

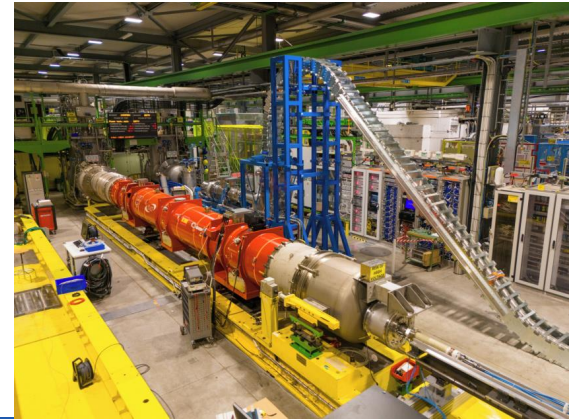
# SM18 magnet test facility upgrade, commissioning and feedback from test operation

Gerard Willering

7 October 2024  
14th HL-LHC Collaboration Meeting  
Genoa, Italy

Franco Mangiarotti, Gaëlle Ninet, Guillaume Pichon, Stian Juberg, Jerome Feuvrier, Patrick Viret, Michael Boczan, Marco Buzio, Stephan Russenschuck, and all other members of the team.

- With many thanks to FSU support and all other teams involved.
- Acknowledgements to WP3, WP6a and all supporting teams.



# Content

- Update
- Upgrade status and feedback
- Test status and feedback
- Outlook

# Update

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 followed by cold test.
- B2 bench upgrade ongoing – Next week ready for pressure test followed by cold test

## Horizontal tests

- 9 full cryo-assemblies tested in 14 cool downs.

## Vertical tests

- 15 magnets tested for HL-LHC, 15 for HFM and other projects.

Upgrade work	F1 (Q2)	F2 (SC-link)	A2 (Q3 and CP)	C2 (D2)	B2 (D1)
CFB modifications, hardware and controls	X	X	X	X	X
Shuffling module installation	X		X	X	X
2 kA leads in CFB	X		X		
Powering circuit change (new PC, EE)	X	X	X		
PPI shuffling module		X			
Full UQDS, used as DAQ, communication software, data storage/transfer and analysis.	X	X			
New anti-cryostats	X		X	X	X
Full recabling, modification of electronics racks and PLC changes	X	X	X		
Shuffling module completed	08-2023		05-2024	09-2024	10-2024
Commissioning completed				12-2024	11-2024
First full assembly test	10-2023	02-2024	06-2024 (Q3)	01-2025	03-2025

All upgrades completed  
B2 and C2 pending commissioning

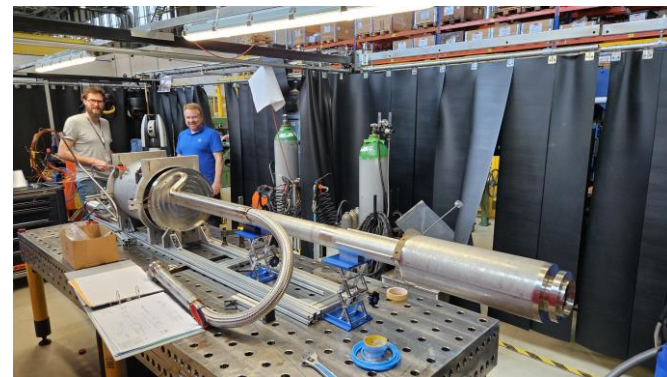
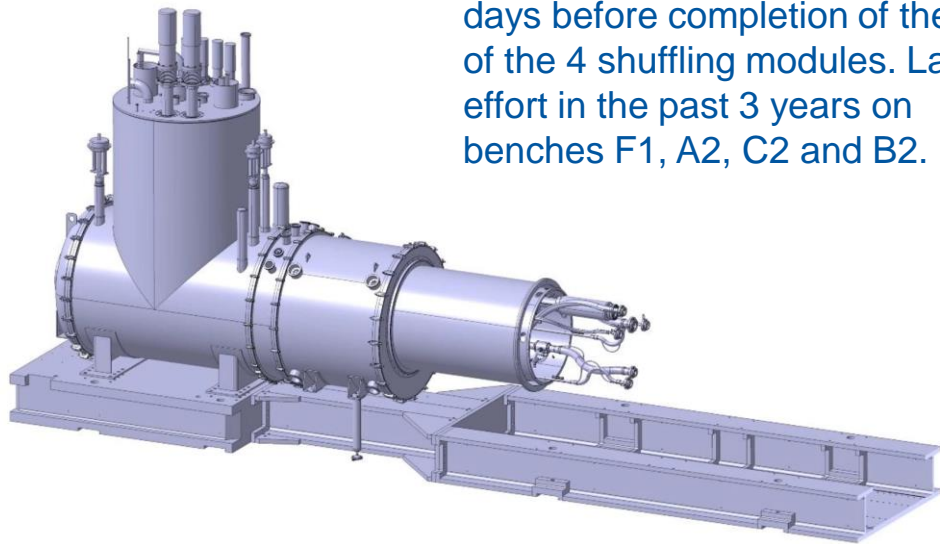
The largest upgrades were for bench F1 and F2.  
Bench A2 still had large modifications also on the electronic and powering systems.  
Bench C2 and B2 required mostly shuffling module upgrade.

