# MBHA-002 test program discussion

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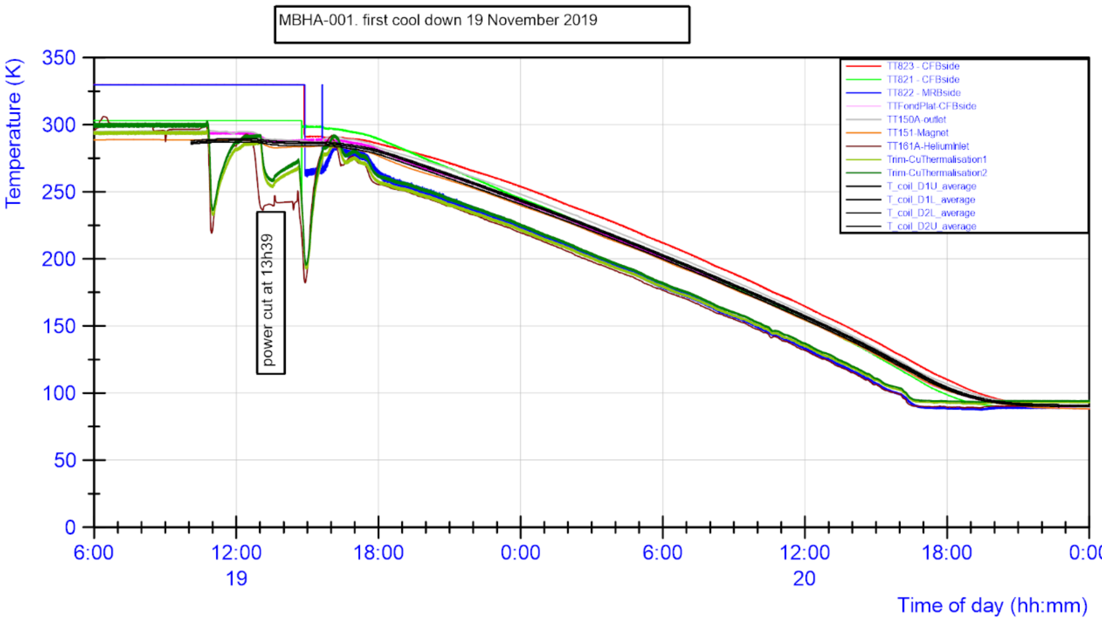
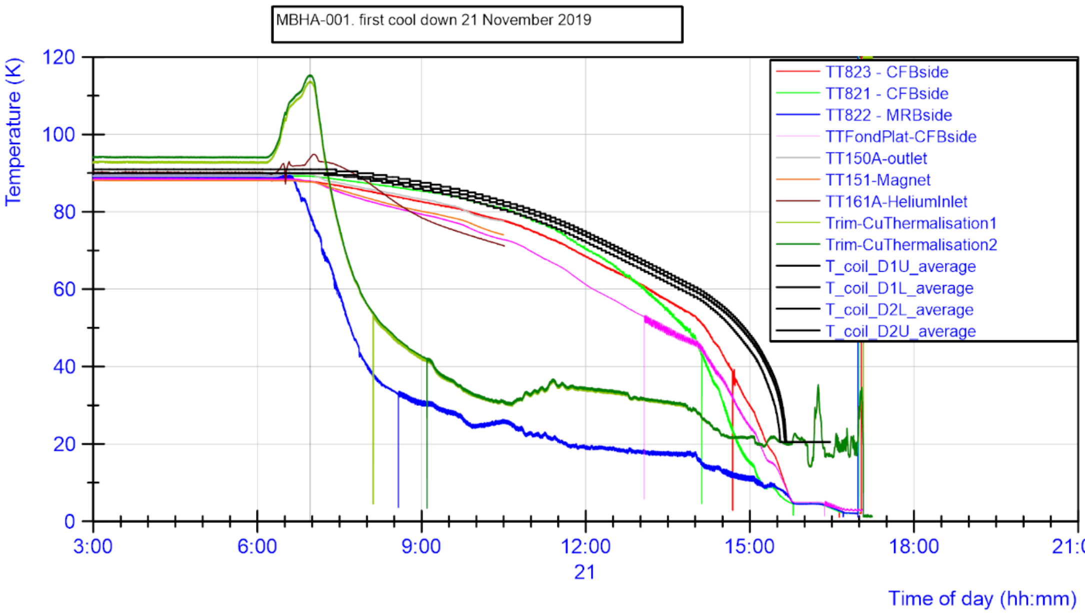
Magnet test program in EDMS 2306899

*2020 November 15 – 11T technical meeting*

# Standard cool down and warm up process

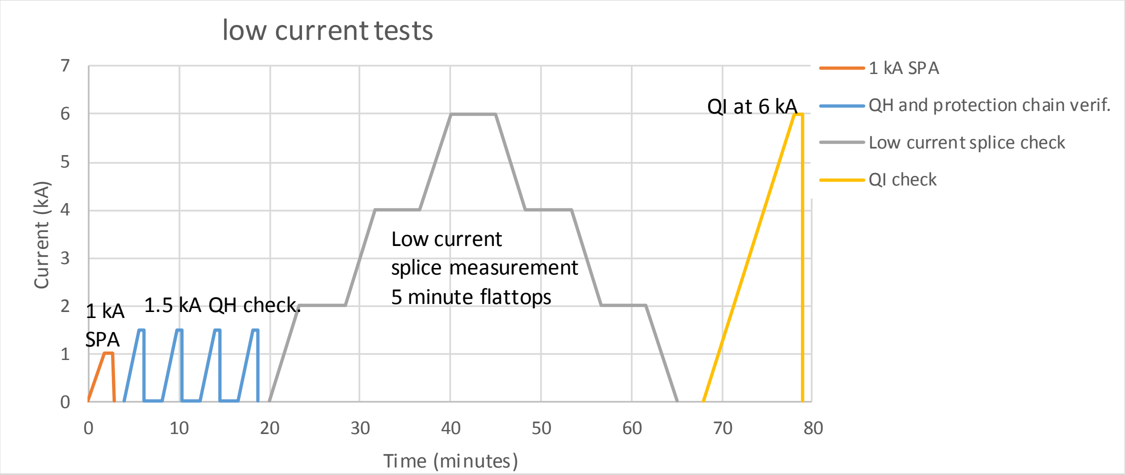
- MBHB-002: ΔT of 30 K (abort process at >45 K)
- MBHA-001: ΔT of 30 K (abort process at >45 K)
- MBHA-002: ΔT of 30 K (abort process at >45 K)



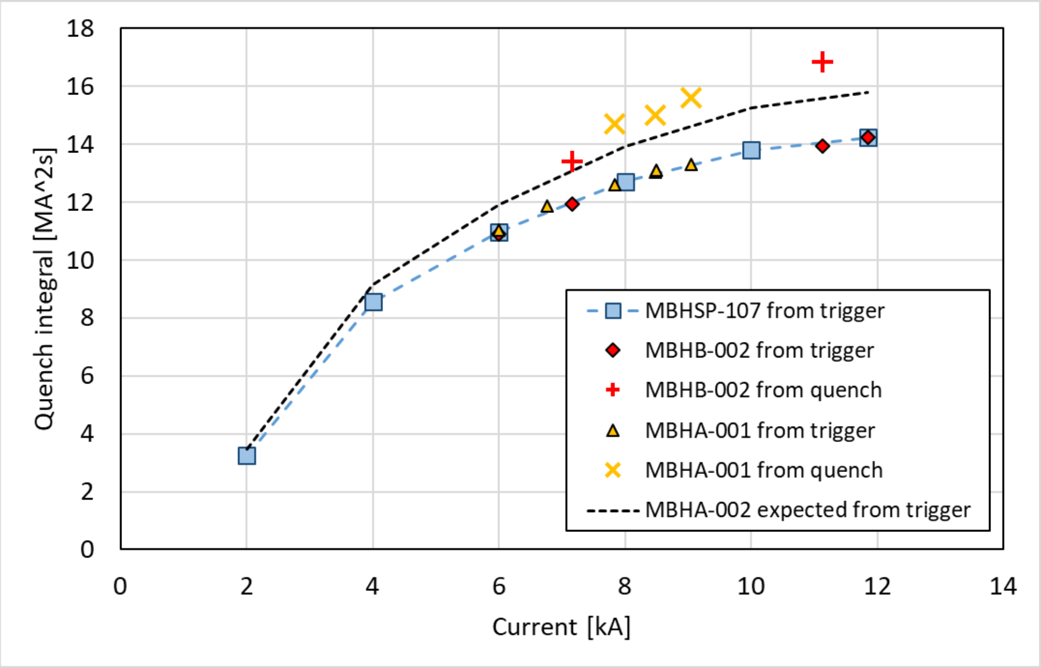
# Overview low current powering up to 6 kA

As for MBHB-002 and MBHA-001




Cool down 2:
Skip low current splice and 6 kA QI.

One important checkpoint: QI at 6 kA
Quench heaters are outside of the impregnation.
Expected QI of 12 $MA^2s$ compared to 11 $MA^2s$ for previous magnets.



