Results of Feather_M0.4 test

Hugo Bajas

Eucard^2 4th Annual meeting
Glasgow, 28-30 March 2017

EuCARD-2 is co-funded by the partners and the European Commission under Capacities 7th Framework Programme, Grant Agreement 312453

Outline

- Feather_M0.4 and its integration in the SM18 variable temperature facility
- Issue with the connections cooling and solutions
- History of the four runs of powering test
- Quench detection
- Optical fiber measurement and other sensors
- Lessons learnt and future tests

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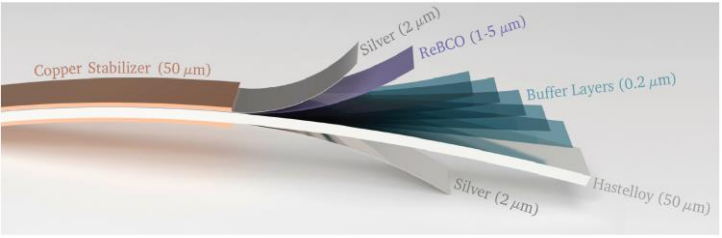
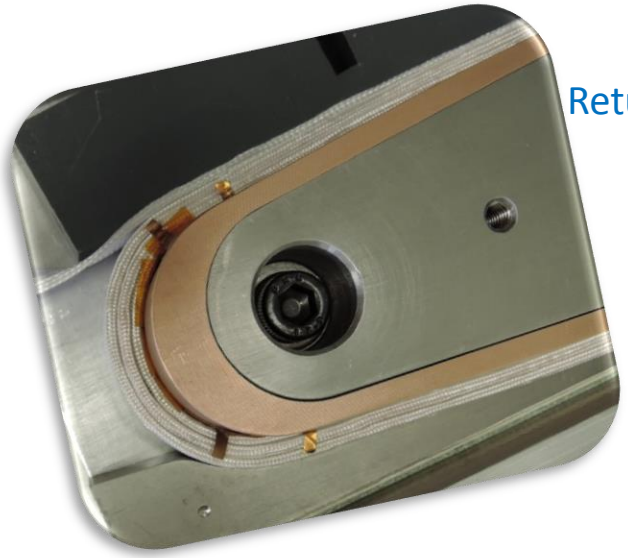
Conductor and coil



15-tape Bruker Roebel cable

Wound into a 3-turn coil



Return end

Lead end

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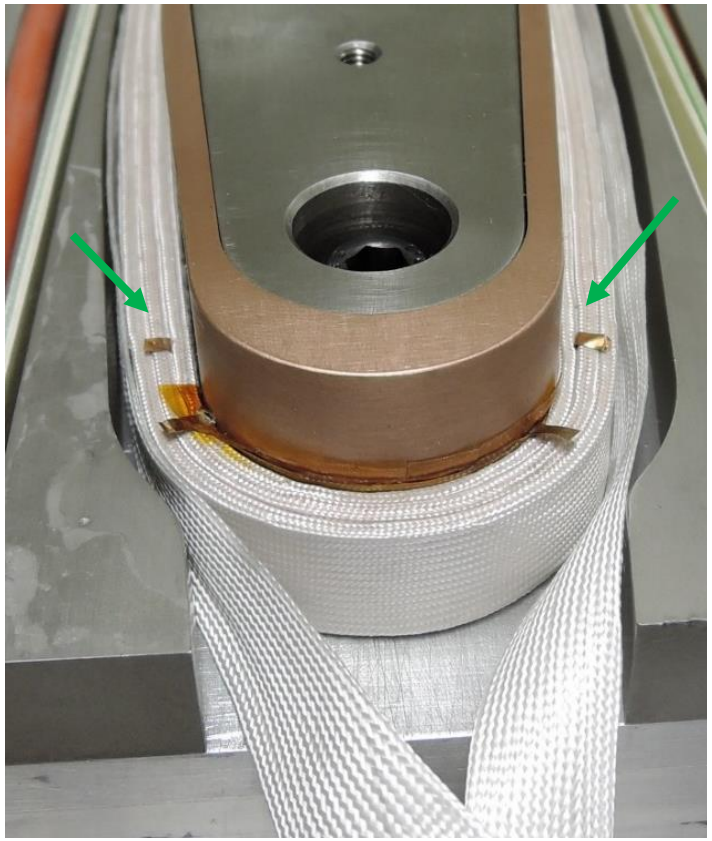
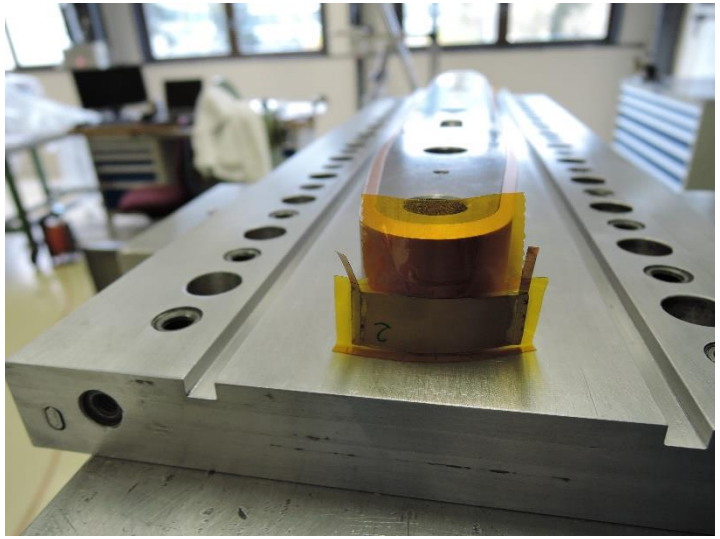
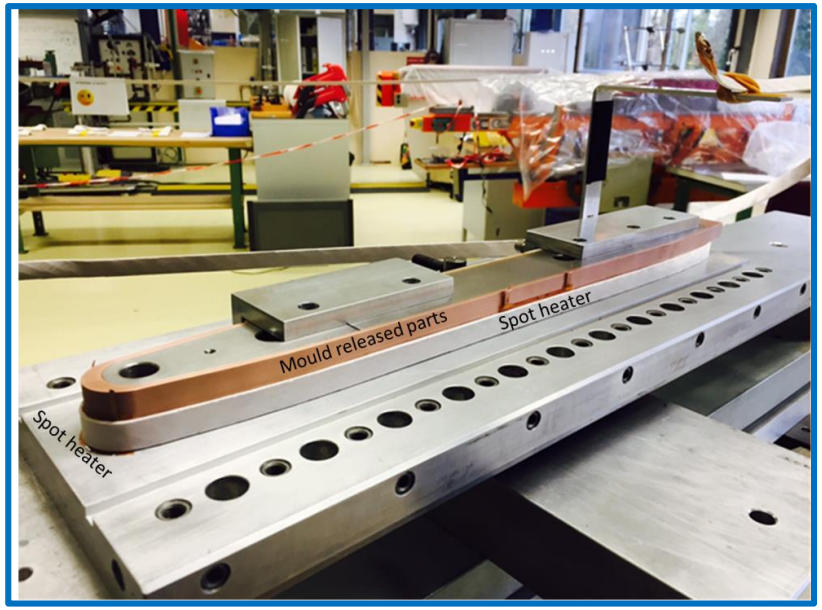
Coil instrumentation

Voltage tap

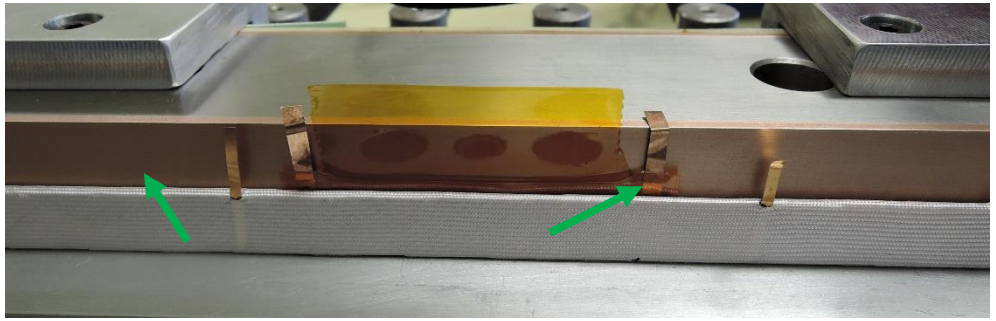




Spot Heater 2



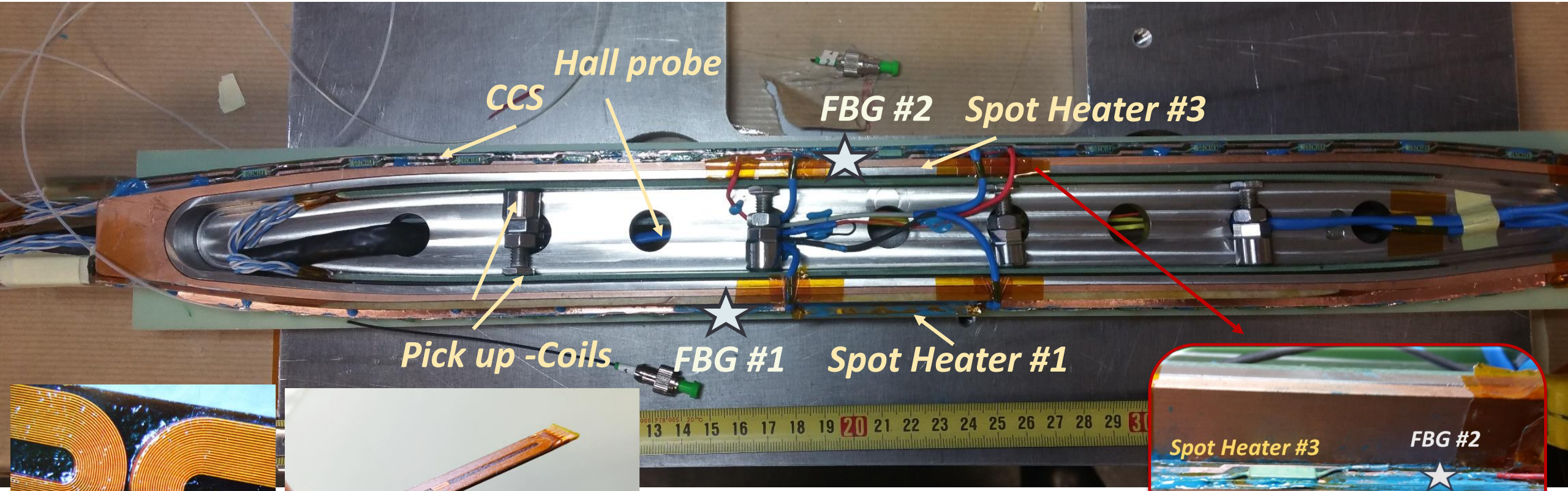
Spot Heater 3



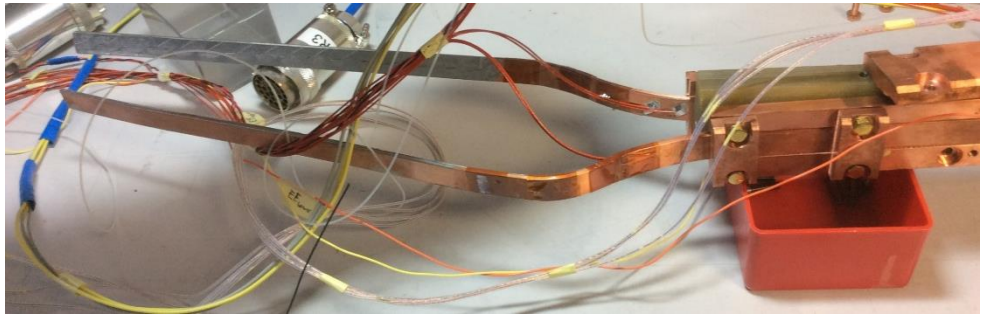
Voltage tap

Other instrumentation…

…Carbon Ceramic Sensors (CCS), Hall Probes, Fiber Bragg Grating sensors (FBG), Pick – up coils

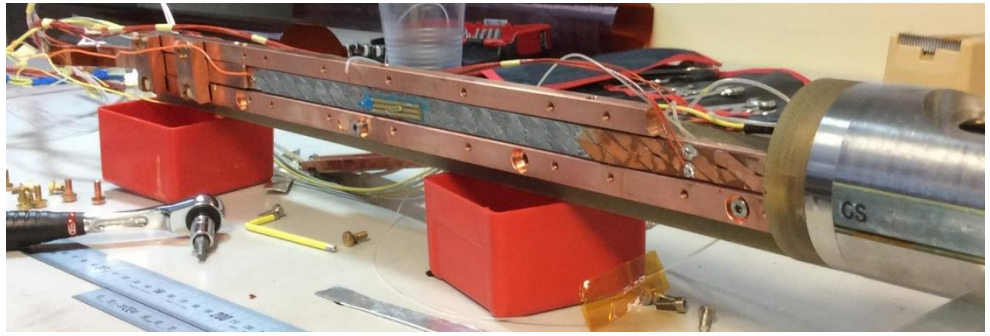


Magnet assembly



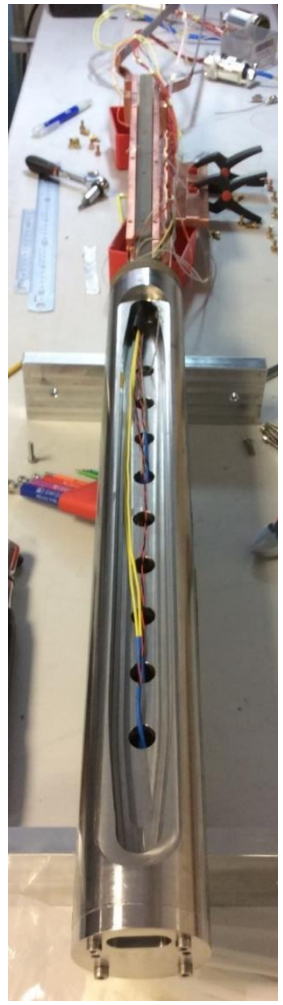
Coil leads

Roebel extension

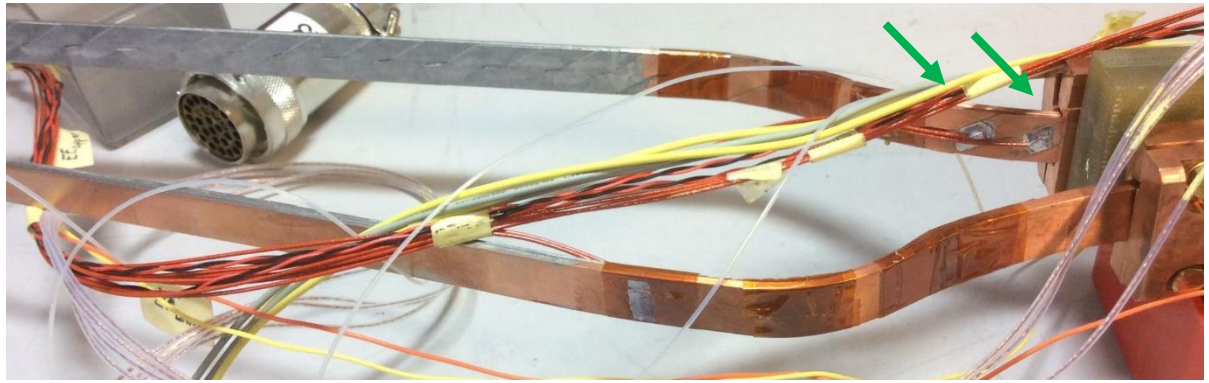


Coil case

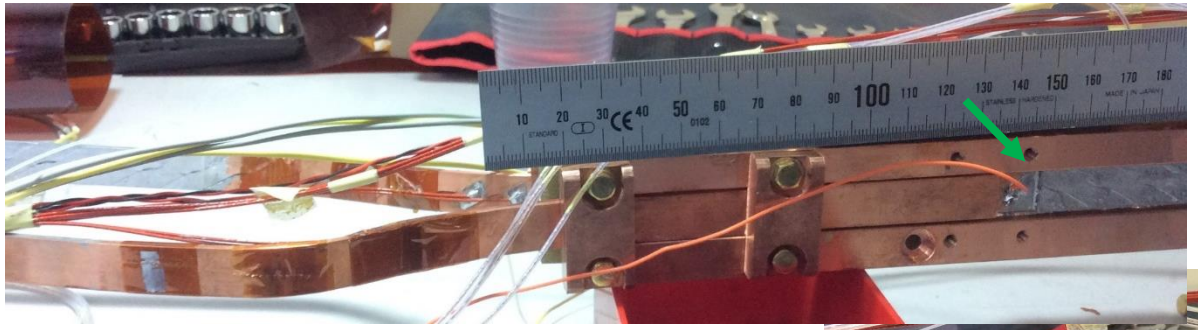
Magnet inside the magnetic laminated yoke