Acknowledgements to all teams involved in the upgrades over the last years MPE-PE, SY-EPC, TE-CRG, TE-MS-CMI, TE-MS-LMF, etc.



# Bench B2 and C2 shuffling module

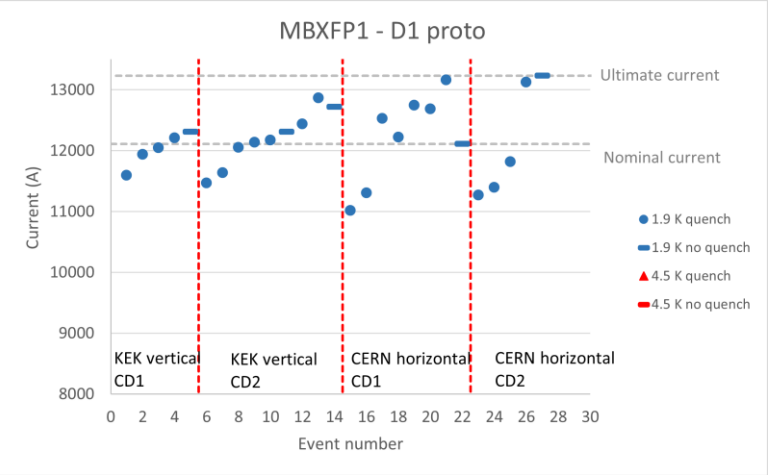
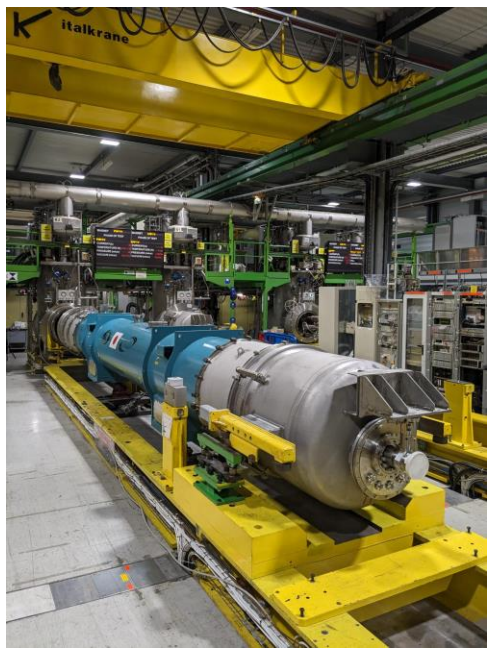
Last actions ongoing in the next days before completion of the last of the 4 shuffling modules. Large effort in the past 3 years on benches F1, A2, C2 and B2.



Many thanks to Tavis Bampton, Arnaud Vande Craen, Benjamin Jones, Olivier Pirotte, Hervé Prin, Gaëlle Ninet, Frédéric Savary, Simon Straarup, and all others for their contribution.

# D1 tests

See plenary by Tatsushi Nakamoto



D1 prototype magnet tested in December 2023 to February 2024 using B1 in 'direct' connection, allowing only tests at 1.9 K.

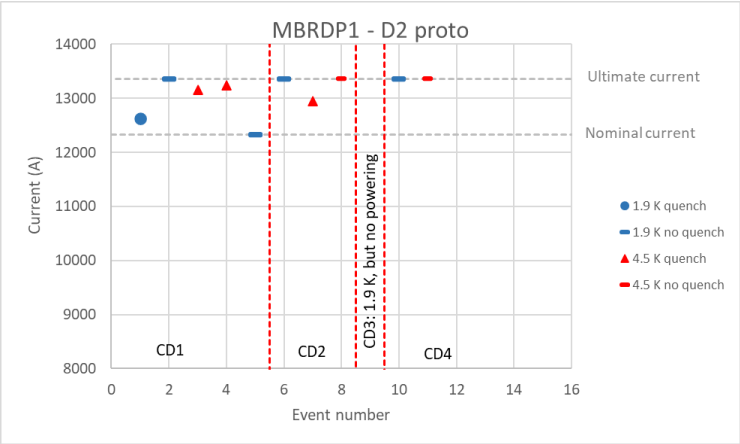
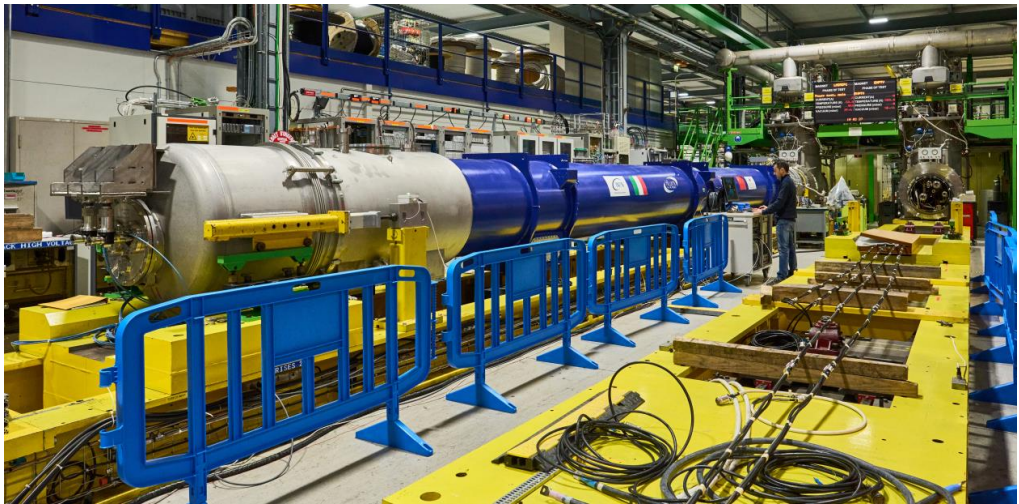
Horizontal tests at CERN confirmed quench behavior as seen in vertical test conditions at KEK. Training to ultimate current successful. The tests included 500 powering cycles to nominal current.