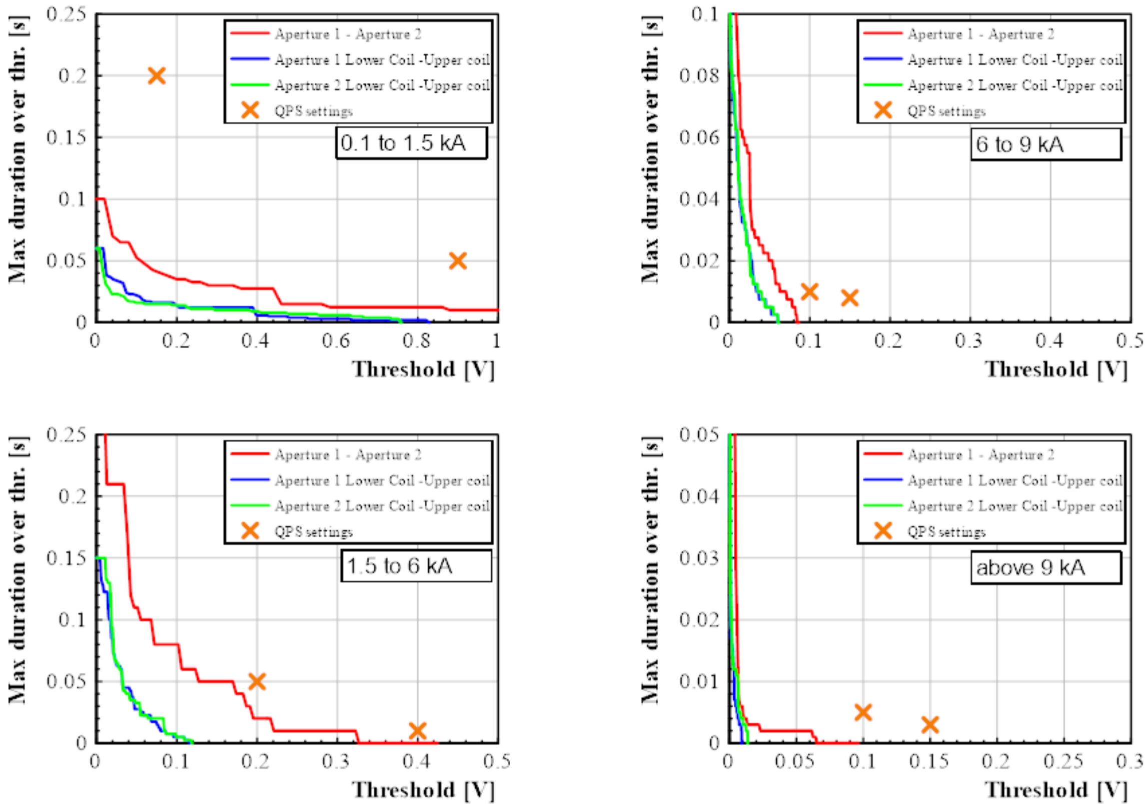

Calculations from S. Izquierdo Bermudez

# Flux jumps and Quench Detection settings

Protection settings optimized for flux jump in MBHB.
Table below shows the settings as used in CD 2.
Proposed for MBHA-001 are the same settings.

**Protection levels at 1.9 K, equal for all three protection channels. Each current range has two protection levels defined.**

| | Threshold, validation time | |
|---|---|---|
| **Current range** | **Lowest treshold** | **Shortest validation time** |
| I < 1.5 kA | 150 mV, 200 ms | 900 mV, 50 ms (insufficient for protection) |
| 1.5 kA < I < 6 kA | 200 mV, 50 ms | 400 mV, 10 ms (insufficient for protection) |
| 6 kA < I < 9 kA | 100 mV, **14 ms** *(was 10 ms)* | 150 mV, 8 ms |
| 9 kA < I | 100 mV, 5 ms | 150 mV, 3 ms |




With QPS an optimization is discussed to gain some detection time.

- Use the settings as in the table above for the differential between apertures.
- Use tighter setting on differential between upper and lower coil in the same aperture (either in time or threshold).

Firmware implementation can be rather soon, but is not foreseen for this magnet yet.

HiLumi HL-LHC PROJECT CERN

# Quench Heater – new test proposal

For MBHB-002 and MBHA-001 always a QH current of 150 A was used.

Specified maximum for the LHC is 200 A and it is likely that 200 A will be reached, so we need to test also at 200 A.

| | In the LHC [1]* | On the test bench |
|---|---|---|
| **Voltage** | 875 V | 900 V |
| **Capacitance** | 7.05 mF | 7.05 mF |
| **Strip resistance** | 3.5 Ω | 3.5 Ω |
| **Wire resistance** | ~2.2 Ω | ~0.2 Ω |
| **Additional variable resistance** | - | ~2.3 Ω (Reostat from 0 to 10 Ω) |
| **Total circuit resistance** | 5.7 Ω | 6 Ω |
| **Peak current** | Minimum 150 A<br>**Maximum 200 A** | Minimum 150 A (6Ω)<br>**Maximum 200 A** (4.5Ω) |
| **Time constant** | 40 ms | 42 ms |
| **Peak heating power** | 78 kW | 78 kW |
| **Energy deposited in heater** | 1570 J | 1660 J |

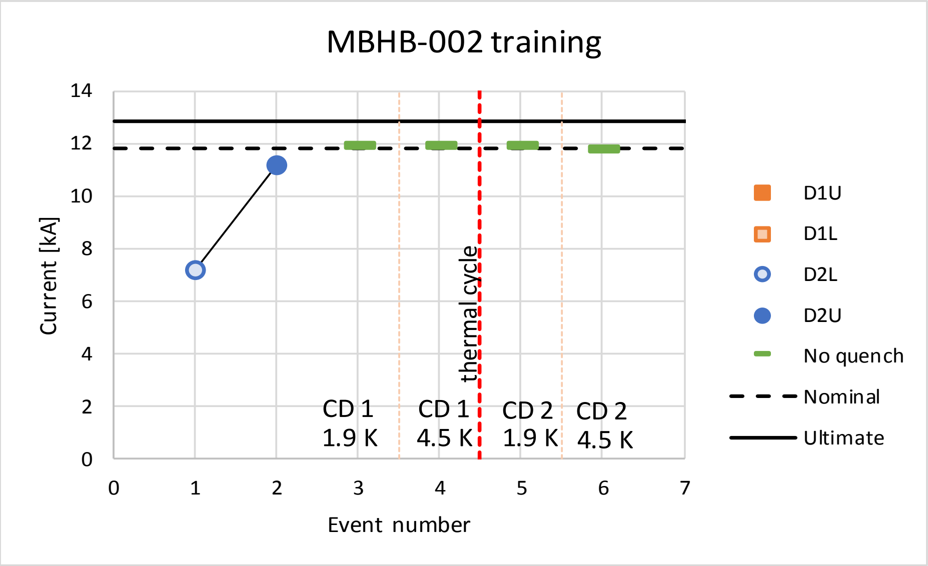
The circuit resistance for each Quench Heater can be varied using a rheostat:

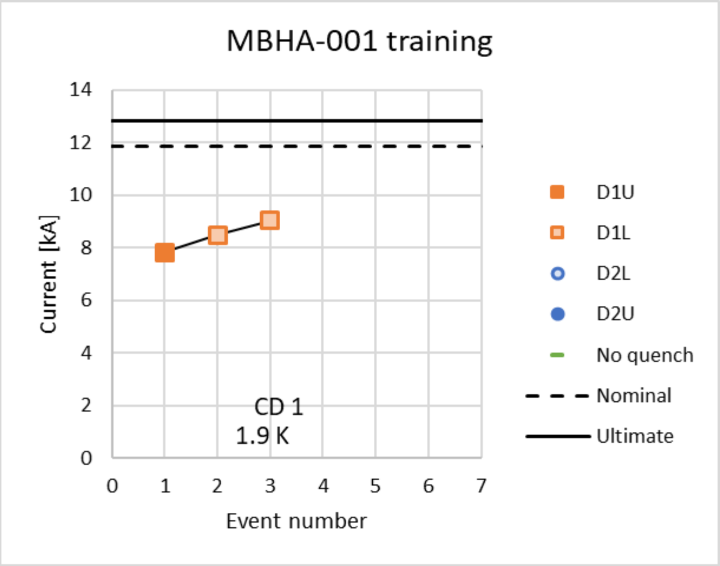
1. The circuit resistance is set to 6 Ohm (150 A peak current in the heaters) during the low current tests.
2. During magnet training and most powering tests the use 150 A.
3. Add 200 A test at 0 A and a 200 A QI test.

Option for discussion:
Use $I_{QH}$ = 200 A for training to keep QI slightly lower. Only a specific QI test with $I_{QH}$ = 150 A.

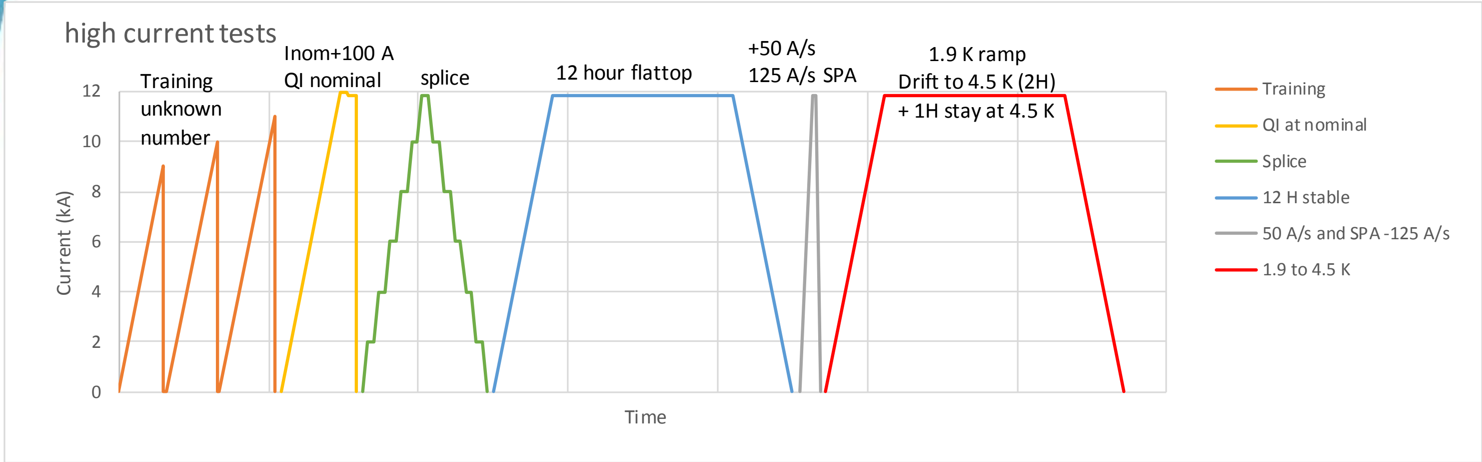
# Magnet training

Training up to 11.95 kA maximum *(see EDMS 2213035).*
Ramp rate 10 A/s.



