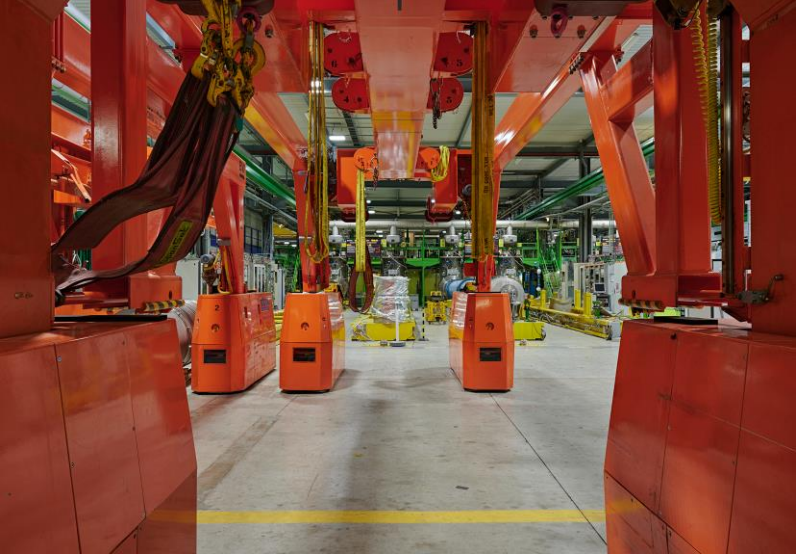


SM18 Test Facility Upgrades and Test Plans

Prepared by S. Russenschuck,
On behalf of the SM18 Test and Magnetic Measurement Team

CERN/TE-MSC Group

EDMS 2780822 V2.0

12th HL-LHC Collaboration Meeting
Uppsala University
20 September 2022

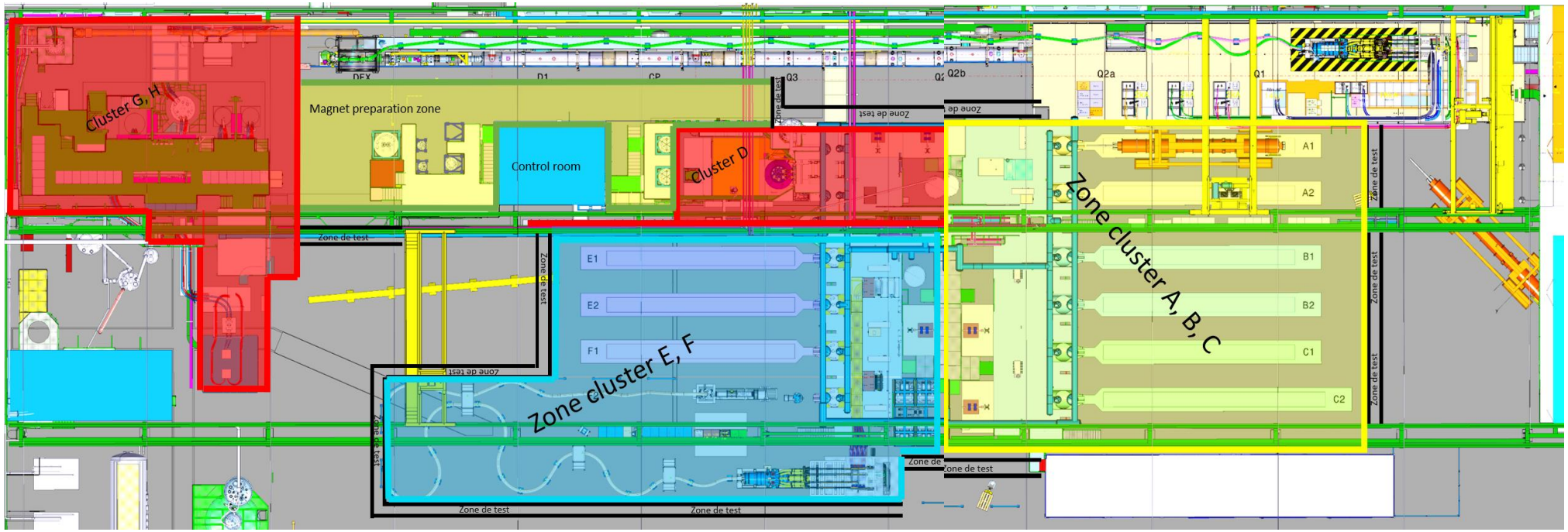
Overview

- Introduction
- Safety Upgrade
- Test-Bench Reconfiguration Project
- Advances in Diagnostics, Test Procedures and Instrumentation
- Recent Results in Cryo-Magnet Testing

Introduction

- **The reconfiguration project** of the SM18 test horizontal test benches **for HL-LHC** was identified as a critical project for the TE-MSC Group in **Q4 2020.**
- Based on the conceptual designs and plans already developed, a large effort was deployed to establish **a detailed implementation plan, WBS, and resource-loaded schedule** in **Q1 2021.**
- The plan was subjected to a thorough **scrutiny by a joined committee** with representatives from **TE-Department and HL-LHC projects** in **Q2/Q3 of 2022.**
- The **Scrutiny Group** eventually endorsed the proposed plan and decided on a **cost sharing** between **TE Department and HL-LHC Project**.
- A **safety issue** in the operation of the vertical test benches (Cluster G) resulted in a **stop of the SM18 operation** between **March and May 2002;** this time was used to carry out a thorough review of **test and safety procedures,** enabling a restart of operation with more **modus operandi** for the upcoming HL-LHC tests.

Safety First: Test Zone Definition and Safety Upgrades (1/2)



- **Test safety zones** are defined according to electrical and cryogenic risks during magnet testing; particularly important in view of numerous **co-activities** (with TE-CRG and TE-MPE).

Safety First: Test Zone Definition and Safety Upgrades (2/2)

Horizontal benches: Blue barriers placed with information panels.

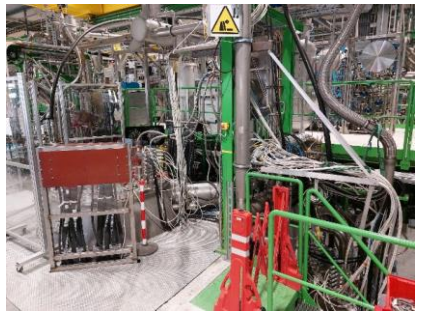
Cluster G,H fencing

Cluster D: Gate and warning signs

Additional insulation of live parts

Proximity between Siegtal and diode

Proximity between diode and HFM

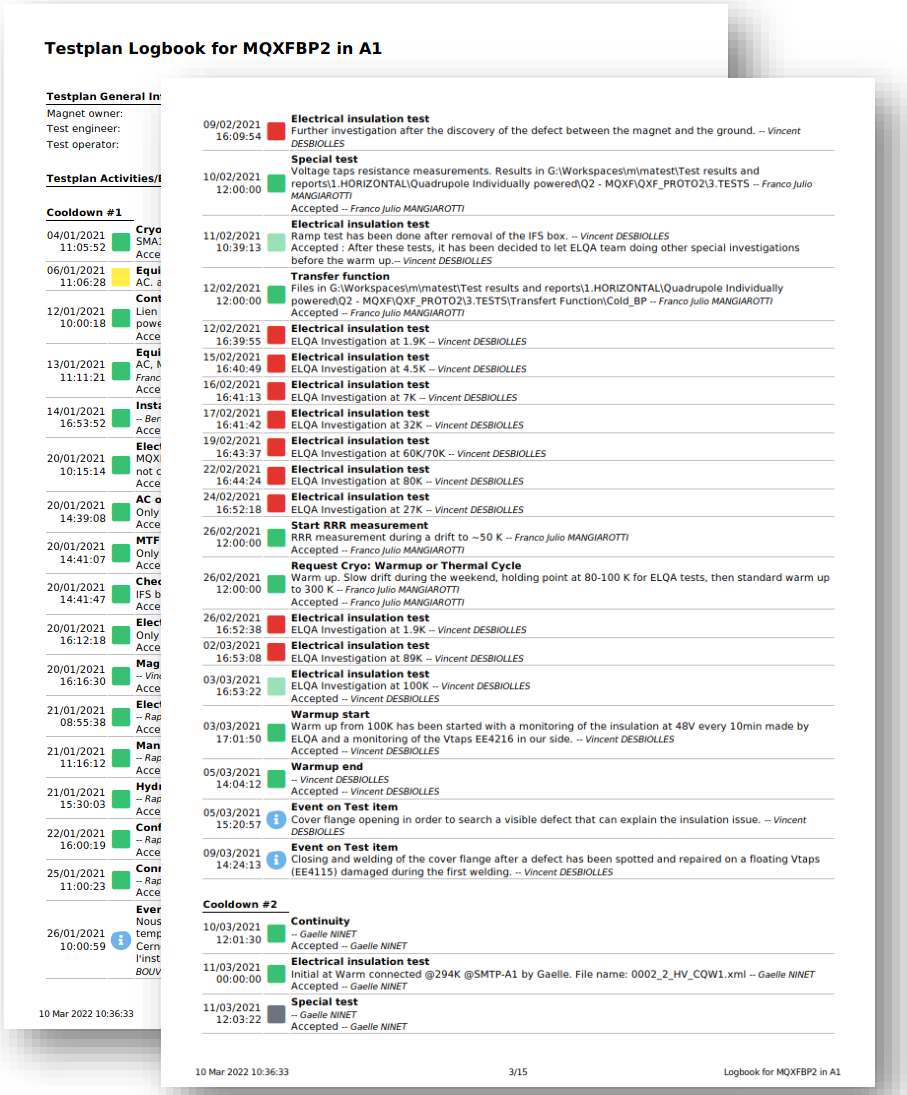


Proximity rules for the G cluster

Mechanical manipulations and installation in	Powering forbidden in
HFM	Diode cryostat
Diode cryostat	HFM and Siegtal
Siegtal	Diode cryostat

Carpenter as a QA and Safety Tool

- All tests done are stored in the database, including status and comments.
- Test order imposed by the approved test procedure.
- Levels imposed by the test plan.
- Easy to follow up the test chronology.
- Sign off at the control points.



