# Progress on qualification tests and status of benches

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# Qualification of magnets and status of test benches in SM18 at CERN

## Vertical benches

- MCBXFA/B
- MCBRD
- MQML
- MSCB

## Horizontal benches

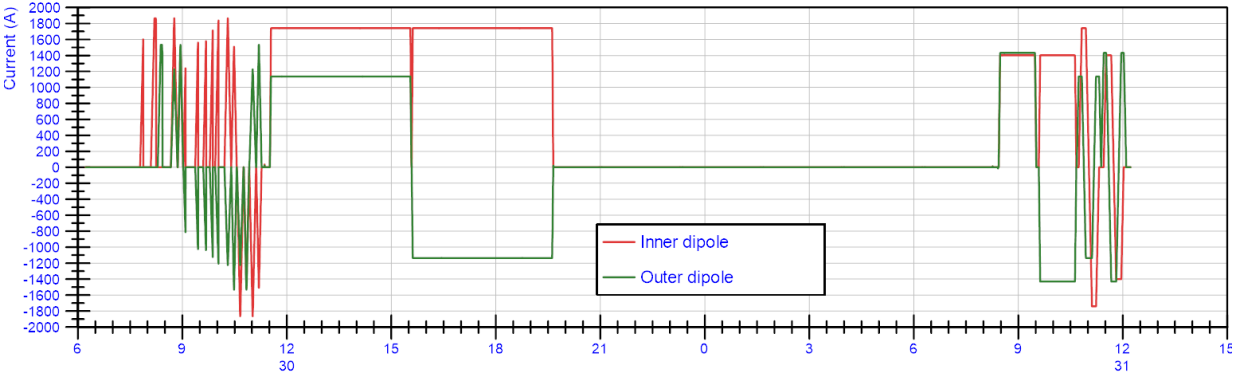
- Q2
- Q1/Q3
- CP
- D1
- D2
- SC-link
- Q10

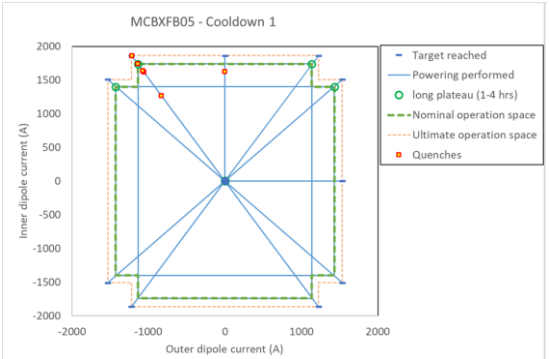
# Tests on Vertical benches

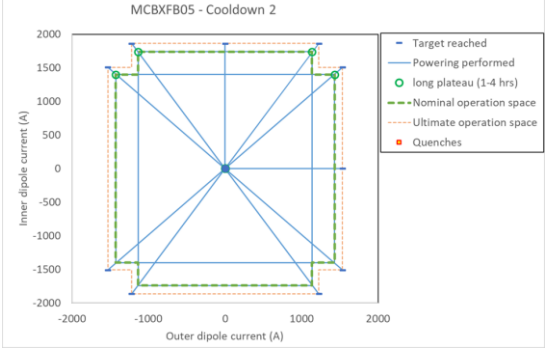
# MCBXFA/B

| Object | Test completed | In test | To be tested |
|---|---|---|---|
| MCBXFA | P1 1 | | 2 3 4 5 6 |
| MCBXFB | P1 P2 01 02 03 04 05 | | 06 07 08 09 10 11 12 |

| | |
|---|---|
| Test station: | Cluster D |
| Number of cool downs: | 2 |
| Test temperature: | Only 1.9 K |
| Test station occupation: | ~ 3 weeks |
| Magnetic measurements: | Yes |
| Cold phase including powering: | 3 days per cool down |
| Units to test: | 12 |