# Overview high current powering > 6 kA




Similar to MBHA-001

# Stable current

## Done for MBHB-002

Cool down 1:
1.9 K, 11.85 kA, 2 hours
4.5 K, 11.85 kA, 1.5 hours

Cool down 2
1.9 K, 11.85 kA, 12 hours
1.9 to 4.5 K, 11.85 kA, 3 hours

## Proposed for MBHA-001 and MBHA-002

Cool down 1:
1.9 K, 11.85 kA, 12 hours
1.9 to 4.5 K, 11.85 kA, 3 hours

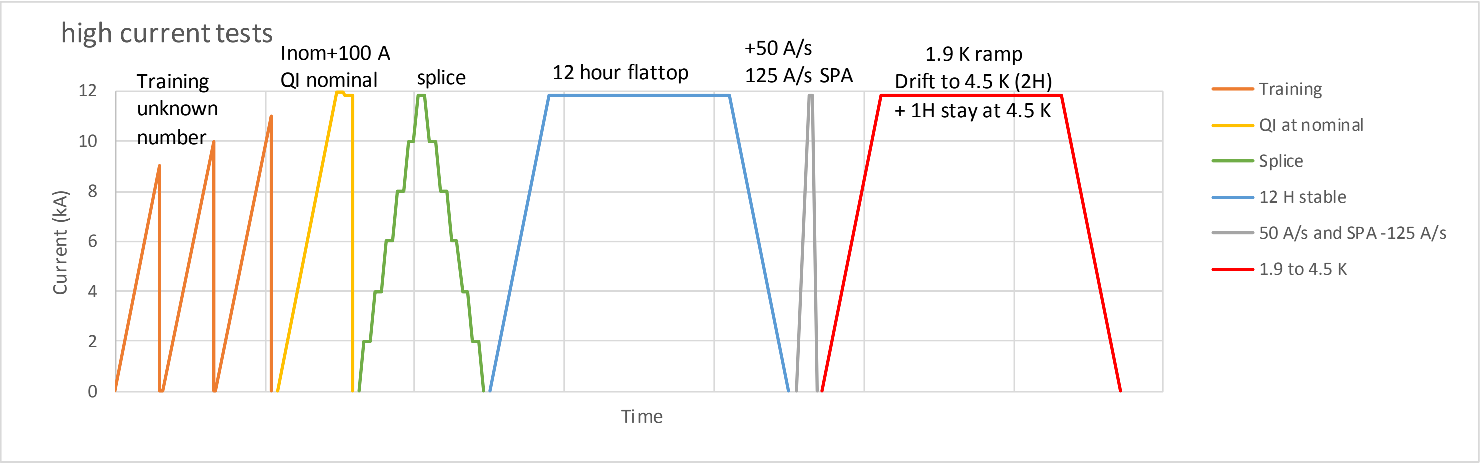
Cool down 2
1.9 K, 11.85 kA, 4 hours
1.9 to 4.5 K, 11.85 kA, 3 hours

# Ramp rate studies

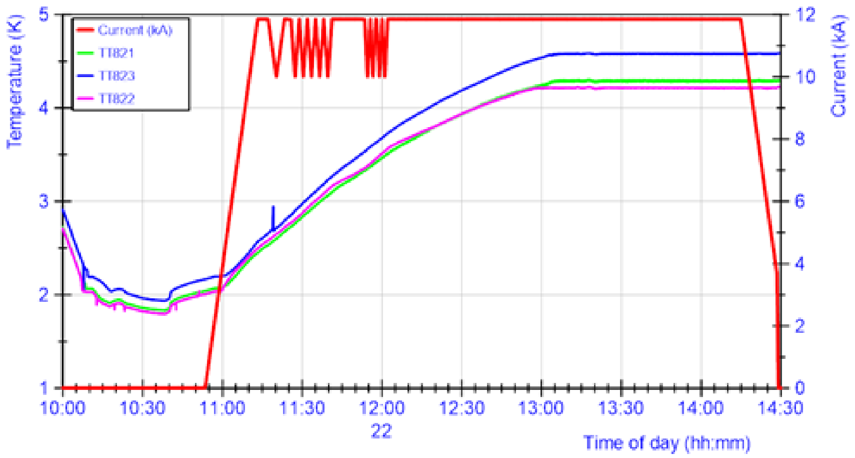
MBHB-002: Ramp up: up to 100 A/s performed.
Ramp down: up to -125 A/s in the SPA test. *(required for the LHC during RB energy extraction).*

MBHA-001 and MBHA-002: One relatively fast ramp at 50 A/s foreseen at 1.9 K, followed by SPA of - 125 A/s to show this gives no false trips.

*Any ramp at 4.5 K will likely not be feasible due to flux jumps in combination with protection levels.*



# Magnet margin at 4.5 K




Done for MBHB-002: Drifting from 1.9 K to 4.5 K while powering. This avoids flux jump trips at low current.

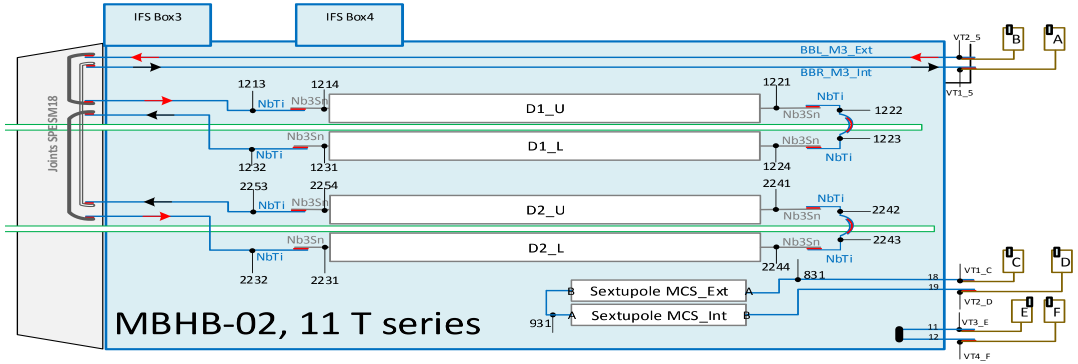
Proposed for MBHA-001 and MBHA-002: Same method is proposed (excluding high current cycling).

Total time about 5 hours (20 min ramp up, 2 hour T-drift, 1 hour flattop, 1 hour back to 1.9 K).

# Splices

MBHB-002

| Splice | Resistance [nΩ] | Comment |
|---|---|---|
| 1213-1214 | 0.15 (1 splice) | NbTi-Nb3Sn |
| 1221-1224 | 0.54 (3 splices) | Nb3Sn-NbTi-NbTi-Nb3Sn |
| 1231-2231 | 0.61 (3 splices) | Nb3Sn-NbTi-NbTi-Nb3Sn |
| 2244-2241 | 0.50 (3 splices) | Nb3Sn-NbTi-NbTi-Nb3Sn |
| 2254-2253 | 0.13 (1 splices) | NbTi-Nb3Sn |

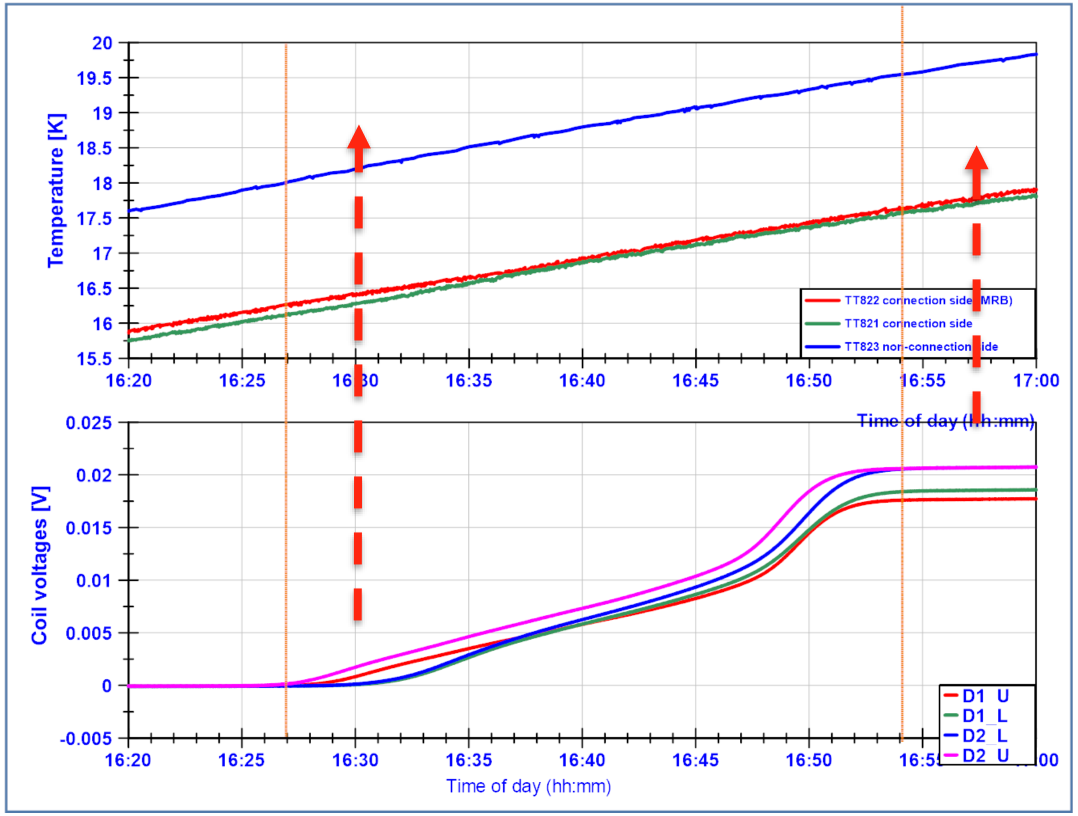



Done in MBHB-002: measure up to 3 splices combined. Only if resistance is high > 1 nOhm per 3 splices, redo measurements for individual splices.