First D1 cryo-assembly is qualified for String installation.



# D2 tests

See plenary by Stefania Farinon



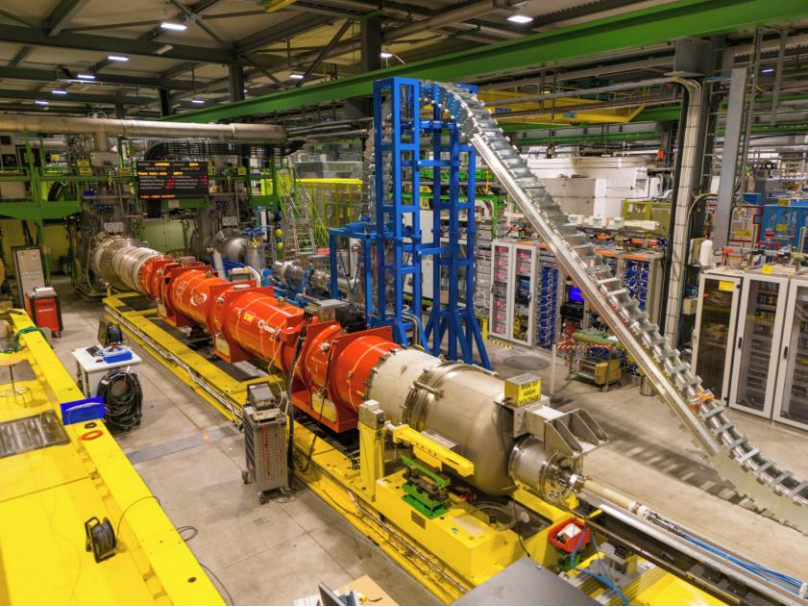
The D2 prototype test was already reported on in the HL-LHC annual meeting in Vancouver. First of series test foreseen at start of 2025.

# Bench F1 - Q2 magnets

October 2023: first Q2 assembly tested  
 Full commissioning of the bench done

### Feedback from tests

- Shuffling module works well for stable operation at 1.9 K and 4.5 K.
- The shuffling module adds ~ 150 liter of helium volume to the cryo assembly, adding time for 1.9 K cryo recovery, taking > 4.5 hours depending on pumping capacity available. For training quenches, limited to 2 quenches per day.
- Test bench well occupied with Q2 magnet assemblies: 5 Q2's in test in 2024 with in total 7 cool downs.



**2024** updated 3 October 2024

2024	Jan					Feb				Mar				Apr				May				Jun				Jul				Aug				Sep				Oct				Nov				Dec						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
No Helium																														SM18 technical stop																						
Q2a/b																																																				





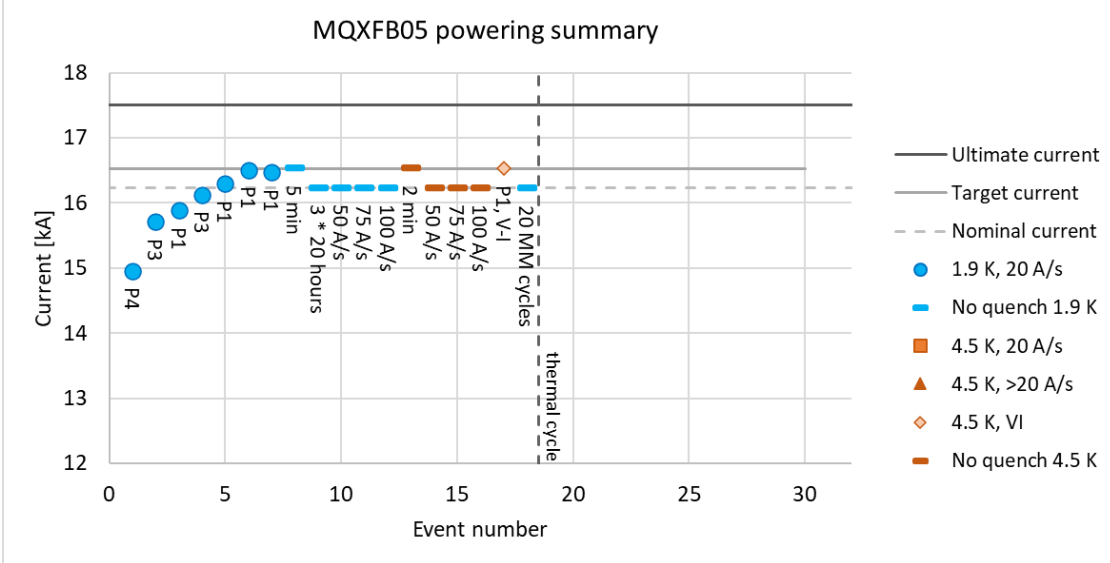
# Bench F1 - Q2 magnets

## Feedback on operation using other systems on the new bench.

- Very good experience with UQDS for protection and DAQ, which has been useful for UQDS developments as well. commissioned and works well.
- Quench antenna play an important role in analysing the few quenches recorded for each magnet to make sure no anomalies are present.