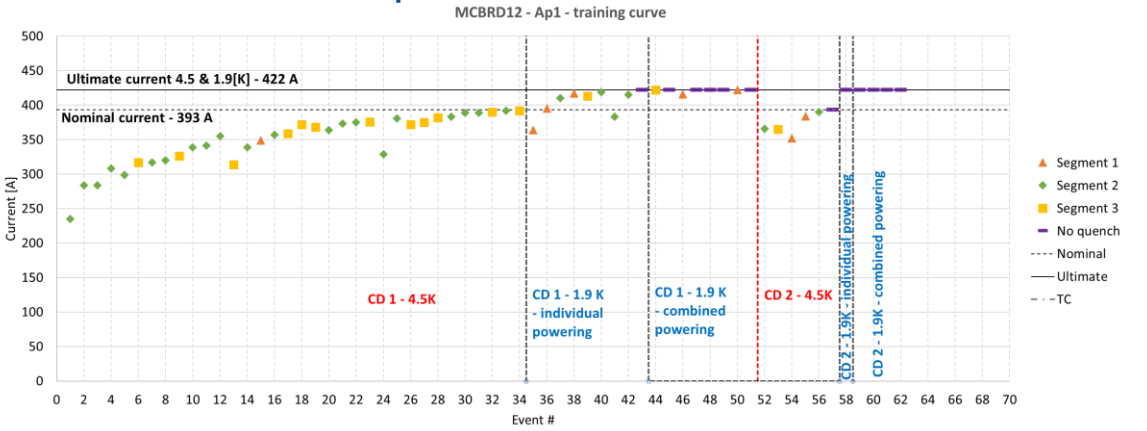
# MCBRD

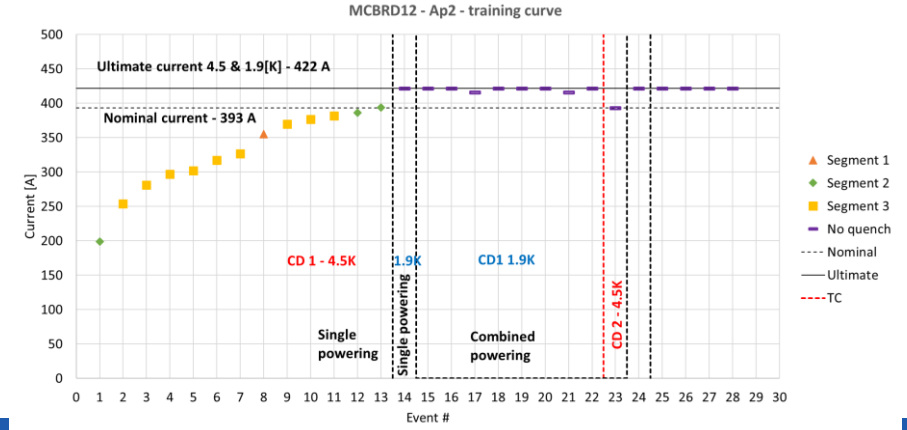
| Object | Test completed | In test | To be tested |
|---|---|---|---|
| MCBRD | P1 P3 P4 01 02 P2c 12 04 | | 11 03 05 06 07 08 09 10 |

| | |
|---|---|
| Test station: | Cluster D |
| Number of cool downs: | 1 if already tested in China,<br>2 if not tested before. |
| Test temperature: | Only 1.9 K |
| Test station occupation: | ~ 3 weeks |
| Magnetic measurements: | No |
| Cold phase including powering: | 4-8 days per cool down (depends on training temperature.) |
| Units to test: | 12 |

MCBRD tests are done at IMP in China.
Magnets 11 and 12 are produced at CERN.
Depending on test strategy (4.5 K training or 1.9 K training, 1 or 2 cool downs) the test can be short or long, see next slide for an example.

# MCBRD – test example




MCBRD12 was produced at CERN, tested in March 2024.

- Although operation temperature is 1.9 K, training was done at 4.5 K to be able to compare with training at IMP.
- The training at 4.5 K with a sum of 47 quenches in both apertures. This costed 4 days of test time.

- For this test campaign, including magnetic measurements, the test time was 2 weeks for the first cool down and 4 working days for the second cool down.
- This can be reduced to 3 days per cool down if tests are only at 1.9 K. This assumes that at 1.9 K the training is much faster.

