Test result of the short models MQXFS-3 and MQXFS-5 for the HL-LHC upgrade

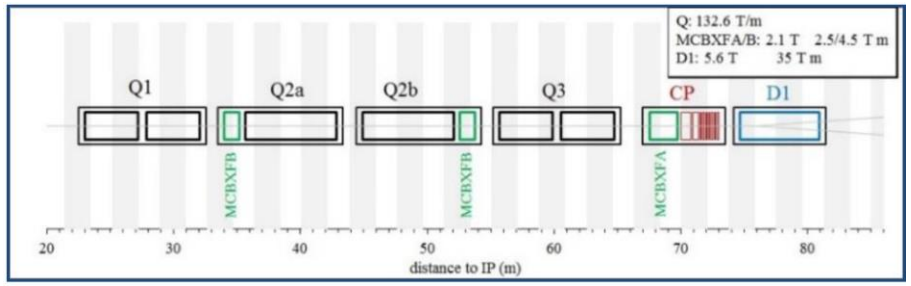
Hugo Bajas *et. Al.*

25th Magnet Technology Conference,
Amsterdam August the 29th 2017

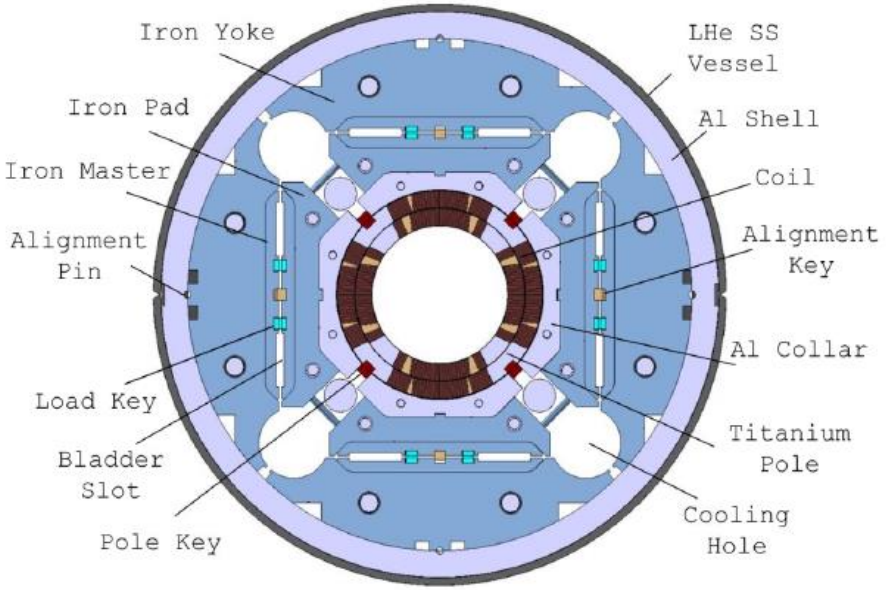
HL-LHC insertion quadrupole models MQXFS-3 and MQXFS-5

- **MQXFS-3**
  - On the High Field Magnet Insert

- **HL-LHC insertion zone**



- **150-mm aperture MQXF cross-section**



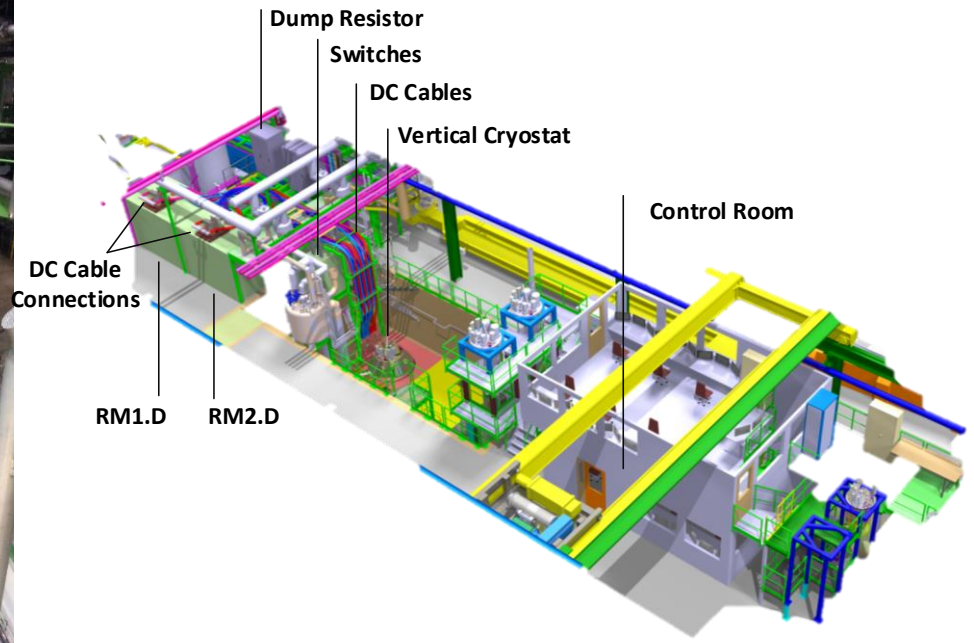
- **MQXFS-5**
  - On the Cluster D Insert

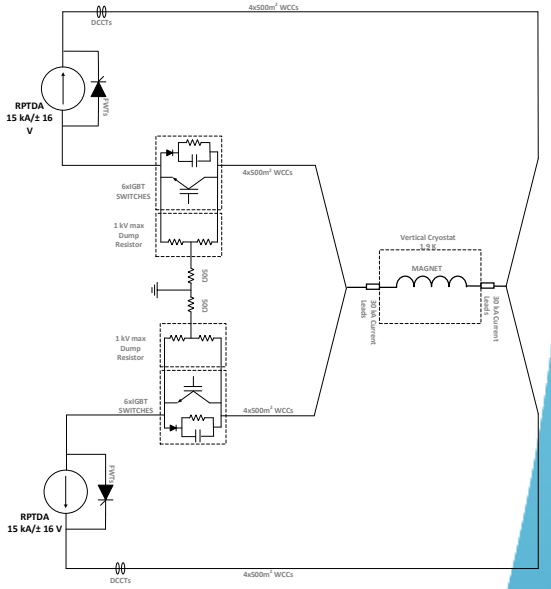
Commissionning of the HFM bench and MQXFS-3

- **MQXFS-3 insertion in the High Field Magnet facility at CERN/SM18 facility**
  - The **final commissioning** of the new bench has been completed with the powering test of **S3 in Autumn 2016**
  - **2.4 long and 1500 mm large magnets** with **a 20 kA** powering capacity **at 1.9 K**.

Commissionning of the Cluster D bench and MQXFS-5

- **MQXFS-5 on the Cluster D header, CERN/SM18 new facility**
  - **The final commissioning** of the new bench has been completed with the powering test of **S5 in Summer 2017**
  - **5.4 long and 900 mm** large magnets with a **30 kA** powering capacity (2 parallel 15 kA circuit with EE) **at 1.9 K**.

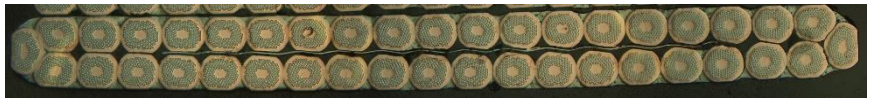


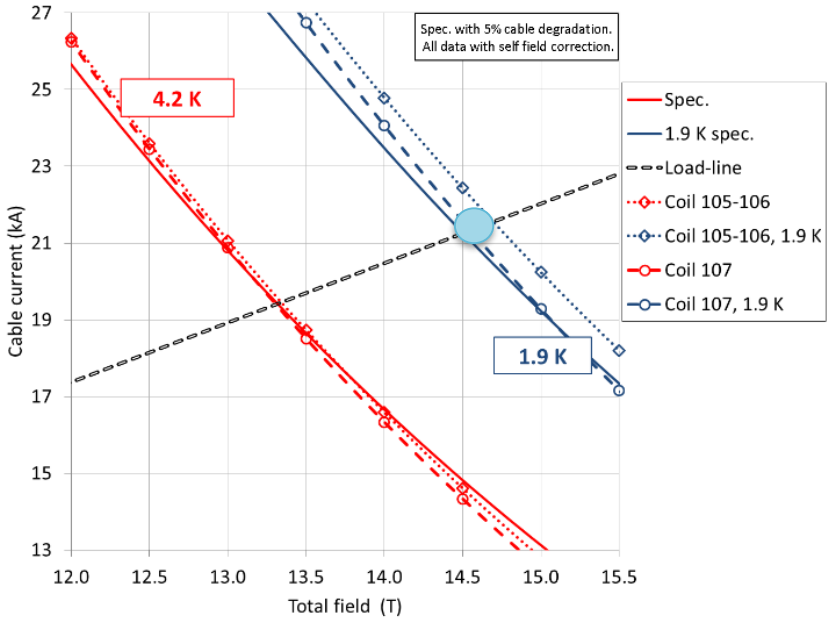


Courtesy of M. Bajko, S. Yamine 2017

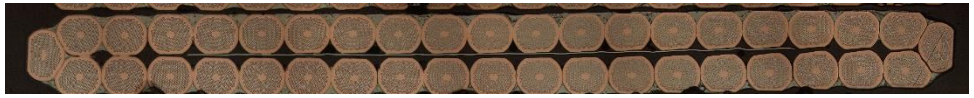
Magnets Load-line, critical surface and Short Sample limit

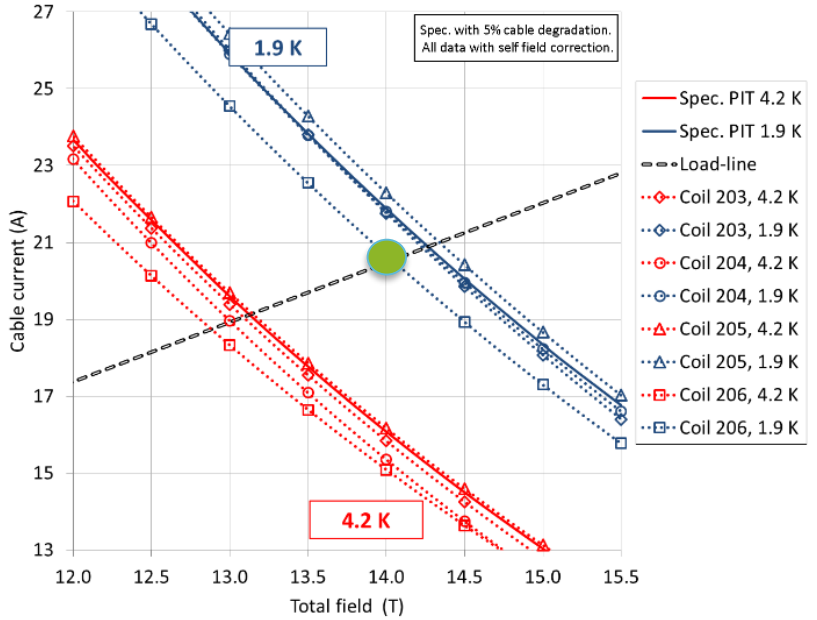
- **MQXFS-3**
  - **RRP** 108/127, 132/169





