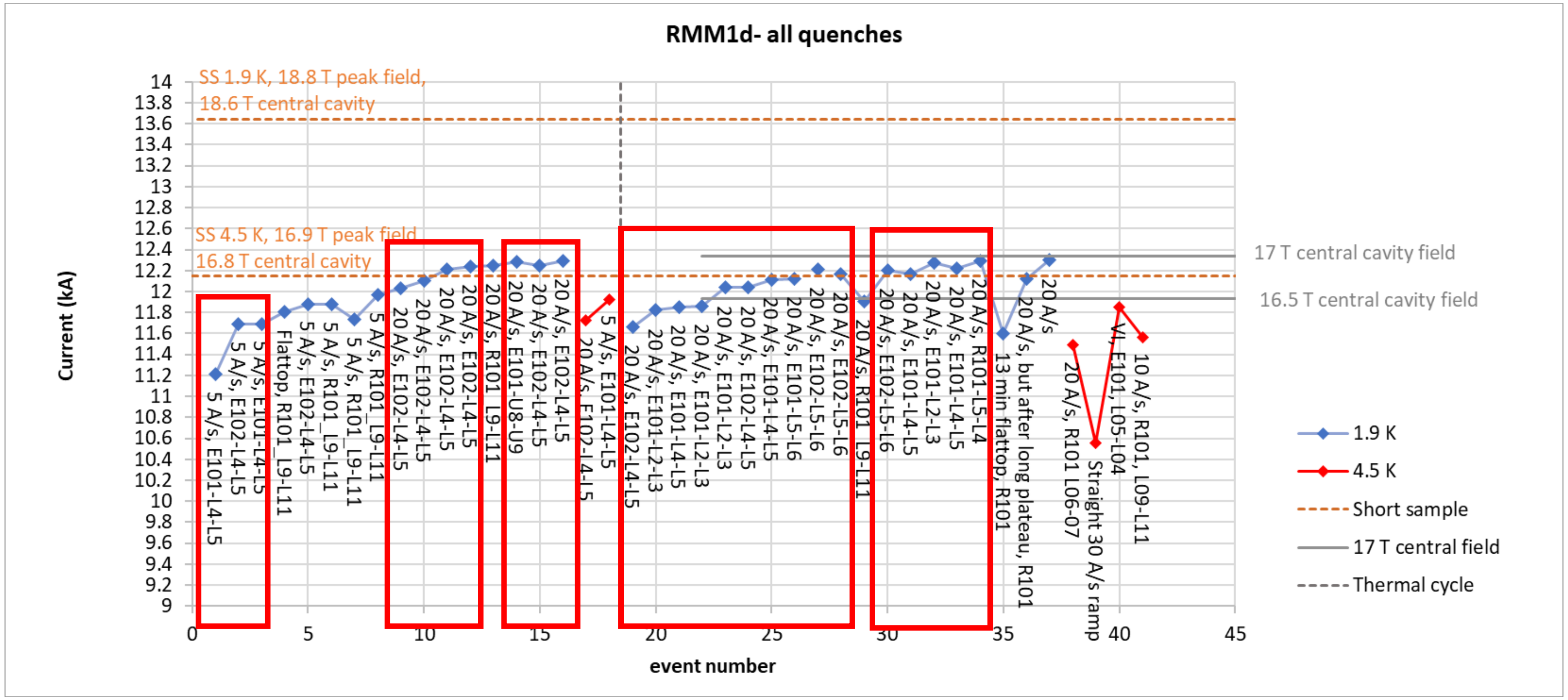
No sign of conductor instabilities during slow ramps as seen at 1.9 K.

Central cavity field reached of 16.5 T at 4.5 K.

As can be expected, quenches start in the high field region. Straigth part, pole turn. eRMC101 coil.