# MQML

| Object | Test completed | In test | To be tested |
|---|---|---|---|
| MQML | 42 41 39 | 38 | 36 |

| | |
|---|---|
| Test station: | Cluster D |
| Number of cool downs: | 1 |
| Test temperature: | Only 1.9 K |
| Test station occupation: | 2 weeks |
| Magnetic measurements: | No |
| Cold phase including powering: | 3-4 days per cool down |
| Units to test: | 1 this week, one to go in 2 weeks |

Each of the four new Q10 assemblies requires one MQLM and one MSCB corrector magnet.

The 5 spare MQML magnets were built during LHC production, but never tested before (never assembled in horizontal cryostat and with 5 meter length there was no vertical cryostat available).

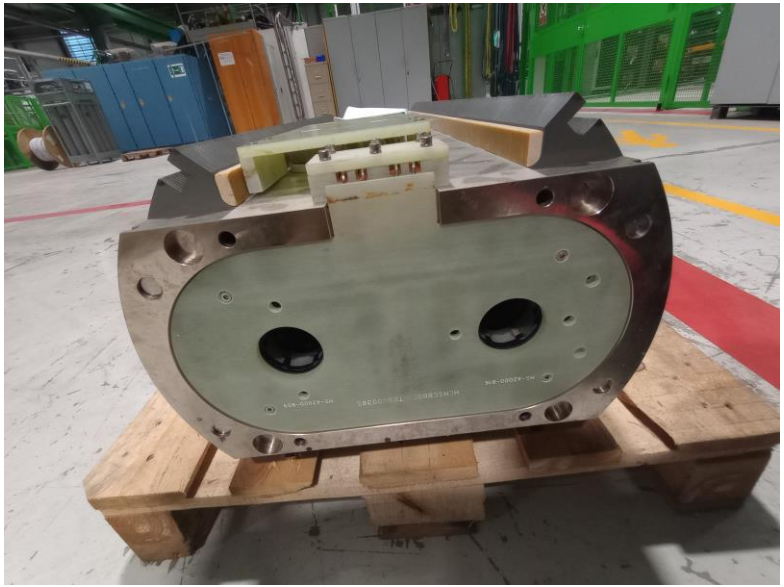
In 2023 the rotation tower for cluster D was completed, allowing magnets up to 5.2 meter length to be tested.

Test results:
MQML42: One quench heater failed during first discharge, causing damage to coil insulation: Coil cannot be re-used and magnet is disqualified.
MQML41: Qualified. 2 training quenches close to ultimate current.
MQML39: Qualified. One training quench close to ultimate current.
MQML38: Today first powering…

# MSCB

| Object | Test completed | In test | To be tested |
|---|---|---|---|
| MSCB | 1 | | 2 3 4 |

| | |
|---|---|
| Test station: | Siegtal |
| Number of cool downs: | 1 |
| Test temperature: | Only 1.9 K |
| Test station occupation: | 2 weeks |
| Magnetic measurements: | No |
| Cold phase including powering: | 3 days per cool down |
| Units to test: | 3 |



Each of the four new Q10 assemblies requires one MQLM and one MSCB corrector magnet.

Retesting these magnets before re-assembly of the Q10.
1 test done last year, 3 to test this year.

The Siegtal test station has a small cryo consumption. Little interference with other tests.

# IT-diode stack

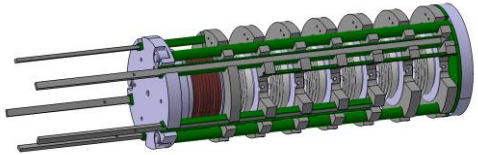
| Object | Test completed | In test | To be tested |
|---|---|---|---|
| IT-diode stack | P1 | | 1 2 3 4 5 |

| | |
|---|---|
| Test station: | Diode |
| Number of cool downs: | 1 |
| Test temperature: | Only 4.5 K |
| Test station occupation: | 2 weeks |
| Magnetic measurements: | No |
| Cold phase including powering: | 3 days per cool down |
| Units to test: | 5 |

The HL-LHC IT-diode stacks consist of 6 diodes and are part of the MQXF circuit.