Testplan Logbook for MQXFBP2 in A1

Testplan General In
Magnet owner:
Test engineer:
Test operator:

Testplan Activities/

Cooldown #1

04/01/2021 11:05:52 — Cryo SMA: Acce
06/01/2021 11:06:28 — Equi AC. a
12/01/2021 10:00:18 — Cont Lien powe Acce
13/01/2021 11:11:21 — Equi AC, M Franc Acce
14/01/2021 16:53:52 — Insta -- Ber Acce
20/01/2021 10:15:14 — Elec MQX not c Acce
20/01/2021 14:39:08 — AC o Only Acce
20/01/2021 14:41:07 — MTF Only Acce
20/01/2021 14:41:47 — Chec IFS b Acce
20/01/2021 16:12:18 — Elec Only Acce
20/01/2021 16:16:30 — Mag -- Vin Acce
21/01/2021 08:55:38 — Elec -- Rap Acce
21/01/2021 11:16:12 — Man -- Rap Acce
21/01/2021 15:30:03 — Hydr -- Rap Acce
22/01/2021 16:00:19 — Conf -- Rag Acce
25/01/2021 11:00:23 — Con -- Rag Acce
26/01/2021 10:00:59 — Ever Nous temp Cern l'inst BOUV

10 Mar 2022 10:36:33

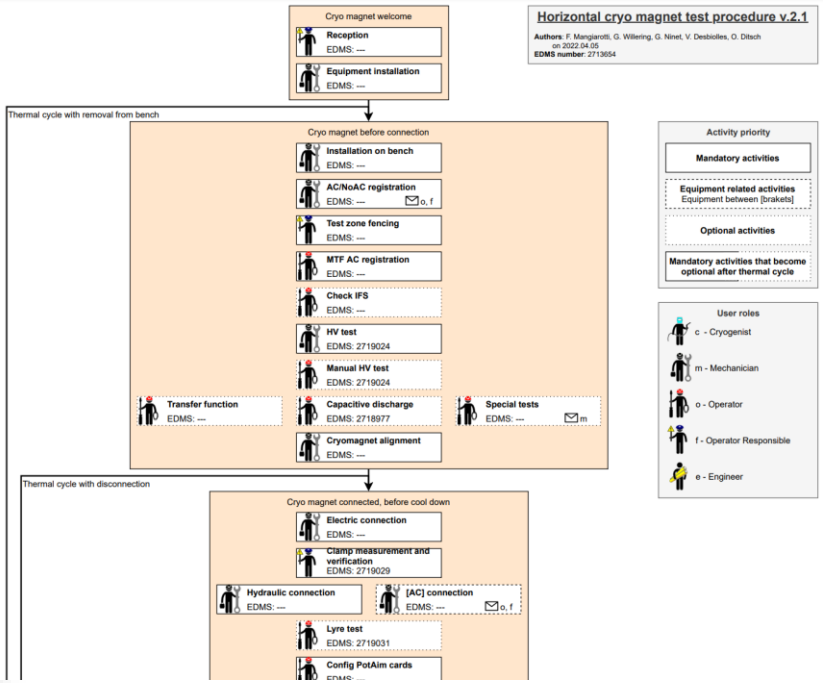
09/02/2021 16:09:54 — **Electrical insulation test** — Further investigation after the discovery of the defect between the magnet and the ground. -- *Vincent DESBIOLLES*
10/02/2021 12:00:00 — **Special test** — Voltage taps resistance measurements. Results in G:\Workspaces\m\matest\Test results and reports\1.HORIZONTAL\Quadrupole Individually powered\Q2 - MQXF\QXF_PROTO2\3.TESTS -- *Franco Julio MANGIAROTTI* — Accepted -- *Franco Julio MANGIAROTTI*
11/02/2021 10:39:13 — **Electrical insulation test** — Ramp test has been done after removal of the IFS box. -- *Vincent DESBIOLLES* — Accepted : After these tests, it has been decided to let ELQA team doing other special investigations before the warm up.-- *Vincent DESBIOLLES*
12/02/2021 12:00:00 — **Transfer function** — Files in G:\Workspaces\m\matest\Test results and reports\1.HORIZONTAL\Quadrupole Individually powered\Q2 - MQXF\QXF_PROTO2\3.TESTS\Transfert Function\Cold_BP -- *Franco Julio MANGIAROTTI* — Accepted -- *Franco Julio MANGIAROTTI*
12/02/2021 16:39:55 — **Electrical insulation test** — ELQA Investigation at 1.9K -- *Vincent DESBIOLLES*
15/02/2021 16:40:49 — **Electrical insulation test** — ELQA Investigation at 4.5K -- *Vincent DESBIOLLES*
16/02/2021 16:41:13 — **Electrical insulation test** — ELQA Investigation at 7K -- *Vincent DESBIOLLES*
17/02/2021 16:41:42 — **Electrical insulation test** — ELQA Investigation at 32K -- *Vincent DESBIOLLES*
19/02/2021 16:43:37 — **Electrical insulation test** — ELQA Investigation at 60K/70K -- *Vincent DESBIOLLES*
22/02/2021 16:44:24 — **Electrical insulation test** — ELQA Investigation at 80K -- *Vincent DESBIOLLES*
24/02/2021 16:52:18 — **Electrical insulation test** — ELQA Investigation at 27K -- *Vincent DESBIOLLES*
26/02/2021 12:00:00 — **Start RRR measurement** — RRR measurement during a drift to ~50 K -- *Franco Julio MANGIAROTTI* — Accepted -- *Franco Julio MANGIAROTTI*
26/02/2021 12:00:00 — **Request Cryo: Warmup or Thermal Cycle** — Warm up. Slow drift during the weekend, holding point at 80-100 K for ELQA tests, then standard warm up to 300 K -- *Franco Julio MANGIAROTTI* — Accepted -- *Franco Julio MANGIAROTTI*
26/02/2021 16:52:38 — **Electrical insulation test** — ELQA Investigation at 1.9K -- *Vincent DESBIOLLES*
02/03/2021 16:53:08 — **Electrical insulation test** — ELQA Investigation at 89K -- *Vincent DESBIOLLES*
03/03/2021 16:53:22 — **Electrical insulation test** — ELQA Investigation at 100K -- *Vincent DESBIOLLES* — Accepted -- *Vincent DESBIOLLES*
03/03/2021 17:01:50 — **Warmup start** — Warm up from 100K has been started with a monitoring of the insulation at 48V every 10min made by ELQA and a monitoring of the Vtaps EE4216 in our side. -- *Vincent DESBIOLLES* — Accepted -- *Vincent DESBIOLLES*
05/03/2021 14:04:12 — **Warmup end** — -- *Vincent DESBIOLLES* — Accepted -- *Vincent DESBIOLLES*
05/03/2021 15:20:57 — **Event on Test item** — Cover flange opening in order to search a visible defect that can explain the insulation issue. -- *Vincent DESBIOLLES*
09/03/2021 14:24:13 — **Event on Test item** — Closing and welding of the cover flange after a defect has been spotted and repaired on a floating Vtaps (EE4115) damaged during the first welding. -- *Vincent DESBIOLLES*