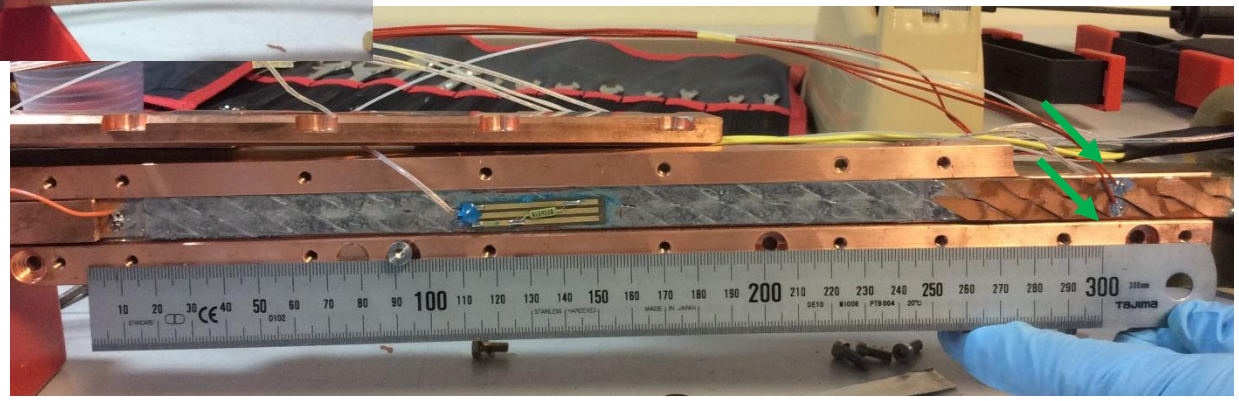
Splice survey



Roebel to Roebel splice



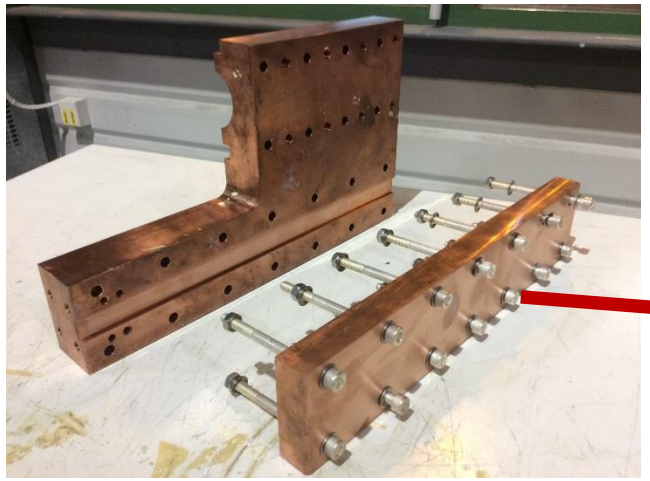
instrumented with voltages taps,

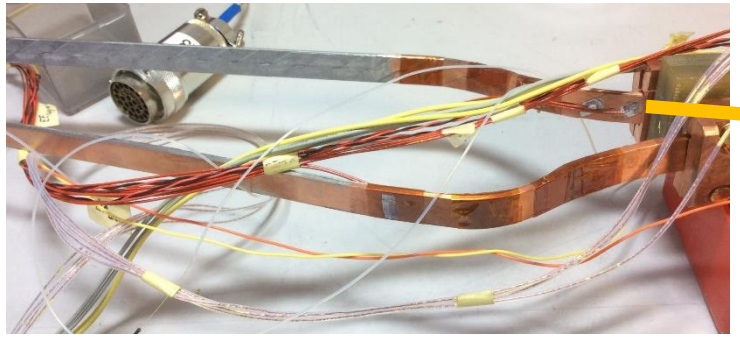


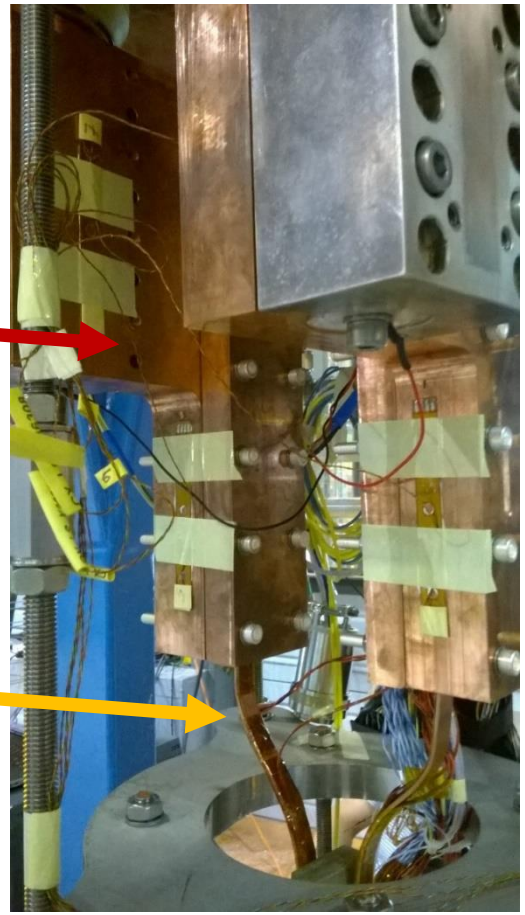
enclosed the copper box
supported to by the copper extension

Connection to the cryostat insert

Roebel/Cu-sheet clamped with copper flag to the current leads







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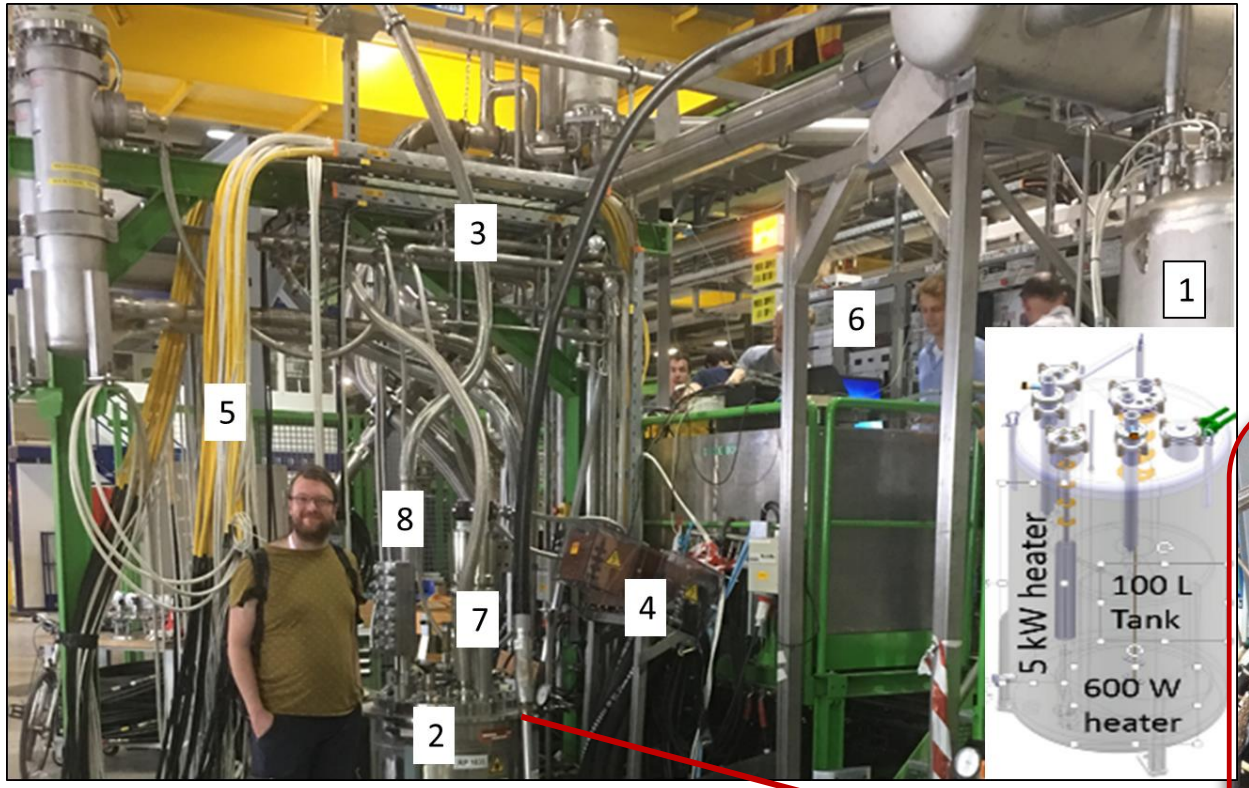
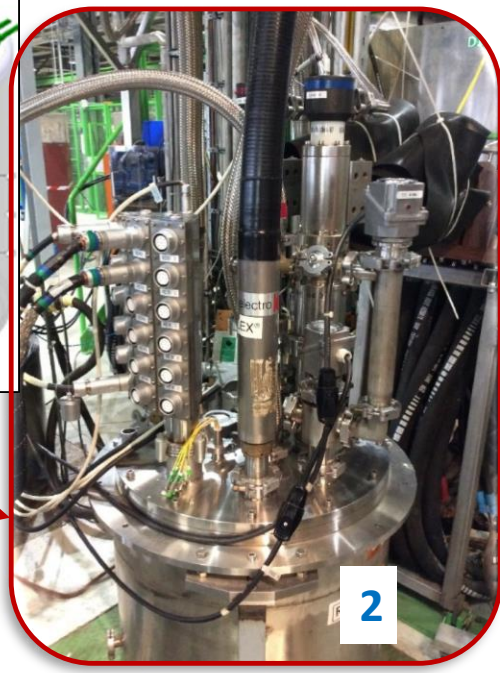
The Diode/Lead, now HTS coil, test bench

1) Variable temperature gas supply cryostat.
2) Magnet test cryostat.
3) Variable temperature Helium gas supply line.
4) Connection to the 20 kA power supply, warm leads limited to 12 kA.
5) Instrumentation shielded cables between magnet and protection system.
6) Instrumentation electronics racks.
7) 13 kA current leads.
8) Fischer instrumentation connector box.





The 4 different Data Acquisition Systems

- **Splice resistance**

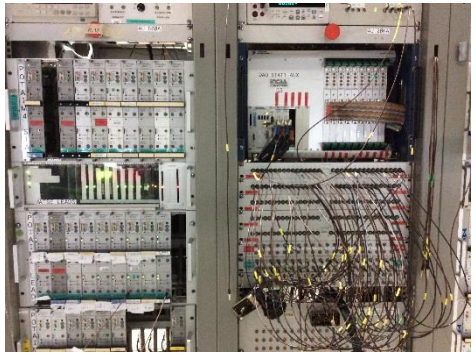
High precision DMM

- current-voltage
- 10 channels
- Low Frequency 0.2-1 Hz

- **Quench monitoring and protection**

SM18-DAQ

- voltage, I, trigger
- High Frequency 200-5 kHz
- Archive 2 mV threshold



- **Pick Up coil and hall probe**

cRIO FPGA DAQ System

- 24 VDC P.S
- 126 Used channels from 256 channels (120 AI + 5 DO)
- 3 Tb Hard disk.
- 10 kHz (fast Acq.) and 100Hz (Slow Acq.)
- FPGA + RT Processor

- **Local strain and temperature monitoring**

Fiber Optic Sensors DAQ

- Micron Optics Optical Interrogator
- 4 channels
- 1 kHz
- Trigger from the cRio
- Ethernet connection (CERN NTP)
- Enlight Software for data recording

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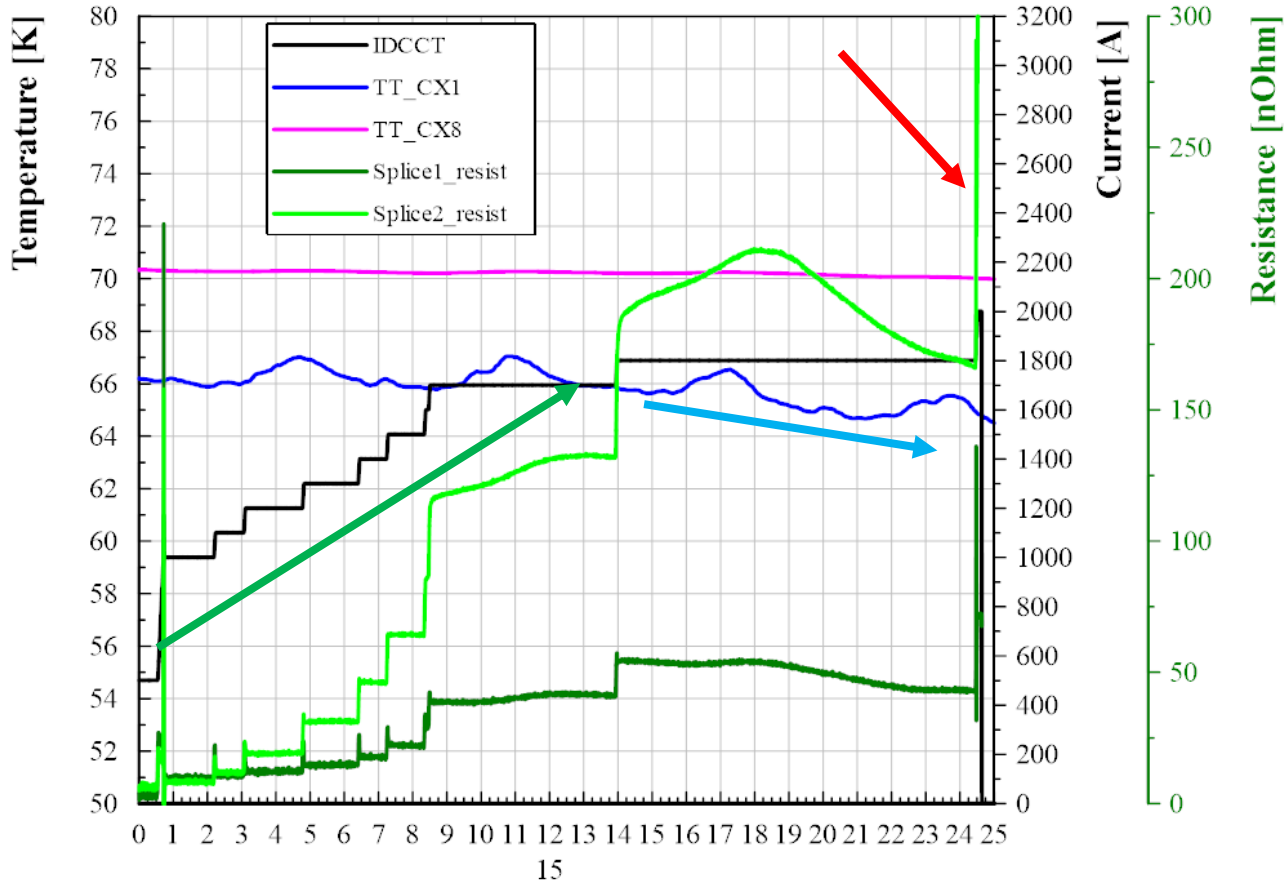
Run 2: Splices thermal runaway prevents from testing the coil