The prototype stack has been tested in 2023 with good results and is qualified for the IT-String. It included LHC ‘standard’ diodes. The five series diode stacks include diodes with higher radiation tolerances.

Test program established. No showstoppers foreseen. Small cryo consumption.

# Cluster D

Cluster D is the work horse for HL-LHC magnets. It is the only cryostat that fits MCBXFA and MQML magnets, and it is the only station optimized for the 2*2 kA circuits for MCBXFA/B and MCBRD magnets.

Test efficiency is very important:

- Recently cryogenics operation fully automated cool down, warm up and thermal cycle processes. Recent re-commissioning of the 25000 liter dewar increased cryo-efficiency.
- Since one year overnight powering reduced test time by 1-2 days per cool down for MCBXF and MCBRD magnets.

Still 21 magnets to test. Critical test facility for HL-LHC as MCBXF magnets need to be delivered for Q2 and CP production.
Large volume of helium needed, and it has a rather large cryogenic consumption.

Important coactivity between cryo operators and magnet test operators.

# Tests on horizontal benches

# Q1/Q3

| Object | Test completed | In test | To be tested |
|---|---|---|---|
| Q1/Q3 | 01 | | 04 |

| | |
|---|---|
| Test station: | A2 |
| Number of cool downs: | 1 (magnet tested before at FNAL.) |
| Test temperature: | 1.9 and 4.5 K |
| Test station occupation: | 5 weeks |
| Magnetic measurements: | Yes |
| Cold phase including powering: | 3 weeks per cool down. |
| Warm up/cool down duration: | ~6-7 days per warm up/cool down |
| Units to test: | 1? (under discussion) |


The test bench has been completed in April 2024 and the Q3 has undergone 2 cold powering phases.

- Maximum 2 quenches per day.
- Test sequence optimized by day/night and weekend powering. (see presentation G. Willering, Monday)
- Stretched wire and alignment measurements are important (see presentation C. Petrone, Thursday).
- Small leak detected from helium to vacuum, but not clear if it is on cold mass side or test bench side. (see presentation by F. Mangiarotti later this session)

# Corrector Package (CP)

| Object | Test completed | In test | To be tested |
|---|---|---|---|
| CP | | | 01 02 03 04 05 |

| | |
|---|---|
| Test station: | A2 |
| Number of cool downs: | 1 (MCBXFA magnets tested at CERN, HO correctors tests at LASA.) |
| Test temperature: | 1.9 K |
| Test station occupation: | 5-6 weeks |
| Magnetic measurements: | Yes |
| Cold phase including powering: | 3 weeks per cool down. |
| Warm up/cool down duration: | TBC |
| Units to test: | 5 |

The first CP will be placed on the test bench this week, following delay due to the second cool down of the Q3.

The bench A2 with shuffling module has been fully commissioned first in stand-alone and then using the Q3 magnet.

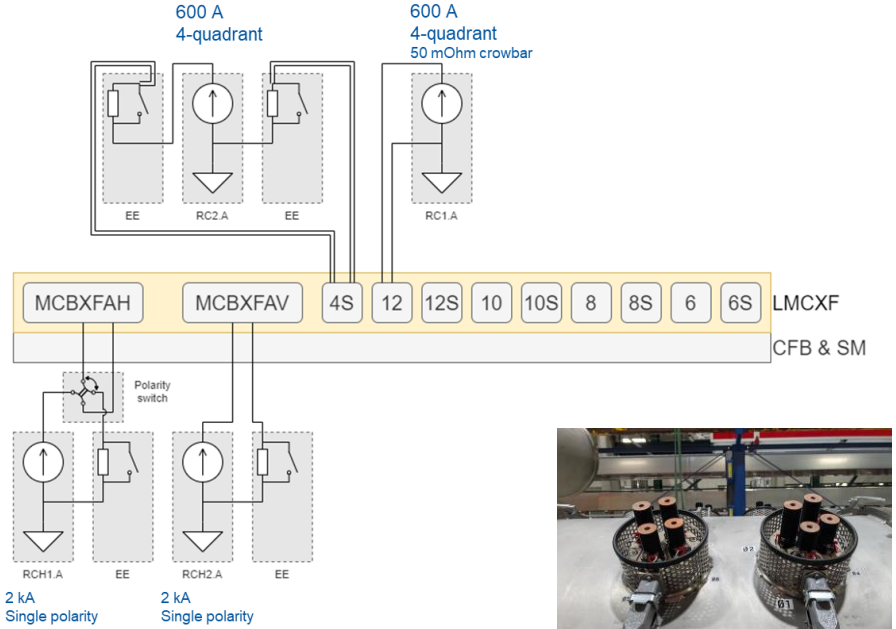
CP is the last cryo-assembly to be tested at CERN for installation in the IT-String (following SC-link, D1, Q2a, Q2b, Q3).