Cooldown #2

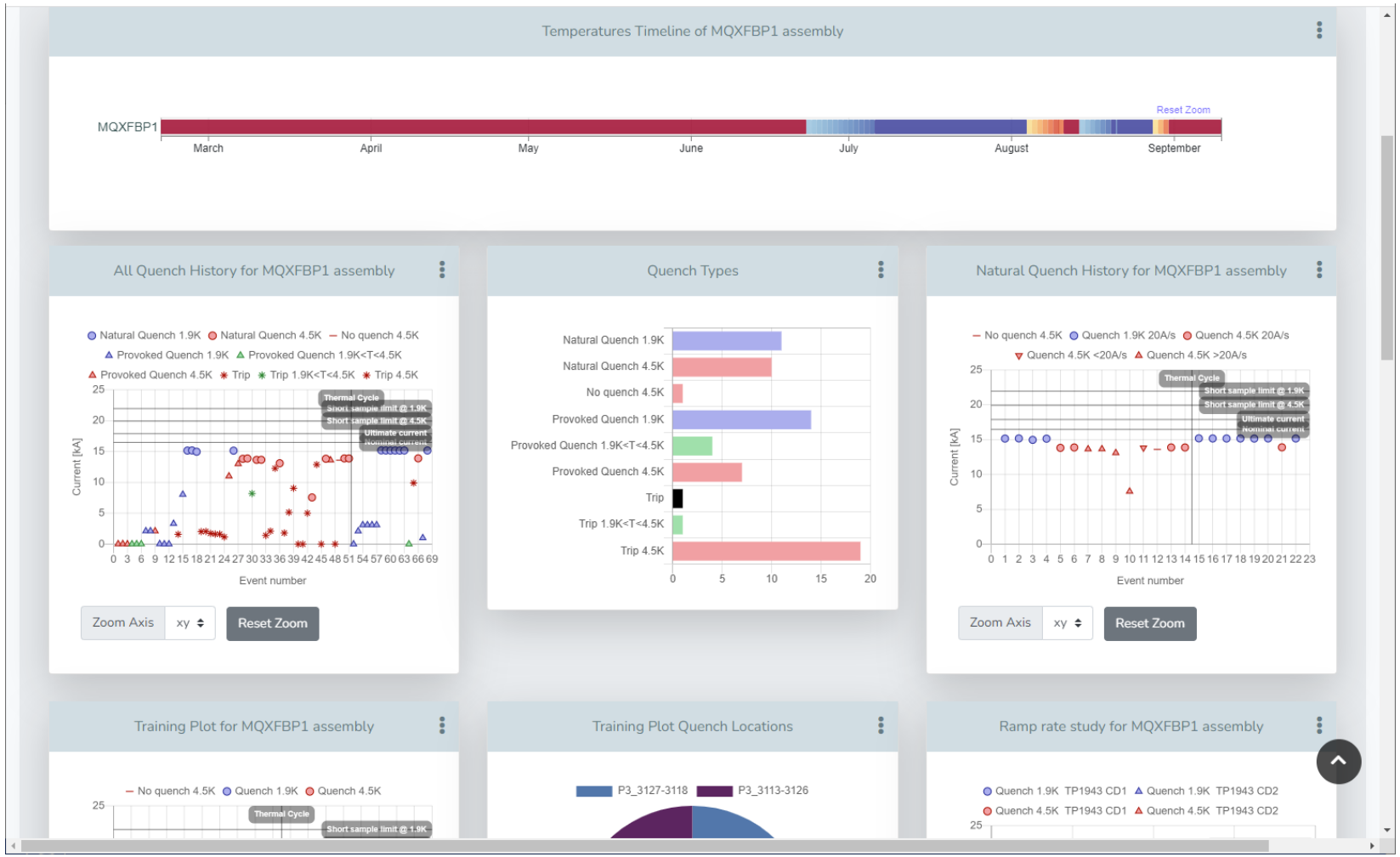
10/03/2021 12:01:30 — **Continuity** — -- *Gaelle NINET* — Accepted -- *Gaelle NINET*
11/03/2021 00:00:00 — **Electrical insulation test** — Initial at Warm connected @294K @SMTP-A1 by Gaelle. File name: 0002_2_HV_CQW1.xml -- *Gaelle NINET* — Accepted -- *Gaelle NINET*
11/03/2021 12:03:22 — **Special test** — -- *Gaelle NINET* — Accepted -- *Gaelle NINET*

10 Mar 2022 10:36:33 — 3/15 — Logbook for MQXFBP2 in A1

Test procedure
- Roles and signatures
- Test follow up
- Formalized in EDMS
- Additional check points added
- Pictograms added



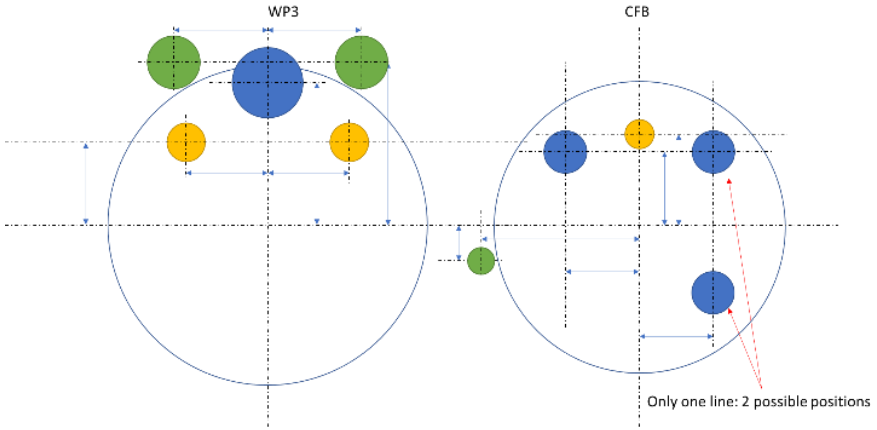
Carpenter for Data Visualization



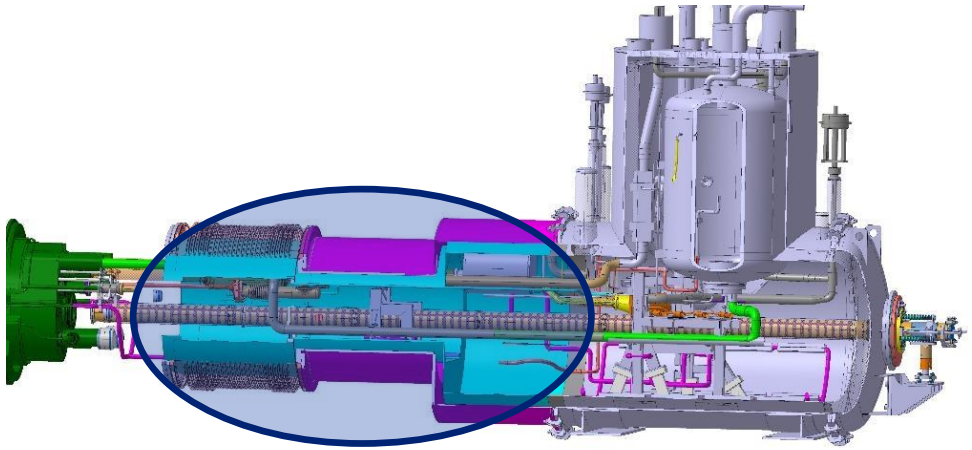
- Main test data uploaded to the database, which allows to automatically generate standard plots (Protocols)

Test-Bench Reconfiguration Project

- **Cryo lines** of HL-LHC cryomagnets are **at different (higher) positions** than those of LHC magnets, requiring a **“shuffling module”** for connection to the existing Cryogenics Feed Boxes (CFBs and MRBs).
- HL-LHC magnets have **different lengths, apertures and current ratings** calling for various adaptations.
- The project involves a **large number of interfaces**
  - ATS-DO, TE-RAS, HSE-OHS (safety)
  - BE-ICS (PLC systems)
  - BE-CM (LabView and other software, front ends, timing)
  - EN-ACE (integration, planning, mechanical infrastructure, operational safety)
  - EN-CV (cooling water)
  - EN-EL (signal and AC/DC power cabling)
  - EN-HE (handling)
  - EN-MME (engineering design, mechanical workshop)
  - IT-CS (technical network, GPS)
  - TE-MSC (magnet, (anti-)cryostats and SC link design, production and testing)
  - TE-MPE (quench detection and protection, energy extraction, CLIQ, signal feedthroughs)
  - TE-CRG (cryogenic systems, instrumentation and controls, facility operation, 2kA leads)
  - SCE-SAM (cabling supports)
  - SY-EPC (power converters, load switches)