RMM1d Training quenches

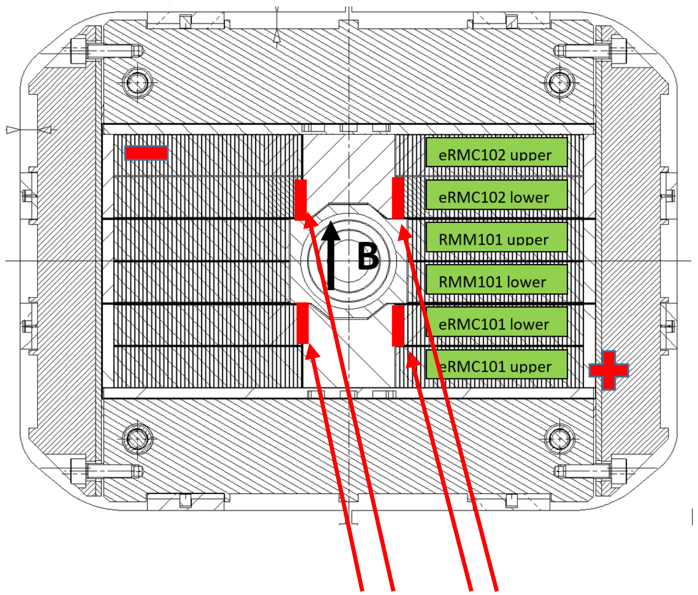
RMM1d Training quenches

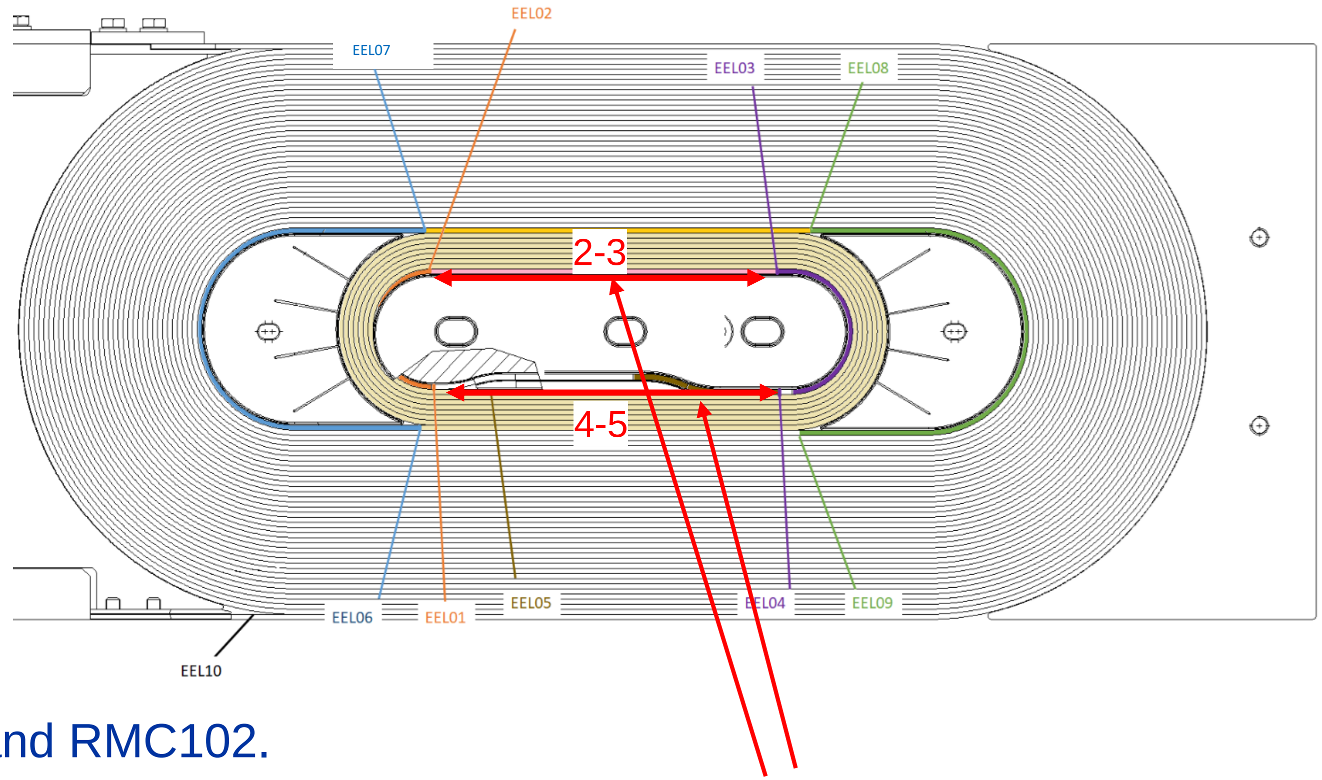


Training quenches

- Not considering the quenches in conductor limited locations, the magnet trained in the first cool down with 3 quenches to 16.5 kA central cavity field (11.95 kA) and in cool down 2 in with 4 quenches.
- Maximum current reached in CD 1 was 12.294 kA and in CD 2 12.301 kA. This is at 16.94 T of central cavity field.