# Corrector Package

## 11 magnet circuits. Powering sequence:

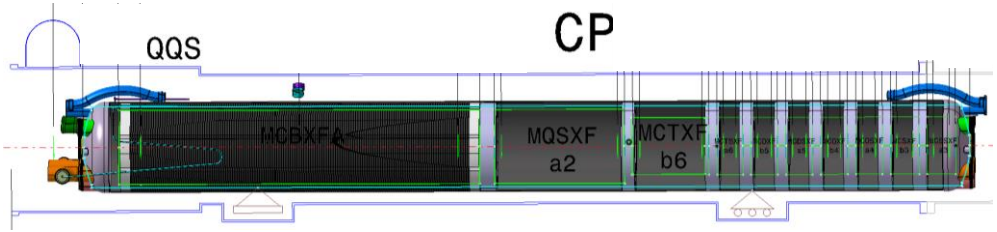
- Single and combined powering for the 2kA MCBXFA magnets horizontal and vertical nested dipoles.
- The MQSXF skew quadrupole remains always connected to the 600 A PC with the 2 EE systems. It is the only magnet requiring 200 A and has a double lead connection.
- Finally the other 8 circuits, all 100 A, no EE will be powered one by one with another 600 A PC. The lead connection is done on on the outside of the cryostat.
- The 120 A lead heat interception point is cooled by gas at ~ 70 K, the control needs to be commissioned.

- The alignment measurements for each magnet are important. The MQXFS will remain connected for powering and will be the reference for the alignment of the other magnets.






120 A leads on the side of the cold mass.
2 kA leads through CFB



# Q2

| Object | Test completed | In test | To be tested |
|---|---|---|---|
| Q2a/b | P3 04 P2 | 05 | 03 06 07 08 09 10 02b |

| | |
|---|---|
| Test station: | F1 |
| Number of cool downs: | 2 (magnet tested before at FNAL.) |
| Test temperature: | 1.9 and 4.5 K |
| Test station occupation: | ~9 weeks |
| Magnetic measurements: | Yes |
| Cold phase including powering: | 3 weeks first cool down, 2 weeks second cool down. |
| Warm up/cool down duration: | 5 days per warm up/cool down |
| Units to test: | 7 + 1 |

The test bench has been operational since 1 year. 5 cryo-magnets have been tested in 7 cool downs.

- Maximum 2 quenches per day.
- Test sequence optimized by day/night and weekend powering. (see presentation G. Willering, Monday)
- Stretched wire and alignment measurements are important (see presentation C. Petrone, Thursday).

# SC-link

| Object | Test completed | In test | To be tested |
|---|---|---|---|
| SC-link type X | P | | 1 2 3 4 |
| SC-link type M | | | P 1 2 3 4 |

| | |
|---|---|
| Test station: | F2 |
| Number of cool downs: | 1 |
| Test station occupation: | ~4-5 weeks (excluding assembly) |
| Cold phase including powering: | 2 weeks cold test, of which 1 week of powering. |
| Warm up/cool down duration: | ~ 4-5 days per warm up/cool down |
| Units to test: | 9 |

The F2 bench has been fully qualified and optimized during the tests early 2024. Important optimization was done of the powering circuits and schemes allows for fast testing.