- **MQXFS-5**
  - **PIT** 192



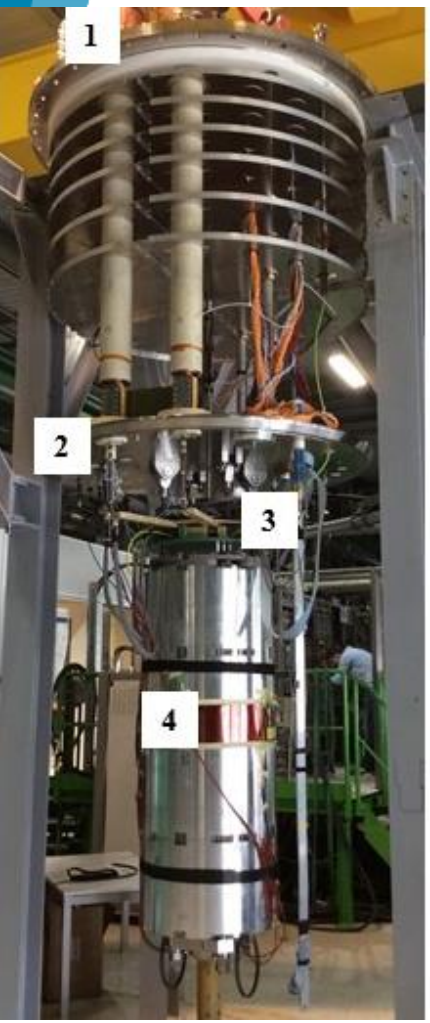


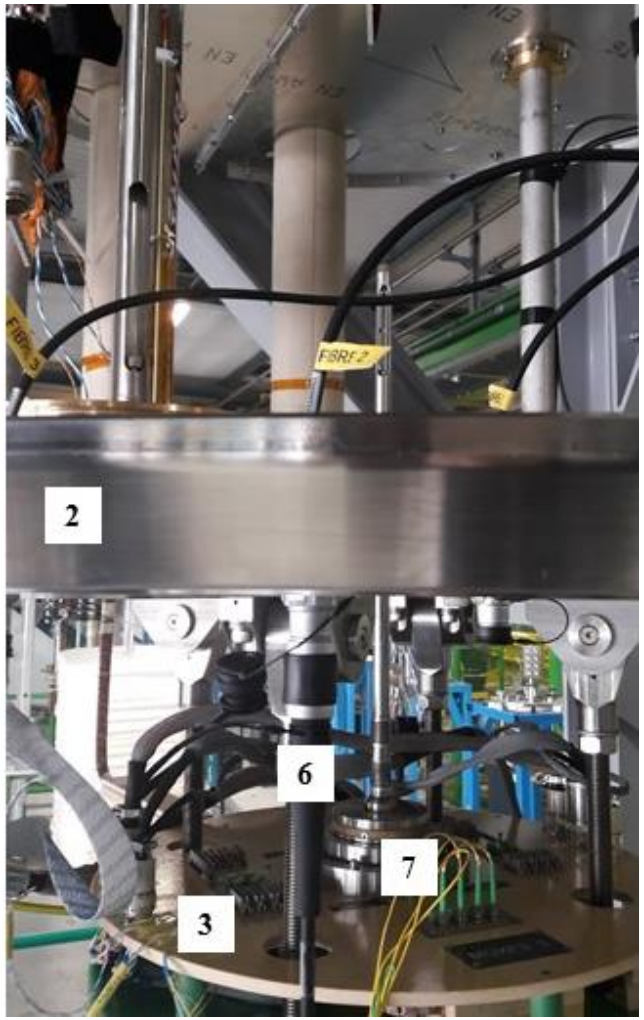
I_{nom}	16.47	[kA]
I_{ult}	17.89	[kA]

	I_{ss} [kA]		I_{nom} / I_{ss} [%]		I_{ult} / I_{ss} [%]	
T [K]	S3	S5	S3	S5	S3	S5
4.2	**19.4**	**18.74**	85	88	92	95
1.9	**21.33**	**20.54**	77	80	84	87

Courtesy of J. Fleiter, P. Ferracin, B. Bordini, 2016, 2017

Magnet integration with upgrade connections





A. Chiuchiolo, 2017

Insert λ-plate/ Magnet connecting Plate

Voltage taps

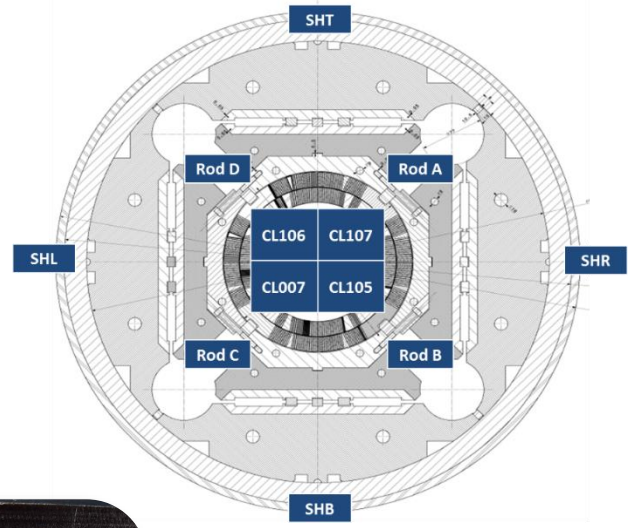
Strain gauges

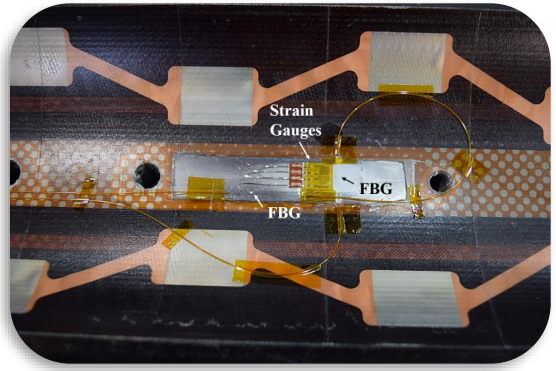
Optical fibers (only S5)

Quench heaters

Magnets instrumentation

- **32 strain gauges** (4-wires resistive)
  - 8 on the shell (4 axial & 4 azymuthal)
  - 4 per rod
  - 2 per coil (1 axial & 1 azymuthal)
- **20 FBG sensors** (only S5)
  - 4 on the coil pole (1 axial & 1 azymuthal)
  - 4 on the shell (1 axial & 1 azymuthal)
  - 4 thermal effect compensator
- **64 voltage taps**
  - 16 per coil (8 inner, 8 outer layer)