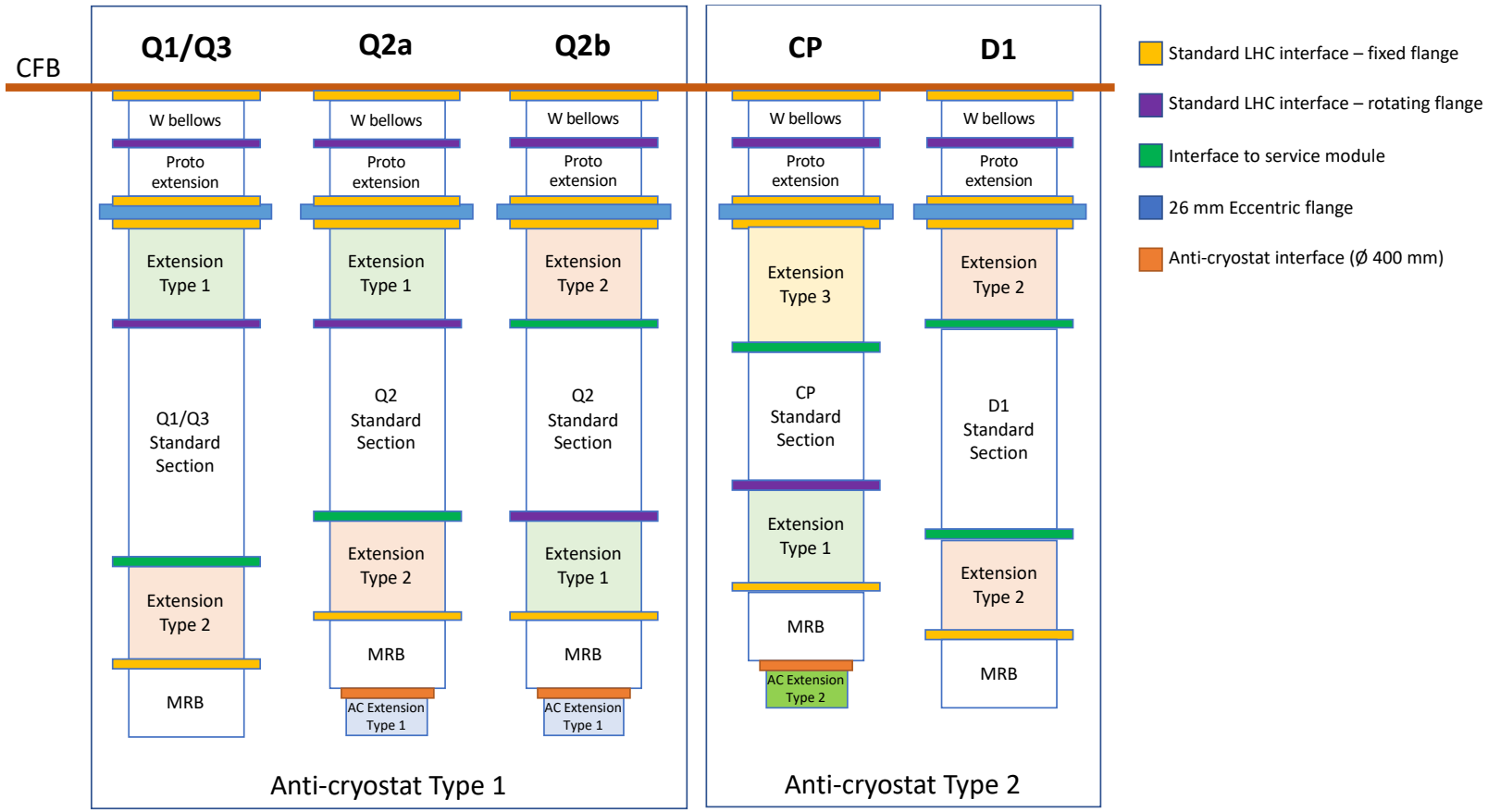


WP3 CFB



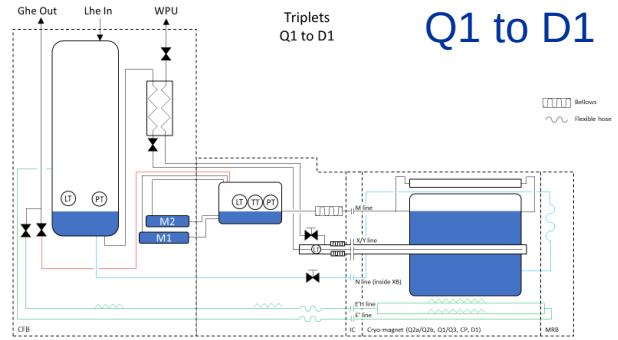
New Shuffling Module

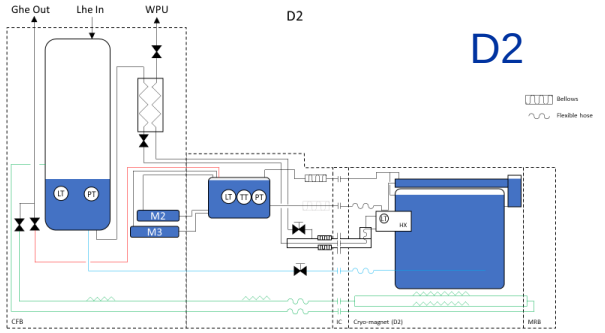
Test-Bench Compatibility



Standardization

as much as possible, in order to limit types of anti-cryostats, shafts for magnet measurements, and quench antenna



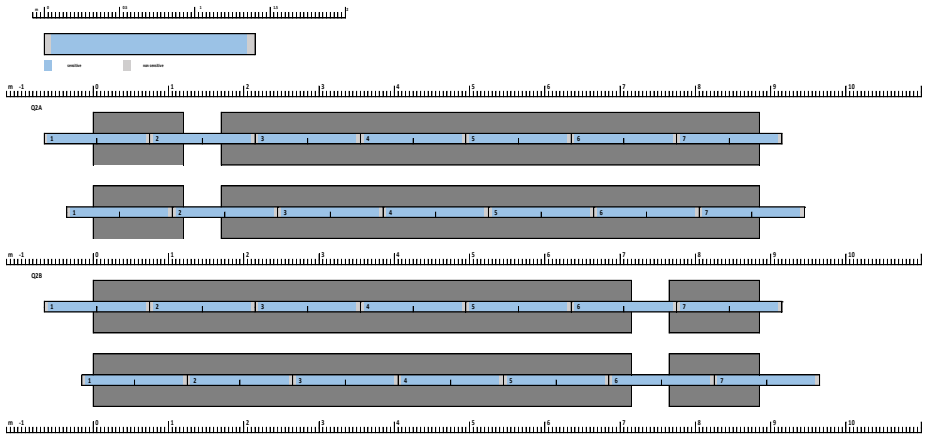


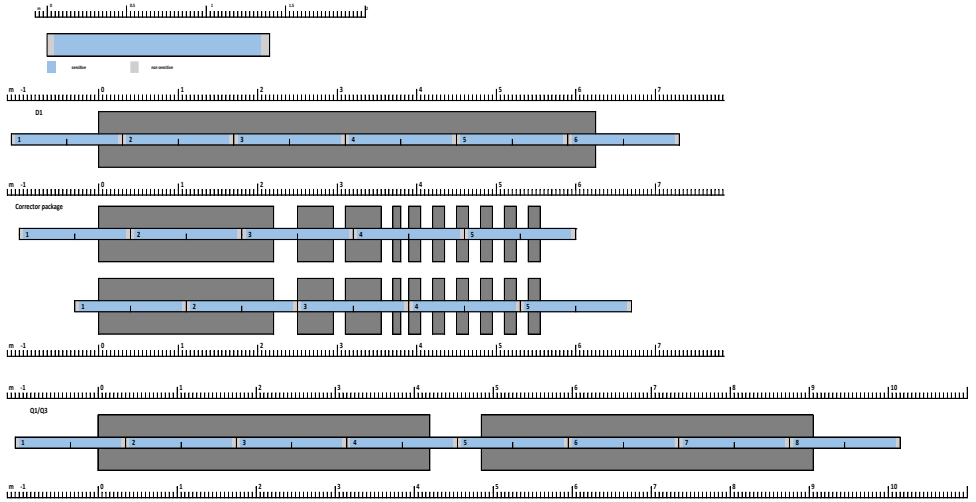
Advances in design reveals that the shuffling module can be made compatible with all WP3 magnets including D2; in total, **5 modules** for the SM18 upgrade.

Anti-Cryostats and Shaft-Configurations for WP3 Magnetic Measurements

Long anti-cryostat sections, family 1	Long anti-cryostat sections, family 2	Short anti-cryostat sections, families 1&2	Long anti-cryostat sections, family 3	Short anti-cryostat sections, family 3
For Q1, Q3, and Q2 proto 2	For Q2 proto 1 (short), CP proto, and D1 proto	For Q1, Q3, Q2 proto 2, Q2 proto 1 (short), CP proto, and D1 proto	For D2 proto	For D2 proto

Optimization of the number and lengths of anticryostats (two diameters)