## Results

- First Q2 assembly (MQXF BP2, Nov 2023) had motion in the bus bar and developed short circuit between magnet circuit and ground outside the cold mass. After repair retested and OK for IT-string
- MQXF BP3 had a insulation non-conformity at the 100 K test for one of the quench heaters. Performance similar to its test in the test cryostat.
- MQXF B04: All OK. First Q2 to go straight to HL-LHC installation.



MQXF B05 on the bench shows good results, thermal cycle ongoing.

See plenary by Susana Izquierdo Bermudez  
See presentation by Franco Mangiarotti



# Bench A2 – Q3 magnets

Bench completed end April 2024: First Q3 assembly tested in time before summer technical stop.

## Q3 tests at CERN

- First Q3 passed acceptance criteria for magnet performance.
- At 7 TeV repetitive instability in one of the 8 coils between 10 and 40 hours of operation.
- Instability and quench location can be well well described by non-uniform current distribution in the superconducting cable, but origin of current redistribution could be far away from quench location.
- A test of 4 times 20 hours stable at 6.8 TeV qualified the magnet for the IT-string (pending Magnet Assessment Board verdict).

Flattop quenches were ‘accidentally’ discovered during long flat top tests for stretched wire magnetic field and alignment measurements. In the standard test program for Q2 and Q1/Q3 magnets, such test duration was not foreseen.



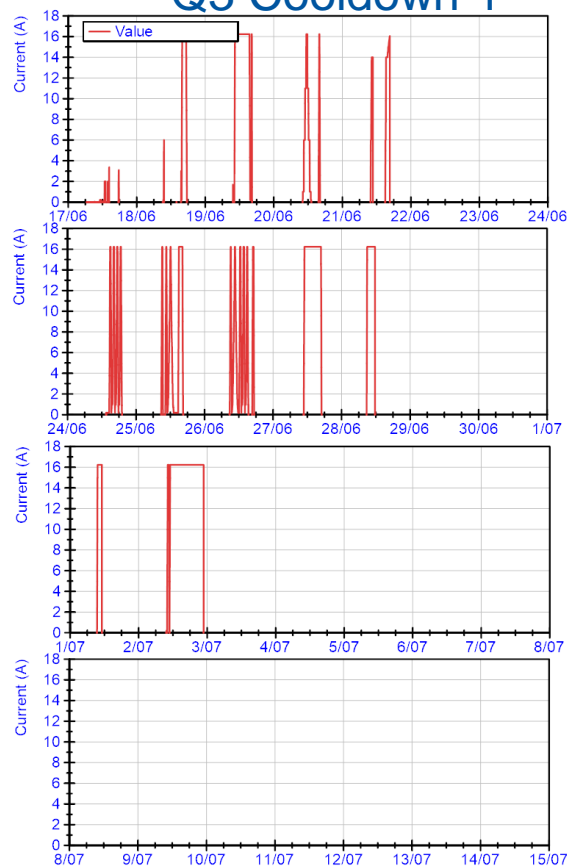
# Test optimization MQXF magnets

So far, test plans were always limited to 10-12 hours of powering, limited by the duration of working days.

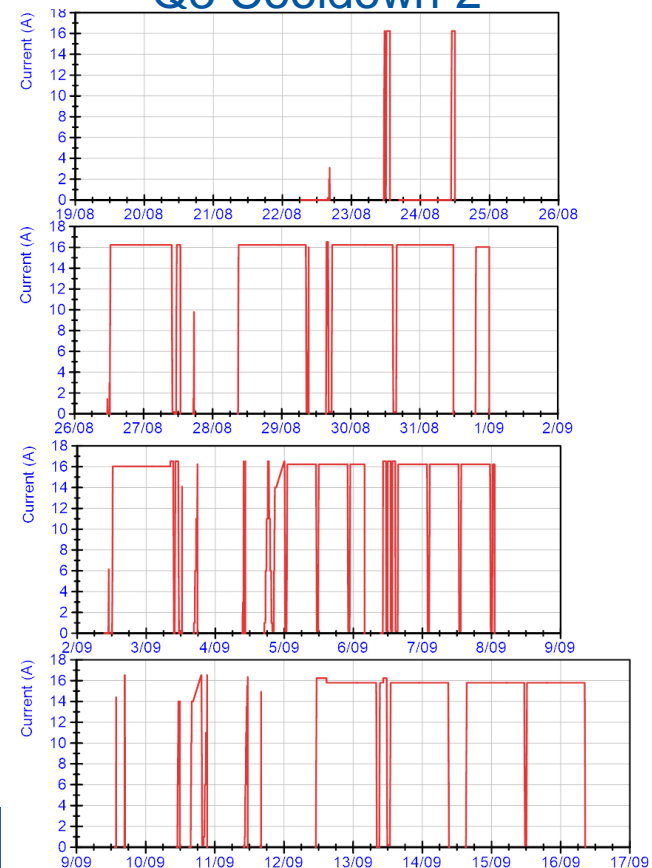
Following quenches at nominal conditions on flattop operation in a Q3 coil, we switched to overnight and weekend testing.

In the plots the difference in powering time over 3 weeks of test is visualized between powering only during working days in cool down 1 and powering overnight and in weekends in cool down 2.