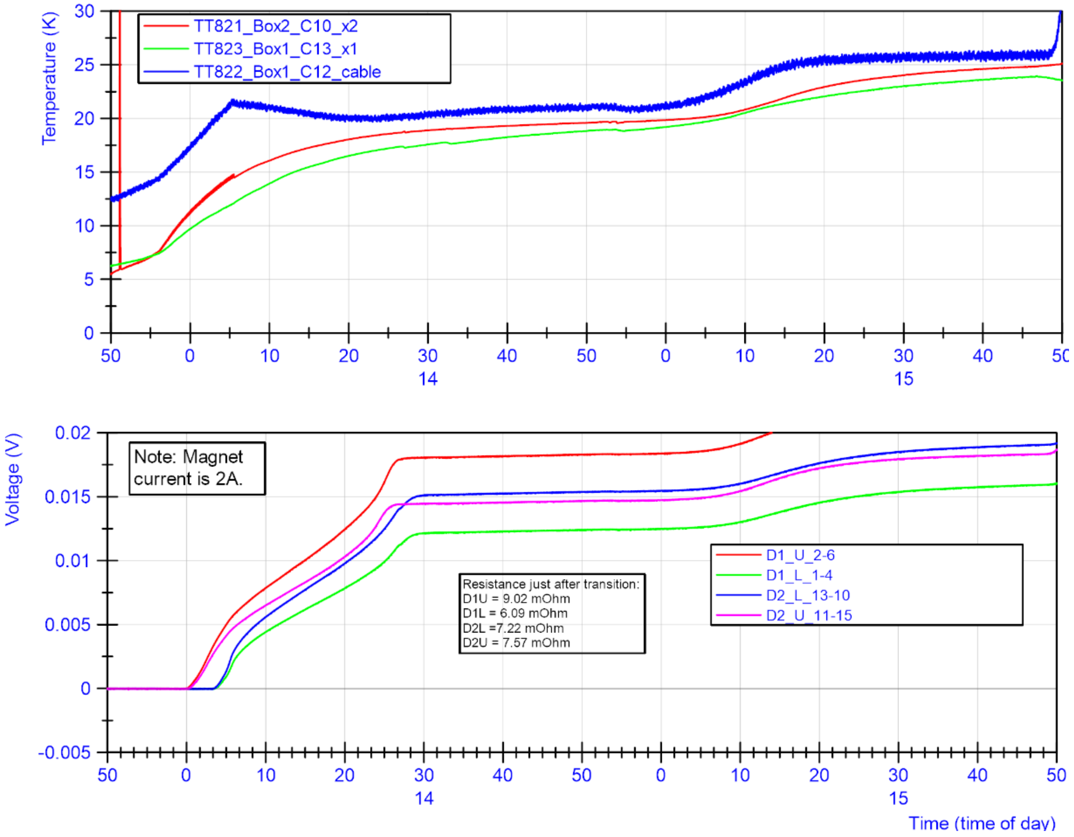
Proposed for MBHA-001 and MBHA-002: Same method.

# RRR

Done in MBHB-002: Accurate transition resistance measurement with slow drift of magnet temperature.



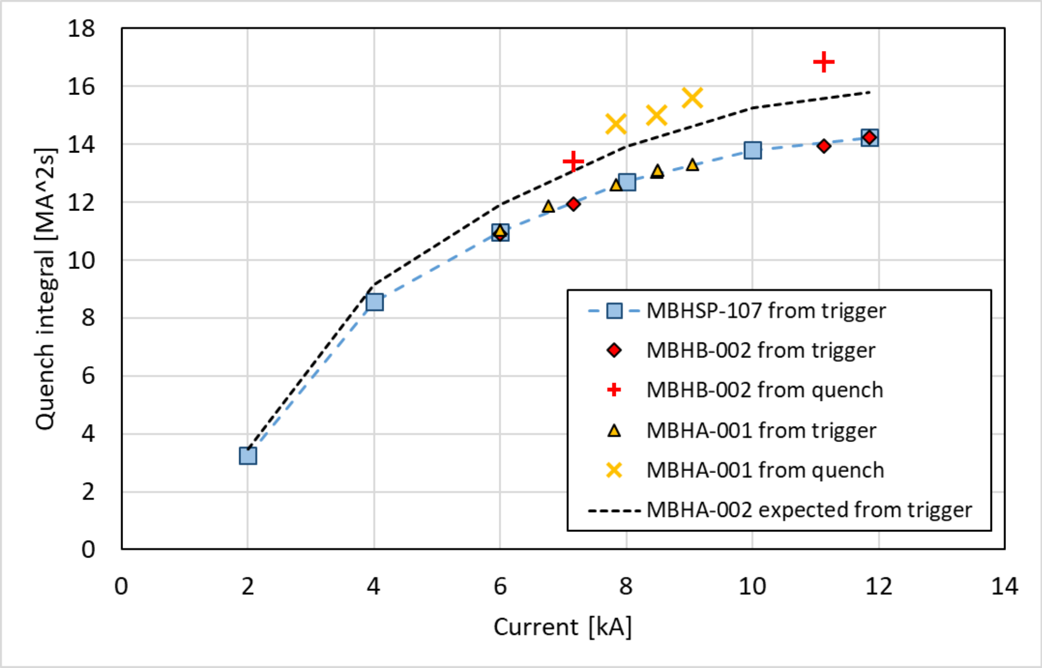

Done in MBHA-001: forced evaporation, and at the moment the transition started, the force He gas flow was stopped.
Faster method, still precise enough.
**Will be repeated for MBHA-002**

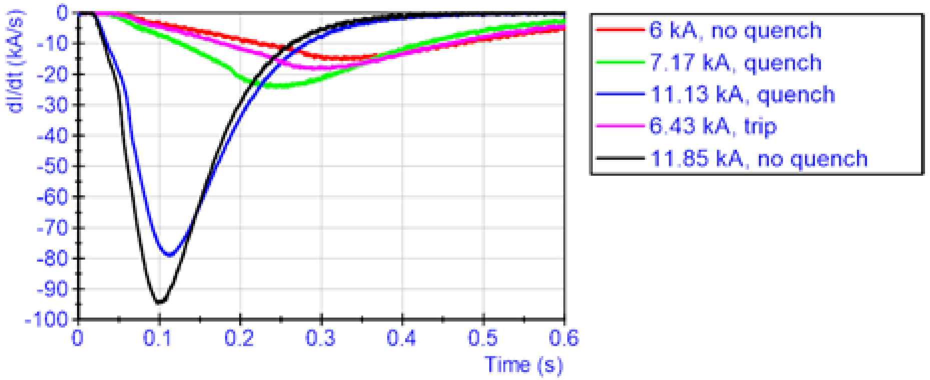


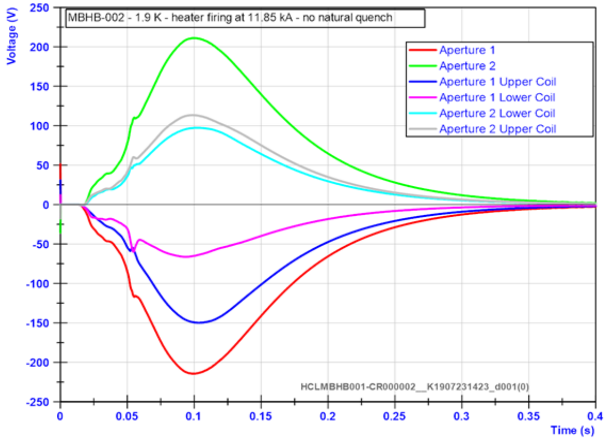
# Quench integral study at 6 kA and 11.85 kA

Quench heater firing at nominal current gives multiple important data:

- Voltage imbalance between coils following heater firing (important in HV calculations)
- Quench Integral
- dI/dt characteristics.
- Quench Heater efficiency




MBHB 1.9 K, 11.85 kA

Total resistive voltage = 6500 V.
Voltage Aperture 1: 3040 V
Voltage Aperture 2: 3460 V
Imbalance of 14 %

Heater firing at nominal current, without a natural quench in the magnet.
420 V resitive voltage imbalance between aperture 1 and aperture 2

# High Voltage insulation test, instrumentation tests

Tests for all MBHA and MBHB magnets identical.

Note:
MBHB cryo assemblies include an MCS magnet circuit.
MBHA cryo assemblies include MCO and MCD magnet circuits.

MBHA-002 has **trim leads**, which are connected to the main circuit. By definition it will see the potential of the main circuit.

| Polarity + | Polarity - | Warm initial | cold | Warm final |
|---|---|---|---|---|
| Dipole-Quench Heaters | Ground | 300/660 | 300/660/1850/**3300** | 300/660 |
| Dipole | Quench Heaters - Ground | 300/660 | 300/640/1850/**3200** | 300/660 |
| Dipole | Ground | 300/660 | 300/660/1850/**3300** | 300/660 |
| Dipole | All Quench Heaters | 300/660 | 300/640/1850/**3200** | 300/660 |
| All Quench Heaters | Ground | 300/660 | 300/660/1850/3300 | 300/660 |
| Dipole | MCS-MCD Correctors | 250 | 250/975 | 250 |
| MCO/MCD Correctors | Ground | 250 | 250/975 | 250 |
| Ext/Int Passive Busbar | Ground | 600 | 600/1850/**3075** | 600 |
| Ext Passive Busbar | Internal Passive Busbar | 600 | 600/1850/**3075** | 600 |
| Cryo Heater | Ground | | 675 | |
| Cold Temp. Sensor | Ground | | 25 | |
| Dipole | QH1 to QH 8 | 300/**660** | 300/640/1850/**3300** | 300/**660** |
| QH1 to QH 8 | Ground | 300/**660** | 300/660/1850/**3300** | 300/**660** |
| Dipole | Lead EF_BB11&12 | 250 | 250/975 | 250 |
| Lead EF_BB11&12 | Ground | 250 | 250/975 | 250 |

Test request: 200 K, 3 bar, 750 V during final warm up.
Not decided yet?
SP109 test starts today and HV results will be available by 24 January.