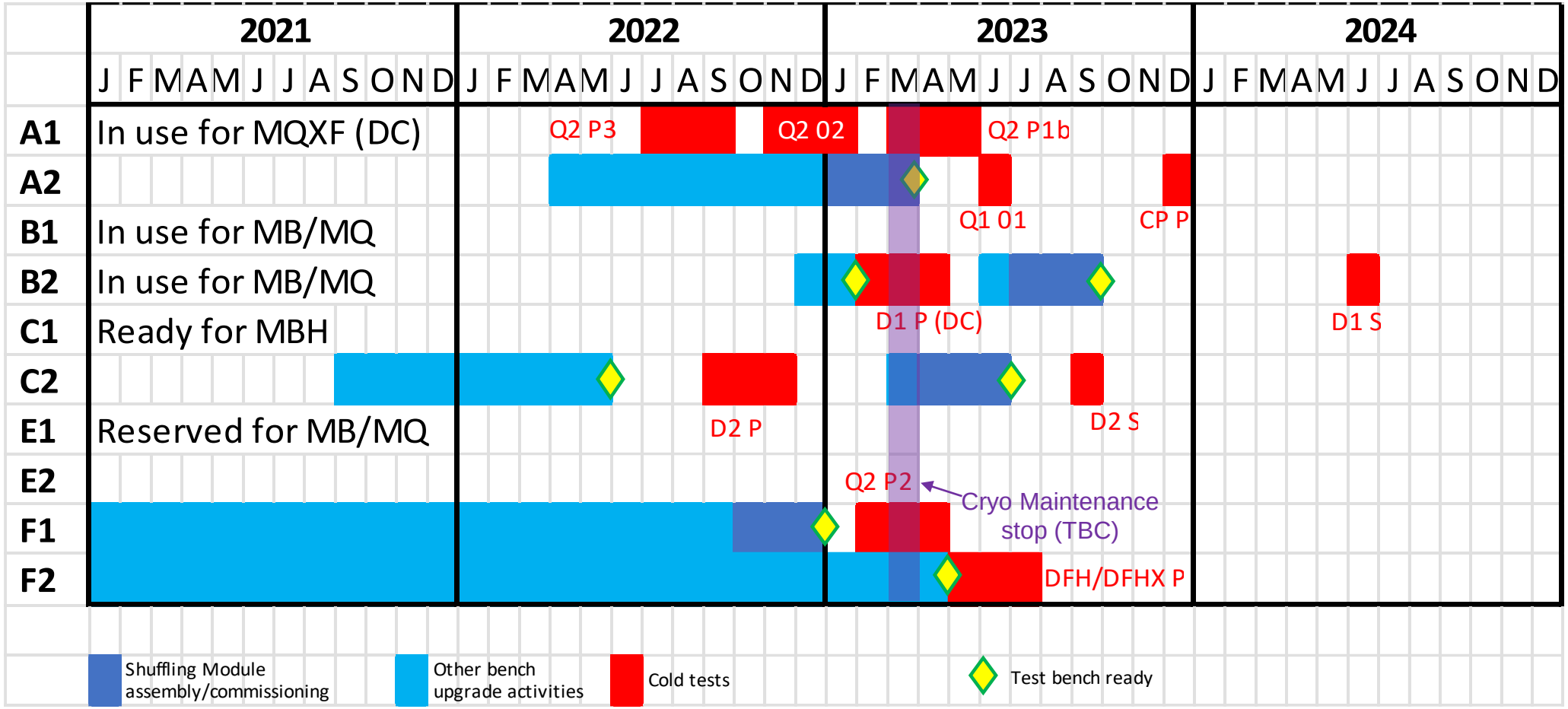


D1 and CP: Resuse of the same shafts as for the Q2 but different number and different extensions; **Q1/Q3:** Reuse of the Q2 shaft chain under the assumption that only 1 or 2 of these magnets will be tested, and no parallel operation on the Q2

Coordination Schedule (1/2)

- A **bottom-up schedule** was developed (with support of EN-ACE) to enable a follow up of critical milestones through a MS Project file + Excel/PDF exports https://edms.cern.ch/document/2488039
- The schedule integrates the main tasks and deliverables of the **various stakeholders,** with their mutual dependencies (assiduous follow-up required!)
- **~640 tasks** in total, **~120 milestones**; re-baselining was carried out in 15.03.2022 (following departure of EN-ACE resource).
- **Dedicated meetings** organized on a regular basis with main stakeholders; **weekly updates** at the Wednesday SM18 Steering Committee meeting; **biweekly meeting** with TE-MSC GL.

Coordination Schedule (2/2)



Only the first HL-LHC cryomagnet of each type is shown
DC = Direct Connection to Cryogenic Feed Box (in alternative/waiting for a Shuffling Module)
Cryo YETS 14 dec to 12 jan
Cryo Maintenance Stop: 4-5 weeks between March/May 2023, TBC 15th Dec [Shown in schedule: March]

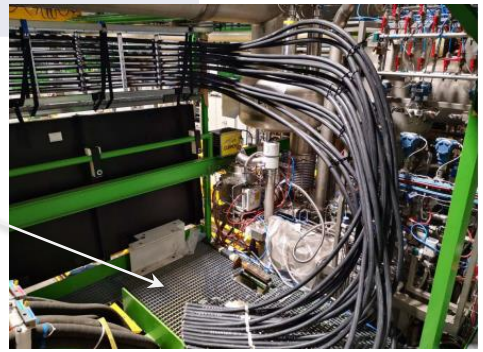
Test Bench F1 Readiness

Q2 prototype 2 in series test configuration with shuffling module expected in **February 2023**

Critical Path Tasks	Due by	Remarks
Quench Detection (10x uQDS)	Nov 22	Channel HW may be borrowed from F2 if needed. Full specifications pending
2kA Current Lads	Sep 22	Global pressure test and CFB modification by TE-CRG pending
Shuffling Module connection	Nov 22	
Shuffling Module commissioning	Jan 23	No interference with cryogenic infrastructure maintenance stop

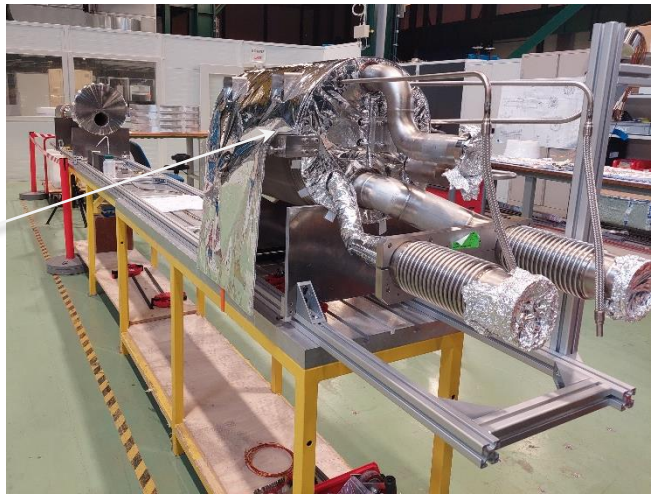
4× 2 kA Current Leads installed, individually tested

CFB instrumentation and mechanical preparations pending



2kA current leads pulled, connection still pending

Phase separator



Shuffling Module in SMI2 being prepared for installation on the test bench

Test Bench F2 Readiness

Ready to start testing prototype SC Link in Q2 2023

Quench detection HW ready for installation

Link mock-up on flexible support

18 kA Water Cooled Cables ready for final pressure test and lug orientation

Patch Panel Interface (PPI) (assembly on track)

CFB connection module/gas mixer installed and commissioned

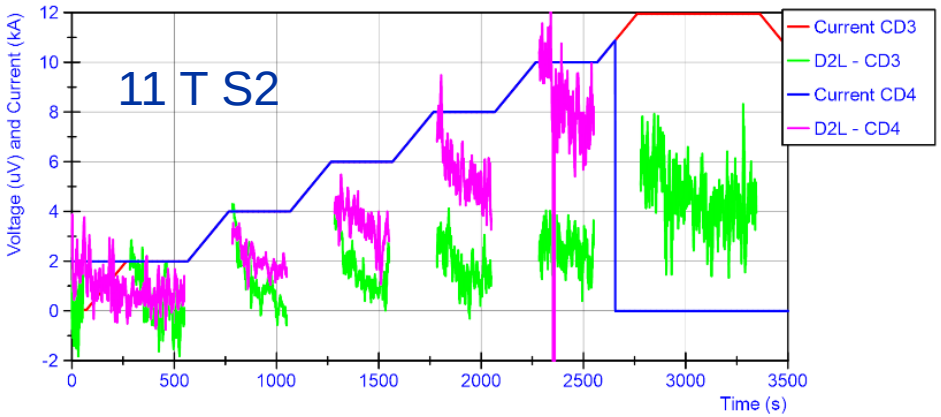
2kA power supplies/EE (switches being procured)

Vertical DFX cryostat support

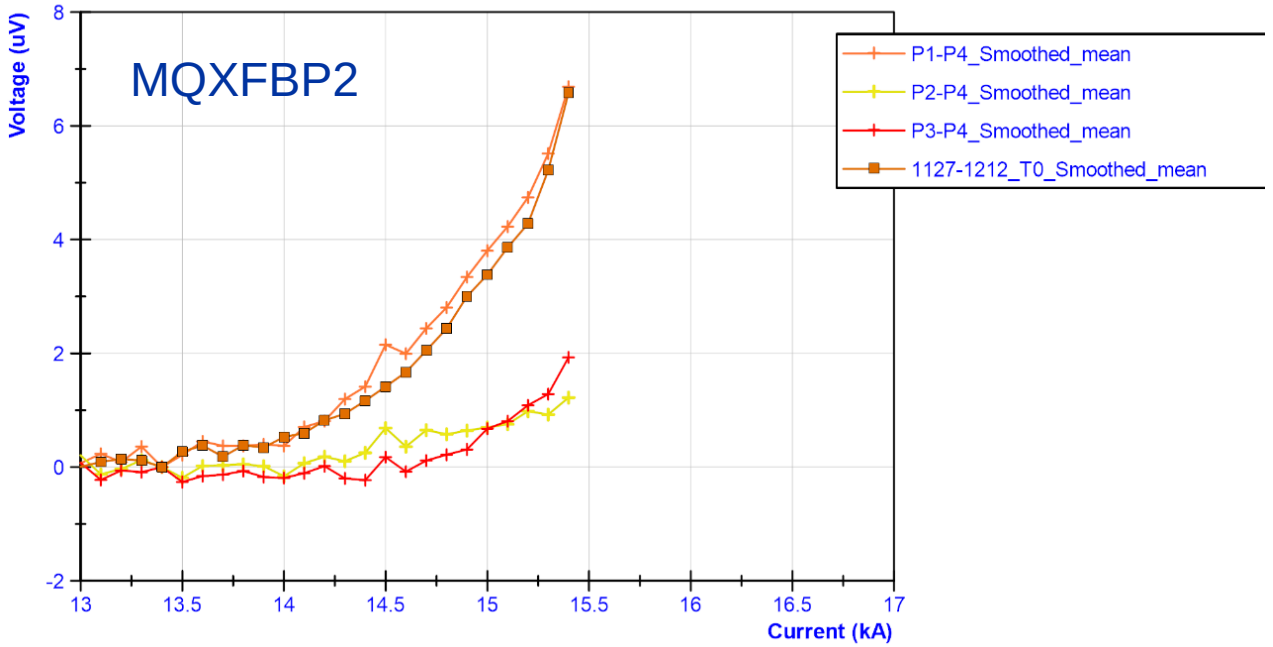
- All major infrastructure and DFX components delivered, some minor repairs ongoing
- Software/firmware development for DAQ, quench protection, interlock and cryo PLC ongoing
- Link cryostat being repaired in UK
- DFHX/DSHX delivery Oct 22 + 6 months assembly