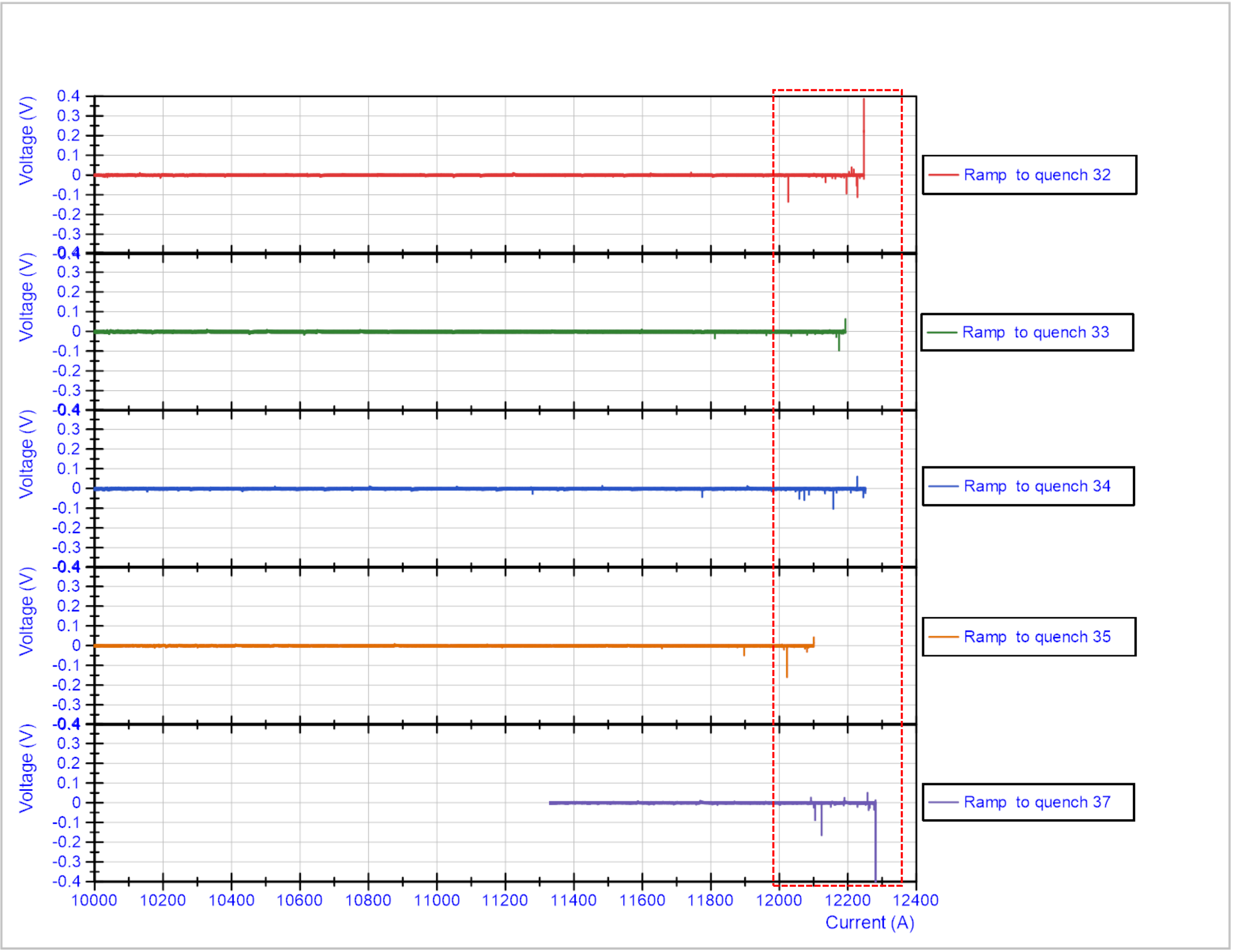
RMM1d Training quenches - location





- Training quenches spread between coils eRMC101 and RMC102.
- All training quenches located in the lower layer, mostly in 2-3 or 4-5, the straight pole turn segment. A few were located in segment 5-6 (second turn).
- Most quenches have a significant precursor (unlike quenches at 4.5 K or in the low-field region at 1.9 K).