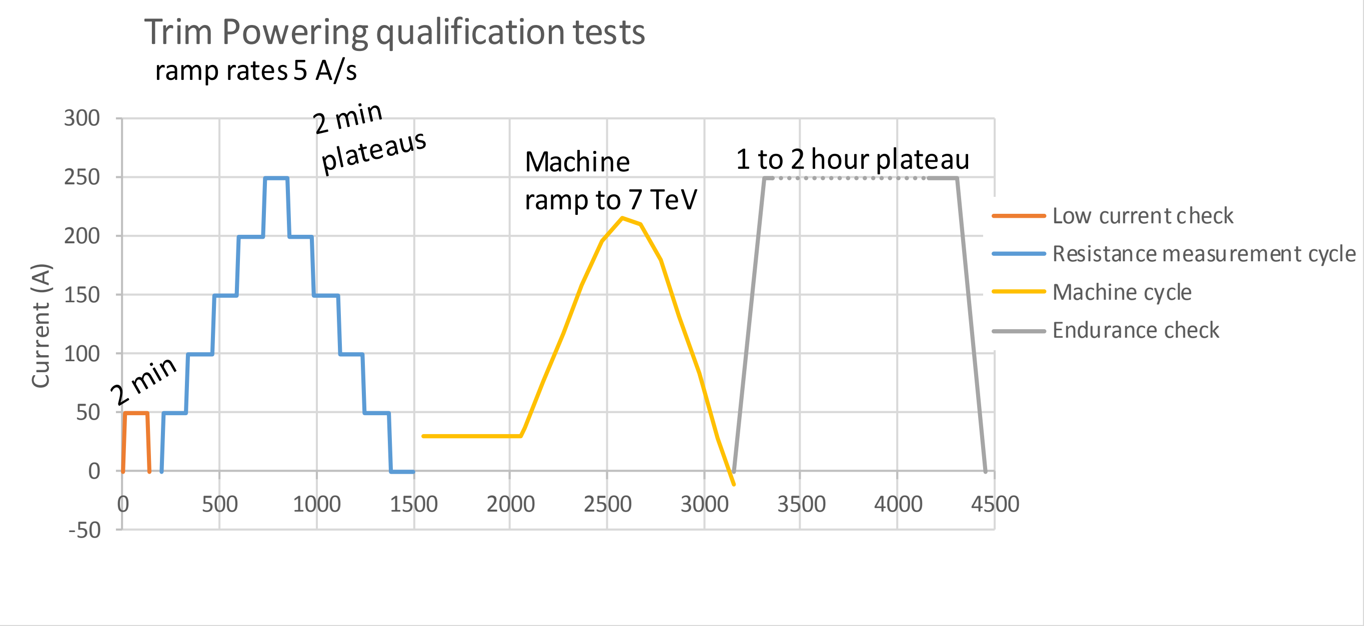
# Magnetic Measurements

MBHB: Full measurement set done by Lucio, see EDMS 2219199

MBHA: No specific time allocated to MM, low priority.
The MM shaft will be used already for quench localisation.
If time permits a machine cycle will be considered.

# Trim Qualification tests

Trim design current = 250 A
Maximum LHC current needed in trim is <220 A
Given nominal He-flow is 0.9 g/s




**Standard** qualification tests at nominal He-flow

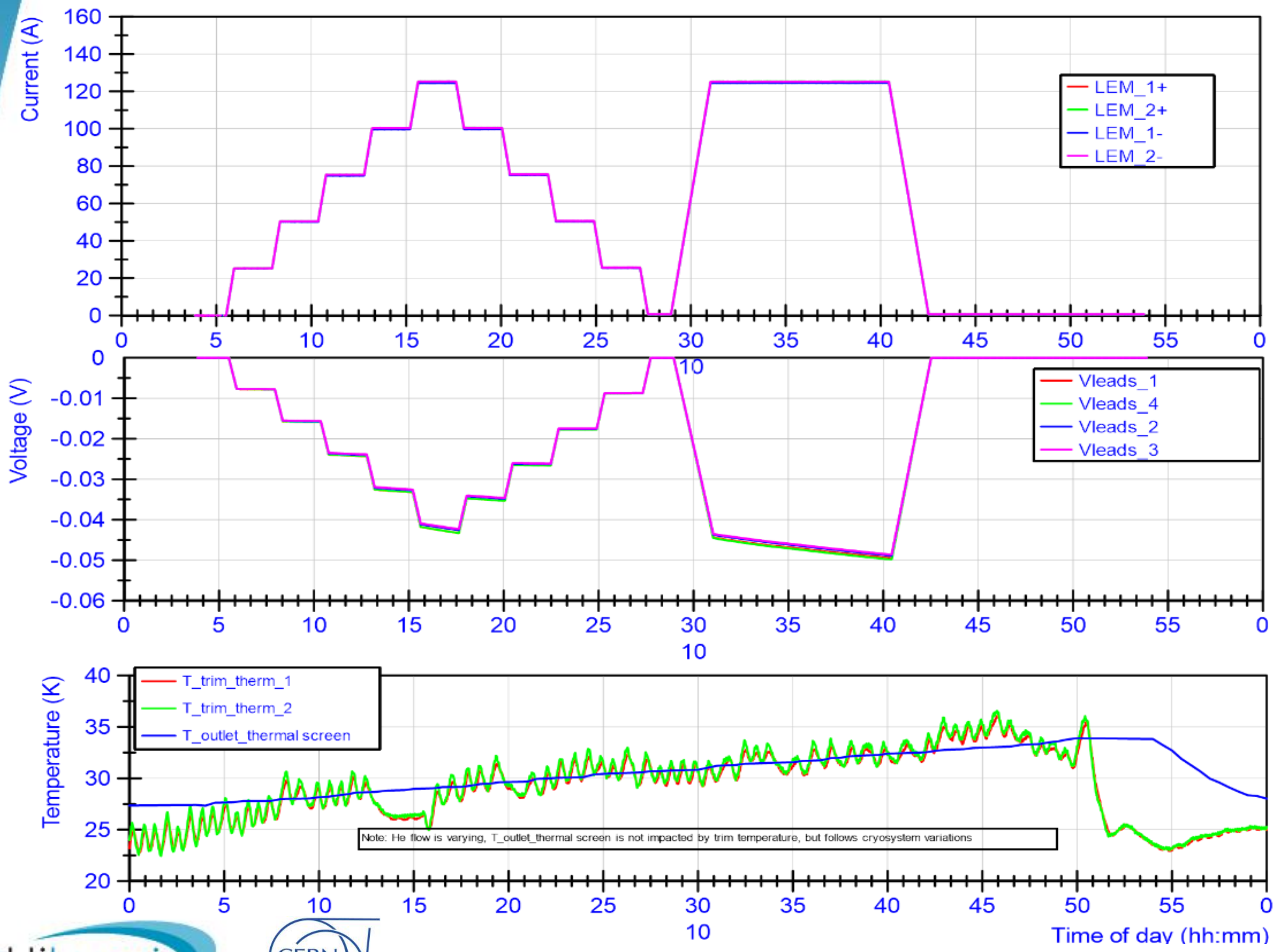
1. 50 A check
2. Resistance measurement plateaus
3. Machine ramp: injection → ramp to 7 TeV
4. Plateau at 250 A design current, wait for stabilization of trim temperature and voltage (Maximum 3 hours). At 0.9 g/s if control is available for MBHA-002. Likely much higher in MBHA-001

Proposal for additional tests specific to MBHA-002

*Repeat test 4 at LHC maximum current of 220 A at 0.9 g/s*

*Repeat test 4 at 250 A with a He flow of 1.5 g/s*

# Results MBHA-001 trim test (1)




The stair case step showed a very good distribution in current between the 2 positive current leads and between the two negative current leads.

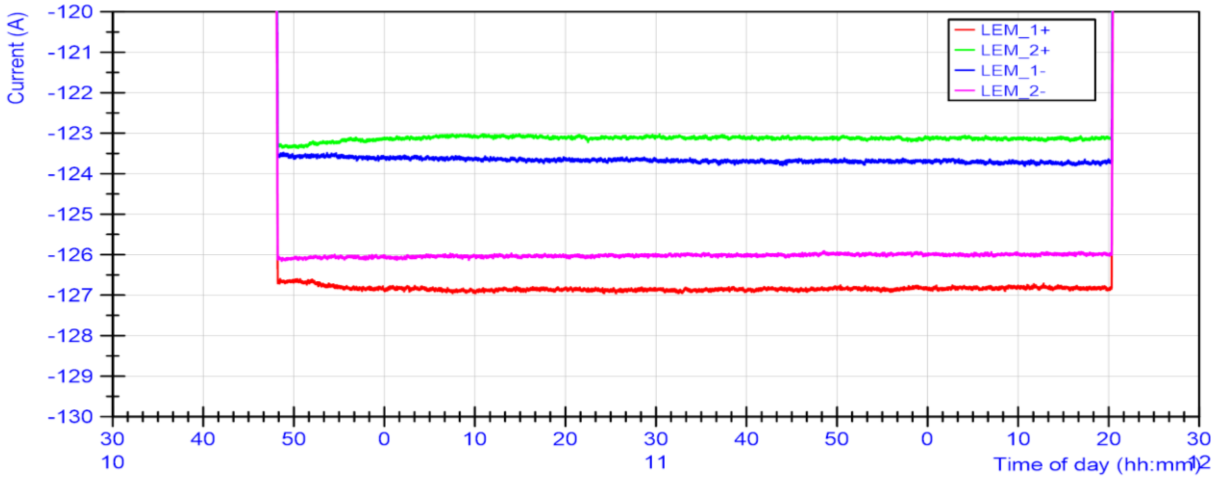
The voltage measurement shows the same

(note that in the first test one lead had a 10 mV higher voltage due to a bad connection on the room temperature side. This was fixed during the test campaign)

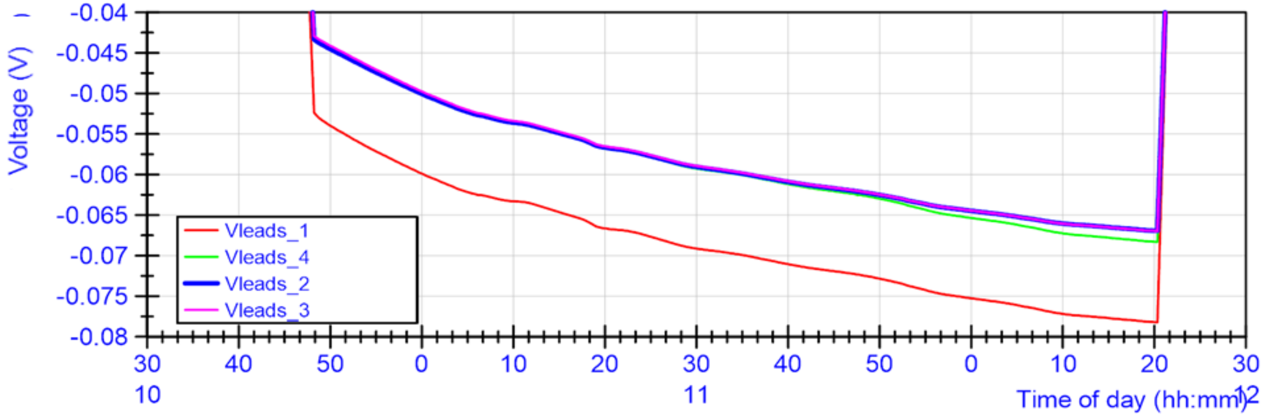
Temperature of the trim block:

The flow was not controlled, and depends on the pressure in the cryoplant (quenches in other magnets). The trim thermalisation temperature variation depends here more on flow than powering.