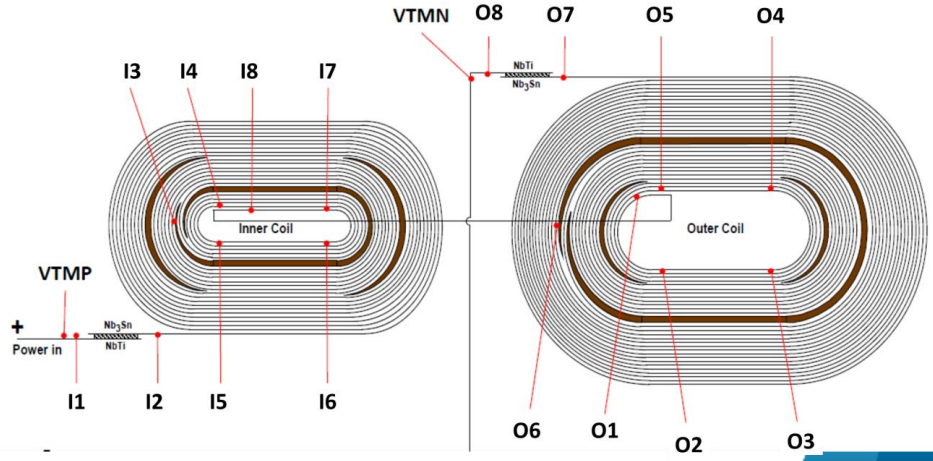




Mechanics

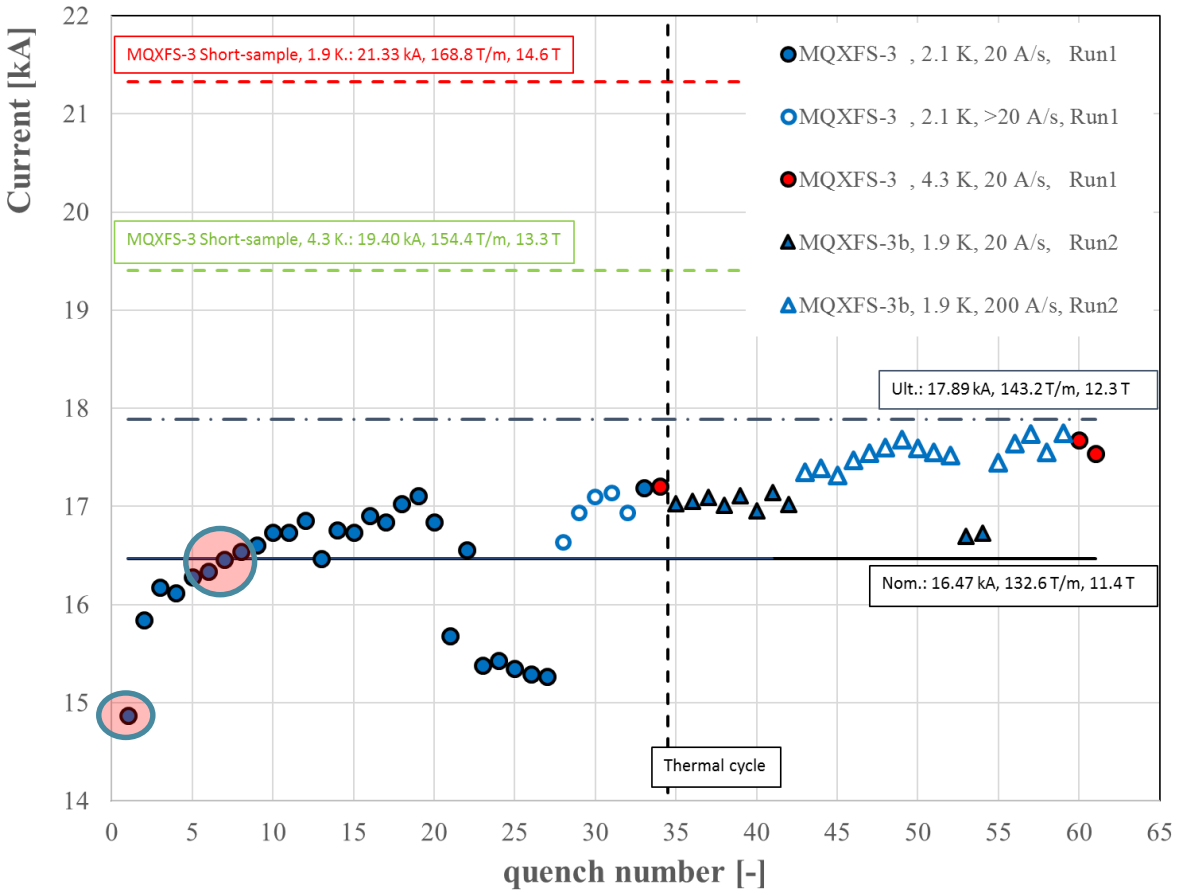
Optics

Electrics

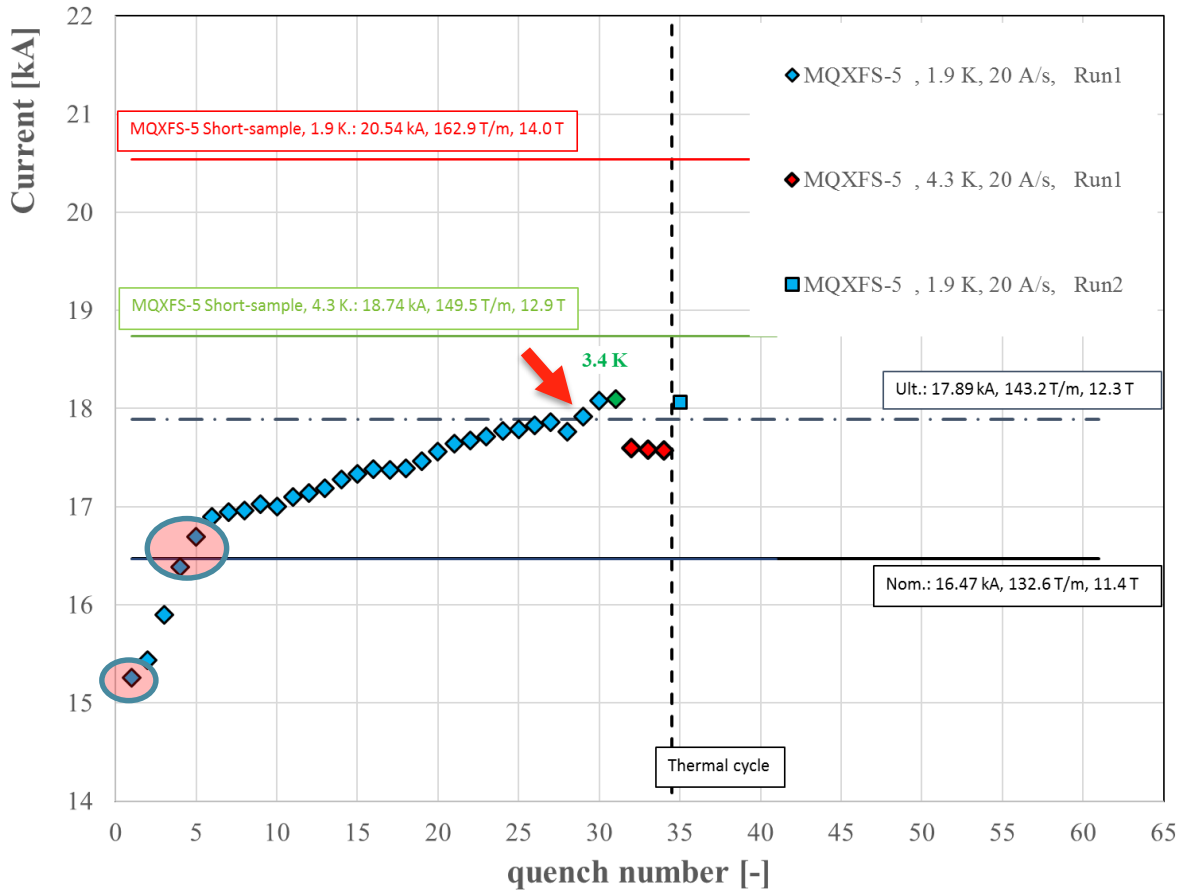


Performance measurements and training

- **MQXFS-3**
  - **2 runs performed in October and December 2016**



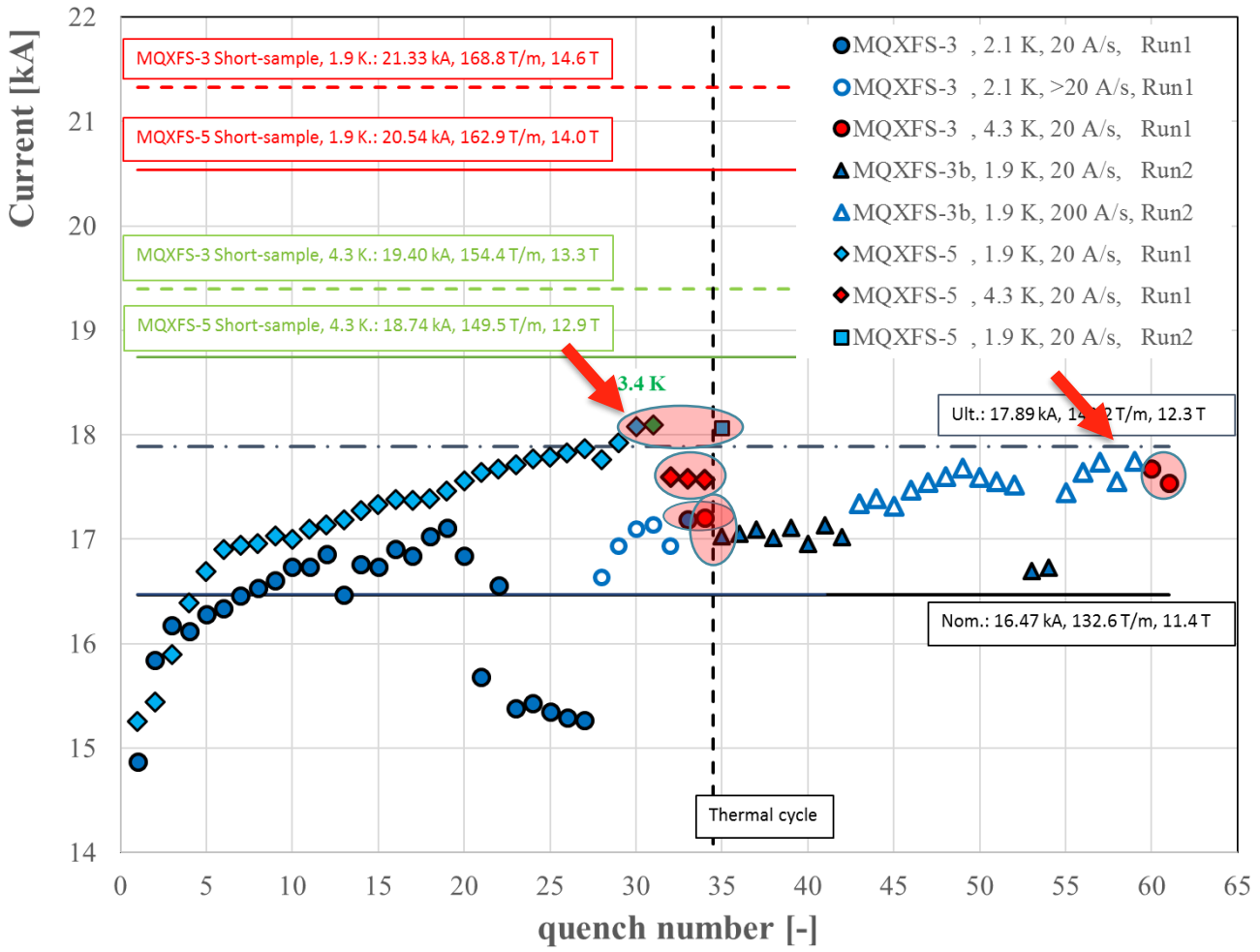
- **MQXFS-5**
  - **2 runs performed in July 2016**



- First quench at 91% and 92% of nominal current for S3 and S5
- Nominal current : 7 quenches for S3 and 5 for S5
- **Ultimate current: not reached by S3, after 30 quenches for S5**

Performance measurements and training

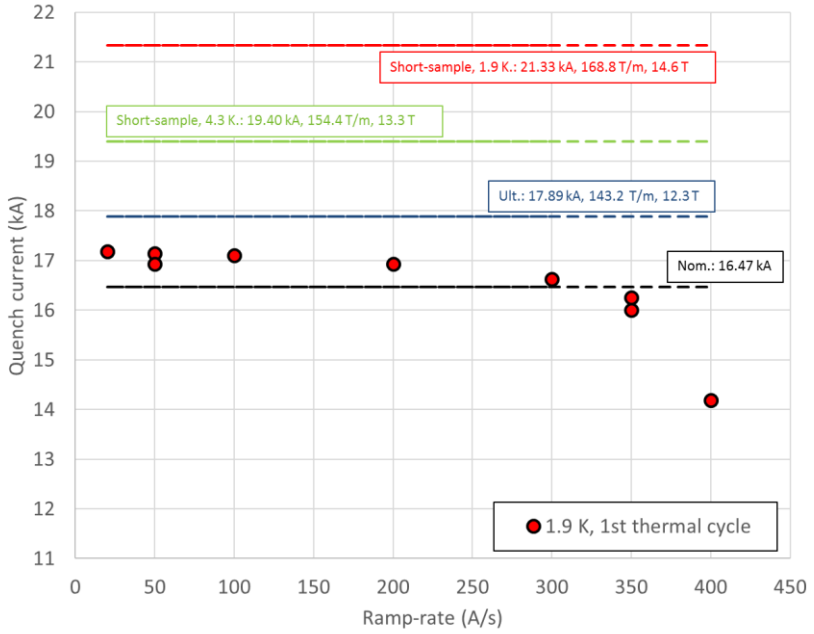
- Maximum current for S3 and S5
  - **83% and 88 % of Short Sample at 1.9 K**
- Performance check at 4.2 K
  - 89% and 94% of Short Sample
- **Good training memory** after thermal cycle (slight decrease for S3)