Improved Diagnostics: *V-I* Measurements

- Sensitive voltage measurements can be carried out on during magnet testing, enabling early detection of resistive transitions and monitoring of their evolutions after EM and thermal cycling.
- Can confirm the presence or not of Nb_3Sn conductor degradation.
- Was successfully developed in later part of 11 T short models and series magnets (circa 2018).



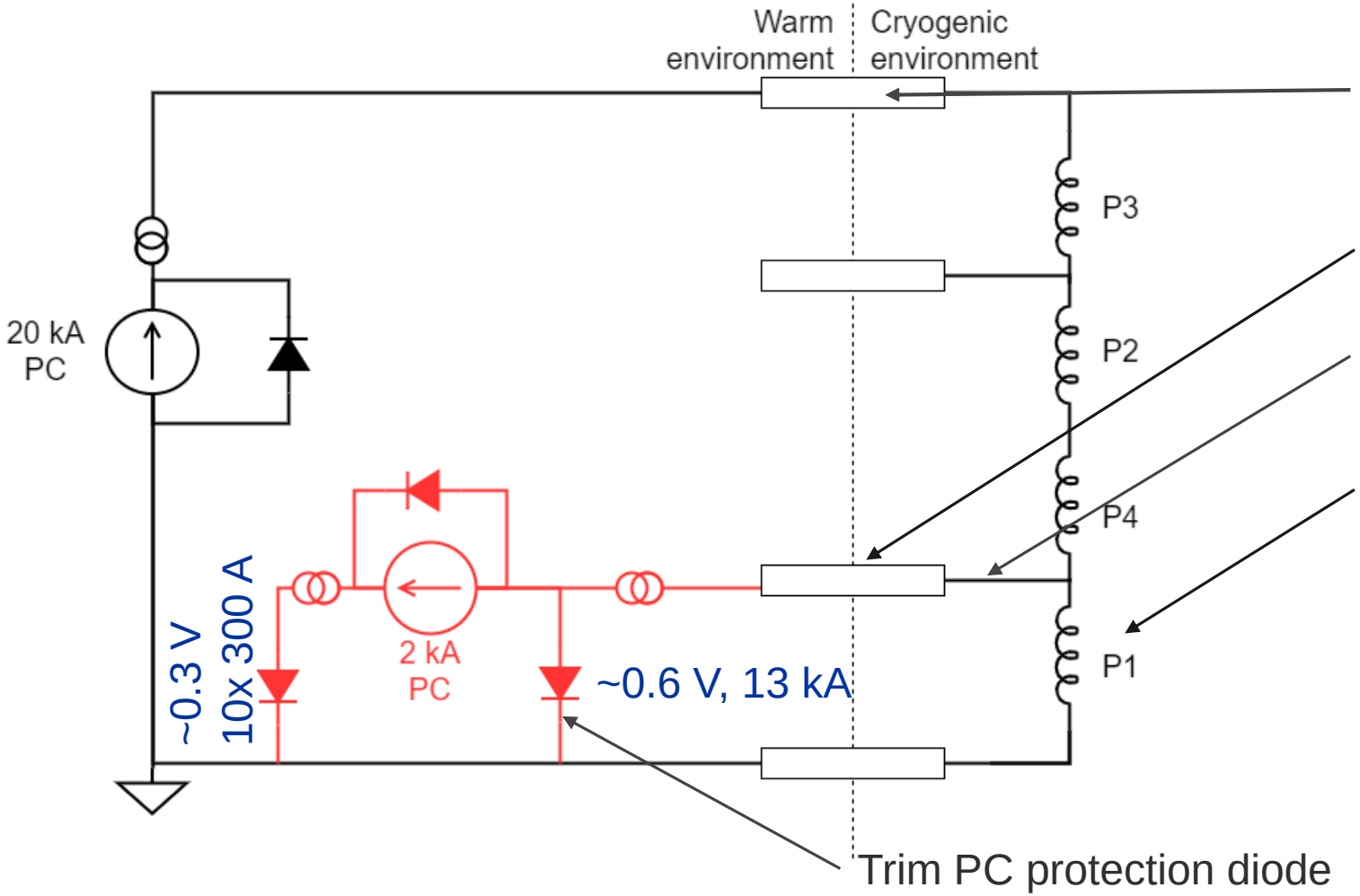
11 T Series #2: Change in full coil voltage between cool down 3 and cool down 4; the method can show degradation and changes in degradation, even before the quench happens.



- Voltage build-up up to 6.5 µV in quenching Pole 1 (P1) of MQXFBP2 at 4.5 K & 15.4 kA.
- Voltage build-up in P2 and P3 that did not show a quench limit at that current level but appeared limited at higher current levels during trim powering (see next slides).
- Even the full coil measurement can show the start of voltage build up.

Innovative Test Procedure: Trim Powering

- In case the performance of a magnet is limited by one coil, this procedure enables to inject additional current in the other coils to assess their performances (concept initially proposed by A. Milanese, CERN/TE-MSC).



Main current leads (20 kA)

Auxiliary current leads (600 A) used for CLIQ in the temporary cold mass configuration

Superconducting CLIQ leads

Coil to trim down

- Next step: Double the leads to allow up to 2 kA trim powering

Additional Test Procedure: First Implementations of Trim Powering

Initial Tests on MQXFS7

2 kA Trim PC

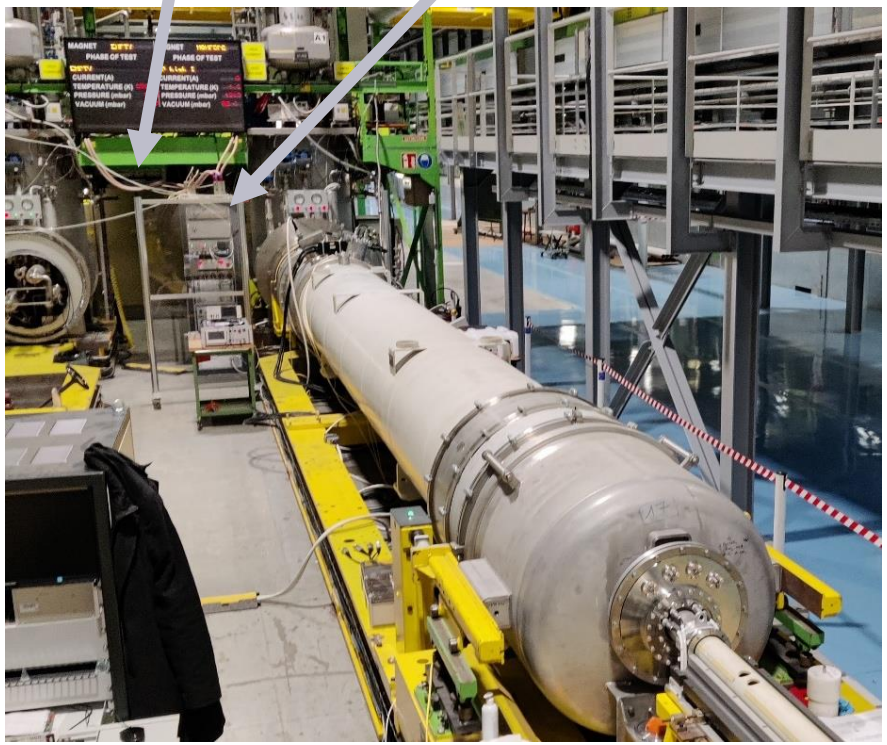
Additional DCCT (to measure trim current)