RMM1d Training quenches - precursors



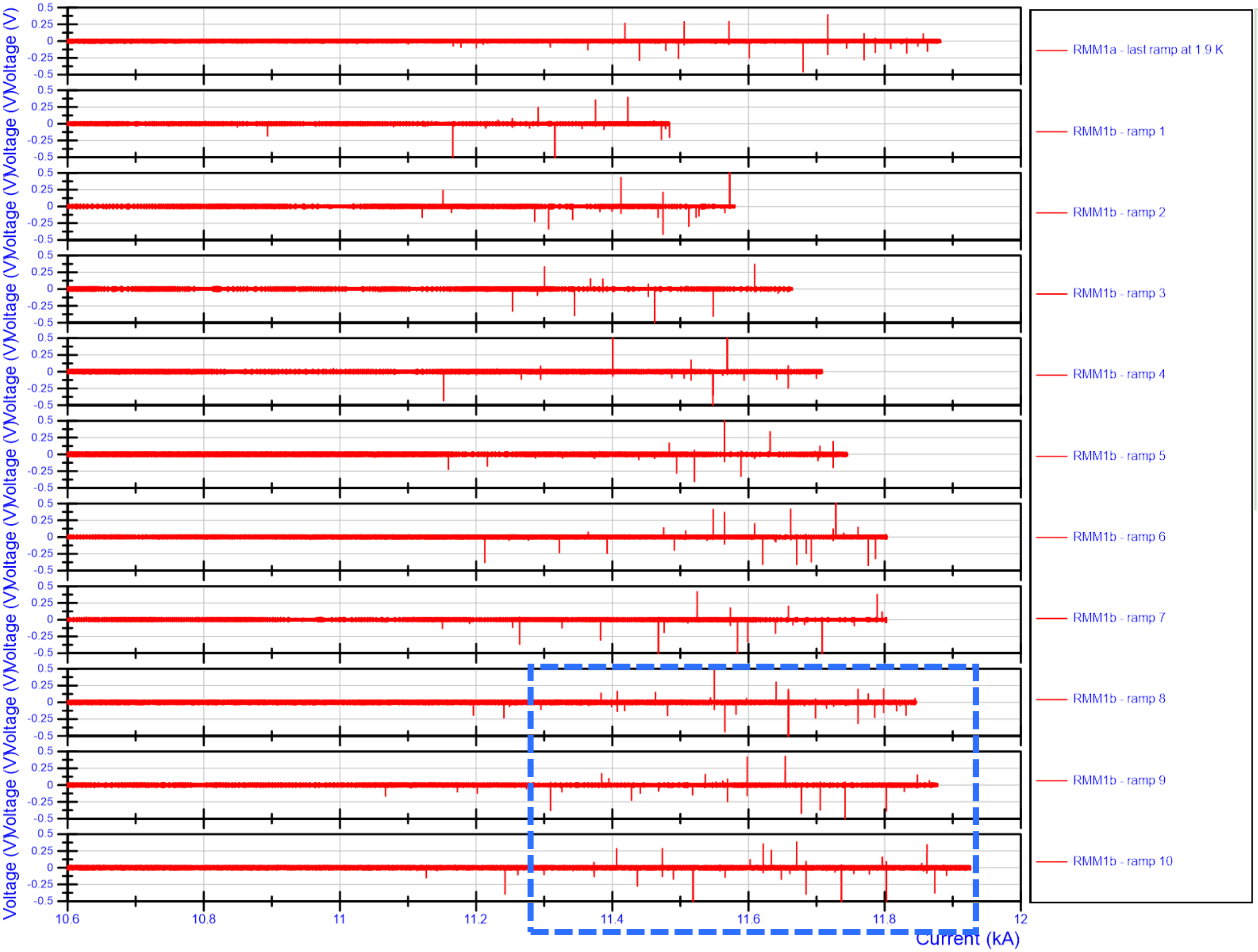
For RMM1d we can see precursors measured in the differential voltage starting from around 12 kA.

Some of these precursors (sign of mechanical transients) do not lead to a quench, but others do.

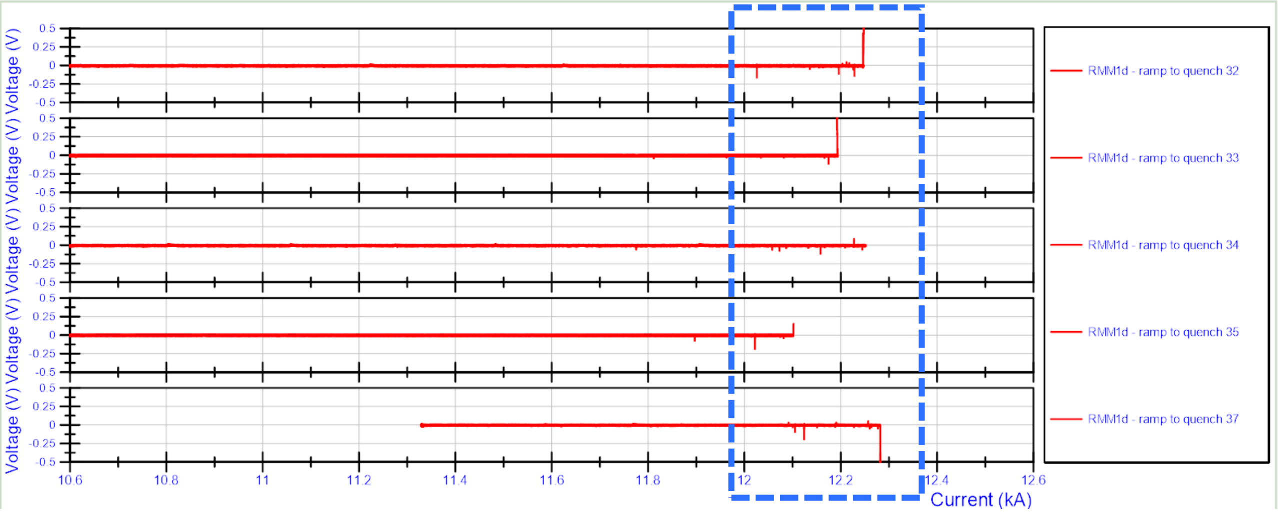
At 4.5 K short sample can be reached without being impacted by these transients.