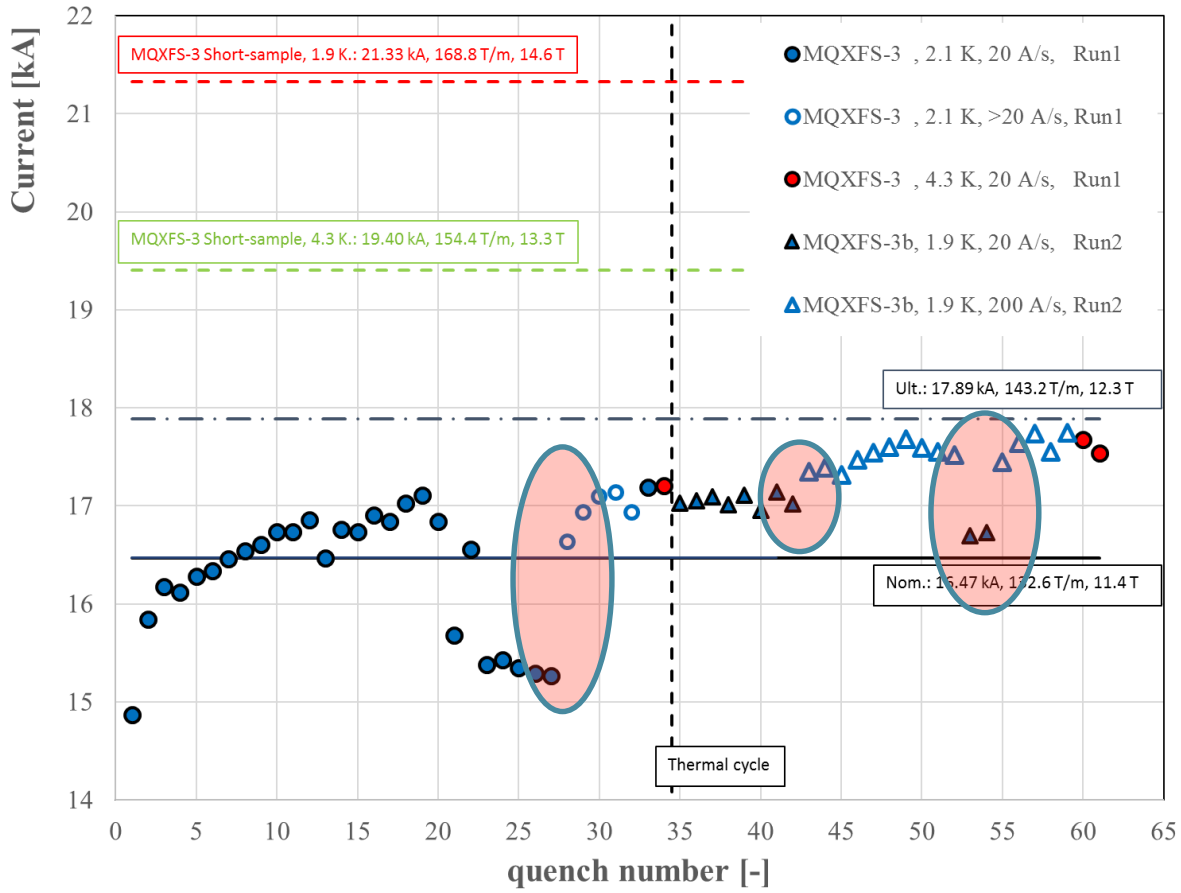


Performance measurements and training

MQXFS-3

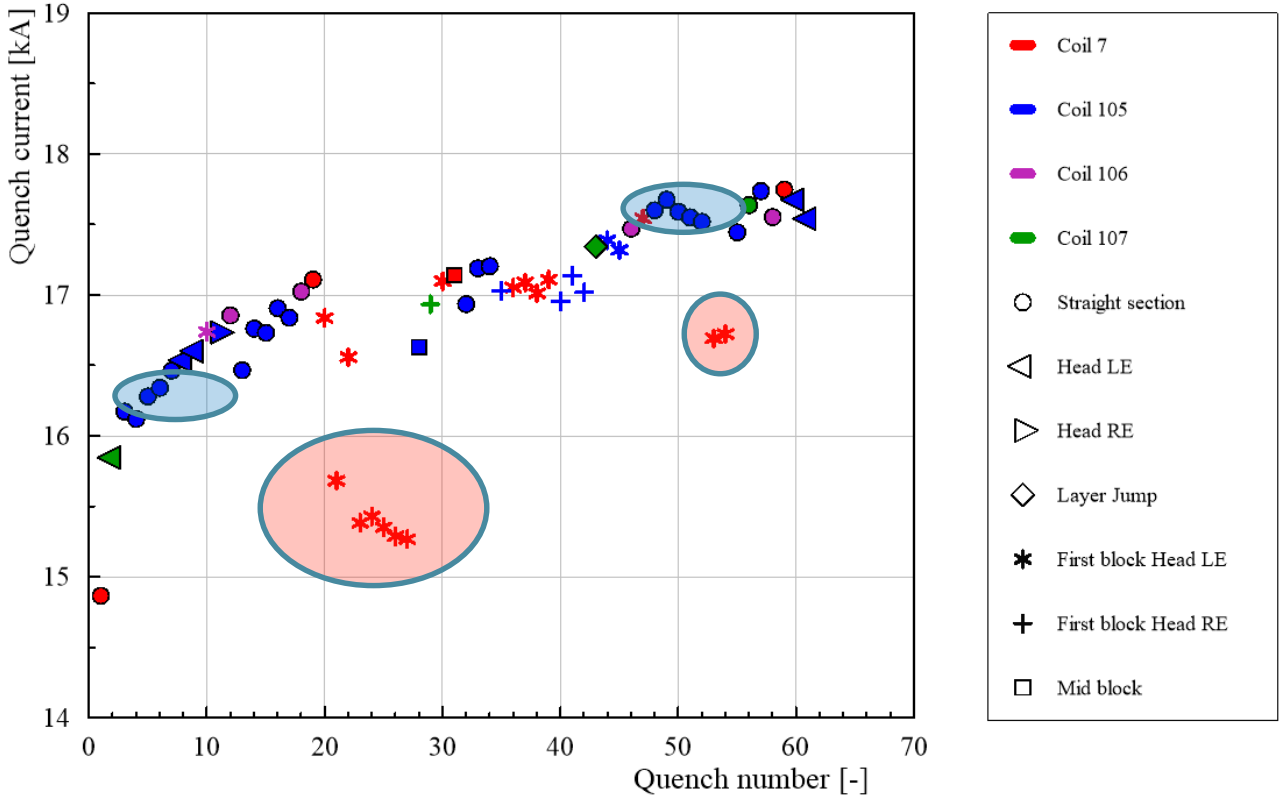
- The ramp rate increase from 20 to 200 A/s
  - allows to keep training the magnet
  - Reconfirmed during run 2
- Ramp rate dependence of the quench current measured

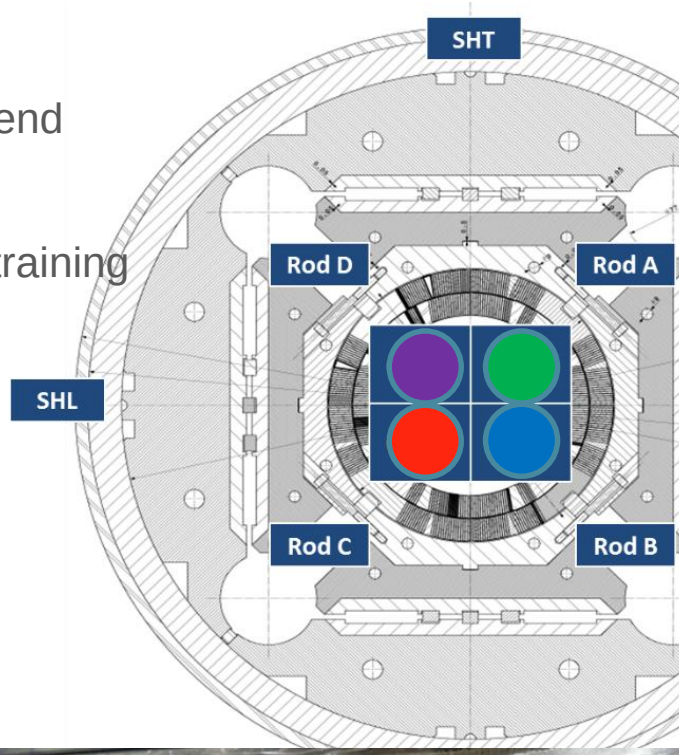


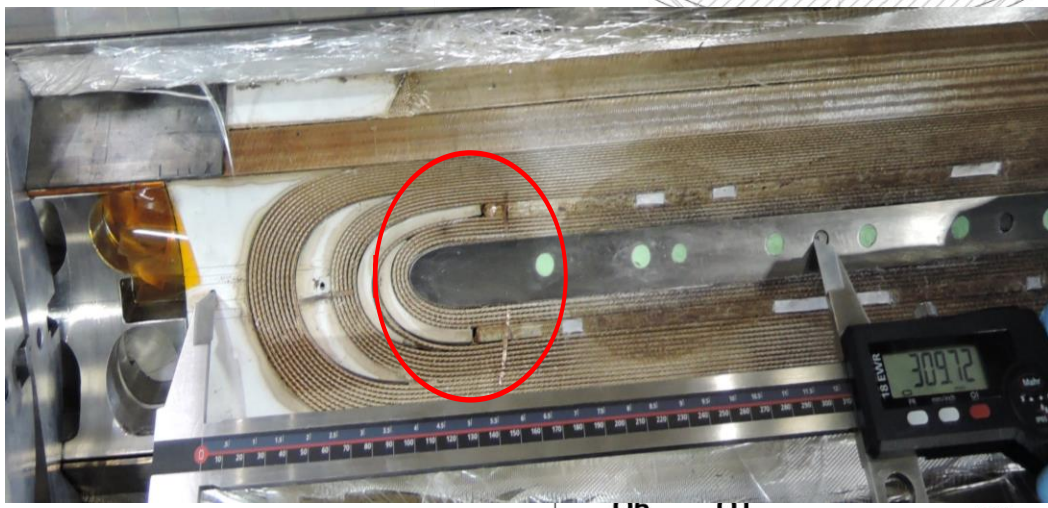


Quench location

- **MQXFS-3**
  - Coil 7 shows issues after quench 19 with systematic quenches at the coil lead end head end spacer zone.
  - Coil 105 limits the performance otherwise with pole turn quench moving along training