SC-link shares the powering circuits with the Q2 magnets in test. The powering phase of the SC-link is short can be done during thermal cycle or installation of the Q2 magnets.

We expect minimal impact of using the same powering circuits for the SC-link as for the Q2.

# Bench F1/F2: Q2 and SC-link

Good experience with UQDS as DAQ.
Critical software layers were built around the DAQ, including a GUI user interface, recording all data on Post-Mortem and in the Logging database.

Data extraction tools were made to be able to analyze the data within 5-10 minutes from an event and the analysis software tools were updated to the new file types and analysis.

# D1

| Object | Test completed | In test | To be tested |
|---|---|---|---|
| D1 | P1 | | 1 2 3 4 5 6 |

| | |
|---|---|
| Test station: | B2 |
| Number of cool downs: | 1 (magnets tested vertically) |
| Test temperature: | 1.9 only |
| Test station occupation: | ~3-4 weeks |
| Magnetic measurements: | Yes |
| Cold phase including powering: | 2.5 week |
| Warm up/cool down duration: | ~3? days per warm up/cool down |
| Units to test: | 6 |

The test bench B2 is ready, the shuffling module is about to be completed in the next days. It requires a pressure test and cold verification this year.

The powering and protection systems are identical to the LHC type magnets and are in operational condition for the bench. No particular difficulties foreseen.

# D2

| Object | Test completed | In test | To be tested |
|---|---|---|---|
| D2 | P1 | | 1 2 3 4 5 6 |

| | |
|---|---|
| Test station: | C2 |
| Number of cool downs: | 2 (Main magnet only tested) horizontally) |
| Test temperature: | 1.9 only |
| Test station occupation: | ~6-7 weeks |
| Magnetic measurements: | Yes |
| Cold phase including powering: | 3 week - |
| Warm up/cool down duration: | ~4? days per warm up/cool down |
| Units to test: | 6 |

The test bench C2 is ready. It requires a pressure test and cold verification this year.

The powering and protection systems were already used for the D2 prototype magnet. No particular difficulties are foreseen, but the commissioning is pending, also including new anti-cryostats.

# Q10

| Object | Test completed | In test | To be tested |
|---|---|---|---|
| Q10 | | | 1 2 3 4 |
| MB spares | 1 2 3 4 5 6 7 8 | | 9 10 11 12 13 14 15 |

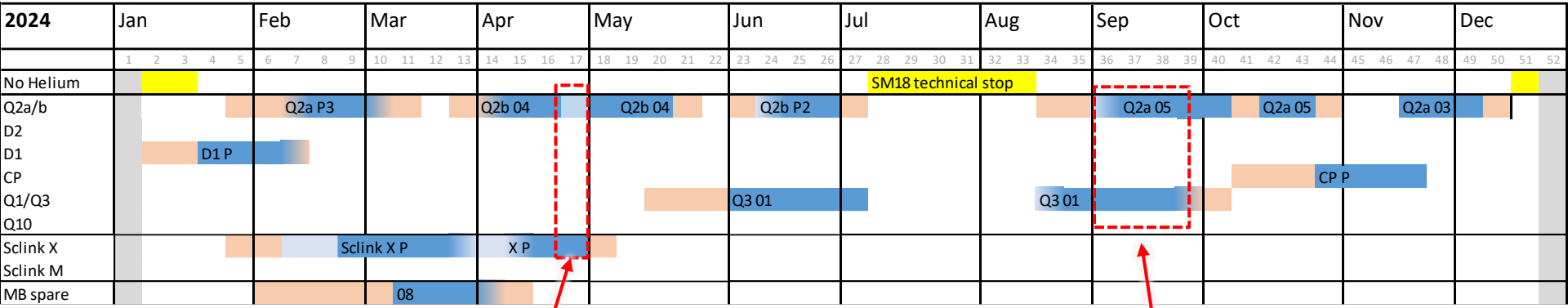
| | |
|---|---|
| Test station: | B1 |
| Number of cool downs: | 1 (magnets tested vertically) |
| Test temperature: | 1.9 |
| Test station occupation: | ~3-4 weeks |
| Magnetic measurements: | ? |
| Cold phase including powering: | 1.5-2 weeks |
| Warm up/cool down duration: | ~2? days per warm up/cool down |
| Units to test: | 4 |

The Q10 assembly is the assembly that draws the least attention so far.
'Standard' LHC configuration, to be tested on bench B1.