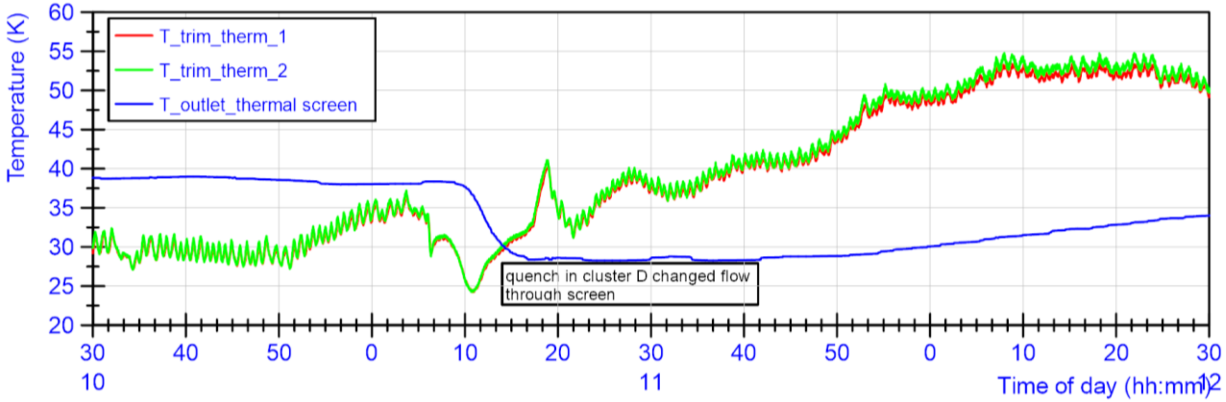
# Results MBHA-001 trim test (2)




1.5 hour duration test.
Stable current distribution between leads.



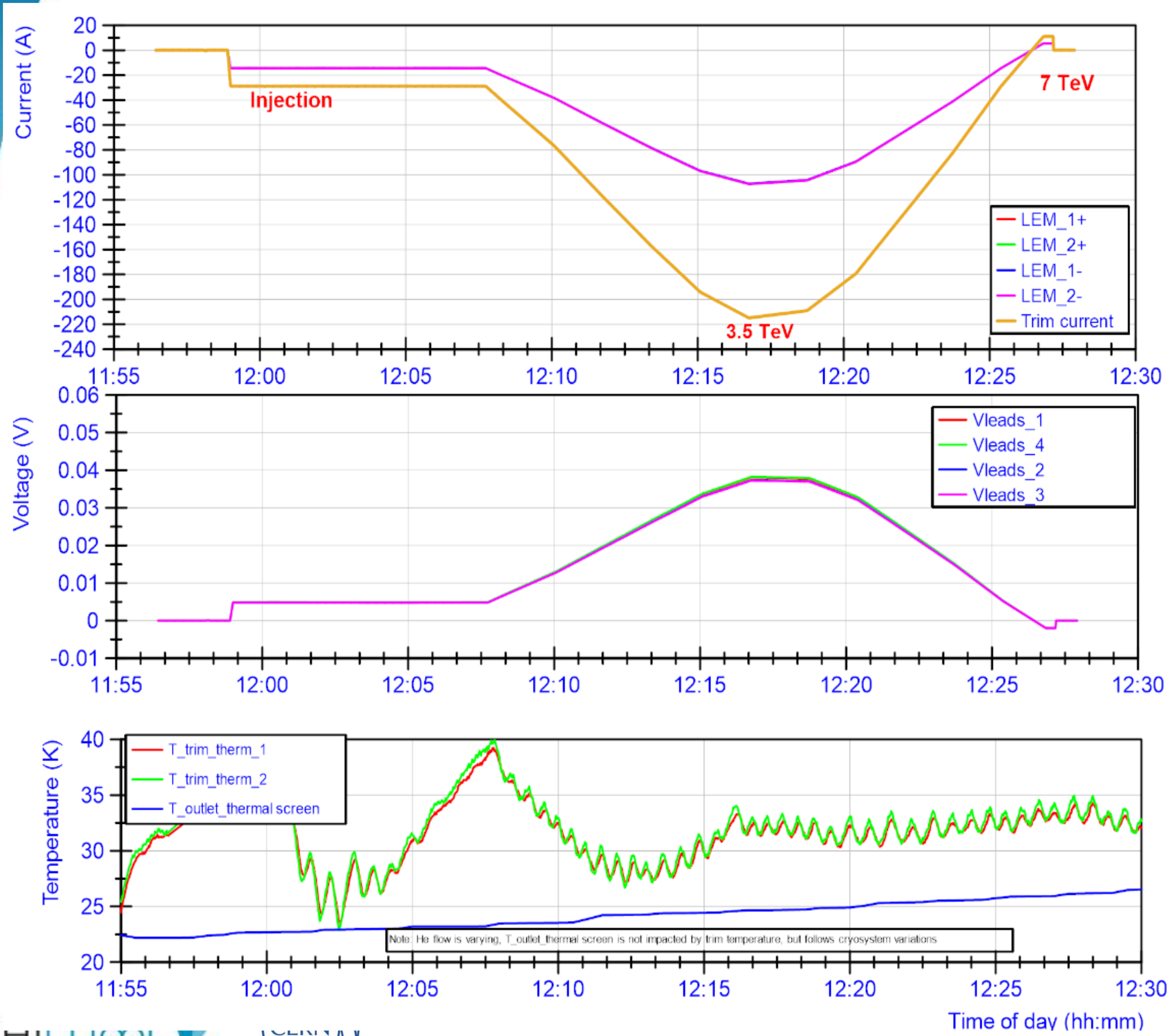

Voltage in normal conducting part is drifting from 44 mV to 67 mV (threshold is 150 mV)
No quench recorded in SC part.




Temperature of the trim block:
Temperature of the trim thermalization higher than the He gas exit. No full heat exchange between block and Helium gas.

*Gas flow and temperature not controlled and depending on cryo system in the building.*

# Results MBHA-001 trim test (3)



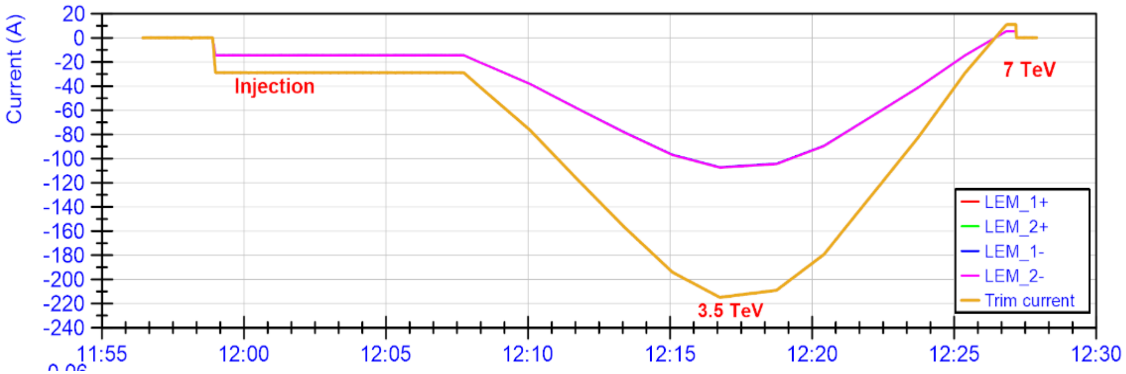

LHC standard ramp: 220 A maximum.

Voltage in normal conducting part remains below 40 mV

Temperature of the trim block:
No significant change during powering

*(Gas flow and temperature not controlled and depending on cryo system in the building.)*