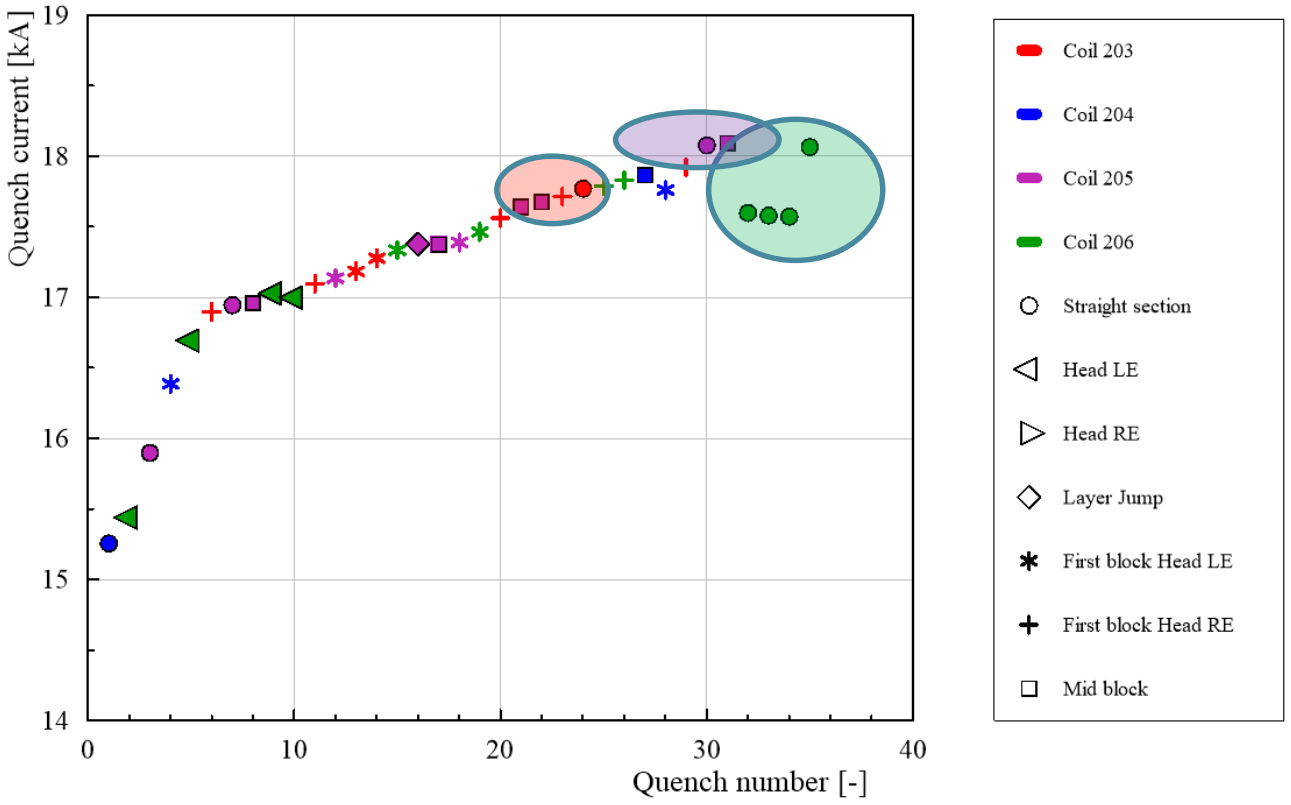


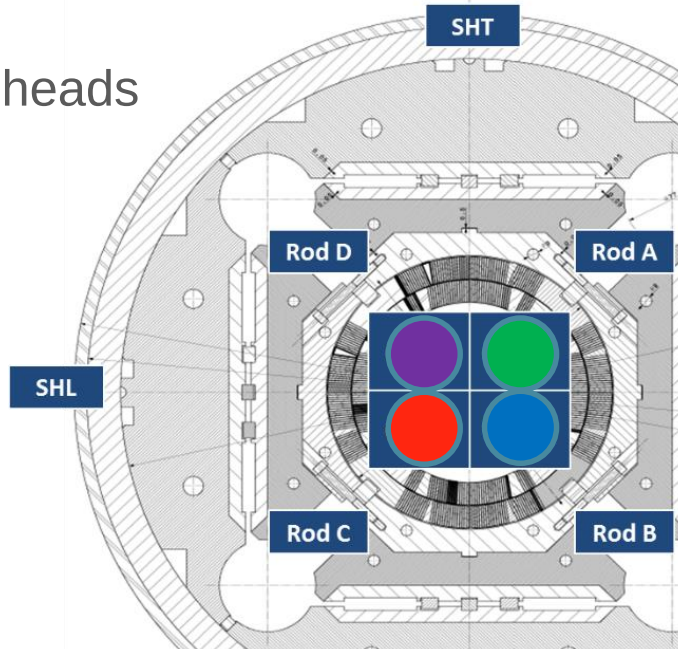


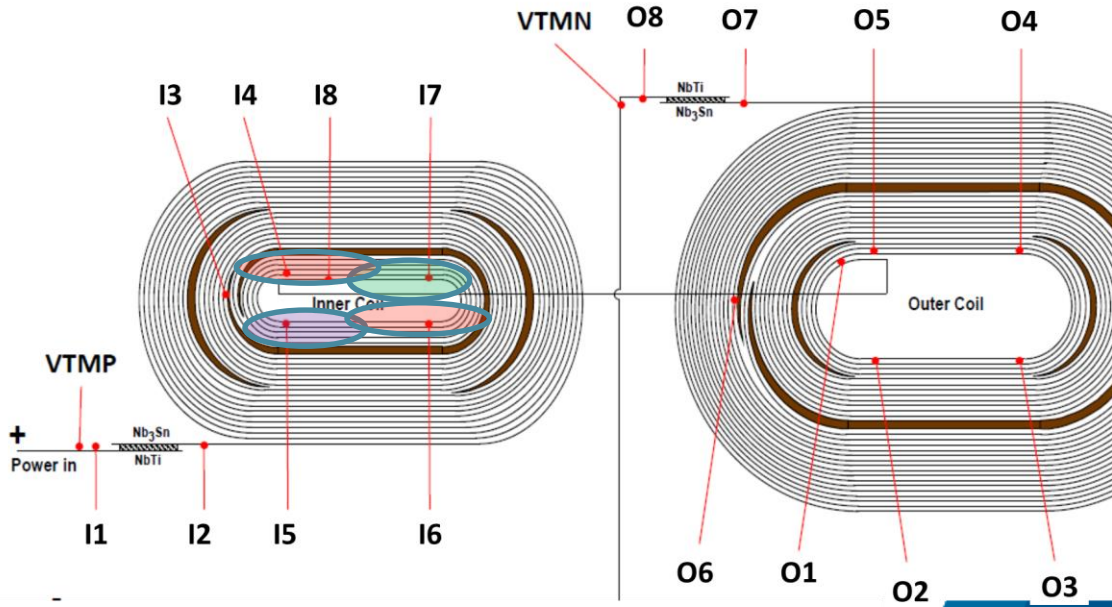


Quench location

- **MQXFS-5**
  - Coil 203 is quench in the 2nd and 3rd turns pole straight part or near the heads
  - Coil 205 is quenching at its lead end heads or first block…
  - Coil 206 limits the performance with pole turn straight part quench.
    It has also the least short sample limit

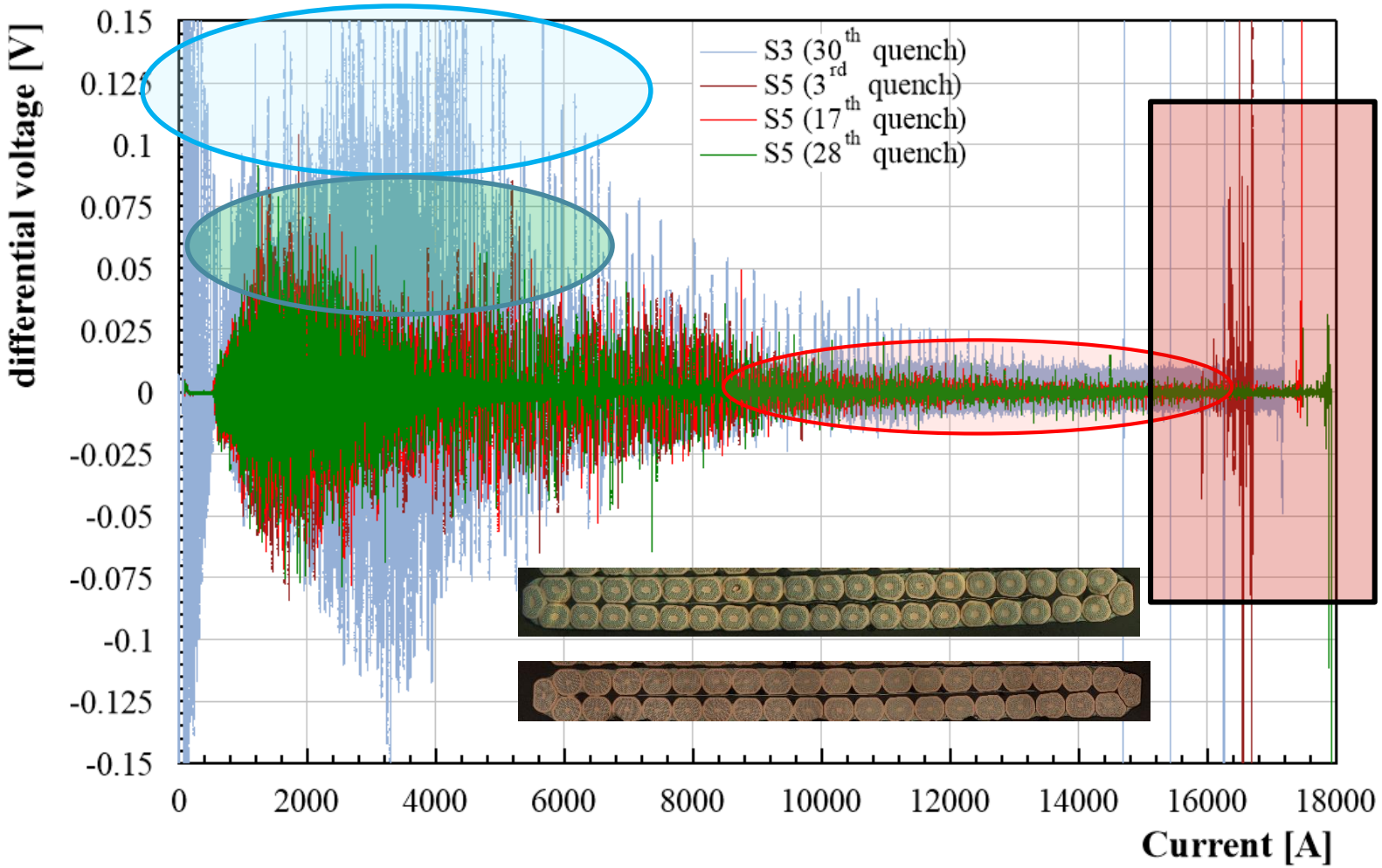






Flux jump measurement

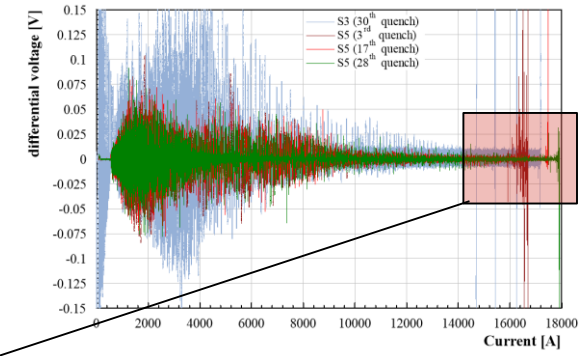
- Greater amplitude of the voltage spike.
  - > 150 mV for S3 (RRP)
  - < 100 mV for S5 (PIT)
- Noise level range amplitude after 10 kA
- Validation of the uQPS detection card prototype under developement
- Validation of the new variable threshold card to protect the magnet
- What happens near the quench…