The level of 12 kA seems to be an improvement compared to RMM1b, see next slide.

RMM1b



RMM1d



In RMM1d, transient activity starts above 12 kA and with lower frequency and amplitude.

This is a major improvement.

- In RMM1d the magnet has been trained much more and longer, so there may be an impact.
- In RMM1c/d coil pack shimming was modified (+100 µm/m for E-RMC coils). It seems likely that there was a positive contribution to the improved maximum current level.

In RMM1b, in ramp 8 to 10, there are systematic transients above around 11.3 kA.

Conclusion RMM1d

- RMM1d reached a record field of central cavity field 16.94 T at a current of 12.3 kA at 1.9 K. This is 90 % of short sample limit. The maximum current/field is limited by transients that cause quench.

- RMM1d has a low-field conductor limitation that leads to holding current quench and low ramp rate quench at 1.9 K at 85 % of short sample limit. This was already present since RMM1b.

- RMM1d reached 98 % of short sample limit at 11.95 kA with a central cavity field of 16.5 T at 4.5 K. This shows that there are no conductor issues in the high-field region.

- RMM1c/d improved from the RMM1a/b assemblies, with mechanical transients indicating successful mechanical adaptations.

Discussion

Our two largest block coil magnets (FRESCA2 and RMM1) have similar limitation by mechanical transients below short sample. RMM1c/d show that improvements can succesfully be applied, but is should remain focus during development.

Diagnostics for testing:

- For block coils we need to focus more on systematic investigations of transients (accelerometers, accoustic emission sensors, transients in voltage signals, pickup coils in the bore, fast readout of strain gauges)
- For block coils without core we have no idea where the quench starts in the multiturn region, in this case for the holding current quenches. More focus needed on getting dedicated quench antenna or other quench localization methods.

Magnetic measurement results of RMM1d

Author: Mariano Pentella, Carlo Petrone

Date: 07/11/2024

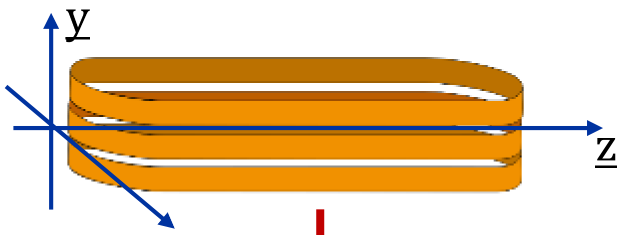
Acknowledgments: M. Liebsch, J. L. Guyon