Resistance increase: drift and thermal runaway



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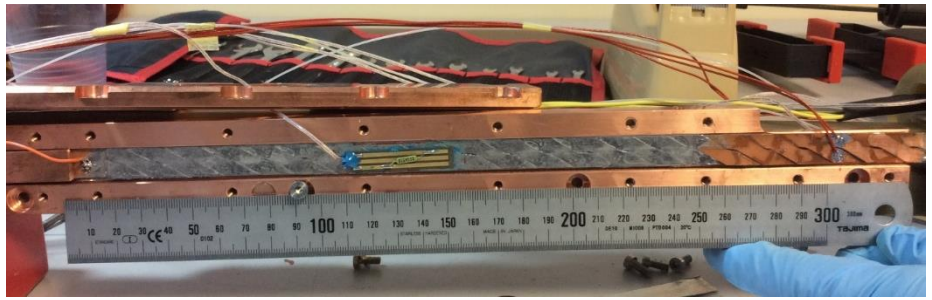
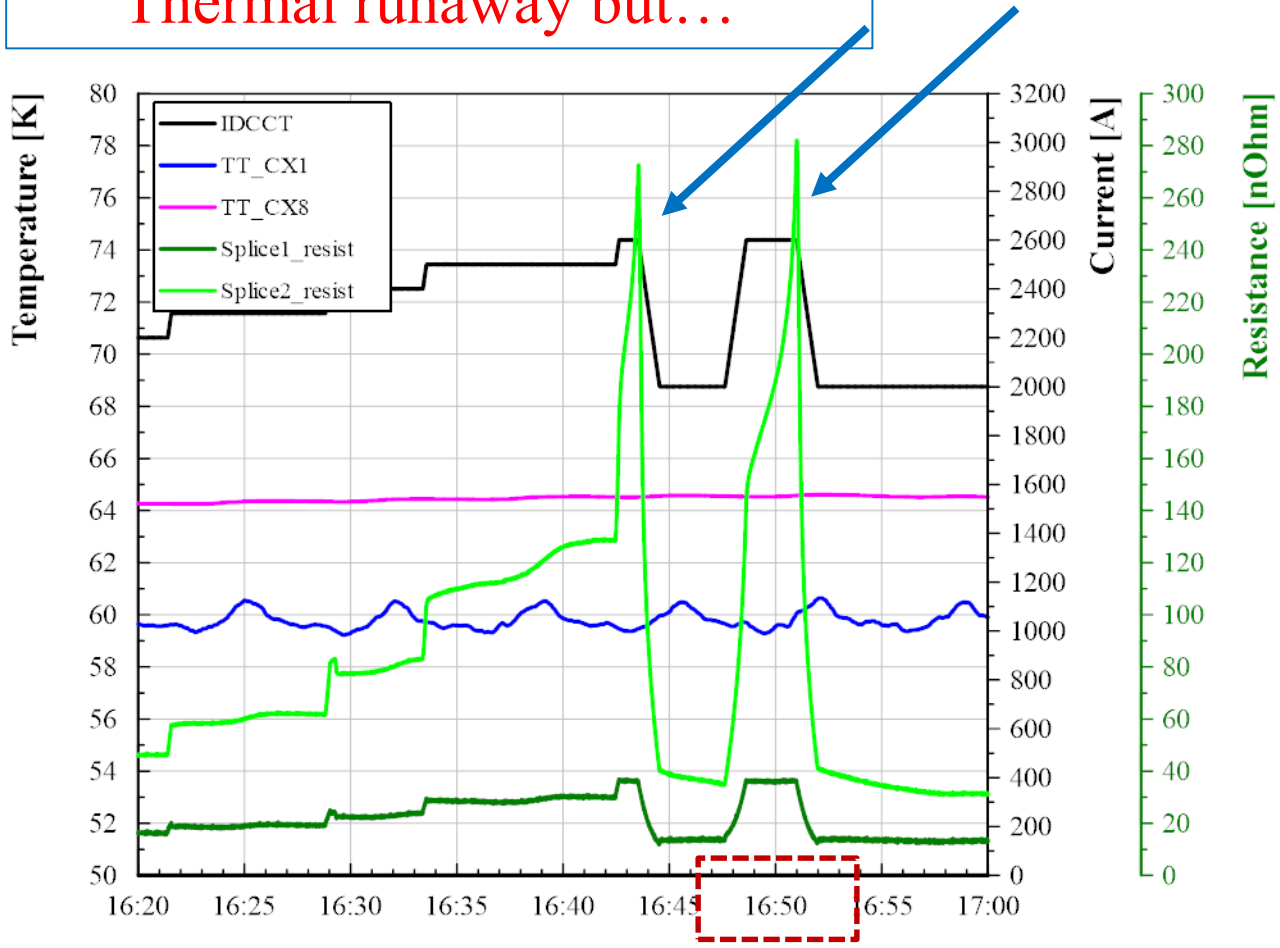
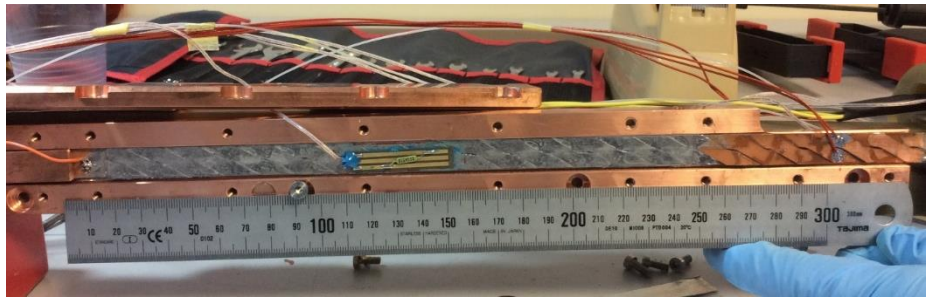


- Resistance
  - increase with the current
  - decrease with the temperature

Run 2: Splices thermal runaway prevents from testing the coil

Thermal runaway but…





- no quench if the current is ramped down soon enough
- Mind the scale… minutes to react

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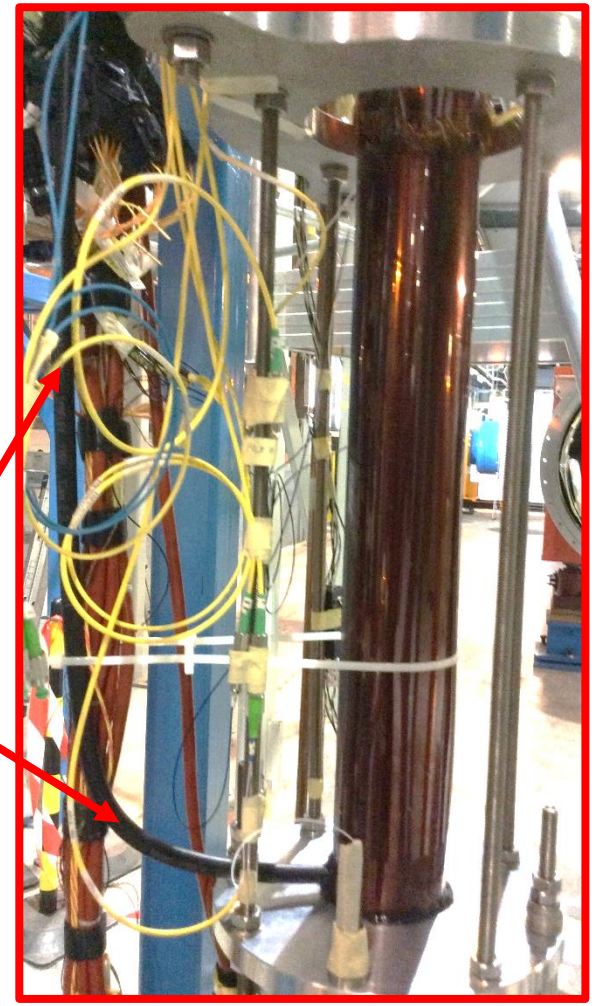
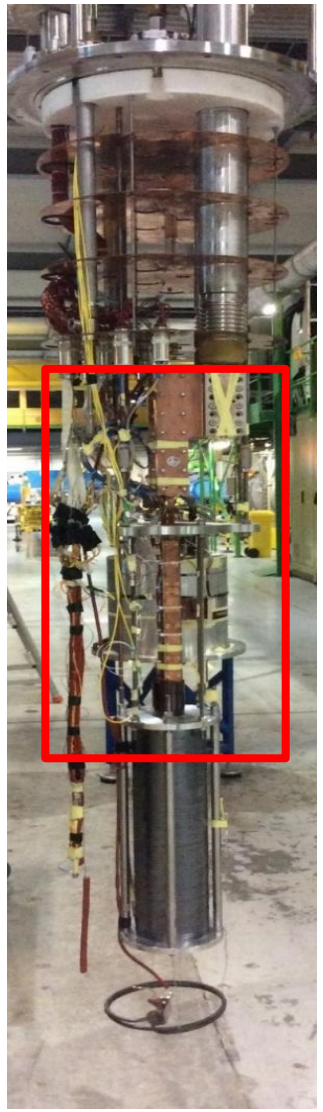
Run 2: Splices thermal runaway prevents from testing the coil

Run3: Modification of the set up

- Need a way to sub cool the splice and connection zones with respect to the magnet itself
- Profit from the test bench capacity to feed independently GHe and LHe in the cryostat
- Deviation of the LHe pipe





Run4: New modification

- Used of a pierced tube for the LHe to better spread the quenching zone (higher in the connection wrt. Run3)

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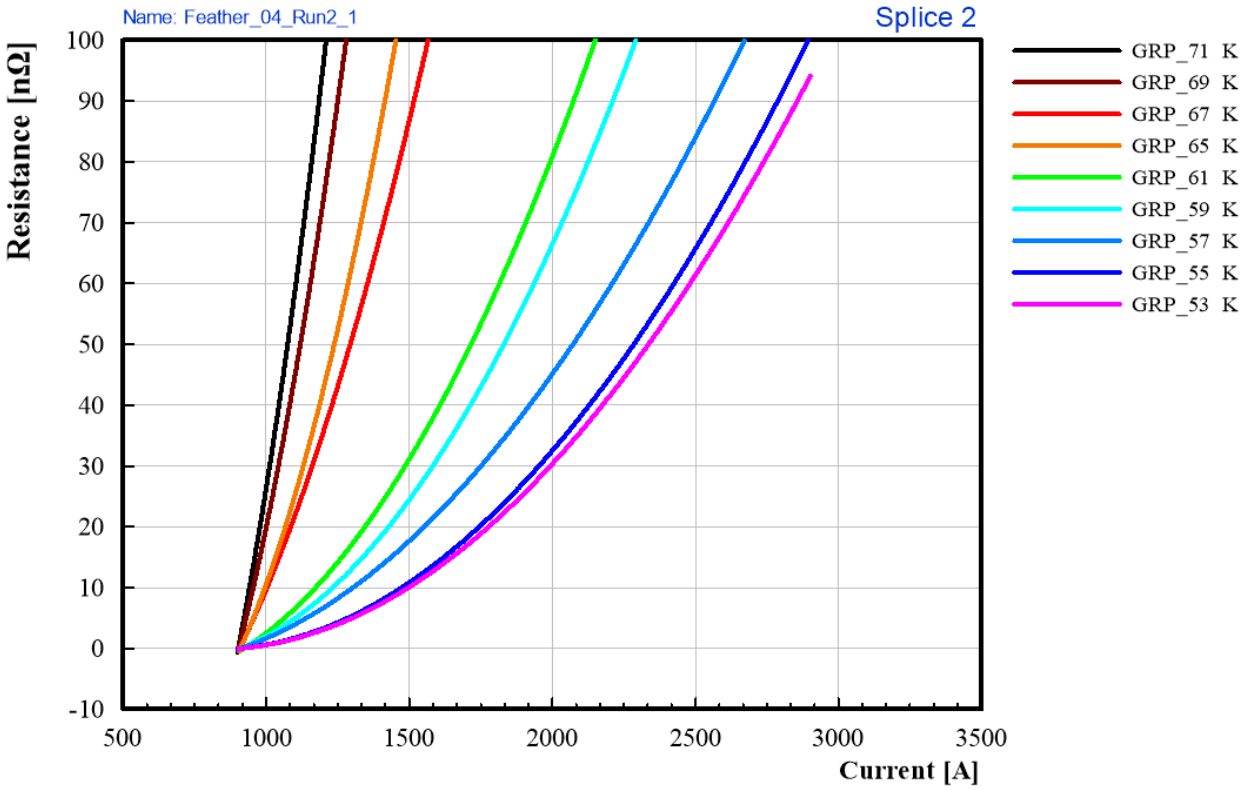
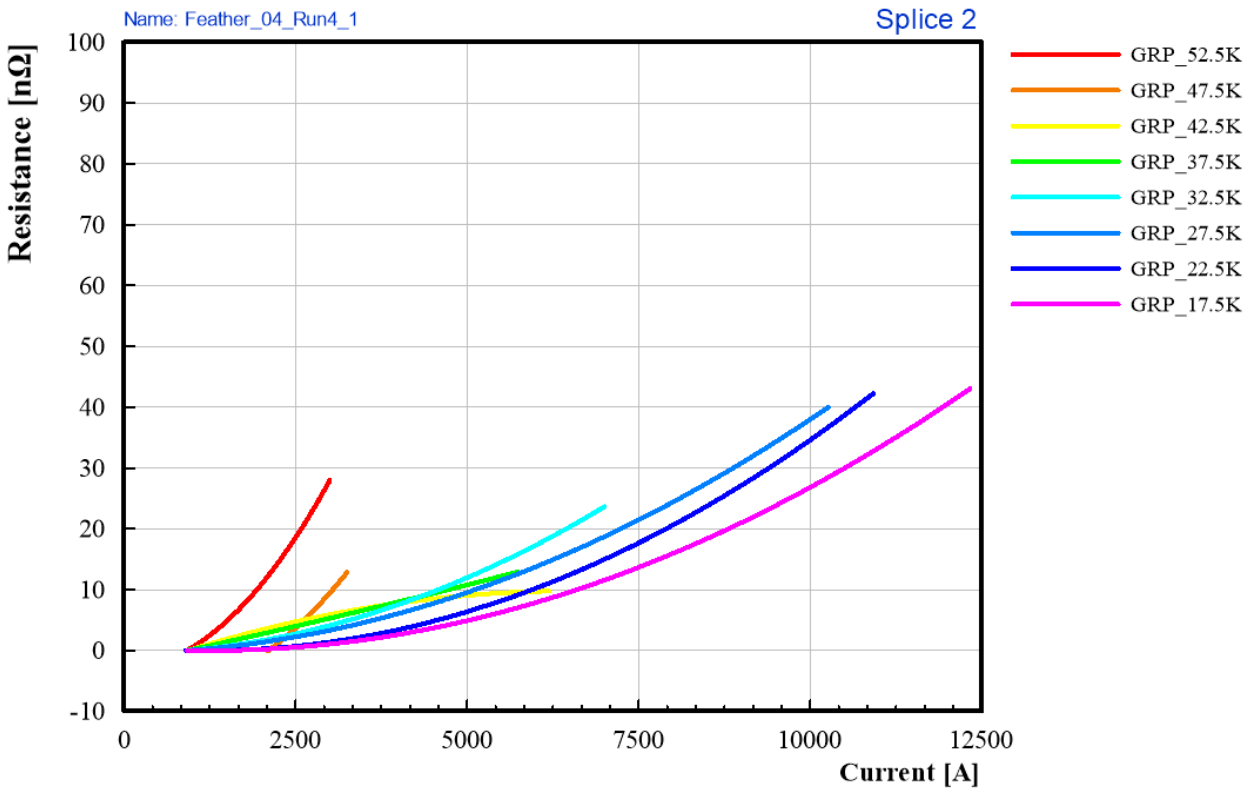
Splice stabilisation with sub-cooling