## Q3 Cooldown 1

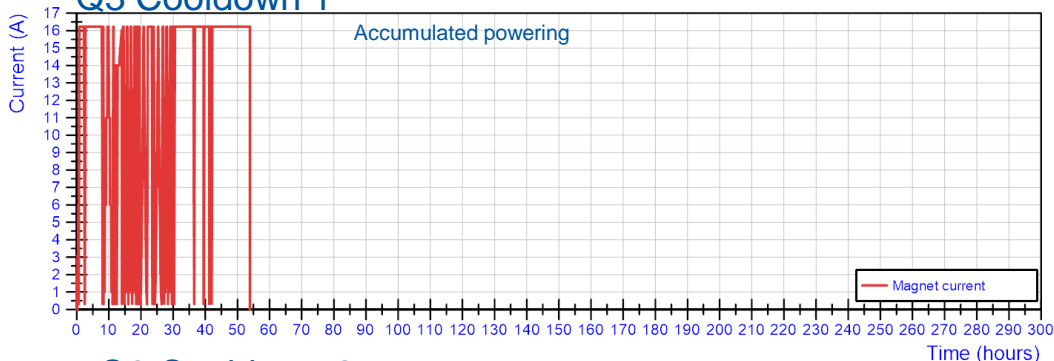


## Q3 Cooldown 2



# Test optimization

## Q3 Cooldown 1



## Cool down 1

17 June to 3 July.

54 hours of effective powering in 17 days

3.2 hours per day on average

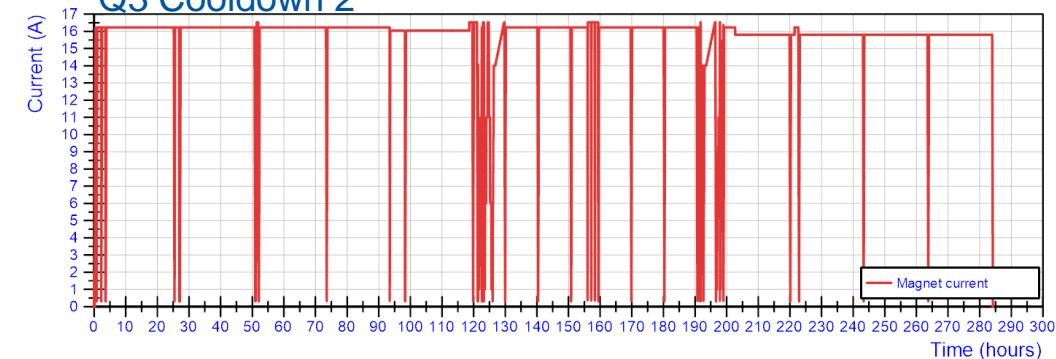
## Cool down 2

22 August to 16 September.

284 hours of effective powering in 26 days

11 hours powering per day on average

## Q3 Cooldown 2



The acceptance criteria of Q1/Q2/Q3 magnets are limited to 5 hours of stable powering.

A new standard cycle we introduce in all MQXF magnet tests at CERN is 3 \* 20 hours (fits in a weekend from Friday afternoon to Monday morning).



## Quick reminder:

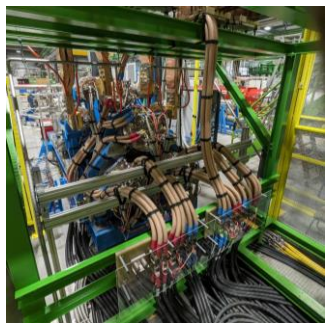
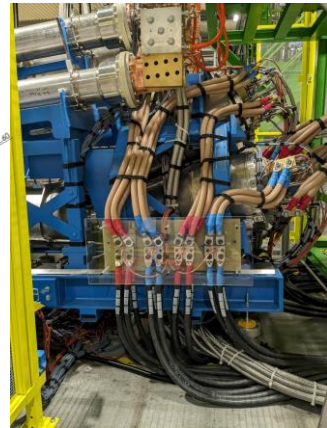
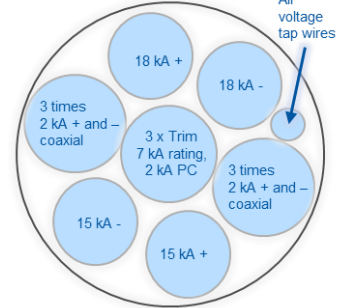
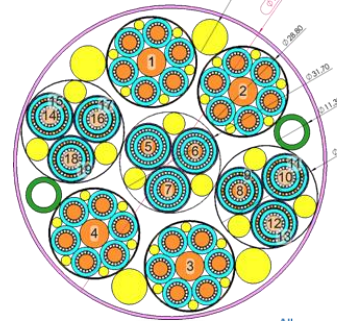
- Test benches are in operation day, night and weekends in the coming years.
- Visits can be arranged, you are welcome, but please let us know.

# Bench F2 – SC-link

Feb-April 2024: First SC-link assembly tested in two cool downs.

- Smooth test
- Stable cryogenics, no quenches, no recovery time like for magnets makes powering tests more efficient.
- UQDS as protection and data acquisition worked very well.
- Important optimization done on 2 kA electrical circuits. With 4 power converters, 18 leads were tested simultaneously with a current of 94 kA combined (~77.5 kA nominal).
- Full test cycle only takes 4 weeks, with 2 weeks for cold verification and powering tests.
- Qualification up to ~ 17 K at the terminations.