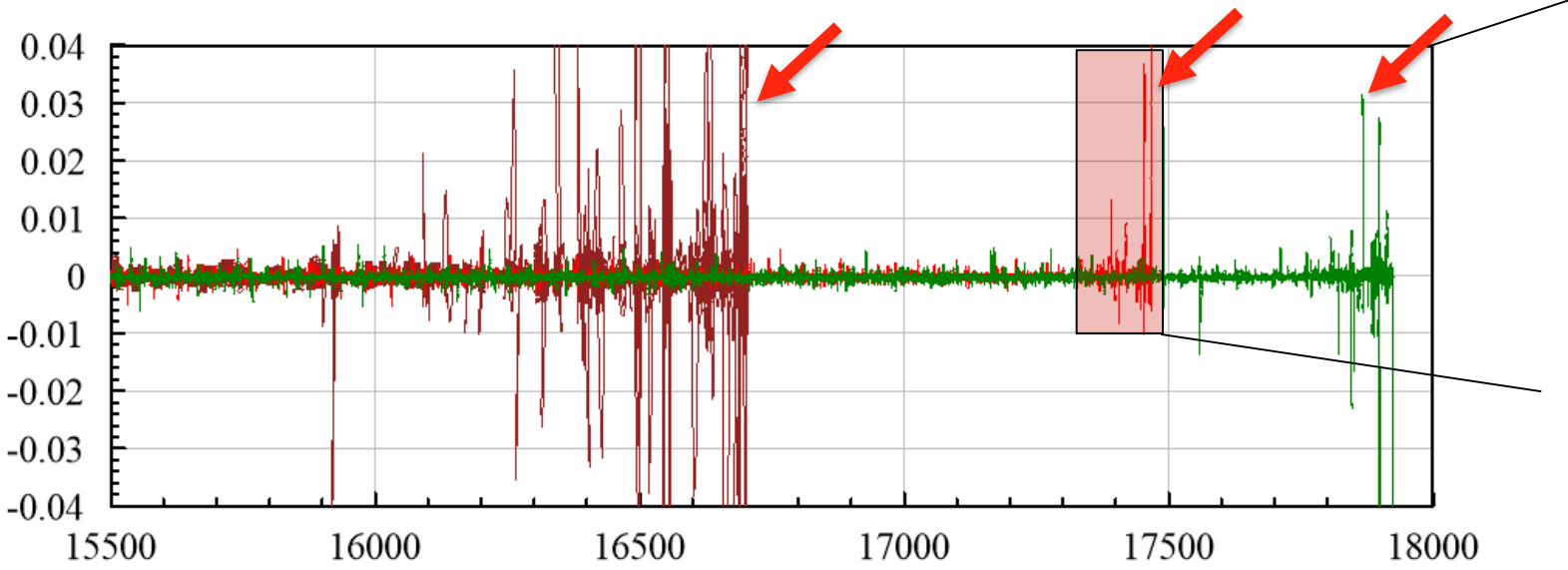


Courtesy of J. Kopal, J. Steckert 2017

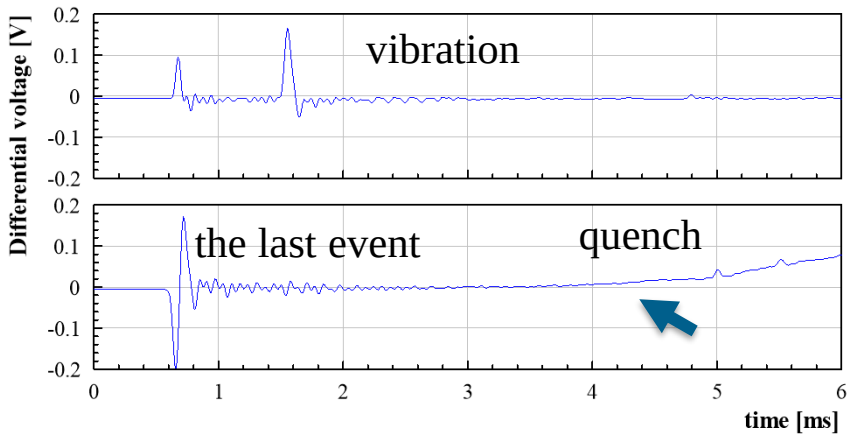
Voltage disturbance measurement

- The prototype of detection cards allows to better detect small voltage variations at 900 kHz that are smeared with classic cards.
- An increase of the activity is measured before the quench and occurs more than 500 A before (>20 s)
- The disturbance happens later and later after each training quench



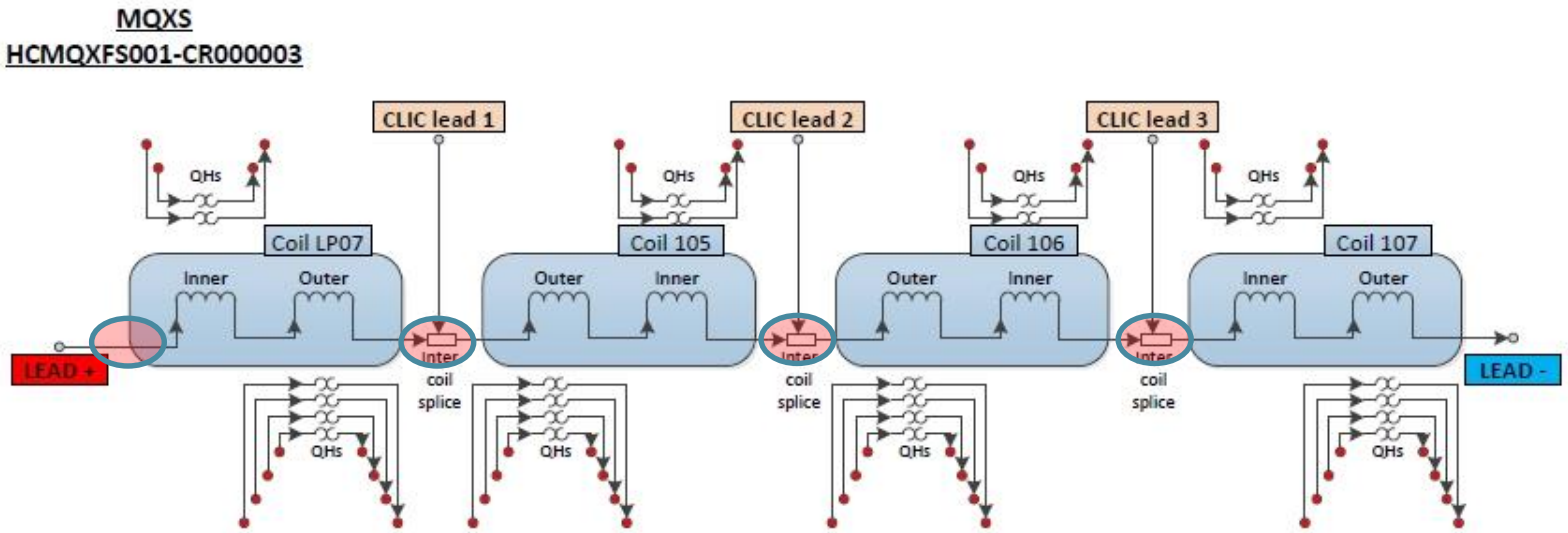


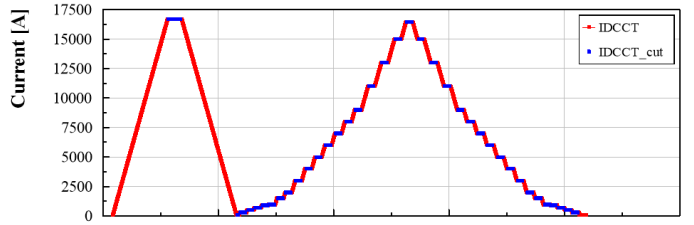
- Example of two typical events,
- one 20 s before the quench, the other precursor to the quench.