Run 2: over high resistance (< 3 kA)



Run 4: stable splice up to 12.3 kA



Splice resistance as function of current and temperature

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Quench current as function of the temperature

Run 2 *(14 August-2 Sept-2016)*

Tested temperature range: 80-70 K

Tested current range: 0-3200 A

Tested temperature range: 80-20 K

Tested current range: 0-9600 A

Quench in the coil

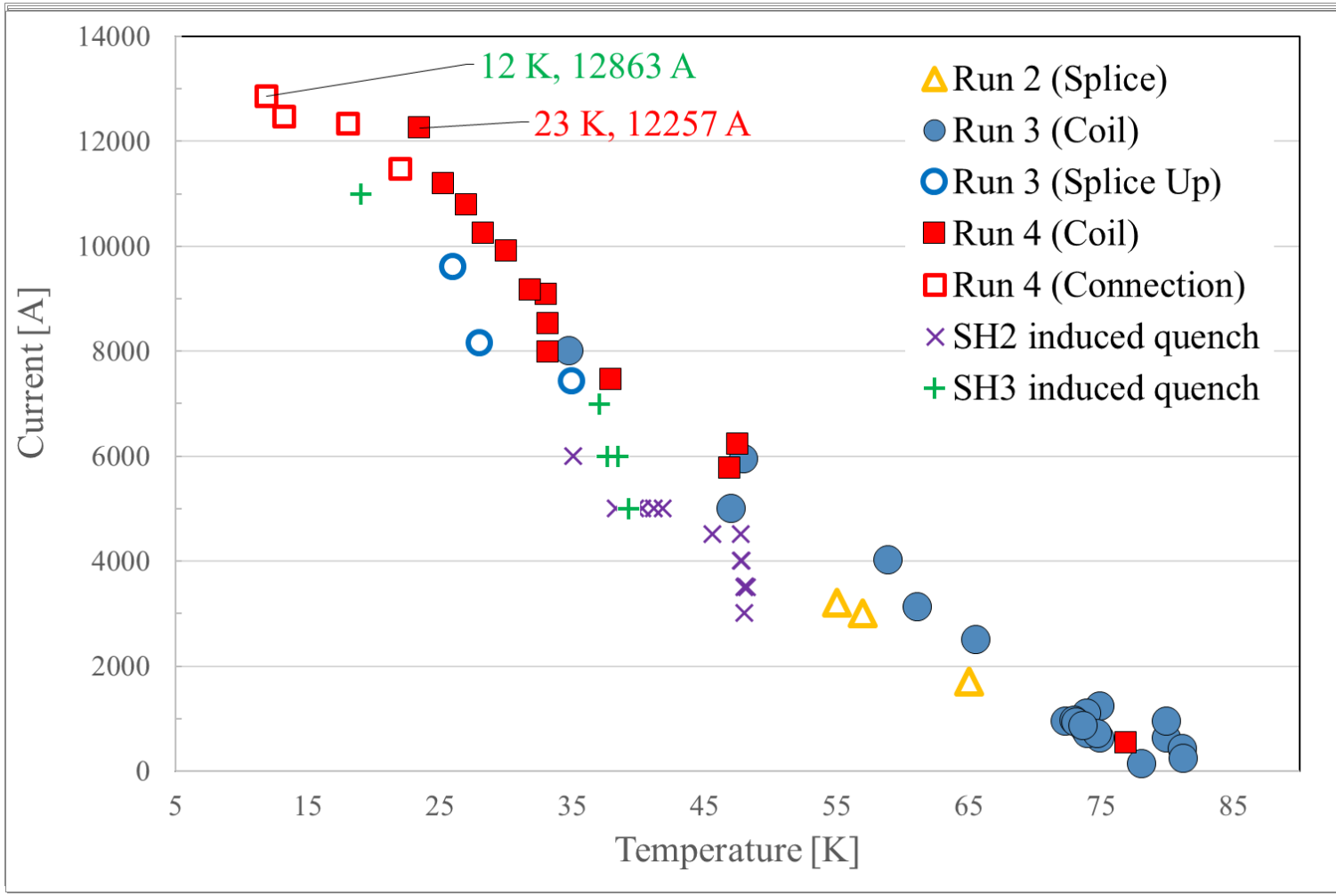
Test stopped due to systematic quench of "splice 2"

Current ramped up to 12270 A

Test stopped due to quench in the splice

Nominal performance at

12 kA at 20 K achieved



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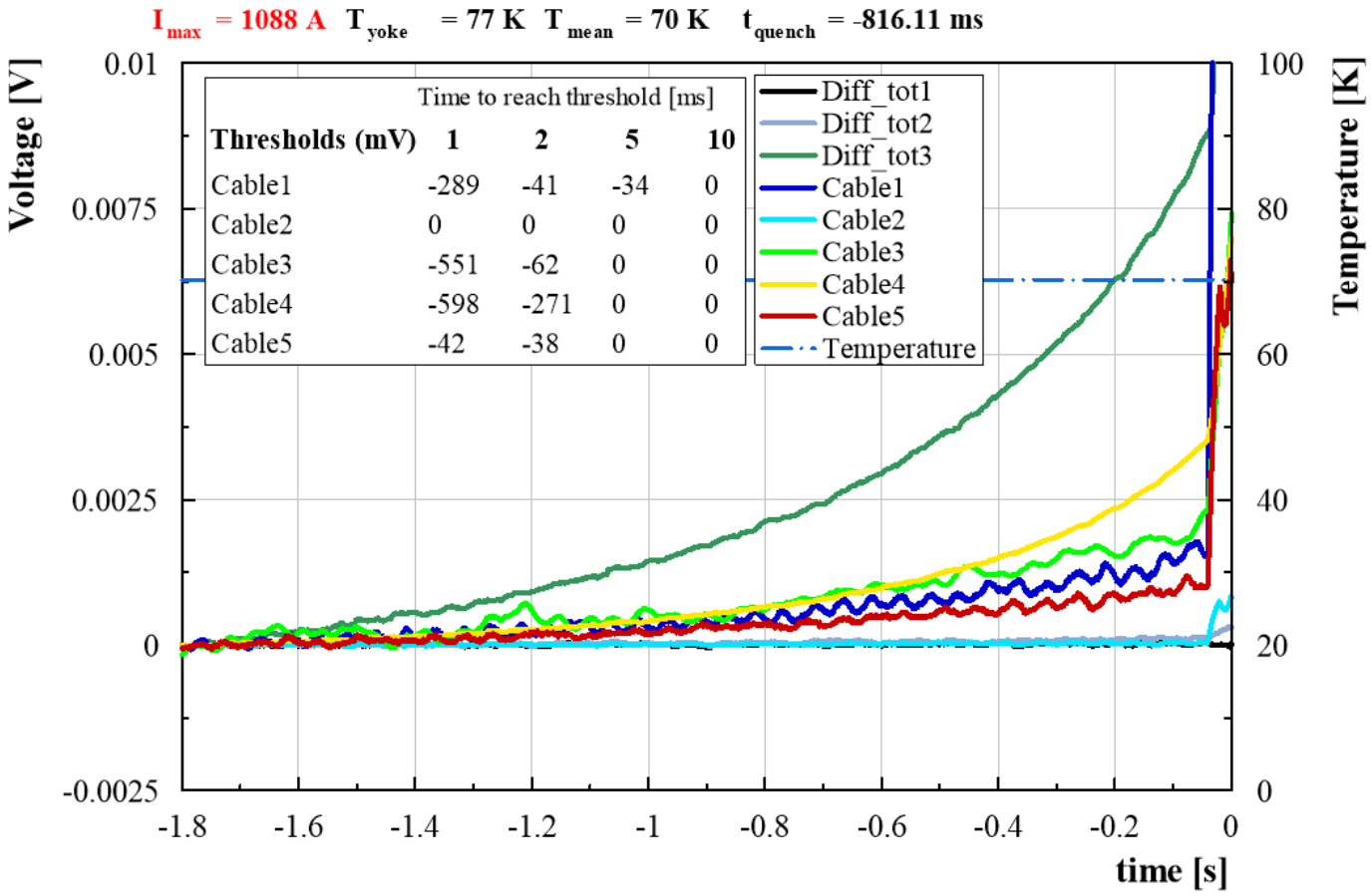
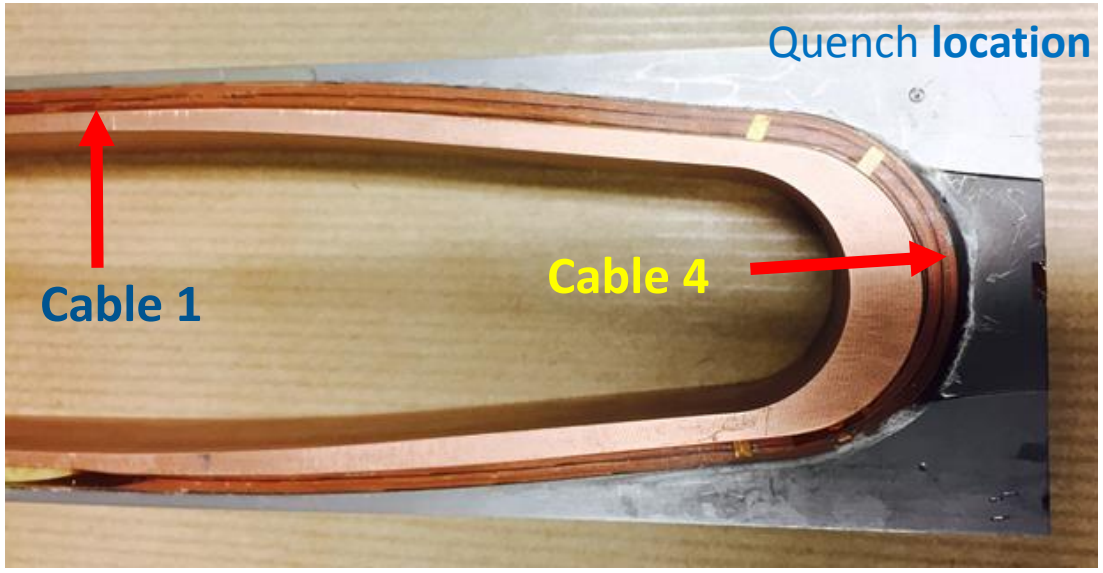
Example of natural quench

Voltage signals as function of time**… a slow transition**



- Clean signals from the voltages taps in the mV range
- Quench **detection** based on voltage taps is OK (10 mV, 10 ms) to **protect** the magnet



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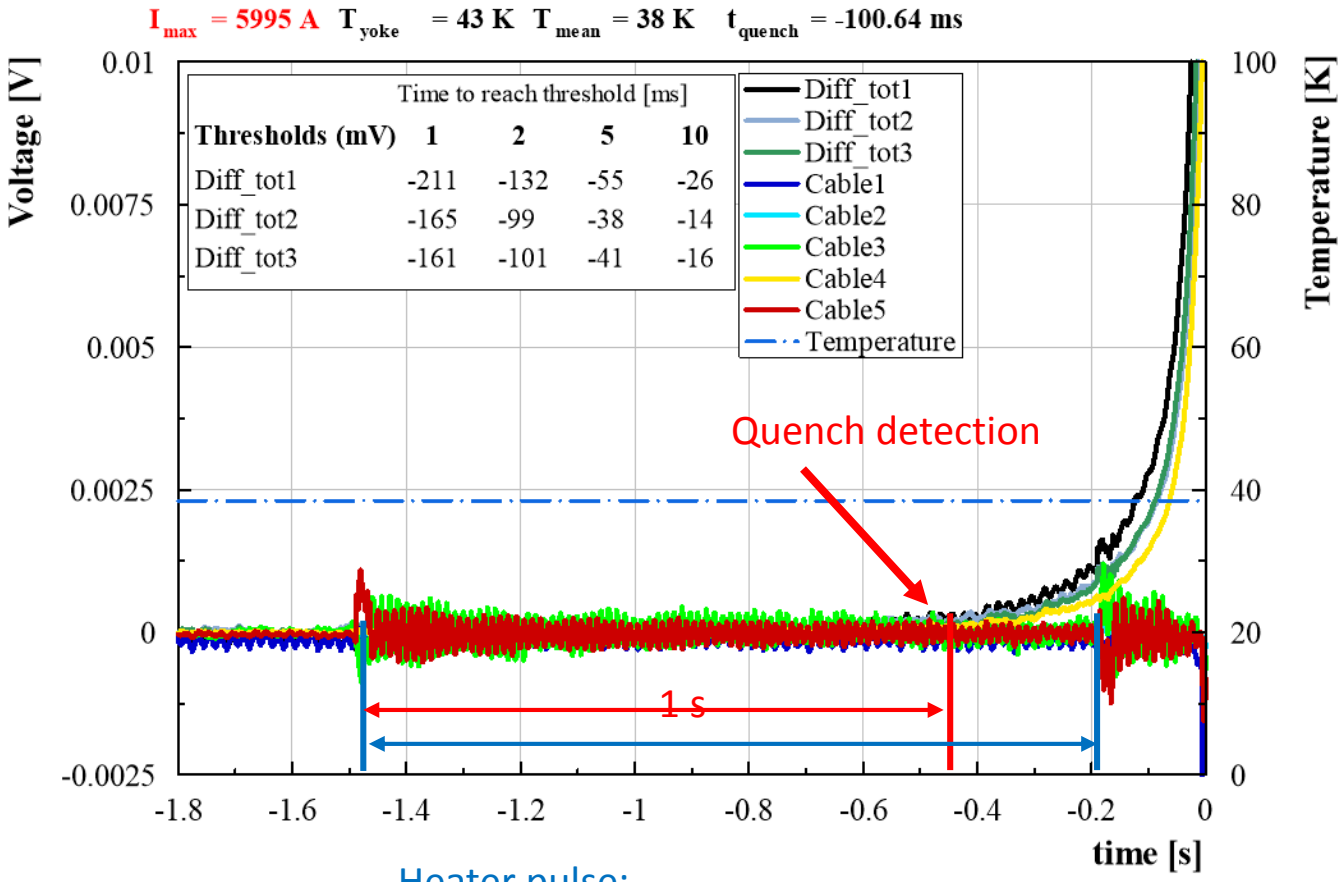
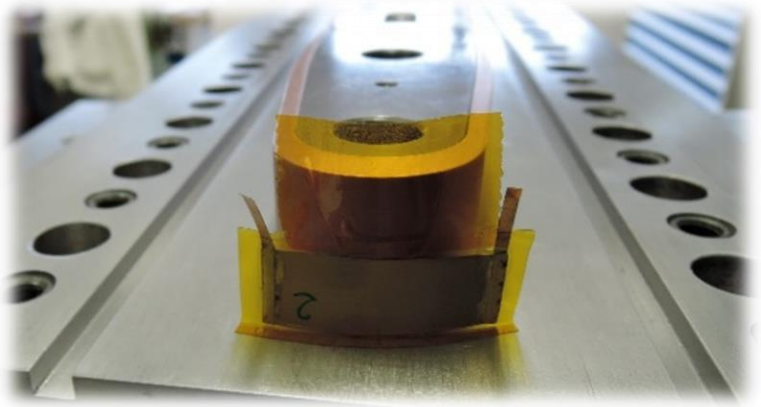
Example of Spot heater induced quench



Heater pulse:
I_SH=30 A, U_SH= 40 V, t_pulse= 1.3 s

- Minimum quench energy… hard to quench!
  At 38 K, 6 kA, MQE=1.2 kJ
- The HTS conductor appears very stable!