See plenary by Amalia Ballarino



# Bench A2 – CP magnets

Due to the additional test campaign of the Q3 magnet (removed from the bench last Friday), the CP installation on the bench is postponed to this week.

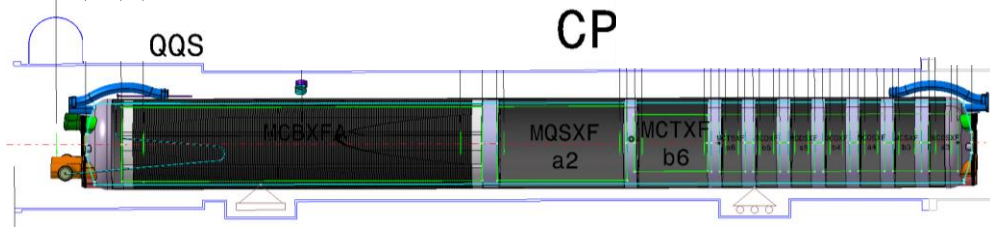
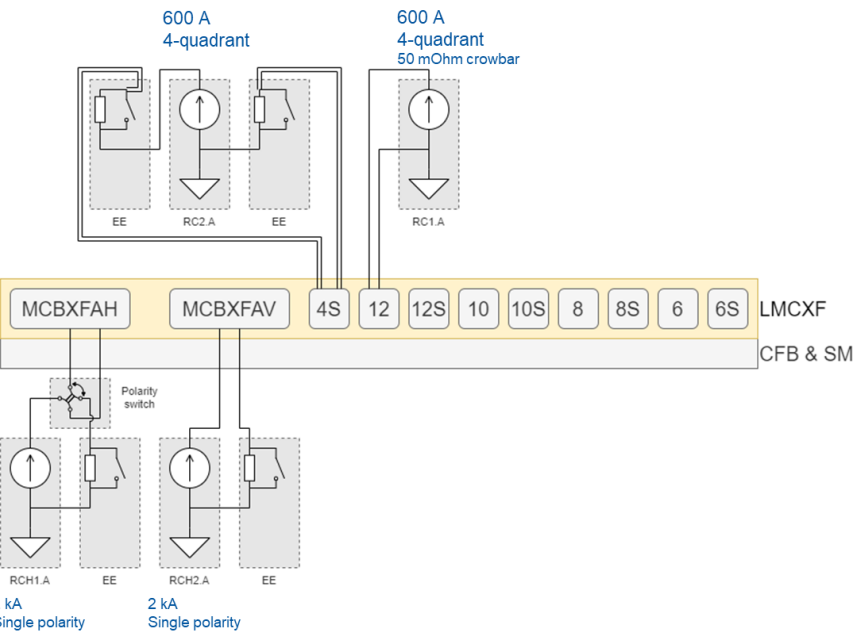
With 11 magnet circuits, more than any other cryo-magnet assembly.

4 different power converter circuits.

Test sequence has been optimized. Powering circuits to be commissioned during test in a few weeks from now.



120 A leads on the side of the cold mass.



# Vertical magnet qualification

7-Oct-2024

Dashboard Vertical magnets to be tested for HL-LHC			
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
MCBRD	P1 P3 P4 01 02 P2c 12 04		11 03 05 06 07 08 09 10
MQML	42 41 39	38	36
MSCB	1		2 3 4
IT-diode stack	P1		1 2 3 4 5

Since october 2023:

15 magnets tested for HL-LHC,

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

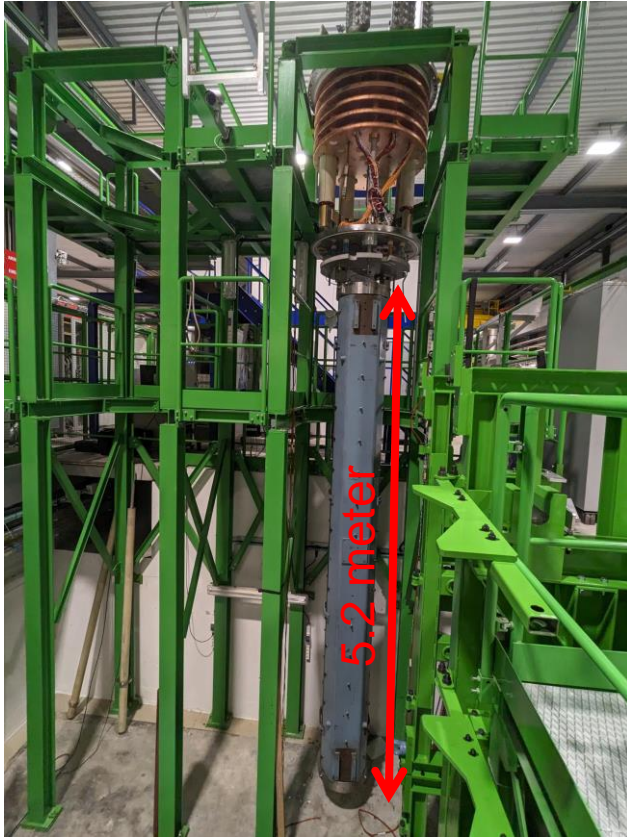
Still to test:

30 Magnets/Sclink





# MQML test for Q10



New feature unlocked in SM18: rotation tower allows to test magnets up to 5.2 meter length in the cluster D cryostat. This came in handy for the MQML magnet qualification for assembly in four new Q10 cryo-magnets.