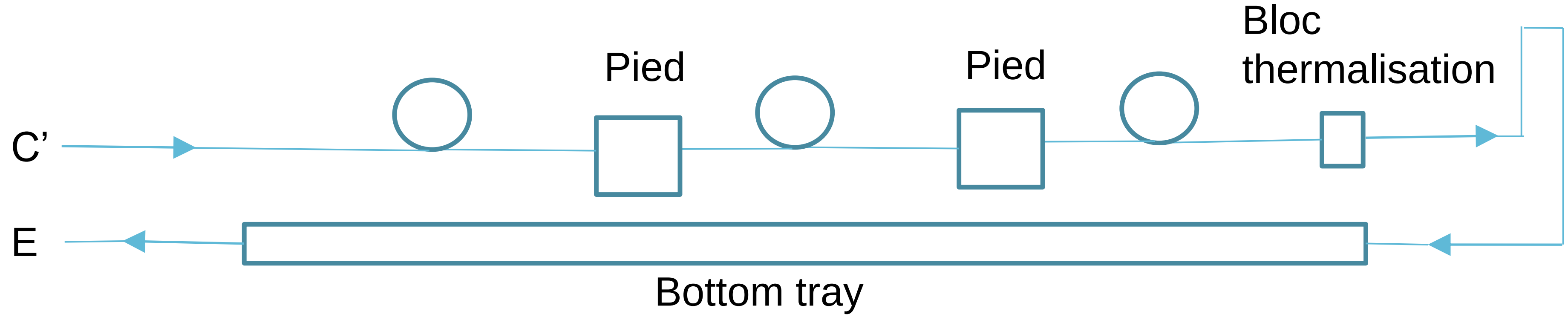
# Conclusions trim test

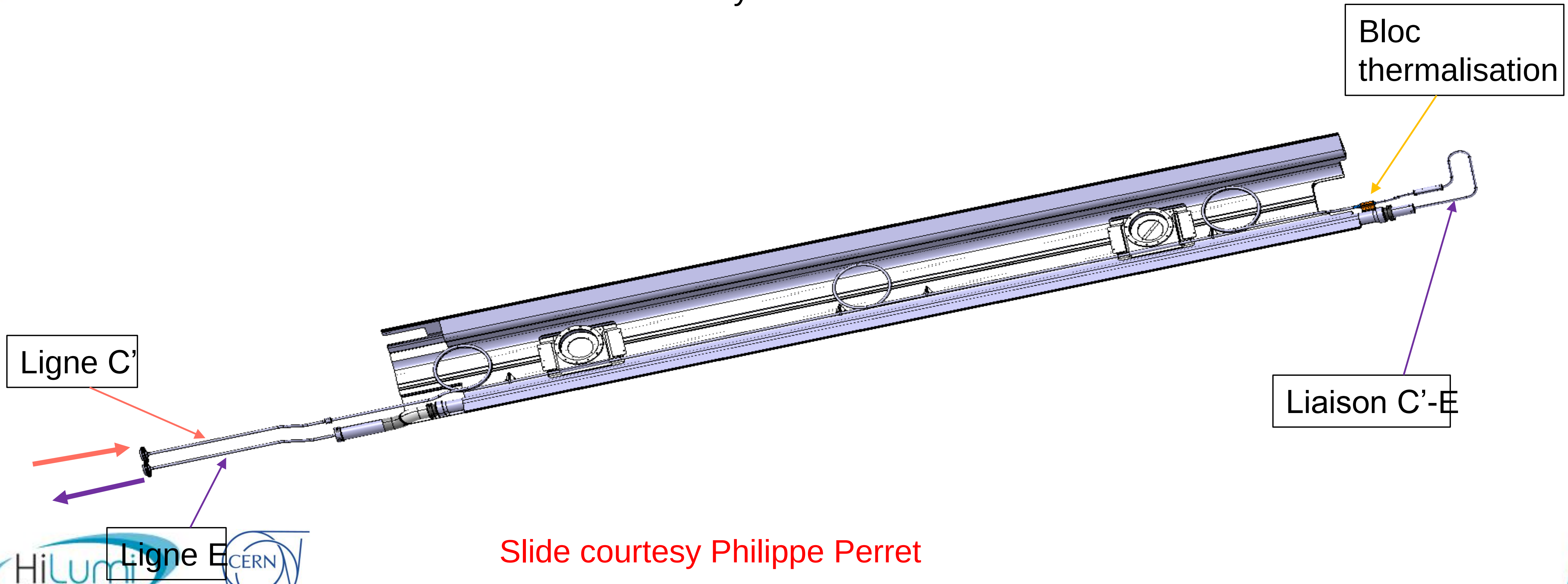



Current sharing and SC part: OK
Total voltage over NC parts: OK, Well below threshold.

**Temperature stability:**
7 TeV machine cycle: OK
Design Current (250 A) endurance test: not so bad, but unknown He-flow and no stabilization after 1.5 hour

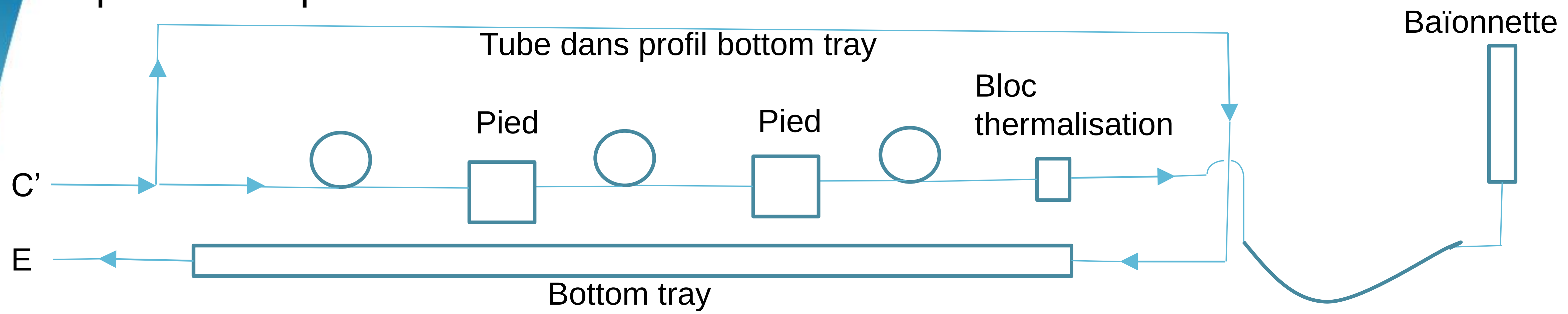
# Normal setup for MBHA magnets (used for MBHA-001)