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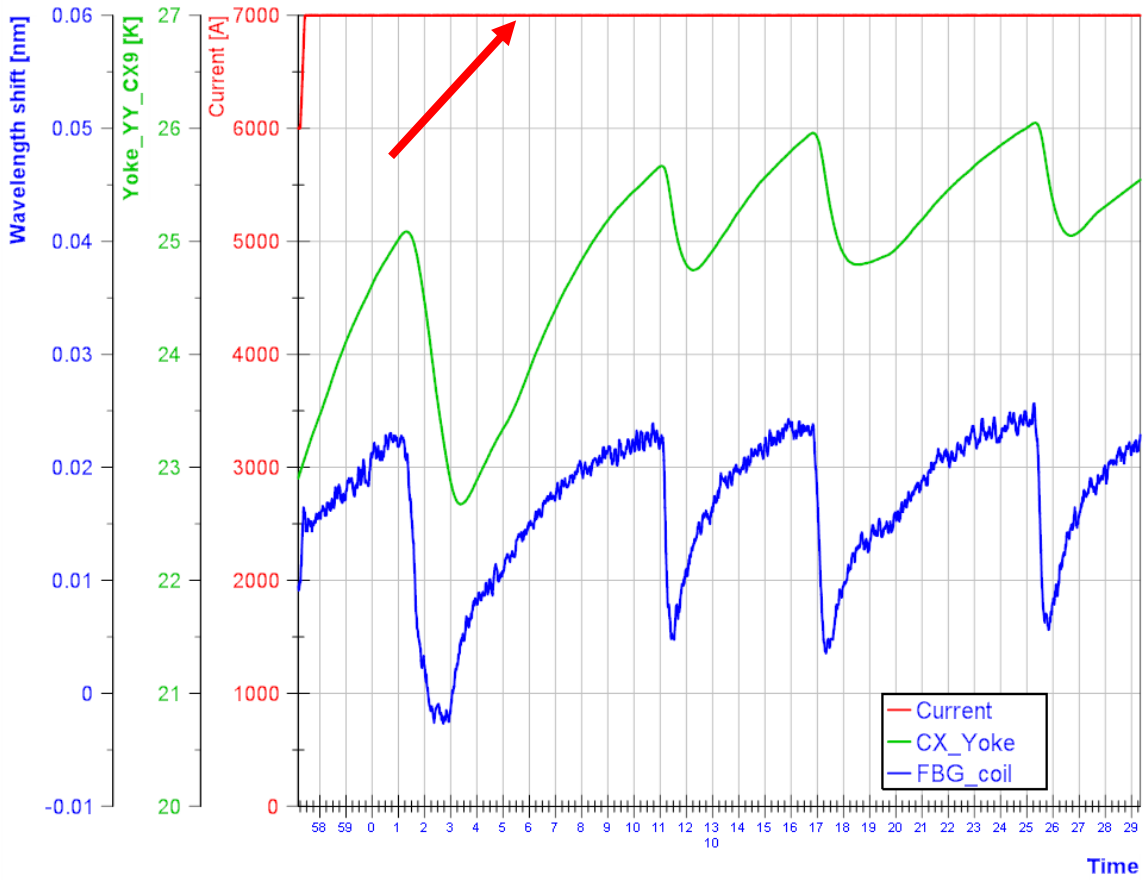
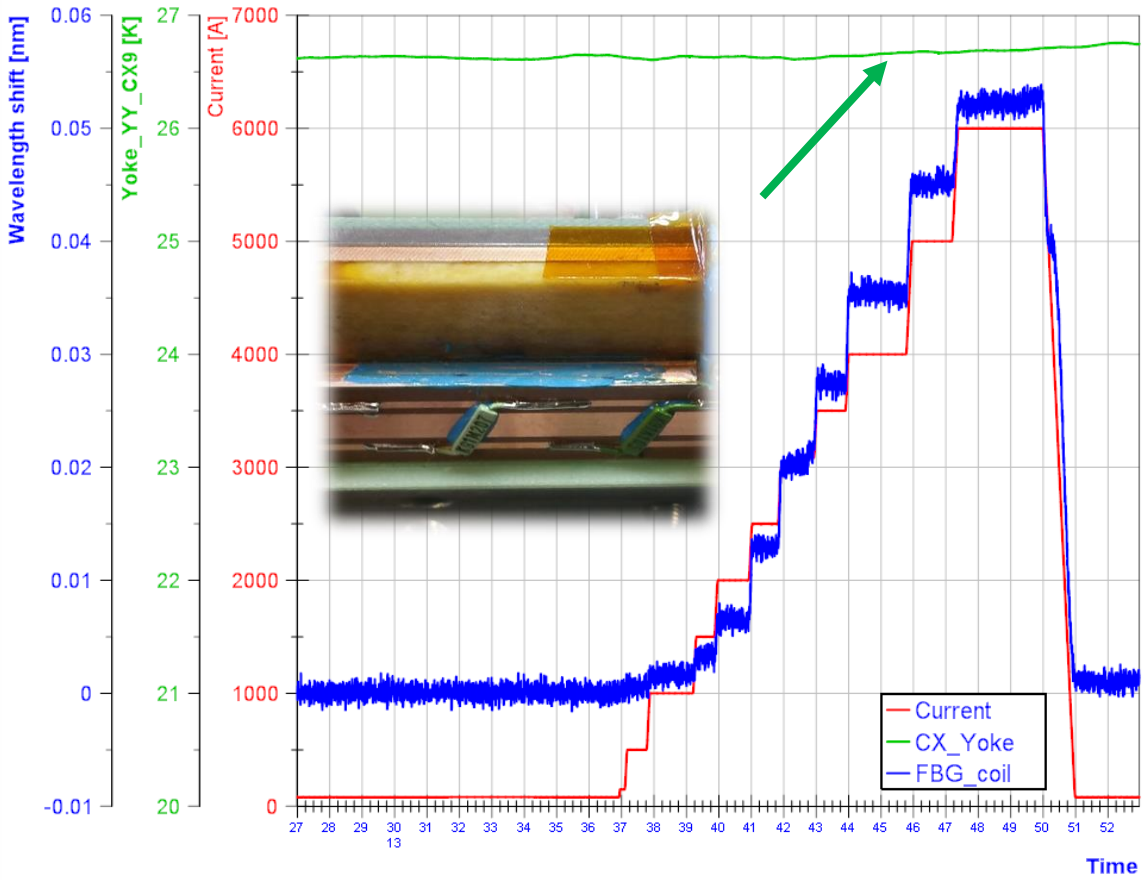
Coil thermo-mechanics study with FOS for different T and I cycles





- **Stable current**: 1 K temperature variation seen by the FGB for induced thermal strain
- **Stable temperature**: mechanics can be followed be the FBG during the current ramp

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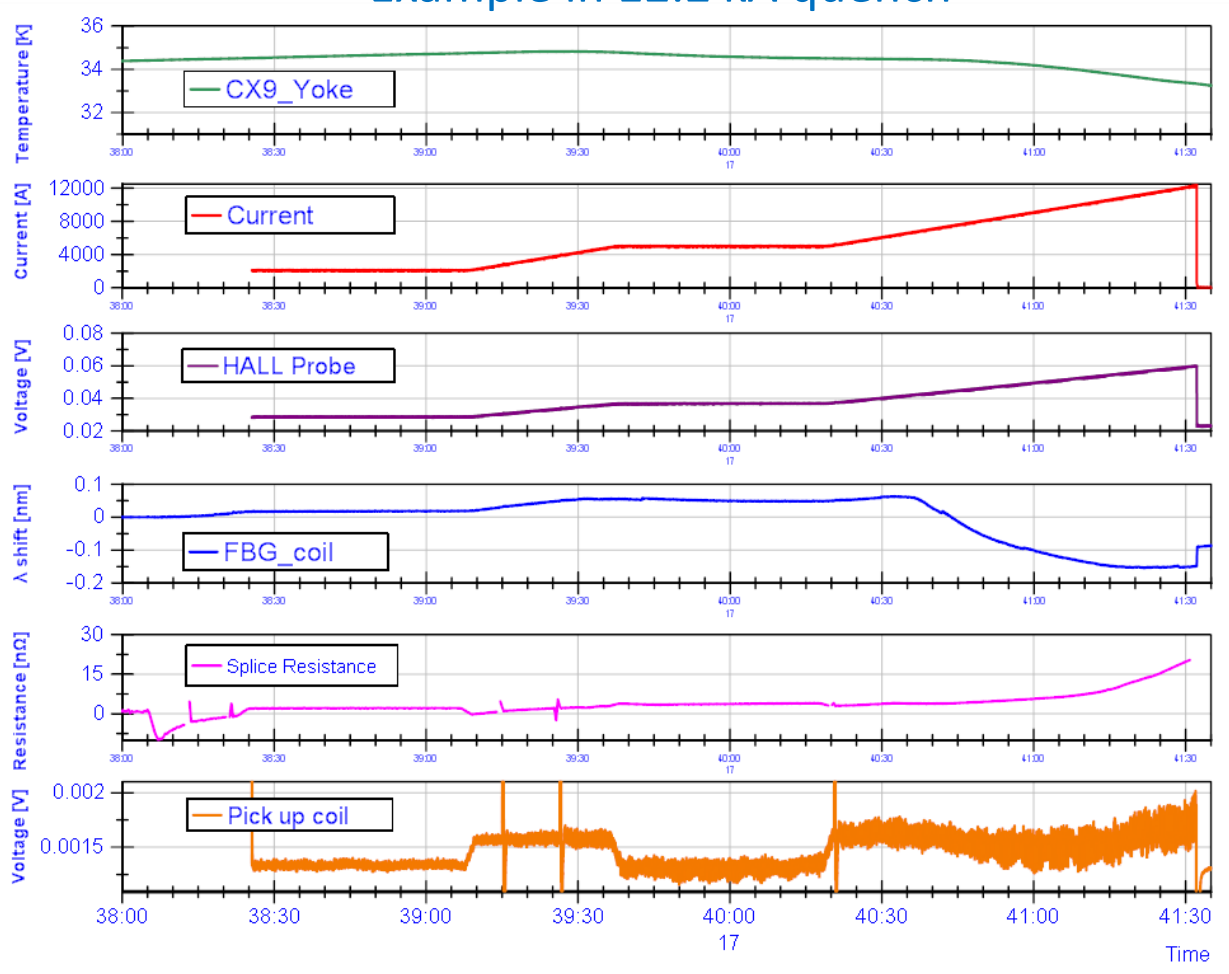
Large data management and synchronisation

Manage to get signals from the 4 different systems and 96 sensors with:

- Data formating agreement
- Signals synchronisation OK
- Data base feeding
- FPGA program needs to be reviewed for the next test (under development).

Example in 12.2 kA quench



T = 33.5 K

I = 12.2 kA

HP = 0.06 V

FOS = - 0.15 nm

Splice 2 = 20 nΩ

PUC= 0.002 V

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Lessons learnt and future tests

- Unlike LHe working condition, a thermal gradient exists in the cryostat when using GHe, with higher temperature at the top where the magnet to lead connections stands.
- In consequence:
  - → the performance are limited by the connections if nothing is done, splices delicate in gas…
  - → a sub cooling of the connections and the splices solved the problem of quench in splice.

- The splice resistance can be lowered to value below 50 nOhm for which splices are stable, avoiding thermal runaway
- The method reached limit during Run 4 at I > 12.4 kA when connection quenches again.

- **The magnet reached the nominal current (12 kA @ 20 K).**

- The magnet can be protected using classic voltage taps with typical (10 mV, 10 ms detection parameters).

- The pick coils, the thermometer and the fiber optic are not able to detect the quench so far…
  - → these are most likely not well placed along the winding.

- More Feather-M0 and Feather-M2 to come with improved joint design.

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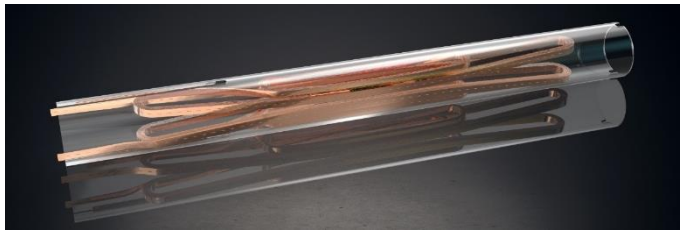
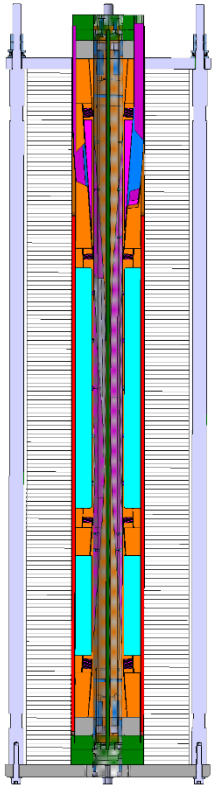
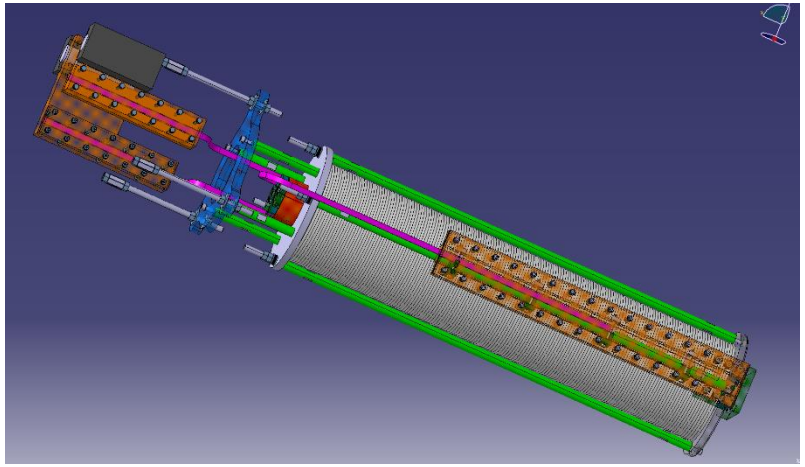
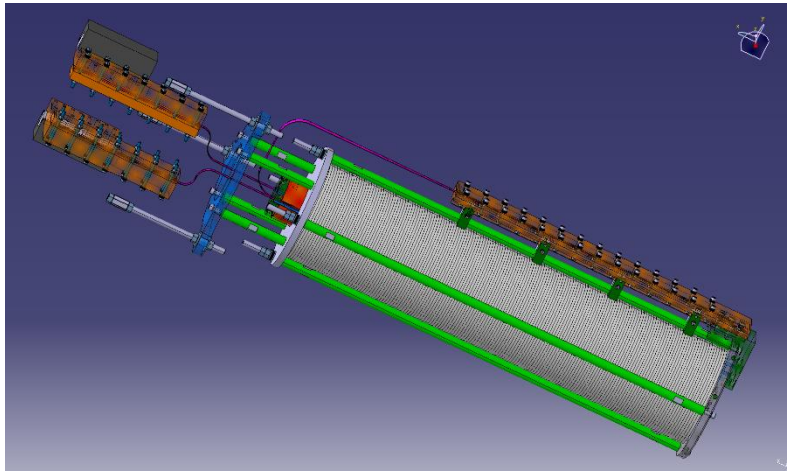
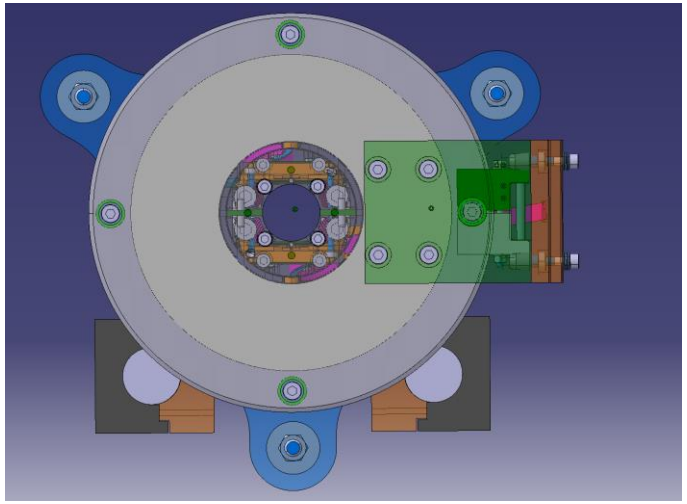
In preparation for Feather-M2