Protection diode

Strong support from TE-MPE & SY-EPC

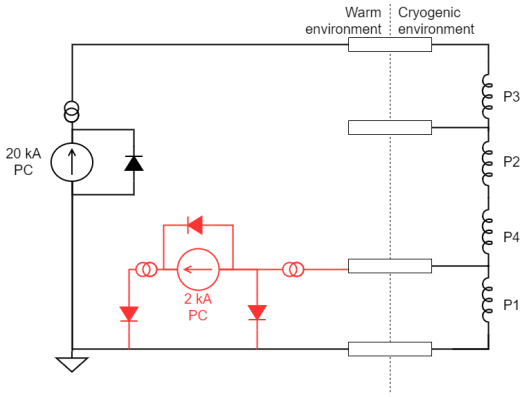
2 kA cables going to the mezzanine

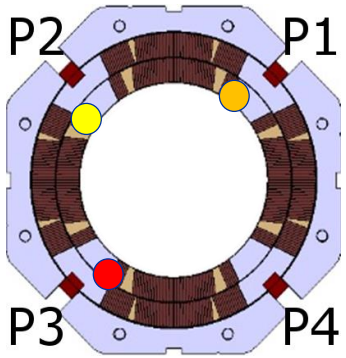
2 kA Trim PC

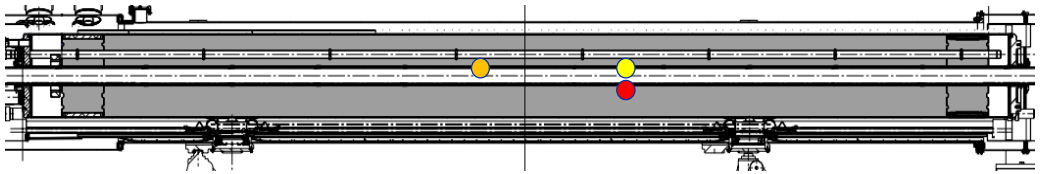


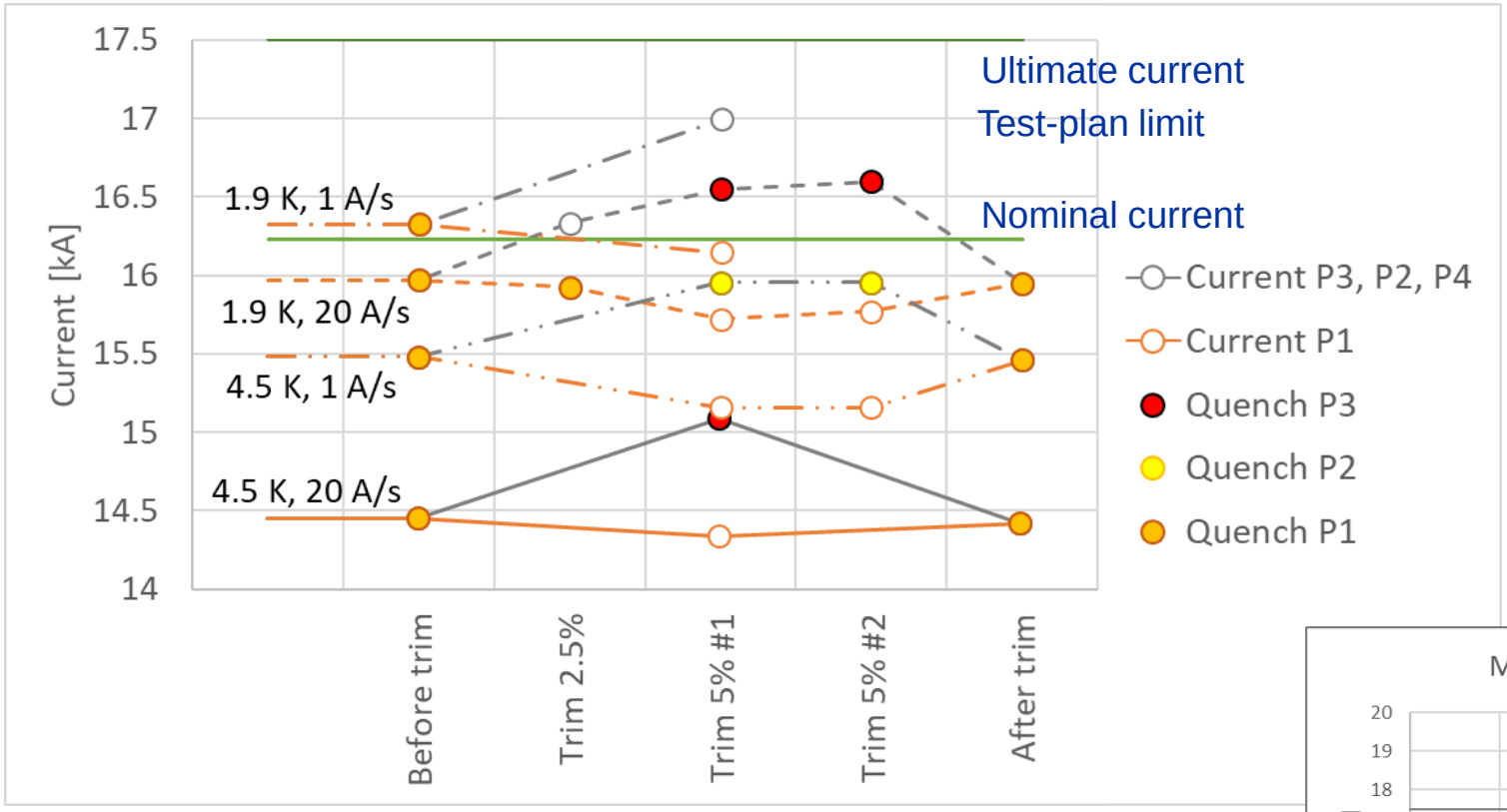
Test of MQXFBP2

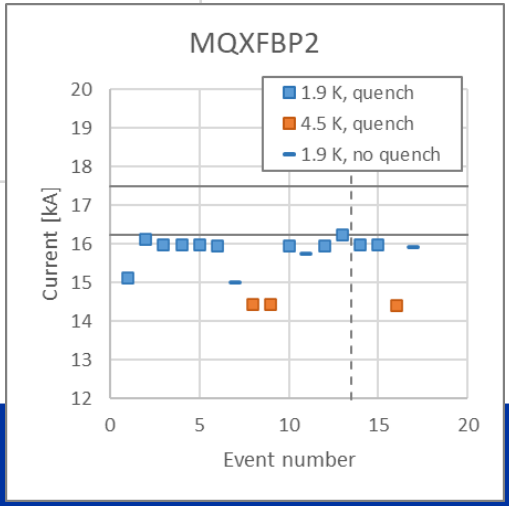
Additional Test Procedure: MQXFBP2 Trim Powering Results





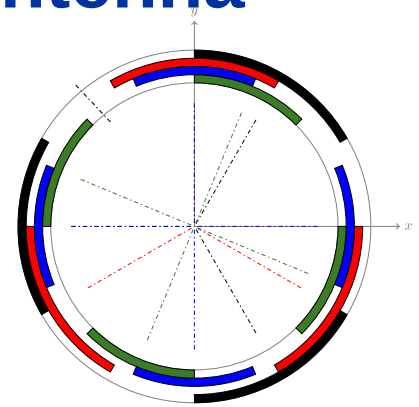


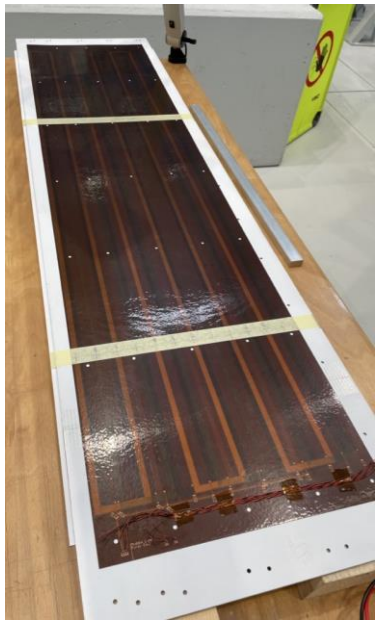


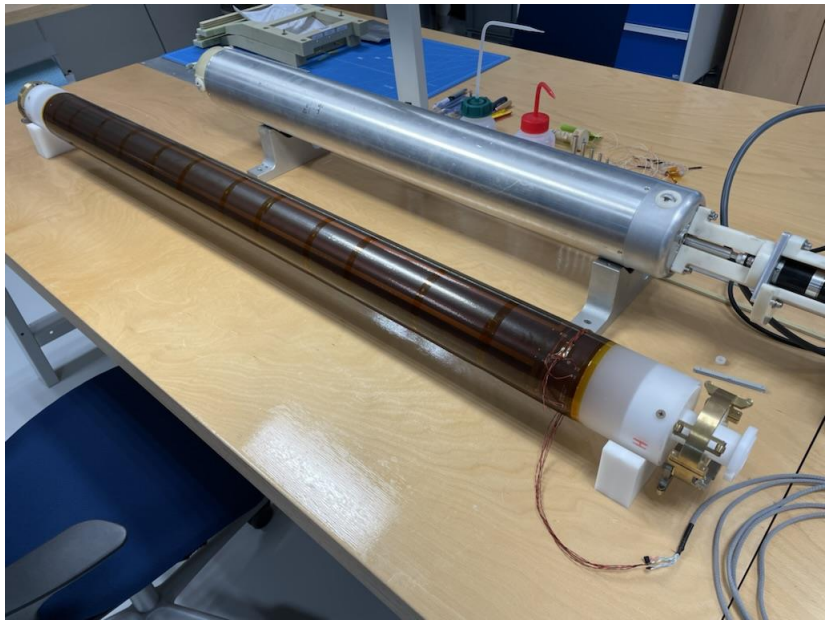


Improved Instrumentation: Multipole-Sensitive Quench Antenna

- Quench antenna configuration enabling accurate quench start localization, both longitudinally and azimuthally (concept initially proposed by T. Ogitsu, circa 1992)
- B3,A3,B4,A4 sensitive through coil design (analogue bucking -> Flex PCB design)
- Compromise between noise (PC, vibrations etc), resolution in radial direction, and signal strength.