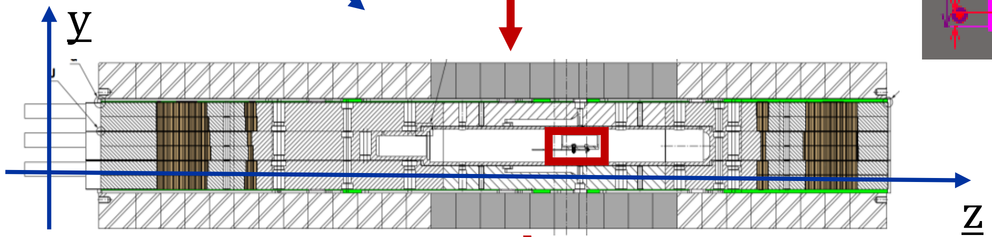
Table of contents

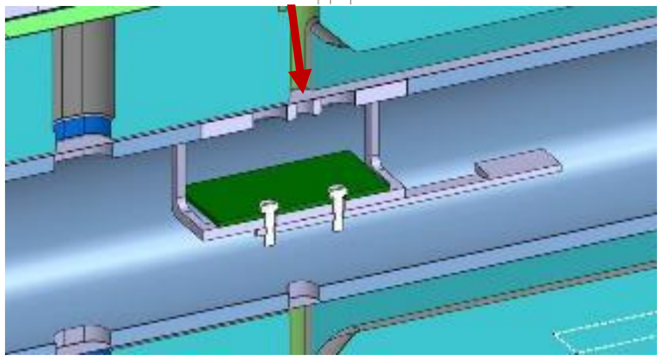
- Measurement setup
- Field vs quench events
- Field homogeneity
- Conclusions

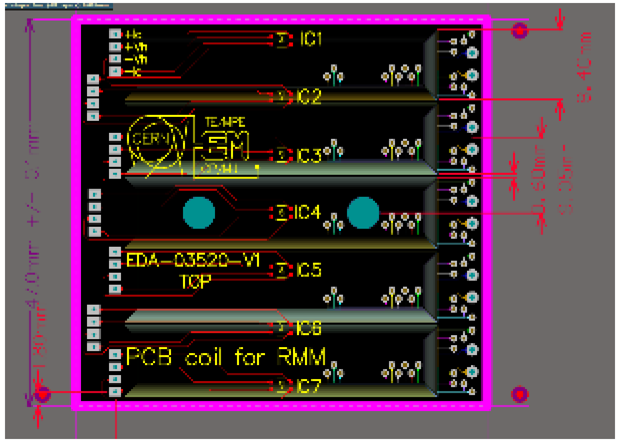
Measurement setup and procedure

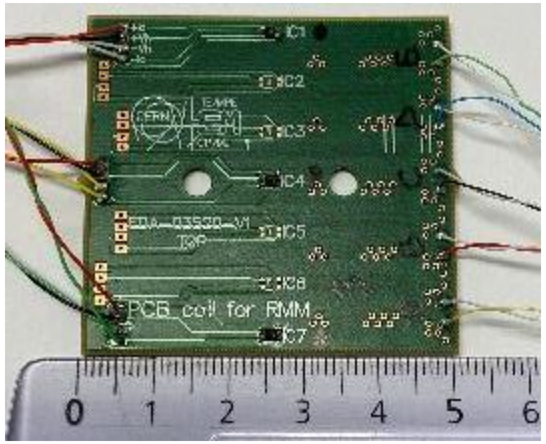
- **Measurement setup and procedure** developed for RMM1a, 1b, and 1c.
- **Induction coils** used to measure **central field and homogeneity** in correspondence with quench/extraction events (≈ 5.5 T/s).
- **Hall sensors** used for quasi-DC measurements (magnet stability and dynamic transfer function)