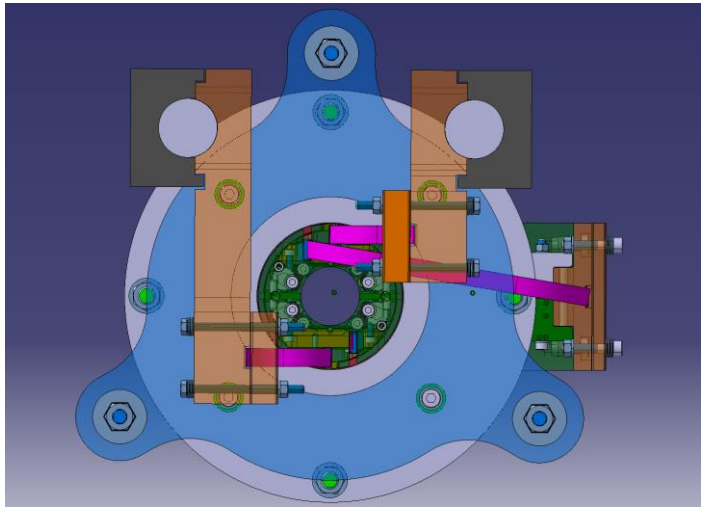




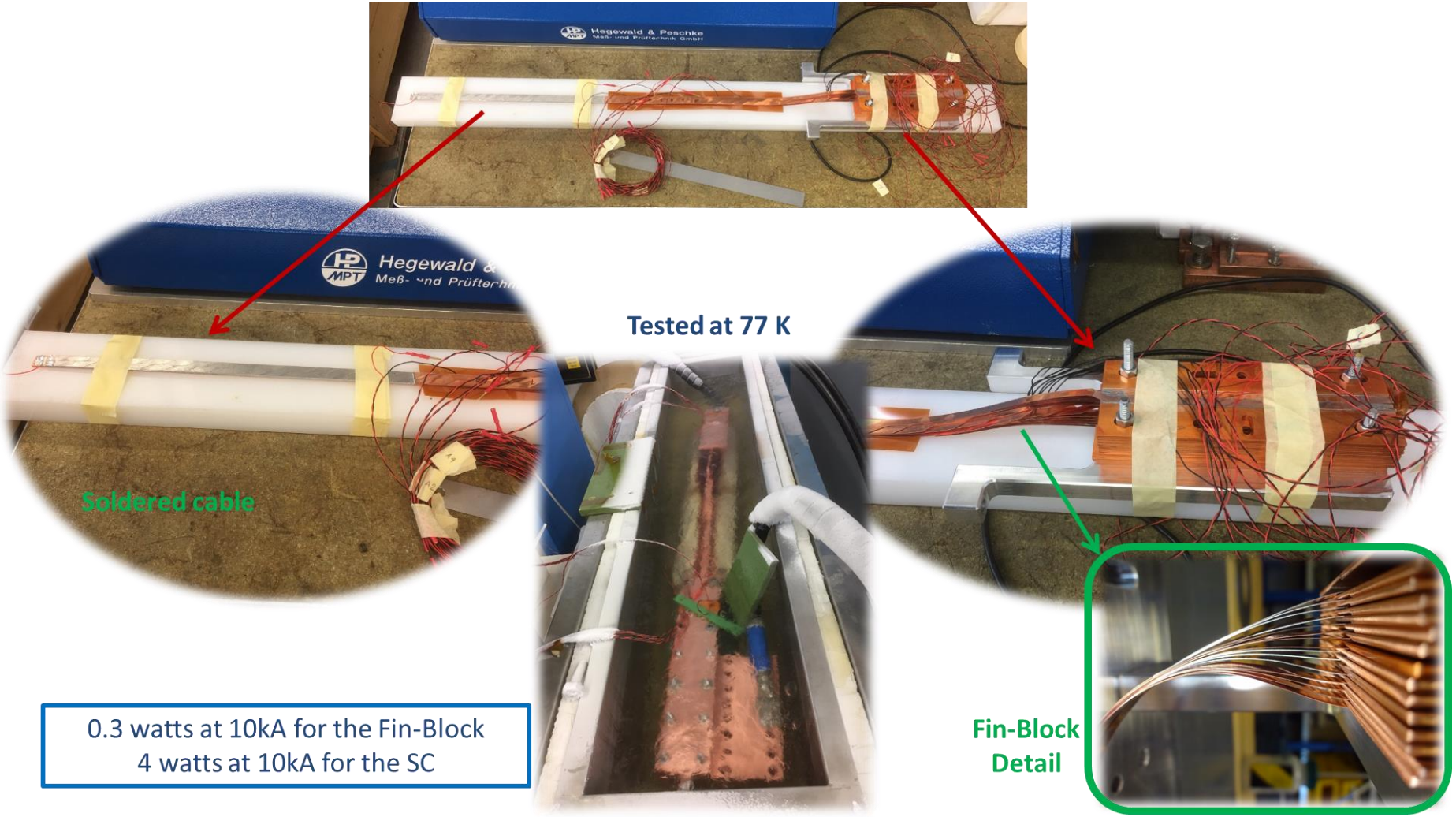








In preparation for Feather-M2

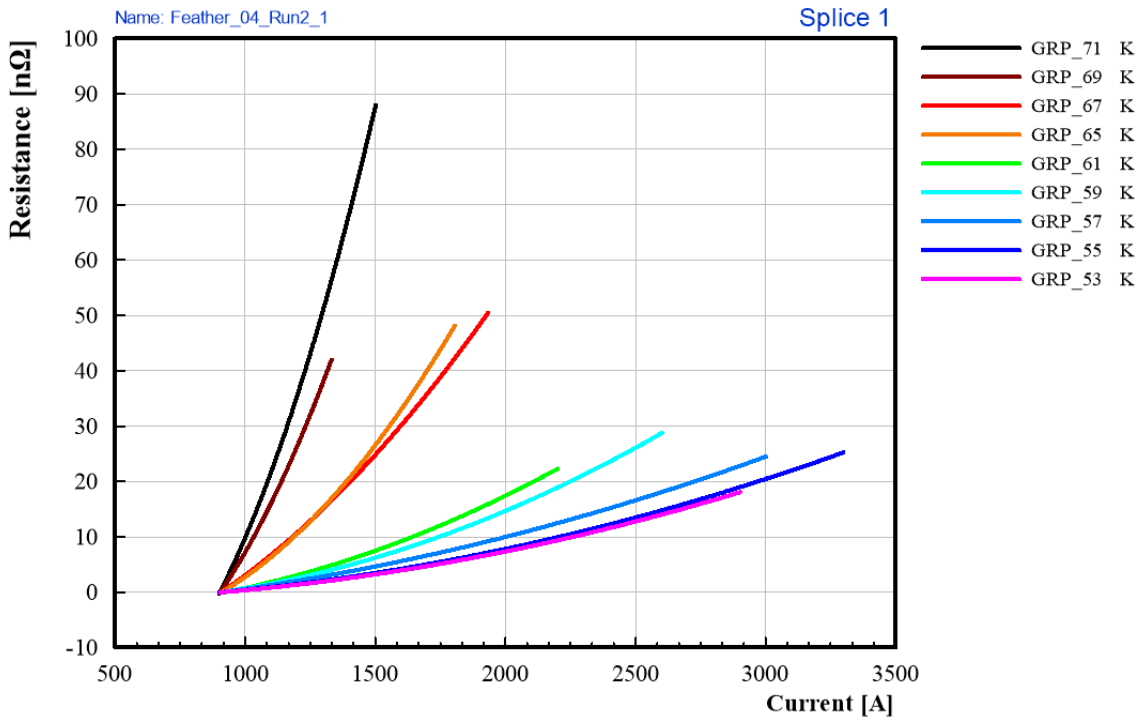


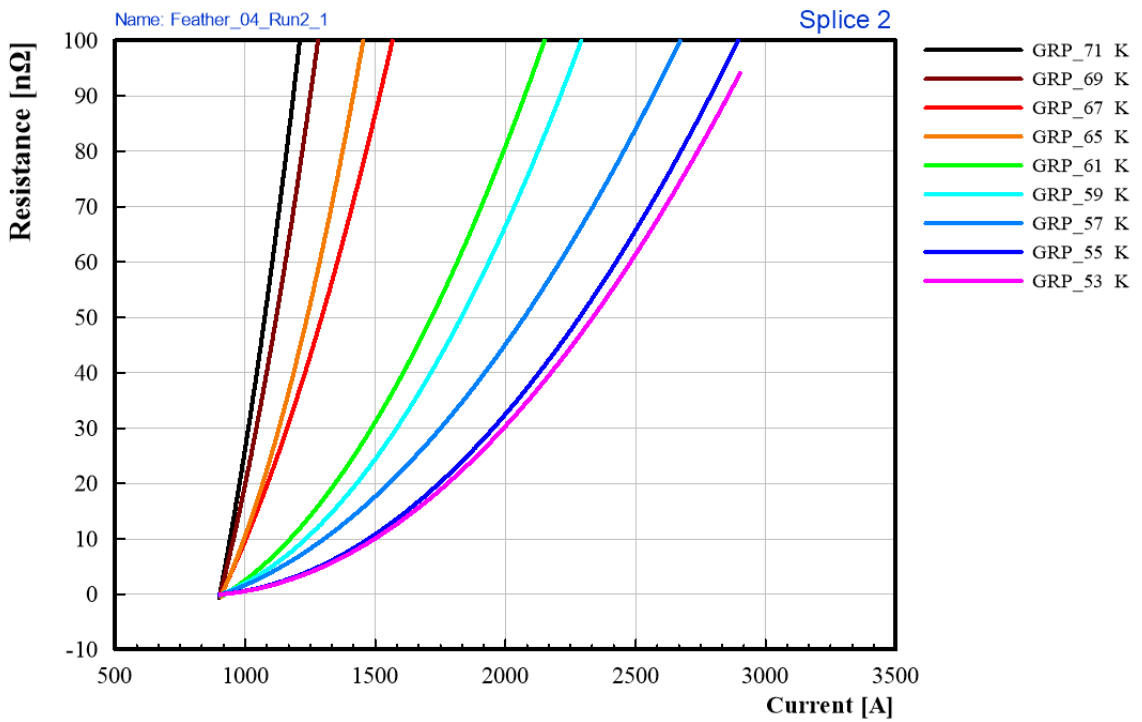
0.3 watts at 10kA for the Fin-Block
4 watts at 10kA for the SC