Note: these standard LHC magnets were constructed 20 years ago, but never tested...



7-Oct-2024

Dashboard horizontal magnets/Slinks to be tested in SM18 for LS3			
Object	Test completed	In test	To be tested
MQXFB - test	P1 P2 P3 MT4 02 03		
Q2a/b	P3 04 P2	05	03 06 07 08 09 10 02b
D2	P1		1 2 3 4 5 6
D1	P1		1 2 3 4 5 6
CP		01	02 03 04 05
Q1/Q3	01		04
Q10			1 2 3 4
SC-link type X	P		1 2 3 4
SC-link type M			P 1 2 3 4

\*note: Q1/Q3 magnets are qualified at FNAL and not retested at CERN.

- Last years were focused on bench upgrades, bench commissioning, prototype testing.
- Bulk of tests still coming, with 29 cryo magnet assemblies + 9 SC-links to test in SM18.
- During IT-string tests 1.9 K pumping capacity for magnets and RF reduces by half, which could impact the test output.

# Summary

## 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.

## Vertical benches

- All testing optimized, still 30 magnets/diode stacks to test for HiLumi.

## Analysis

- Even in series production phase detailed analysis, investigations, quality control remains high priority to avoid surprises after magnet installation. For example bus bar motion, insulation issues, flattop quenches, etc.

Transition from bench upgrade to series qualification testing successfully done.  
Bulk of magnet tests still to come.



Thank you



SM18 test benches and operation team ready for qualification tests of all HL-LHC magnets

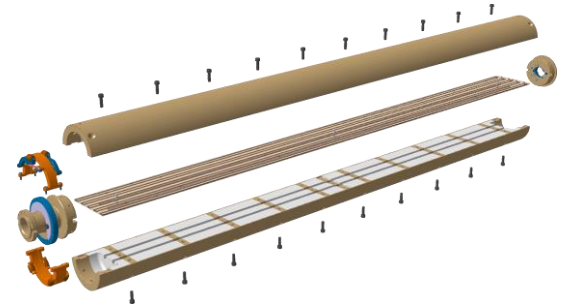


# Backup slides

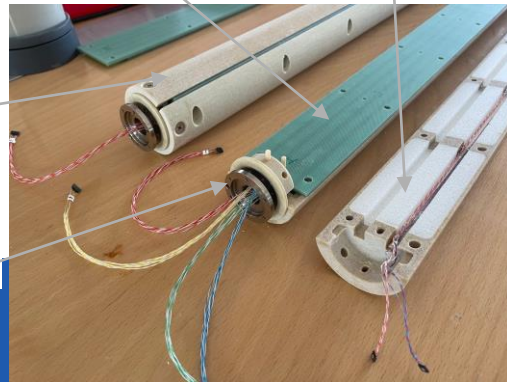
# Rotating coil chains

- **3 configurations**

- For Q1, Q2 & Q3 magnets : 6 segments  $\varnothing 103$  mm (1 unit available, 1 spare unit under assembling)
- For D1 and CP correctors packages : 5 segments  $\varnothing 103$  mm (2 units under assembling)
- For D2 magnets : 7 segments  $\varnothing 66$  mm (2 units under calibration)



PCB board      Structural-foam filling



Roller with ceramic ball-bearing

Cables with nano connectors

By Lucio Fiscarelli

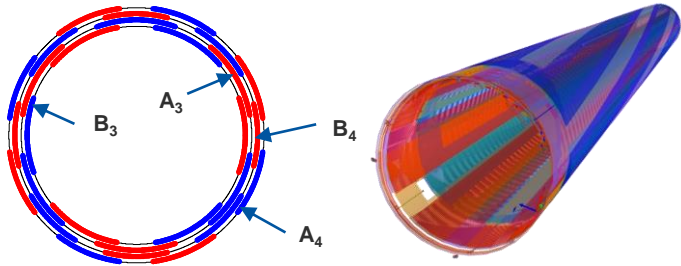
Titanium bellow



# Quench antenna

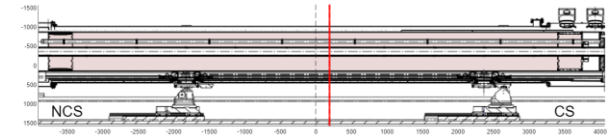
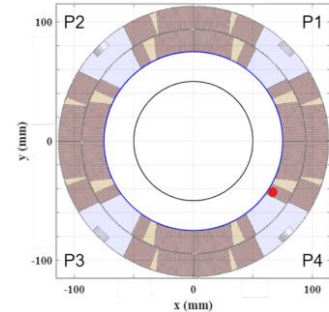
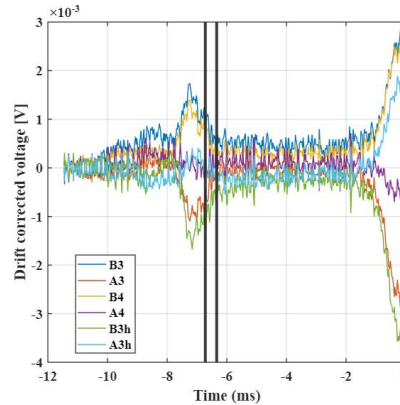
- **2 configurations**

- For Q2, Q1/3, and D1 : 13 segments  $\varnothing 103$  mm (1 unit available, 1 spare unit with improved design under construction)
- For D2 magnets : 2 segments  $\varnothing 66$  mm integrated on the rotating coil shaft (2 units under production)



By Lucio Fiscarelli

## Measurement on the MQXF�P3



Long. loc.: 194 mm



# Cryogenics

Cryogenics is the most important service for testing magnets.