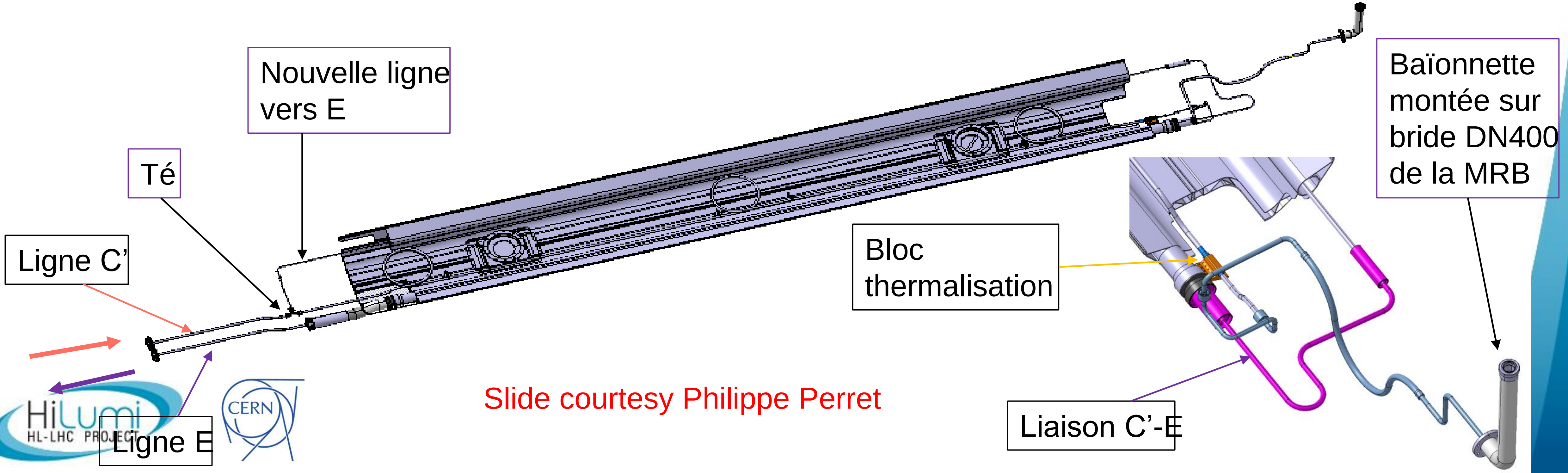



Slide courtesy Philippe Perret

# Special setup for MBHA-002



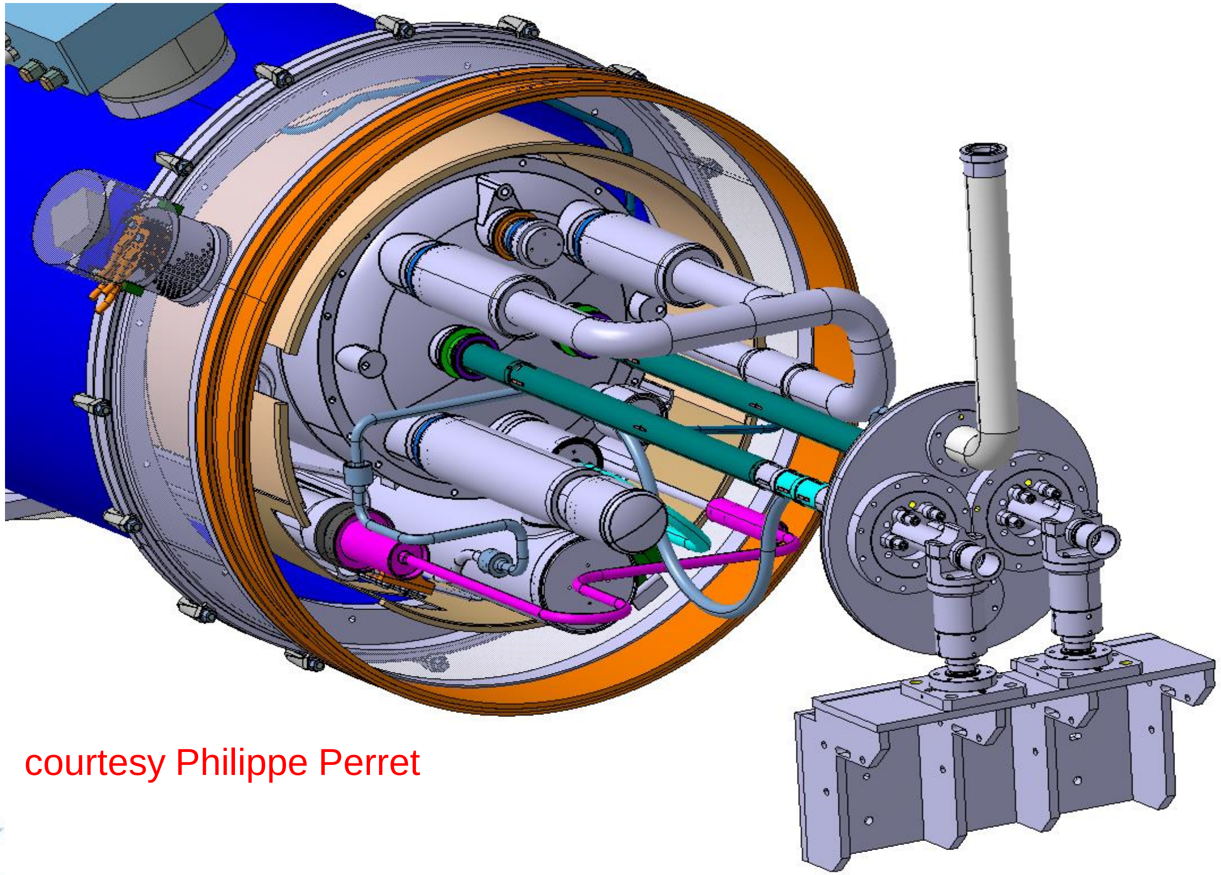




Slide courtesy Philippe Perret

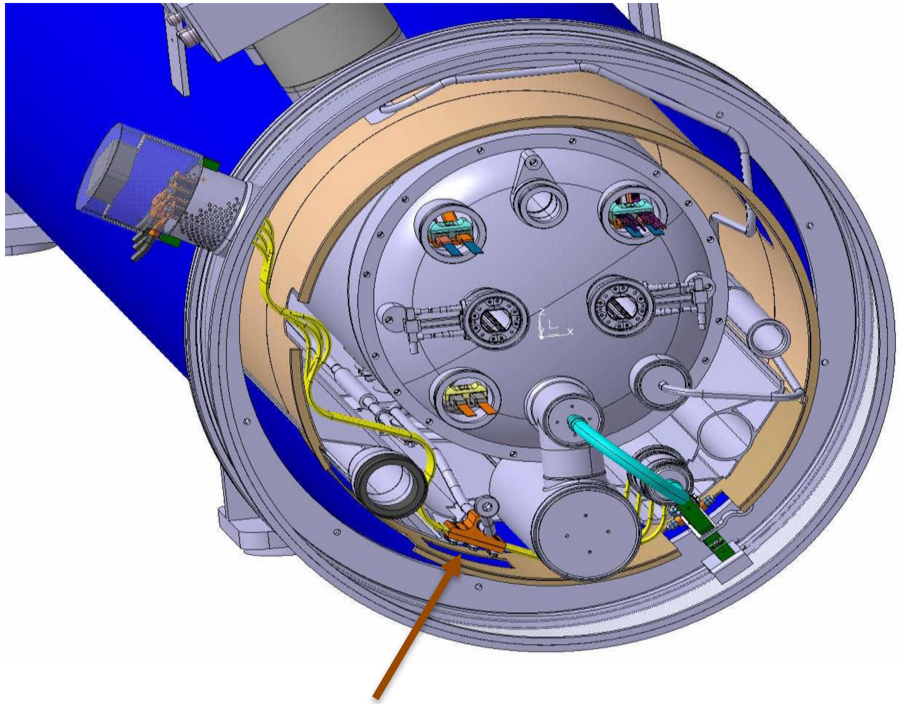
# Trim lead configuration MBHA-002

Special configuration for MBHA-002:
Helium gas flow from CFB boiloff, through magnet feet, then through thermalisation, returning through screen.

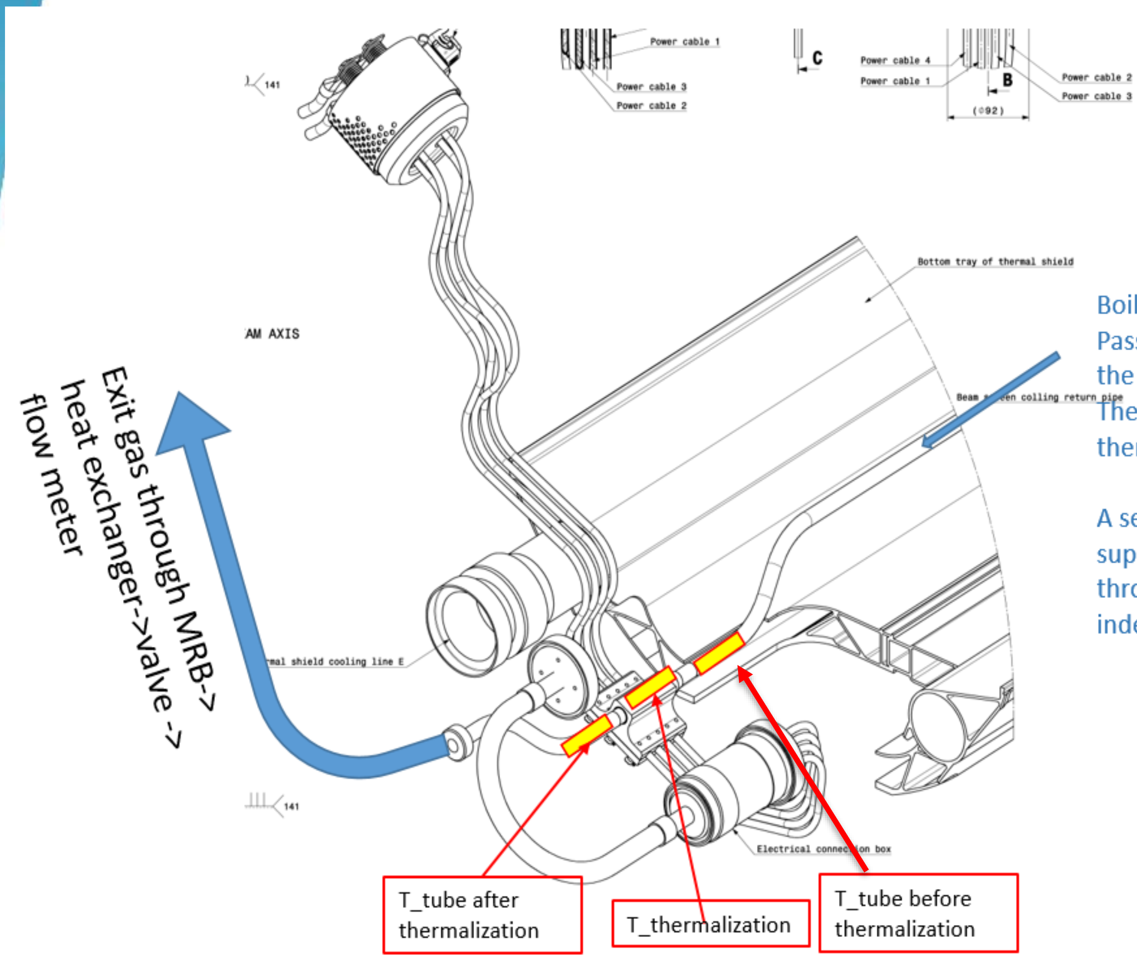
Added system to control and measure the flow. Thanks to the fast response of a large team, it was actually a **large modification:**
Herve Prin, Philippe Perret, Delio Duarte Ramos, Graeme Barlow, Gabriella Rolando, Jeremy Mouleyre, Nicolas Vauthier.



courtesy Philippe Perret



# MBHA-002: Trim temperature and He-flow measurement




Boil-off from CFB He-gas Passing through the feet of the magnet Then through the thermalisation of the trim.

A second line is installed to supply helium gas flow through the thermal shield independently.

T-probe on the tube before trim thermalization
T-probe on the trim thermalization block
T-probe on the tube after trim thermalization
He-flow meter after the heat exchanger

**Manual valve, manual control.**

- Up to the valve, the trim circuit can withstand 20 bar. The flow meter and helium return circuit (both after the valve) cannot withstand 20 bar.

**Safety measures:**

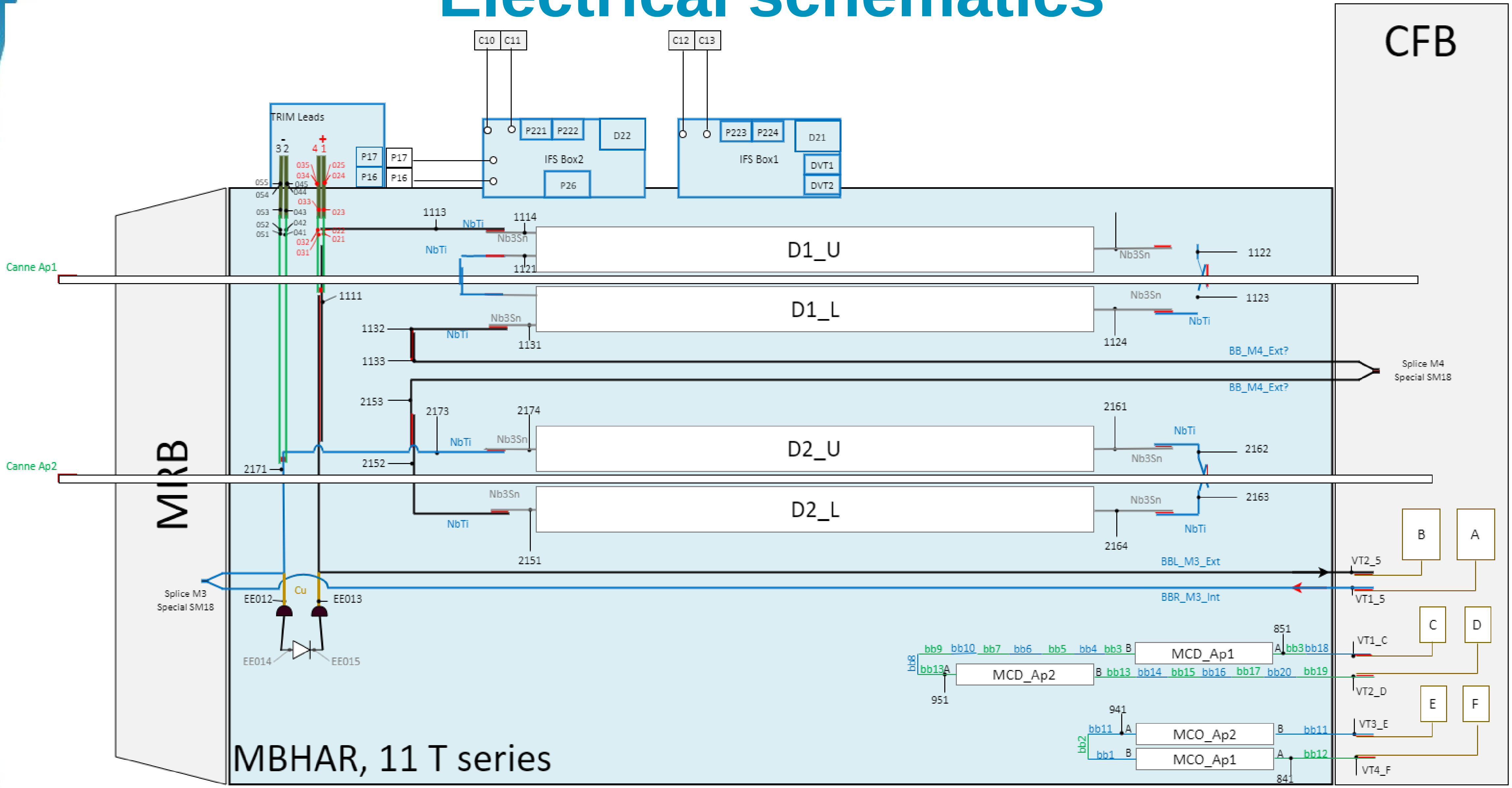
- **Valve remains closed** during all magnet powering with the 13 kA PC and during warmup, cool down, weekends and night.
- The valve will only be opened during the trim powering up to 250 A.
- The zone between bench C1 and C2 will be physically blocked with barriers and signs.

# MBHA-002 test planning

- Start with 1.9 K tests tomorrow.
- Extended working hours with two teams (operator+engineer)
- Target: Warmup start the latest by by Friday 7 February.

# Backup slides

# Electrical schematics



Slide courtesy Philippe Perret