- Thank you very much for your attention

Resistance as function of current and temperature

Run 2

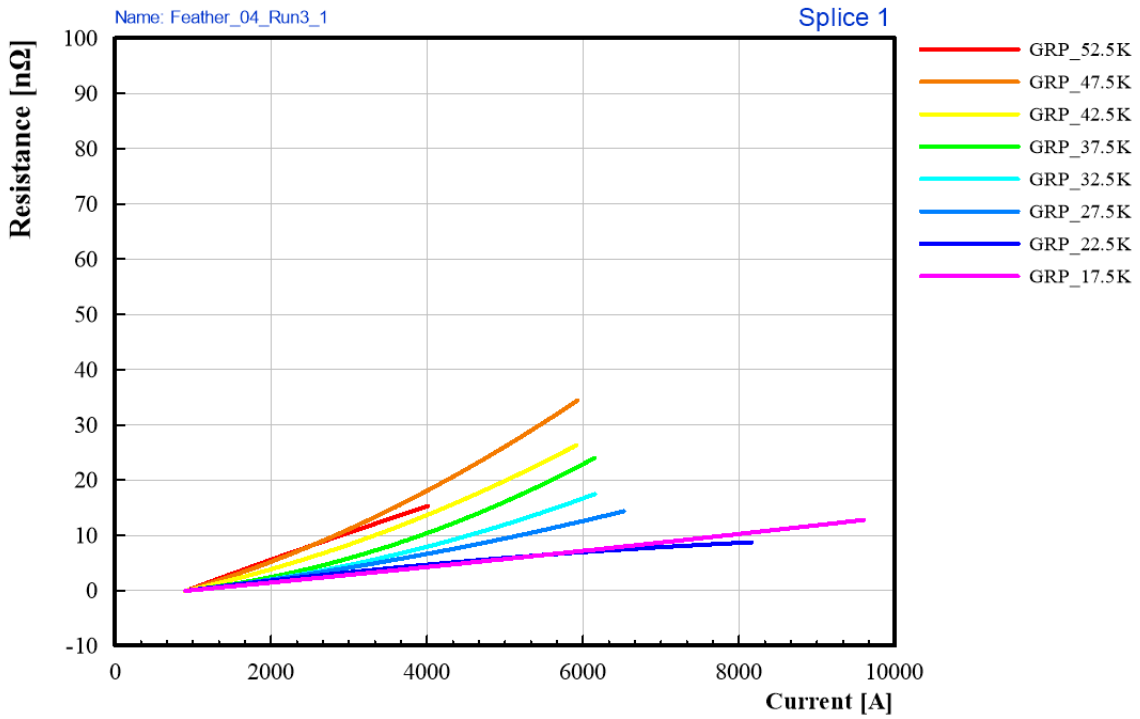


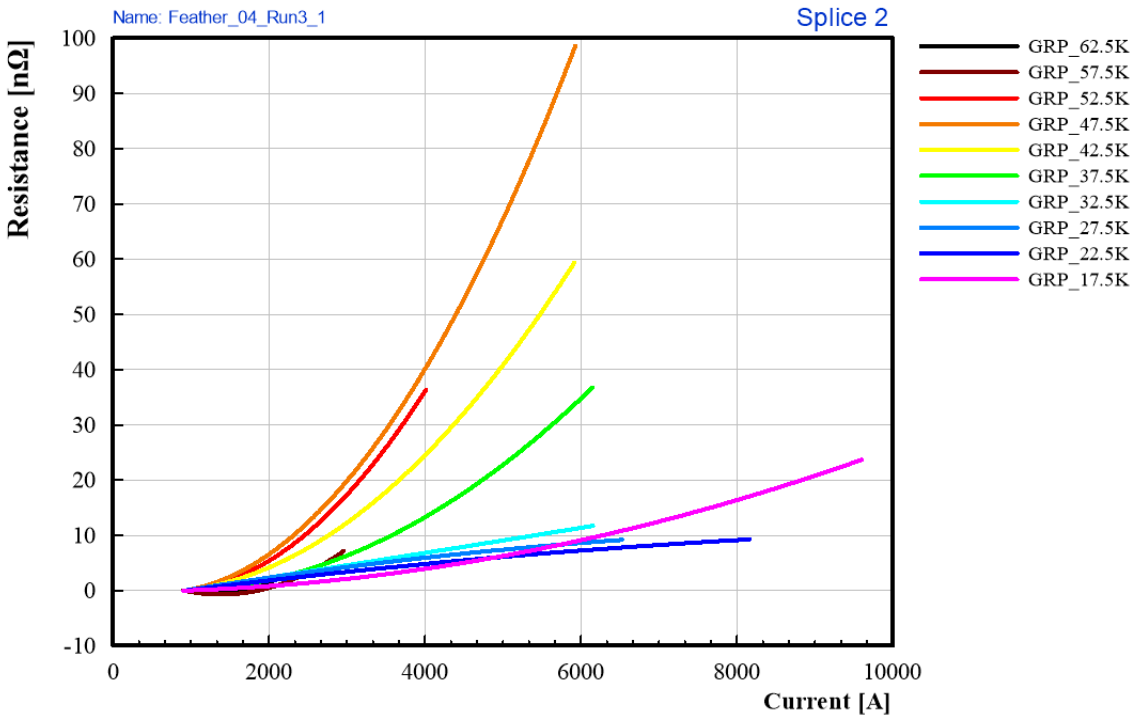


Splice 2 largely exceed 100 nΩ

Resistance as function of current and temperature

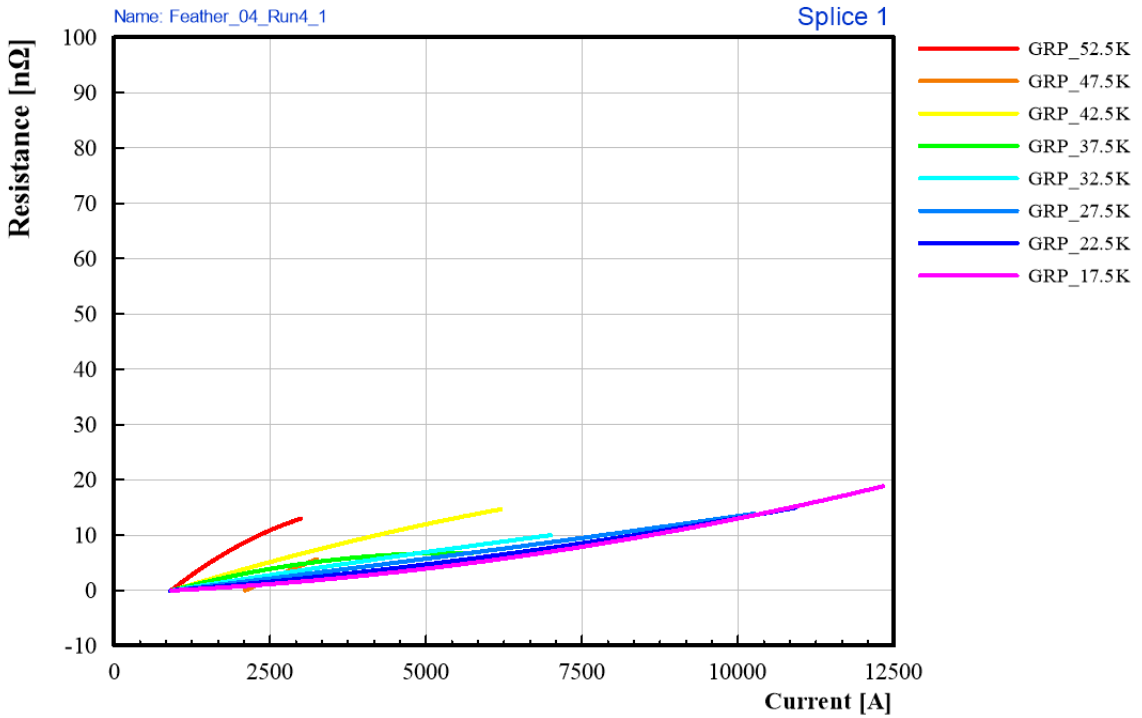
Run 3

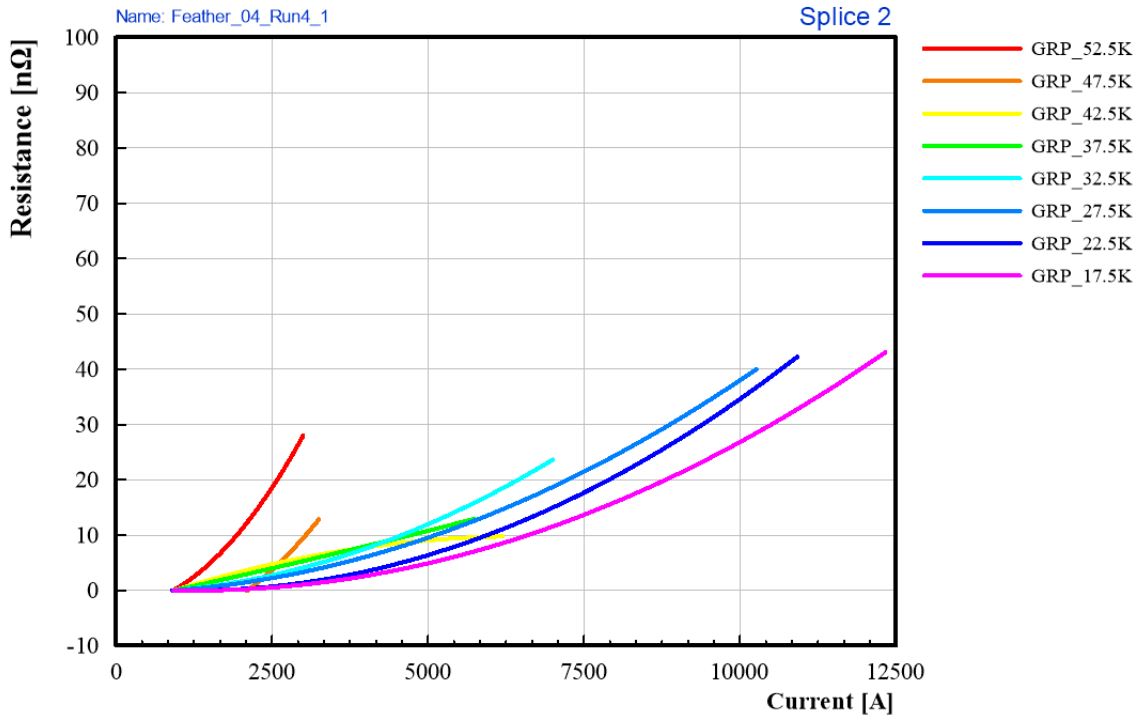




Resistance as function of current and temperature

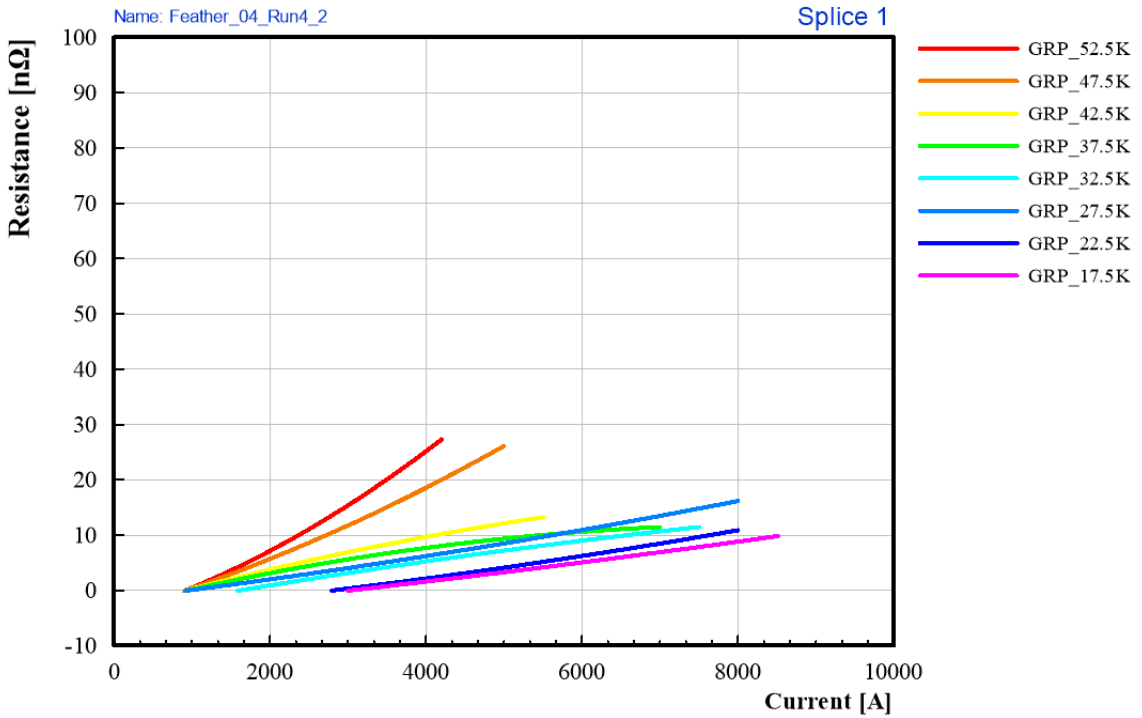
Run 4-A

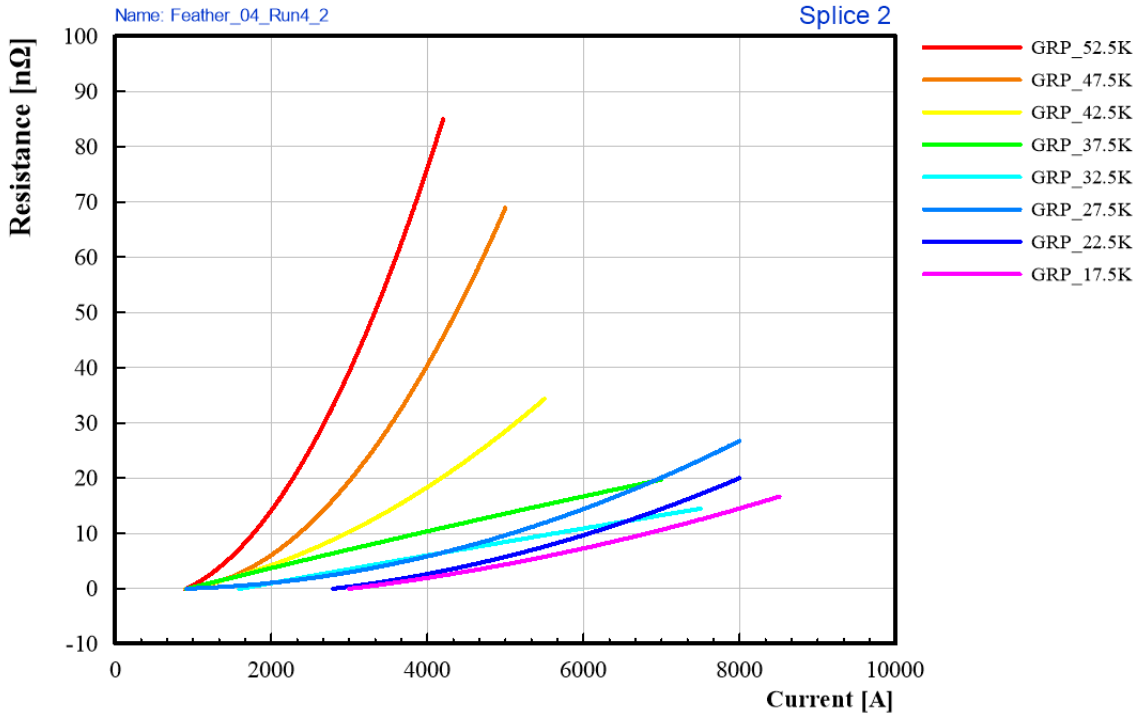


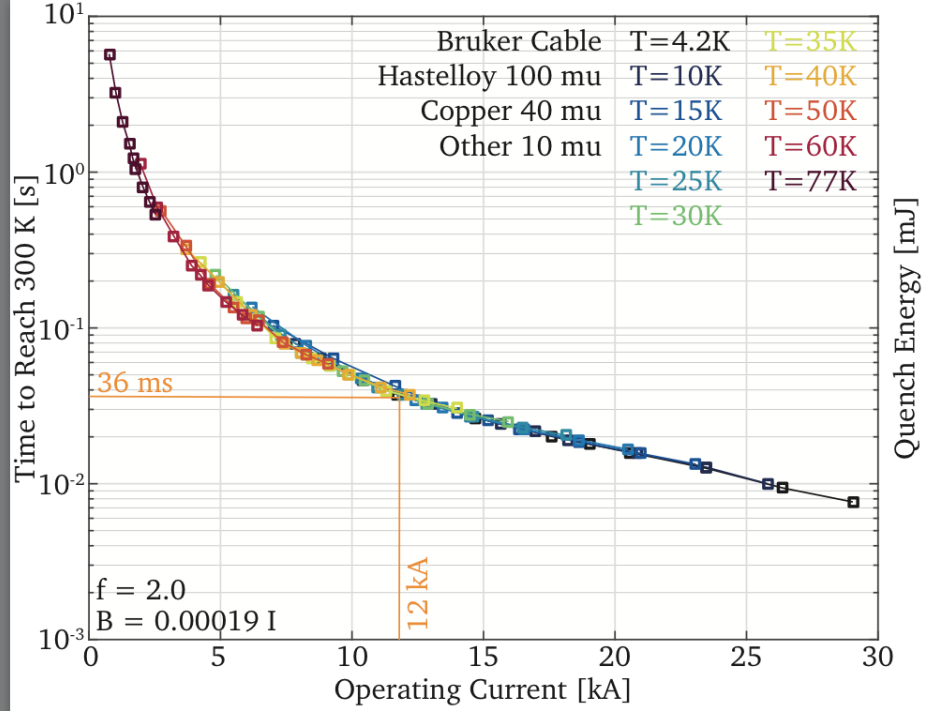


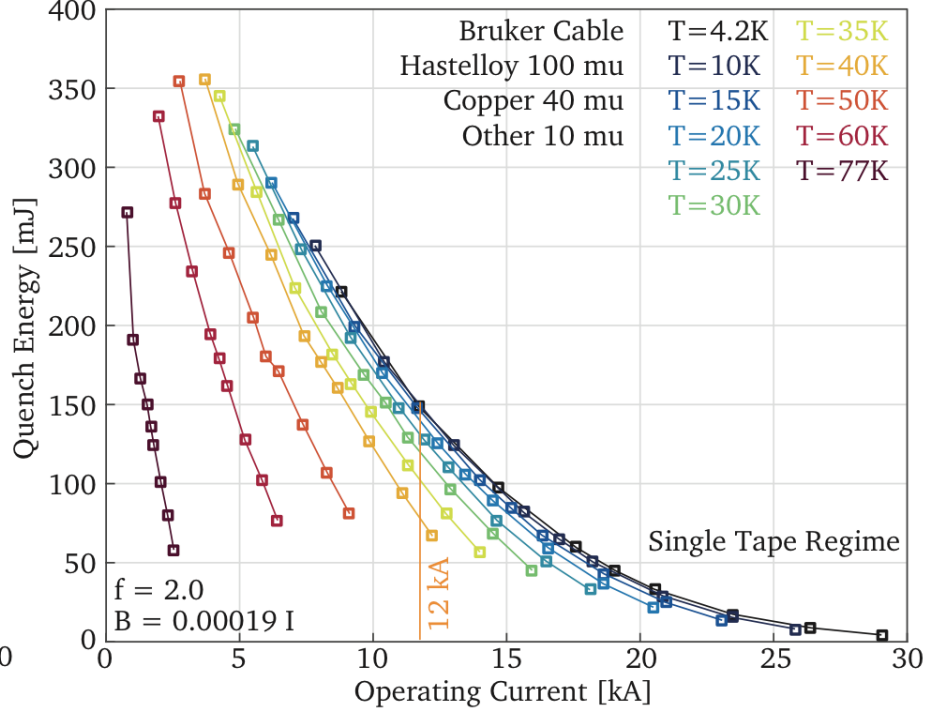
Resistance as function of current and temperature