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. Excellent

Throughout the last years many optimizations have been done.

- Good 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.
  
- 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.

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 – 9 full cryo-assemblies tested in 14 cool downs.

- One cool down MQXFB in test cryostat on bench A1.
- One D1 prototype test 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 – 15 magnets tested for HL-LHC, 15 for HFM and other projects.

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

# Dashboards

7-Oct-2024

Dashboard horizontal magnets/SCLinks to be tested in SM18 for LS3			
Object	Test completed	In test	To be tested
MQXFB - test	P1 P2 P3 MT4 02 03		
Q2a/b	P3 04 P2	05	03 06 07 08 09 10 02b
D2	P1		1 2 3 4 5 6
D1	P1		1 2 3 4 5 6
CP		01	02 03 04 05
Q1/Q3	01		04
Q10			1 2 3 4
SC-link type X	P		1 2 3 4
SC-link type M			P 1 2 3 4
MB spares	1 2 3 4 5 6 7 8		9 10 11 12 13 14 15

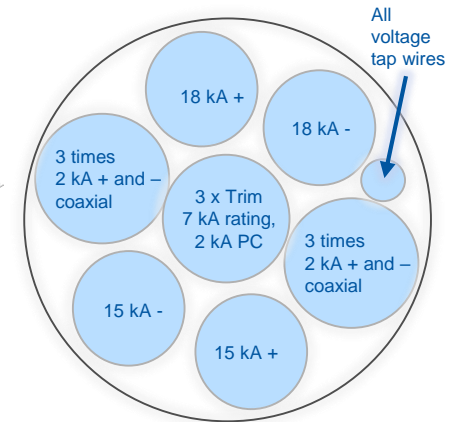
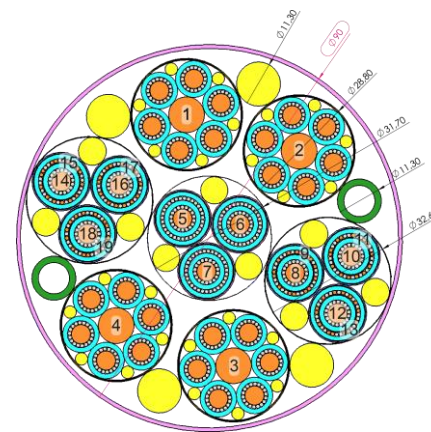
7-Oct-2024

Dashboard Vertical magnets to be tested for HL-LHC			
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
MCBRD	P1 P3 P4 01 02 P2c 12 04		11 03 05 06 07 08 09 10
MQML	42 41 39	38	36
MSCB	1		2 3 4
IT-diode stack	P1		1 2 3 4 5

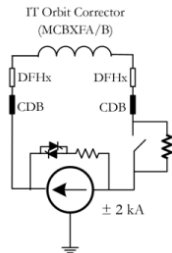


# SC-link circuits test currents

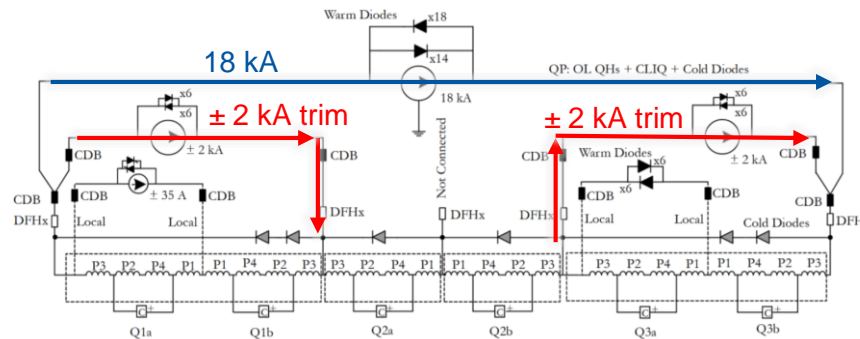
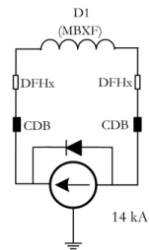
Circuit	Nominal current (kA)	Maximum magnet test current (kA)	ScLink test current (kA)
MQXF	16.23	16.53	18
D1	12.11	13.23	15
MQXF-Trim	1.8 (TBD)	-	2
Q2a-MCBXFB	1.74 + 1.14	1.86 + 1.22	2 + 2
Q2b-MCBXFB	1.74 + 1.14	1.86 + 1.22	2 + 2
CP-MCBXFA	1.59 + 0.74	1.71 + 0.79	2 + 2
<b>Total</b> (for 2 polarities)	<b>77.5</b>		<b>94</b>



## 2 kA circuits



## D1 circuit



## Trim circuit – 2 kA vs 7 kA

Trim cables 5, 6 and 7 designed for 7 kA continuous current.

The trim circuit has a 2 kA power converter, but could see in rare cases a current pulse up to 5 kA with 100 ms above 2 kA.

No pulse in test plan as discussed and agreed at MCF.