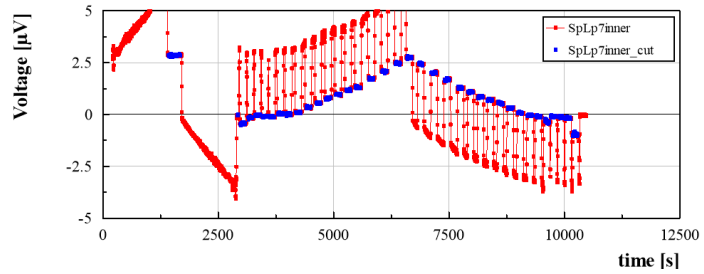


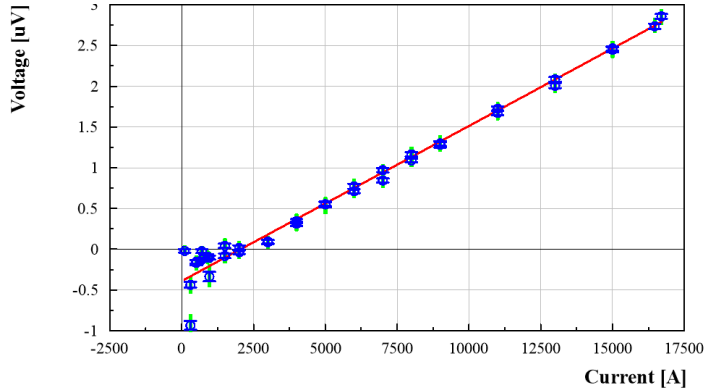
Splice resistance measurement

- No issues with the Nb_3Sn/NbTi connection between coils and with current leads.
- For both magnets, all measured splice **resistances** are **below 0.3 nΩ.**

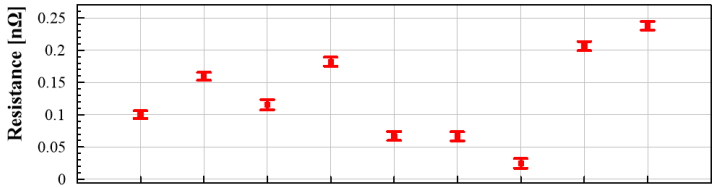






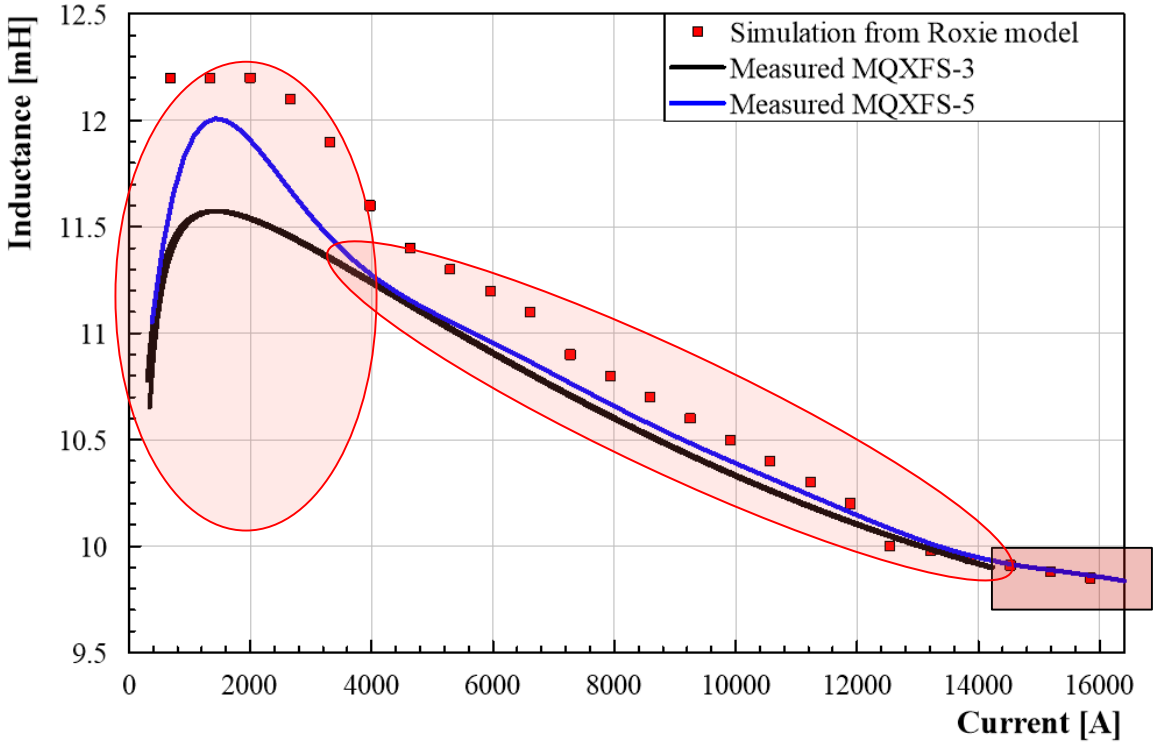


Splice name	Resistance [nΩ]	Resistance error [nΩ]
EE203I1-EE203I2_cut	0.10	5.86E-03
EE206O8-EE206O7_cut	0.16	6.10E-03
EE206I2-EE206I1_cut	0.12	8.06E-03
EE205O8-EE205O7_cut	0.18	6.84E-03
EE205I2-EE205I1_cut	0.07	7.02E-03
EE204I1-EE204I2_cut	0.07	6.93E-03
EE204O7-EE204O8_cut	0.02	7.39E-03
EE203O8-EE206O8_cut	0.21	7.36E-03
EE206I1-EE205O8_cut	0.24	6.77E-03



Inductance measurement

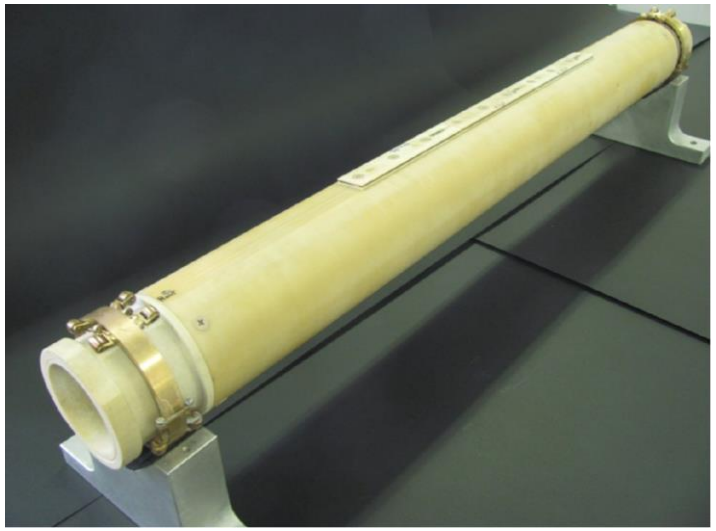
- Non linear behavior of the inductance as function of the current
- Conductor magnetization up to 4 kA
- Iron saturation effect up to 14 kA
- **Nominal value of 9.8 mH**
- Agreement between S3 and S5



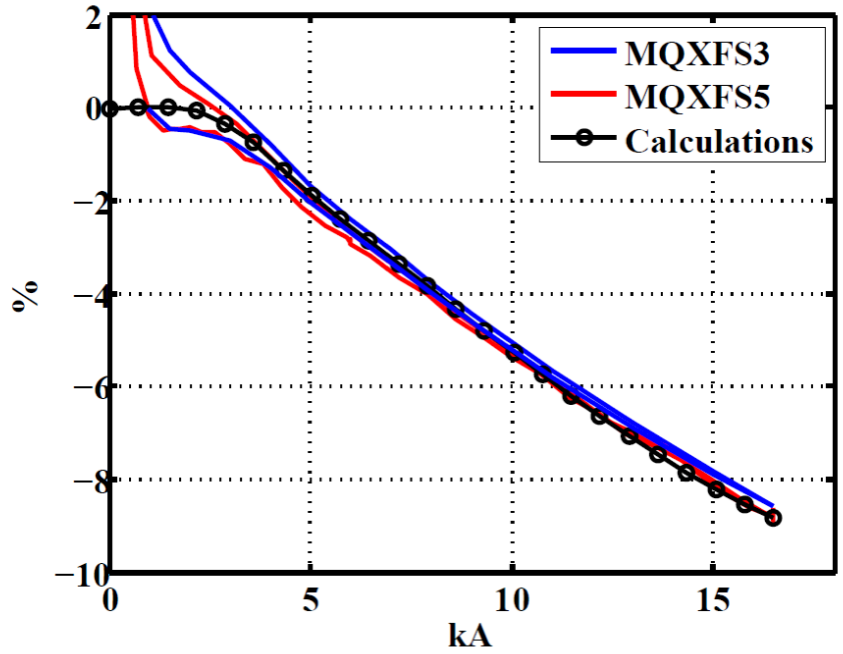
Magnetic measurements

- Magnetic field quality has been measured
  - L. Fiscarelli - Mon -Af-Po1.01
  - S. Izquierdo Bermudez - Wed-Af-Or23

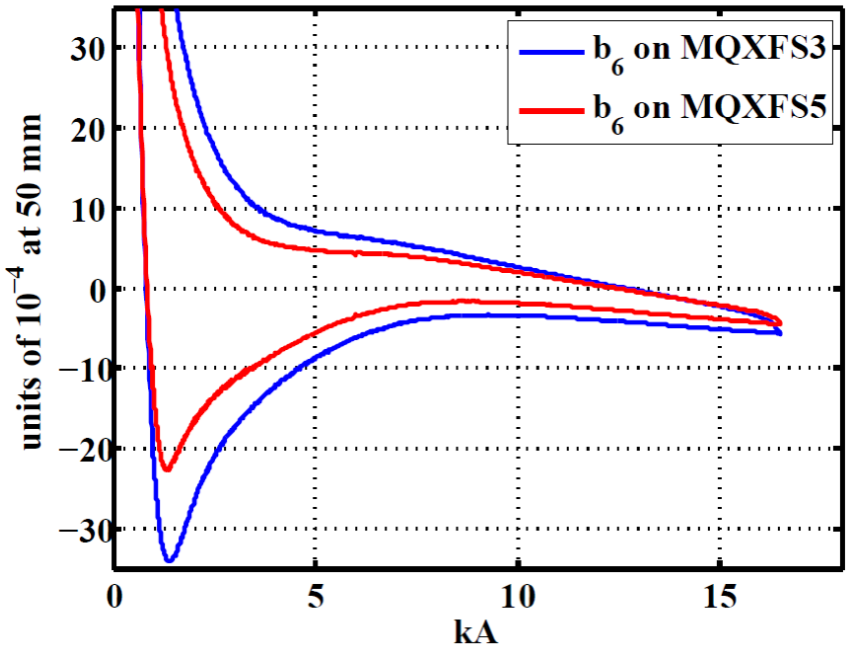
View of the rotating coil array



Iron saturation effect on the transfer function.