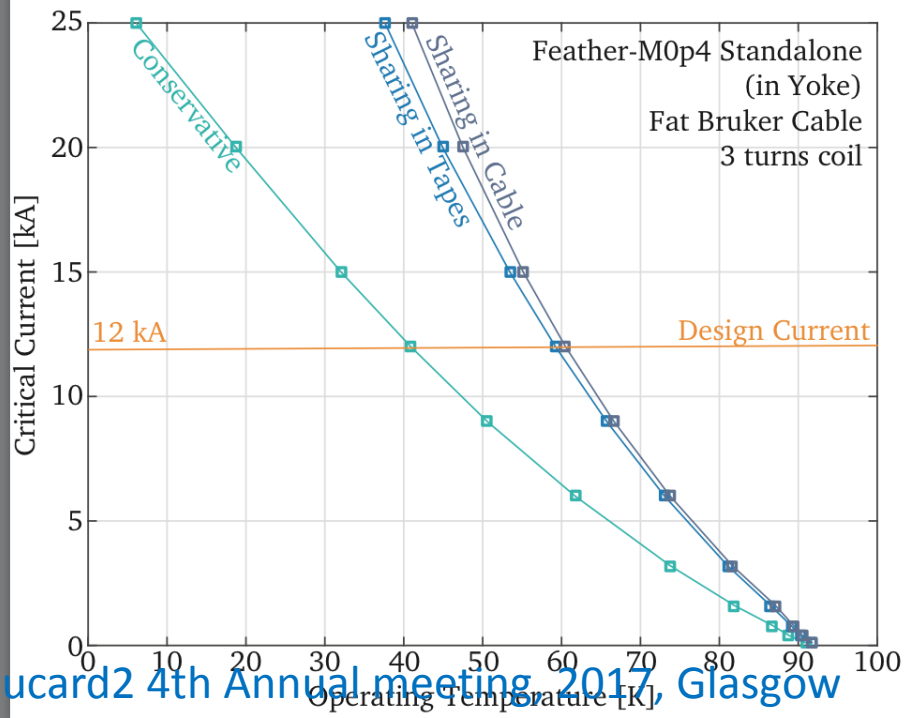
Run 4-B






Bruker Cable
Hastelloy 100 mu
Copper 40 mu
Other 10 mu
T=4.2K
T=10K
T=15K
T=20K
T=25K
T=30K
T=35K
T=40K
T=50K
T=60K
T=77K
36 ms
12 kA
f = 2.0
B = 0.00019 I
Time to Reach 300 K [s]
Operating Current [kA]

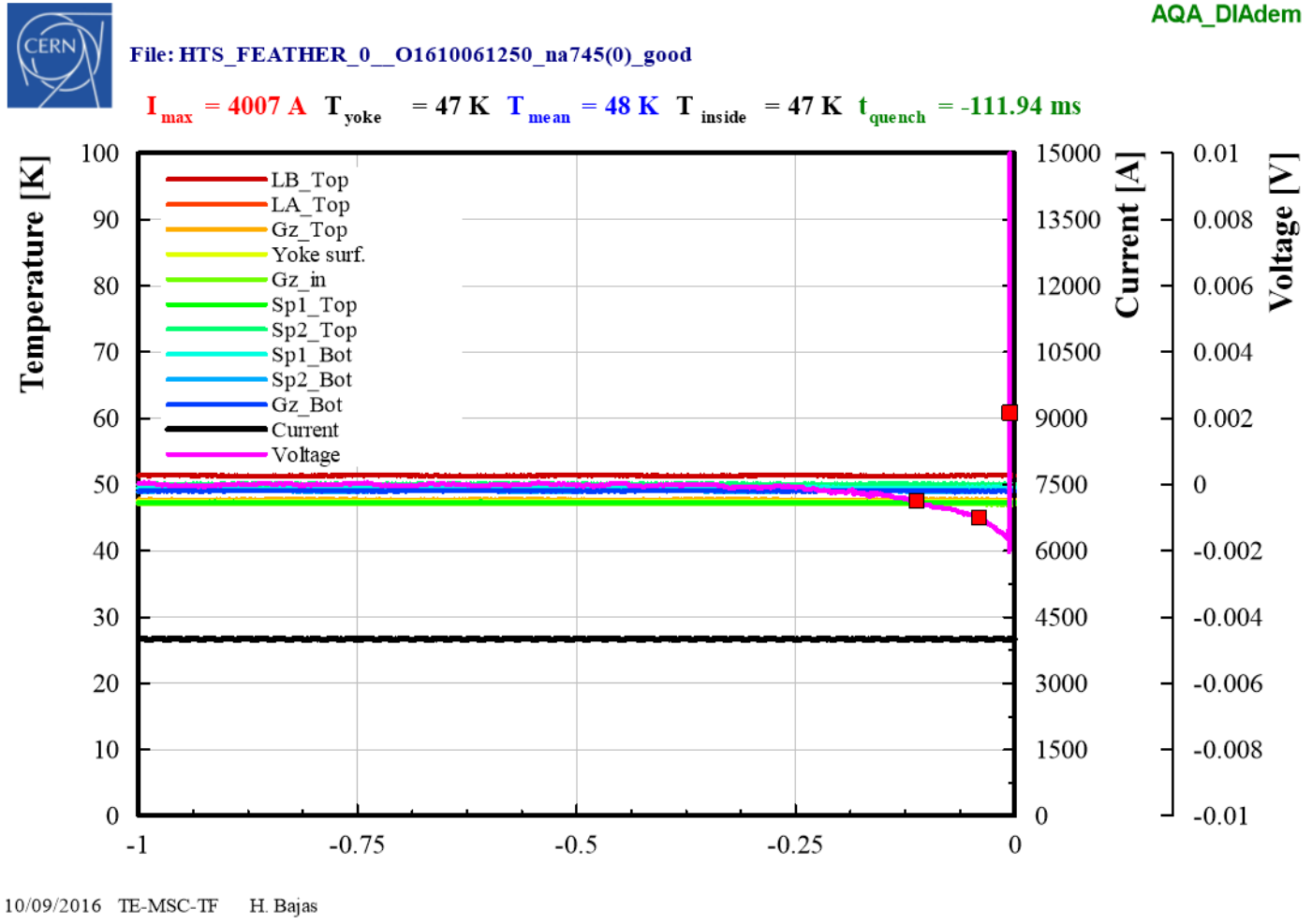

Bruker Cable
Hastelloy 100 mu
Copper 40 mu
Other 10 mu
T=4.2K
T=10K
T=15K
T=20K
T=25K
T=30K
T=35K
T=40K
T=50K
T=60K
T=77K
Single Tape Regime
12 kA
f = 2.0
B = 0.00019 I
Quench Energy [mJ]
Operating Current [kA]


Feather-M0p4 Standalone
(in Yoke)
Fat Bruker Cable
3 turns coil
Conservative
Sharing in Tapes
Sharing in Cable
12 kA
Design Current
Critical Current [kA]
Operating Temperature [K]

Run3: Protection parameters adaptation

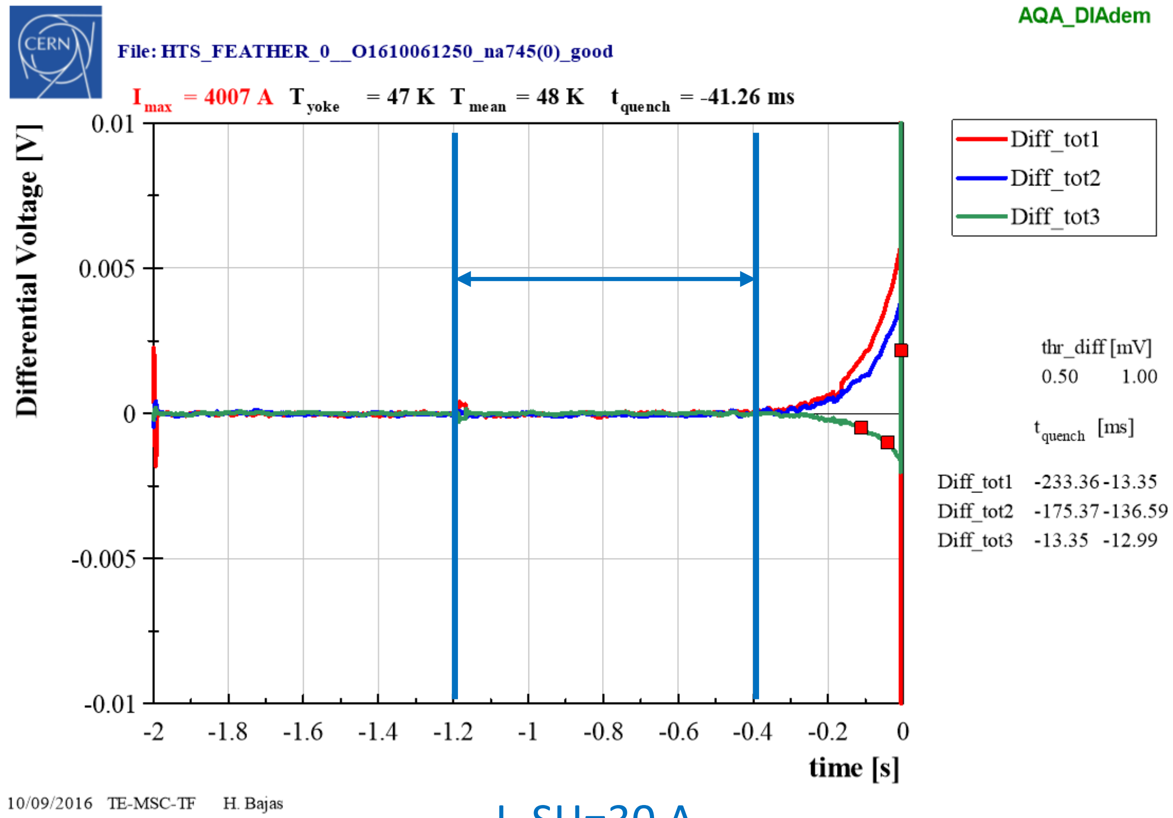
Voltage taps	Segment	Gain	Threshold [mV]	Time window [ms]
EE0.4U3-EE0.4L4-EE0.4L6	Vdiff 0	0.1	11	20
EE0.4U1-EE0.4L4-EE0.4L8	Vdiff 1	0.1	10	20
EE0.4U2-EE0.4L3-EE0.4L7	Vdiff 2	10	1160	30
EE0.4U1--EE0.4L8	Vsum 1	4	71	30
EE0.4U2--EE0.4L7	Vsum 2	0.04		10
EE0.4U2--EE0.4U3	Splice 1	40	10	10
EE0.4L6--EE0.4L7	Splice 2	40	20	20
EE0.4L4--EE0.4L5	cable 1	40	5	20
EE0.4L3--EE0.4L4	cable 2	40	3	10
EE0.4L2--EE0.4L3	cable 3	40	3	10
EE0.4L1--EE0.4L2	cable 4	40	3	10
EE0.4U4--EE0.4L1	cable 5	40	3	10
VleadA+--RF8_1_1	Vgaz A	40	60	10
RF8_1_2--VleadB	Vgaz B	40	60	10
RF8_1_1--EE0.4U1	Vcon A	40	10	10
EE0.4L8--RF8_1_2	Vcon B	40	10	10

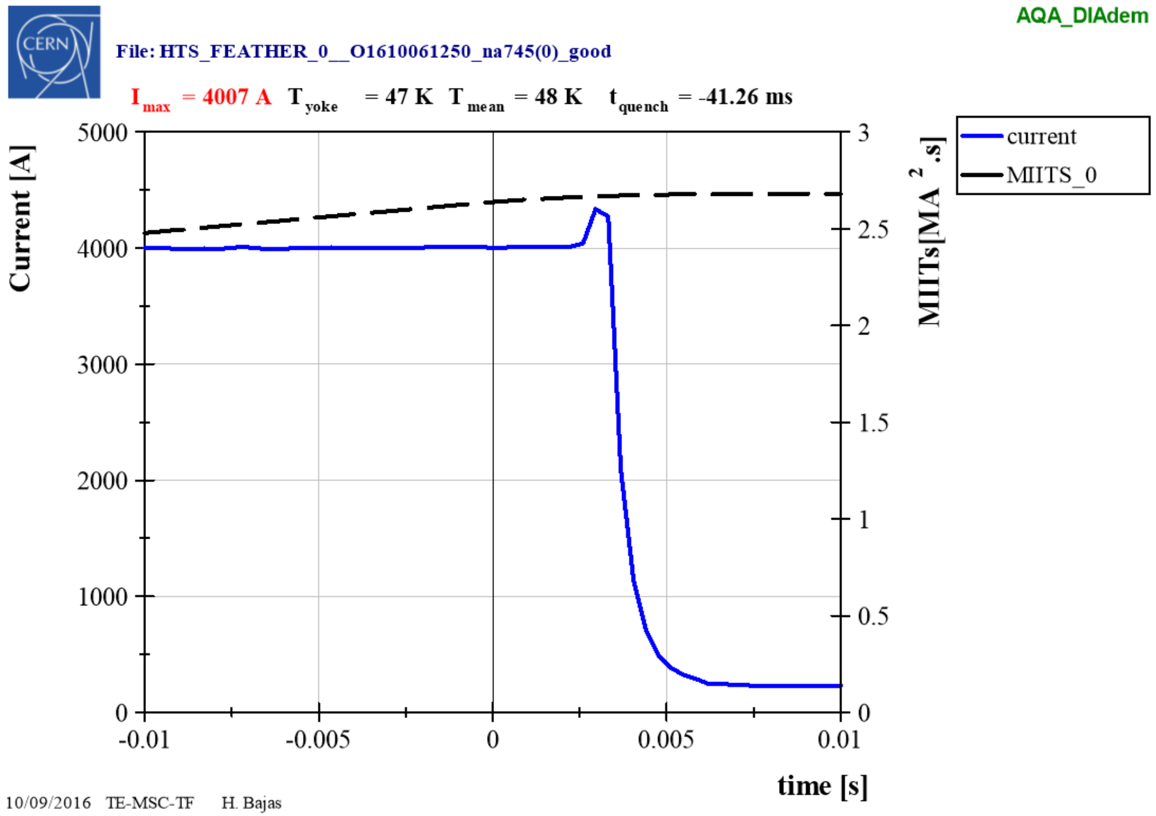
Run 4: Spot Heater test



H. Bajas, Eucard2 4th Annual meeting, 2017, Glasgow

Run 4: Spot Heater test





I_SH=30 A
U_SH= 24 V
t_pulse= 1 s

Current decay: 2.5 ms to extract

MQE(47 K, 4000 A)=30*24*8=576 J

Test Set-Up description: instrumentation

Separated Helium inlet for either gas or liquid cryostat feeding

- 10 Cernox T_sensors (2 on the copper leads, 2 on the Cu. Extension, 4 for the cryostat T monitoring)
- 38 Carbon Ceramic T-sensors (2 arrays (11 & 25) and 2 independent calibrated)
- 4 Optical fibers with 1 FBG T-ε-sensors (2 glued on winding (T-ε) and 2 for the gas monitoring)
- 14 voltage taps (2 for lead, 2 per splices, 5 for the cable)
- 20 Pick Coils for quench detection (10 per side)
- 2 Hall Probe for magnetics field measurement
- 3 Spot heaters