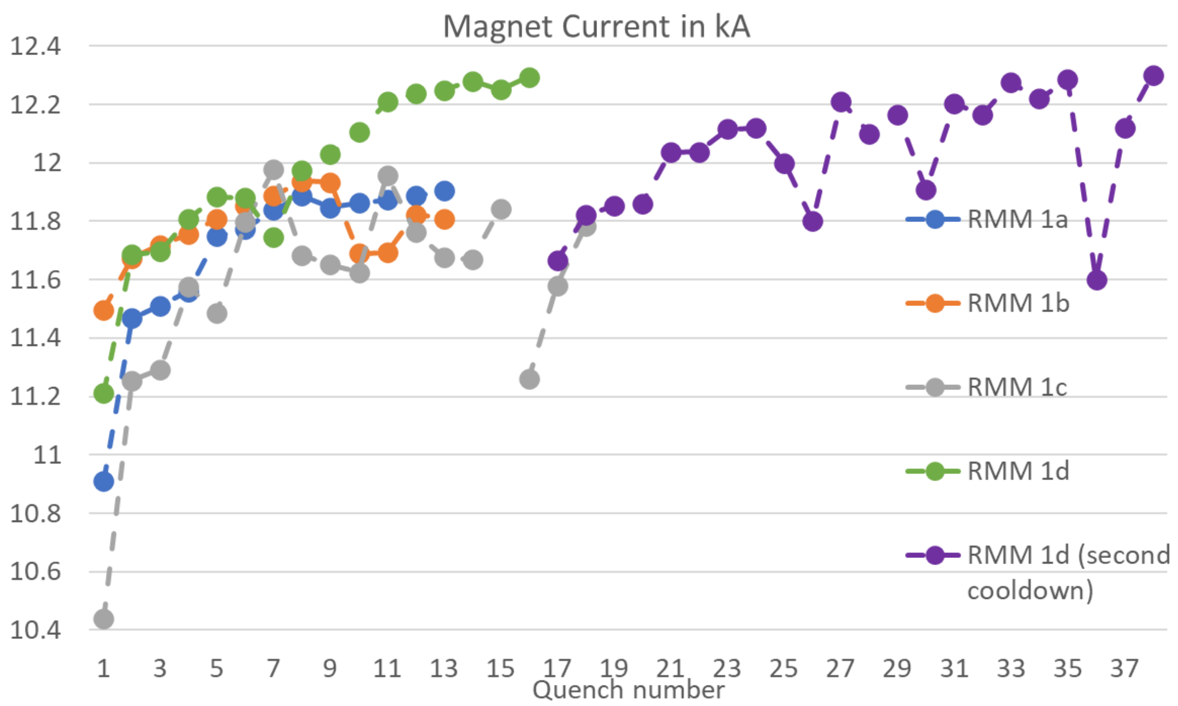


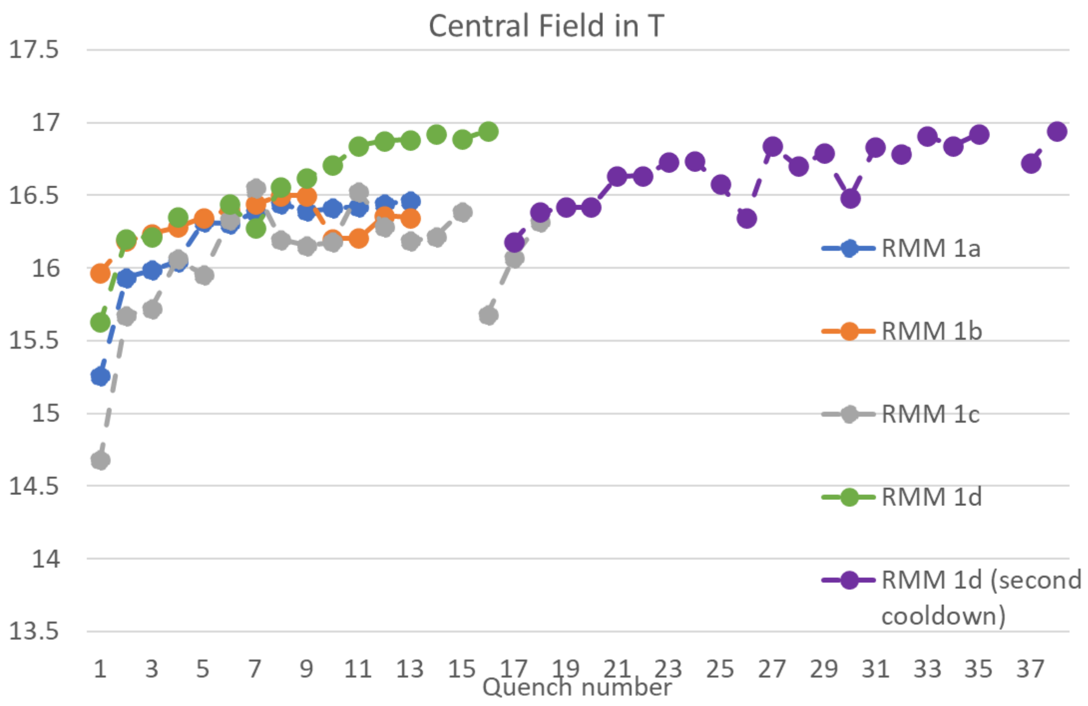




Quantity of interest	Measurement system
Central field	Central induction coil (PCB)
Homogeneity	5 induction coils (PCB)
DC transfer function	Central induction coil (PCB)
Dynamic transfer function	3 cross calibrated Hall sensors
Magnet stability	3 cross calibrated Hall sensors

Central field vs quench event (1.9 K)