Side note: 7 spare MB magnets require retest on the same bench. Some benches will keep their configuration for LHC cryo assemblies.

# Parallel testing

**2024** updated 3 October 2024




SC-link powering test during thermal cycle of the Q2. Minimum impact expected, with some flexibility in the test plan, we can obtain maximum efficiency.
Insulation and instrumentation checks can be done at cold in parallel to other tests on the neigboring bench.

Two magnets tested in parallel on the horizontal bench is about the limit for cryogenics and human resources. As test plans get shorter, the same amount of work (preparation, installation, mechanics, etc.) needs to be done in a shorter amount of time.

# Cryogenics

Cryogenics is the most important service for testing magnets.
Throughout the last years many optimizations have been done

- Flexibility between using 35 g/s and 25 g/s cold box.
- Re-installing 25.000 liter dewar with improved range.
- Additional automation of cool down and warm up processes for vertical and horizontal benches.
- Direct and daily coordination between test operators and cryogenics operators strongly improves efficiency.

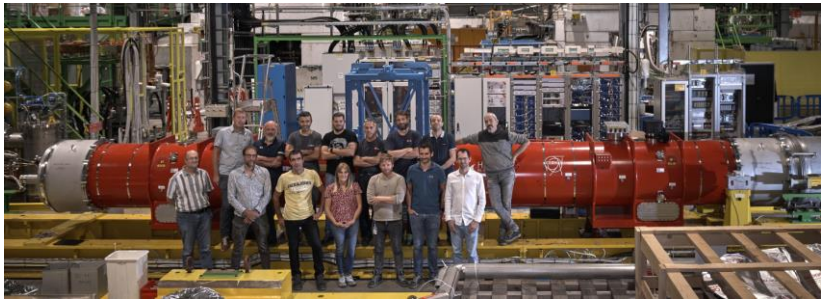
After summer 2024, often 3 magnet test stations in test in parallel, while also 2 or 3 RF cavity test stations were in test, always using full capacity.

- 1.9 K pumping (2*12 g/s) is the main factor limiting capacity.
- When the IT-string is in operation, it will use one pumping unit of 12 g/s, reducing pumping for magnets and RF to half capacity. This is foreseen to have a major impact on the test operation.

# Summary

**Vertical benches**
- Smooth test operation
- All test plans well established and most magnets qualify without major issues. (Exception for one MQML magnet.)

**Horizontal benches**
- Since last year bench F1, F2 and A2 are fully in operation.
- Proven efficient test operation for Q2, Q3, SC-link.
- Bench B2 and C2 have been completed, but not yet commissioned.
- 1.9 K pumping capacity could reduce test station throughput when IT-String operation starts, which is foreseen end 2025.



**SM18 magnet test station is ready for HL-LHC!**
**Fully focused on test from now on.**

# Done since the 13th Hilumi collaboration meeting in the SM18 superconducting magnet test facility

## Upgrades

- Commissioning F1 bench with first Q2 cryo assembly
- Completion and commissioning F2 bench with first SC-link full system
- Completion and commissioning A2 bench with first Q3 cryo assembly
- Completion C2 bench upgrade – ready for pressure test and cold test.
- B2 bench upgrade ongoing – Next week ready for pressure test and cold test

## Horizontal tests

- One cool down MQXFB in test cryostat on bench A1.
- One D1 prototype tests with two cool downs
- Five Q2 cold mass tests (4 cold masses) with six cool downs.
- One SC link full system type X tested with two cool downs.
- One LHC MB test
- One Q3 cold mass tests with two cool downs.

## Vertical tests

- Four MQML tests
- One MSCB test
- Three MCBXF tests
- Two MCBRD tests
- Five MQXFS tests
- (15 tests for HFM and other projects.)

## 2024

updated 3 October 2024