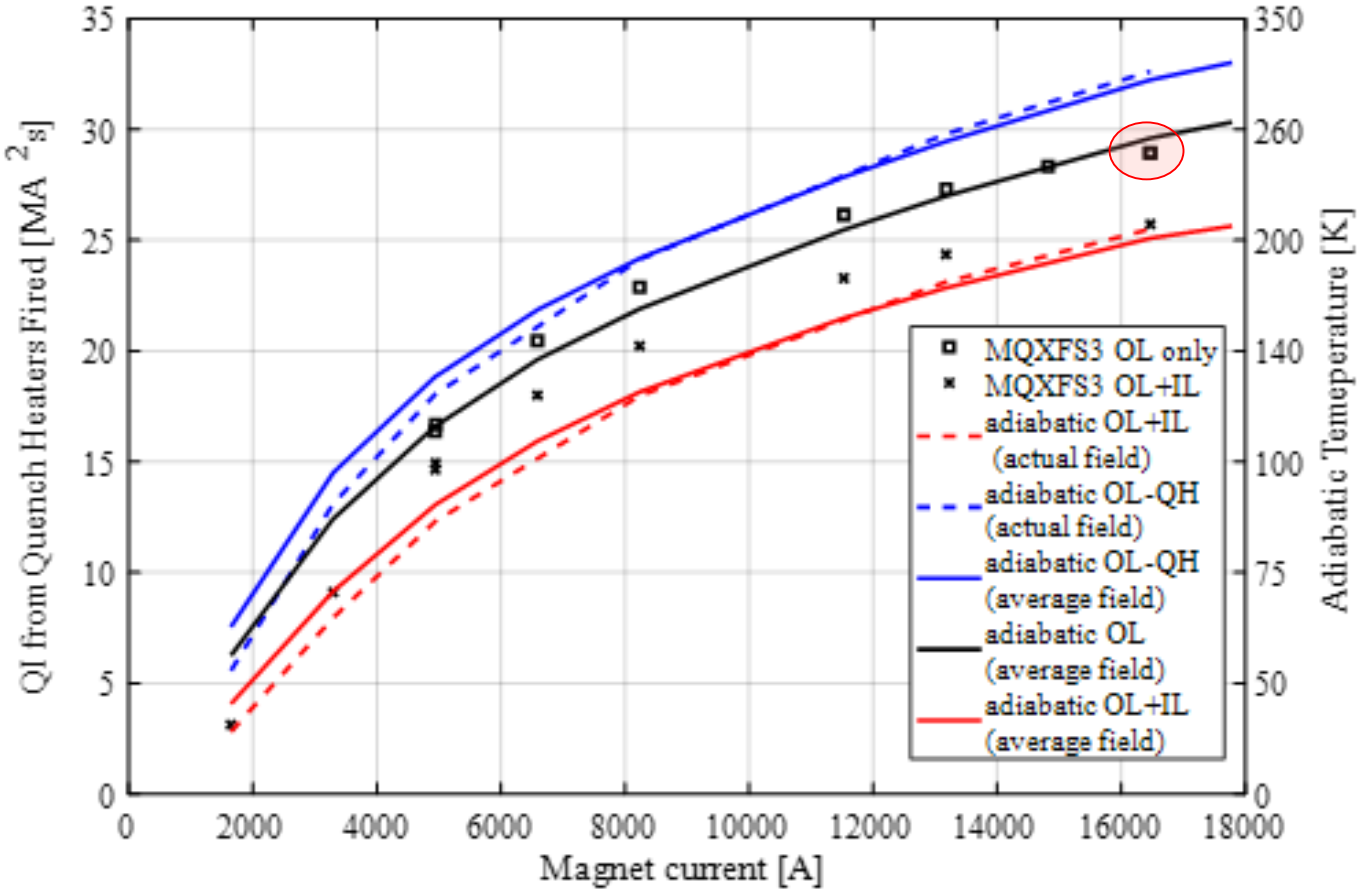


Persistent currents effect on b_6.



Magnet protection study

- Intensive Quench Heater efficiency tests have been performed on S3
  - E. Ravaioli- Wed-Af-Or24



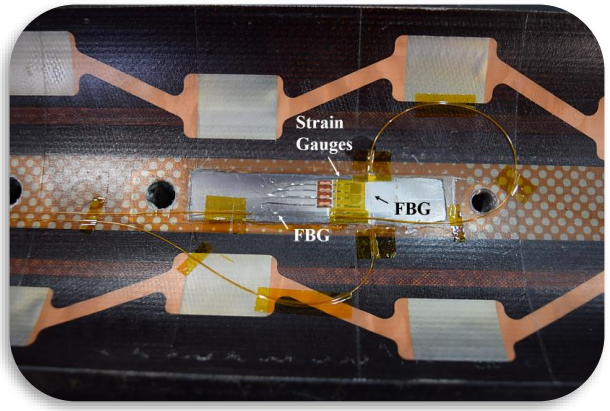
Courtesy of S.I. Bermudez 2017

- The magnet has been protected using only the outer layer quench heater (no external dump, no inner layer QH)

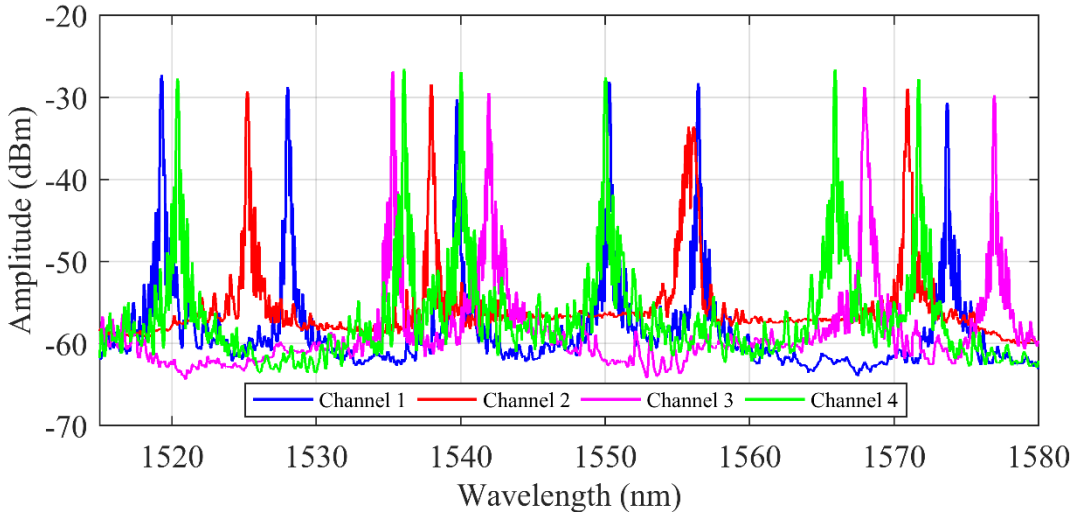
- Quench integral: 28 $MA^2.s$
- Hot Spot Temperature: 250 K
- Magnet resistance: 164 mΩ
  - C7: 35 mΩ
  - C105: 42 mΩ
  - C106: 39 mΩ
  - C107: 48 mΩ

Mechanical measurements

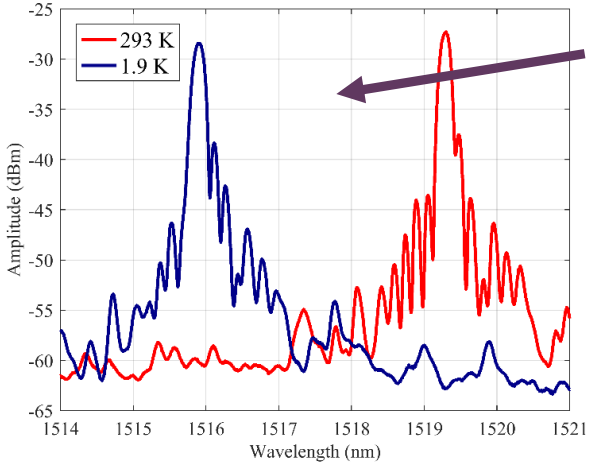
Fiber Bragg Grating based sensor measuring strain in MQXFS-5



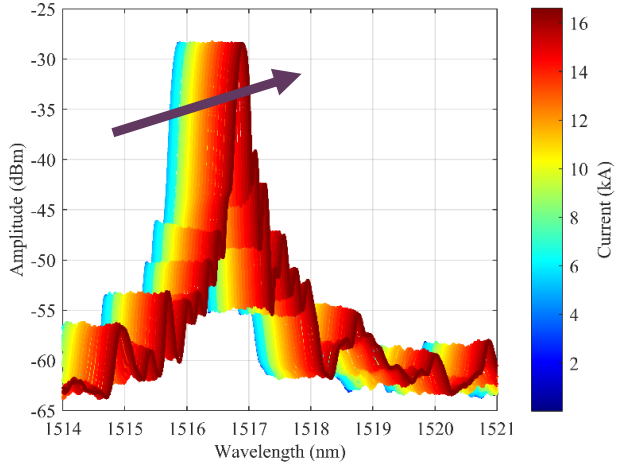
20 FBG sensor multiplexing in five channels



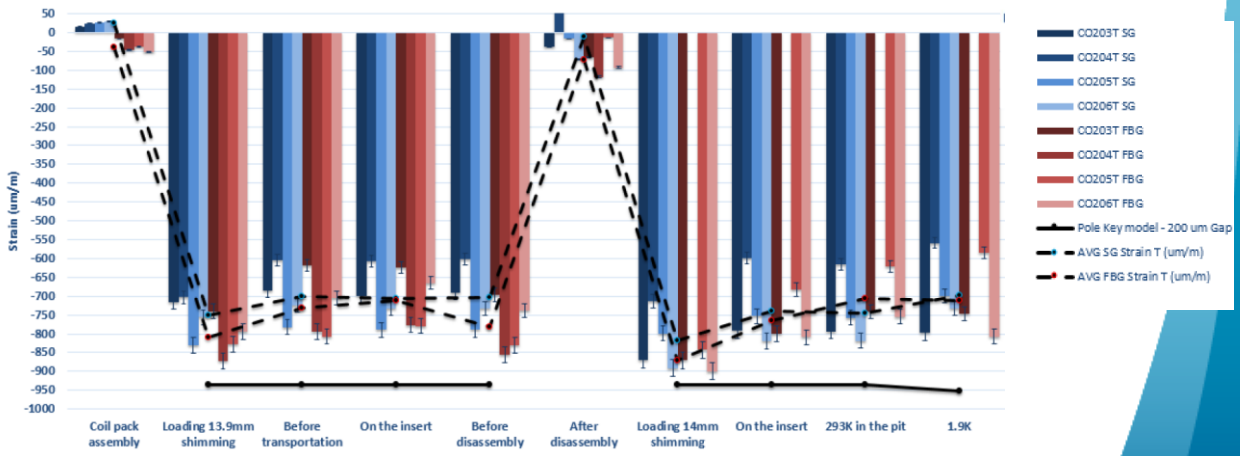
Cooldown (FBG)



Powering (FBG)



Validation wrt. Strain Gauges



Courtesy A. Chiuchiolo, M. Guinchard, 2017

Conclusive remarks

- Successful commissioning of two new test benches at SM18, the HFM and Cluster D.
- Two powering runs performed on the last two HL-LHC insertion quadrupole short models MQXFS-3 and 5.
- Both magnet quickly reach nominal current but only MQXFS-5 reached ultimate. Both now stand at
- A deficient coil (7) has been identify in MQXFS-3 that will be replaced for magnet re-testing.
- Due to commissioning, the test of S5 has been largely shortened. A new run is soon foreseen.
- New analysis tools allow to observe important increase of activity second before the quench.
- Regarding magnet protection study, measurements have been done on the Quench Heater and external dump resistance systems efficiency but not yet on CLIQ system.

Thank you for your attention!