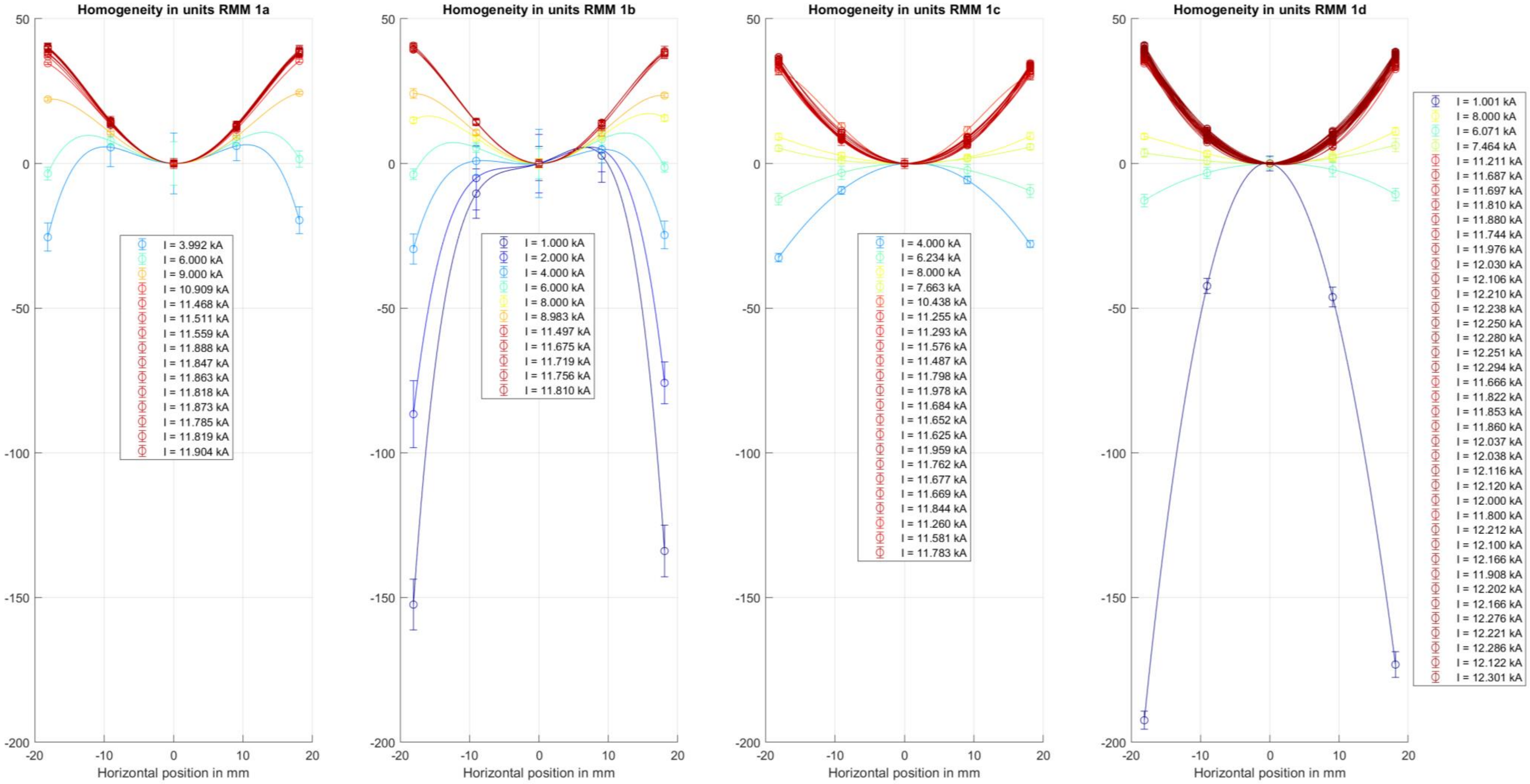


- **Record field** achieved in correspondence at the end of both cooldowns
  - **16.94 T**, 12.294 kA, event 16, first cooldown
  - **16.94 T**, 12.301 kA, event 38, second cooldown

		Field (T) – Uncertainty (1 unit)				
	Current (kA)	***x*=-18.1 mm**	***x*=-9.05 mm**	***x*=0 mm**	***x*=9.05 mm**	***x*=18.1 mm**
Event 16	12.29	17.01	16.96	16.94	16.96	17.01
Event 38	12.30	17.01	16.96	16.94	16.96	17.01

Data source previous RMM iterations: (EDMS 2843400, 3060891)

Field homogeneity (1.9 K)



- **Homogeneity similar to RMM1c**: <50 units for |x|<20 mm, but slightly worse at 18.1 mm (+5 units), at 12.3 kA.

Data source previous RMM iterations: (EDMS 2843400, 3060891)

Conclusions

- Record field achieved at **16.94 T**, twice, at **12.294 kA** and **12.301 kA**. **17.01 T** achieved at 18.1 mm from the center.
- Homogeneity below 50 units, with similar behavior to RMM 1c. An additional 5 units was measured at 18.1 mm, due to the heavier saturation state in the yoke (+316 A).
- Data analysis from Hall sensor still ongoing, to check for presence electromagnetic instabilities before the quenches.

Backup slides