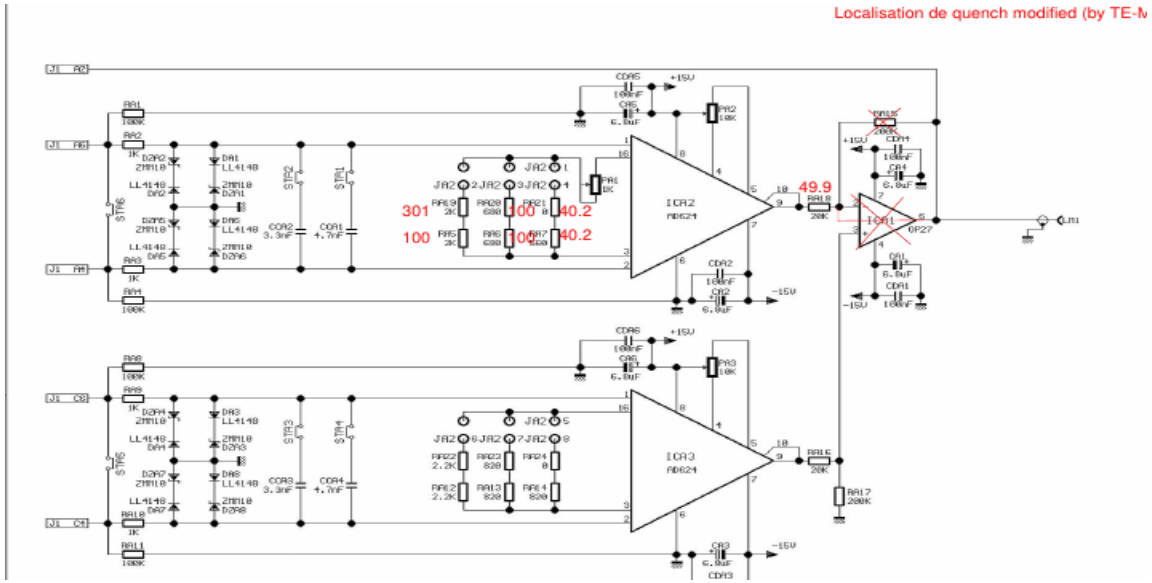


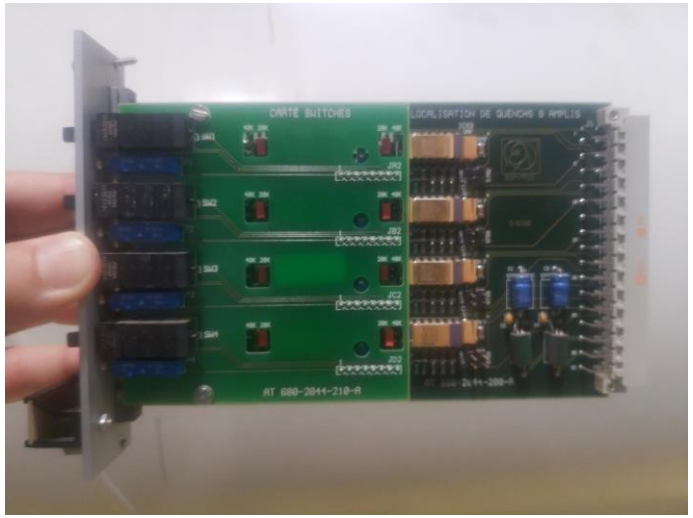


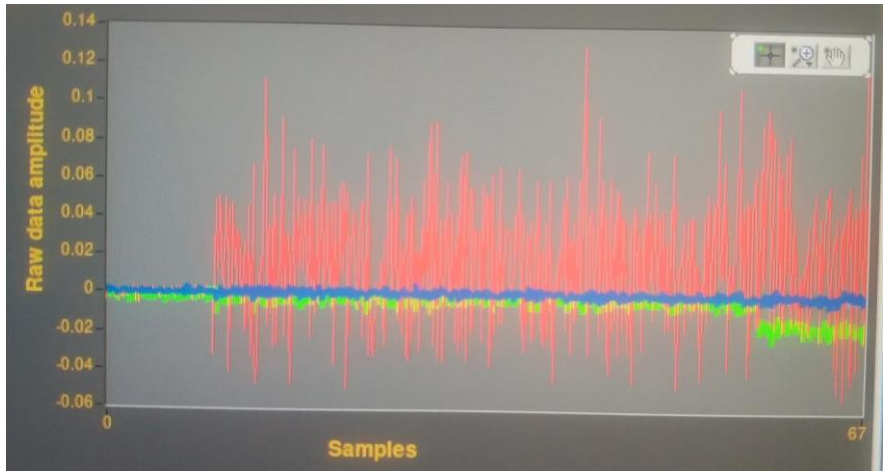


Improved Instrumentation: Signal Acquisition for Quench Antenna

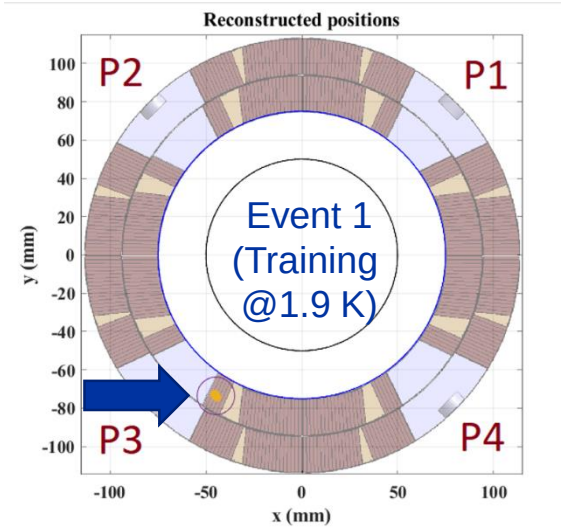
- 15 amplifier cards have been modified to improve the SNR
- We see an improvement of **a factor >10** (blue and green signals)

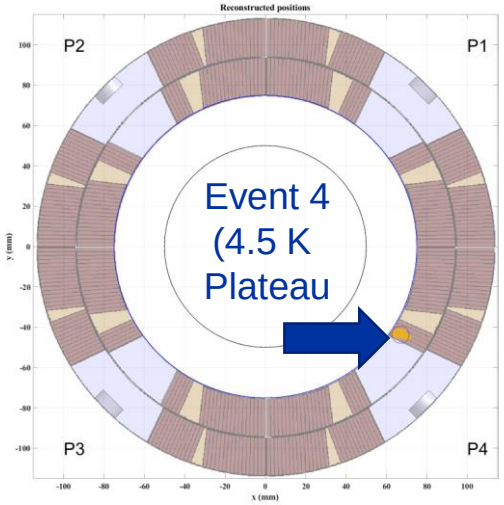


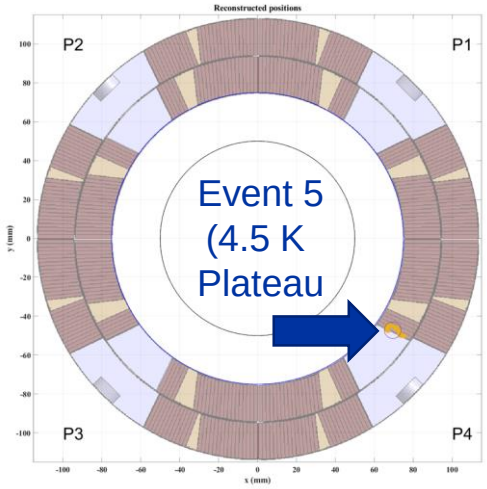


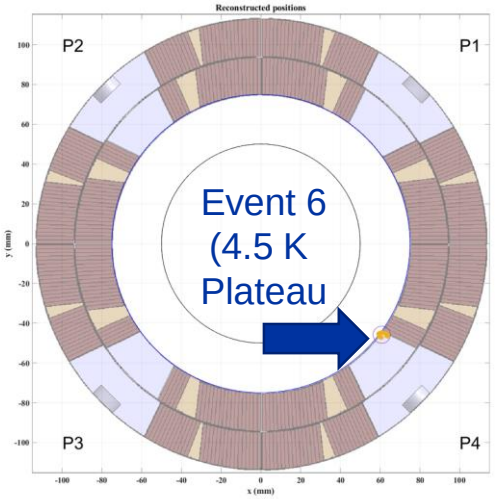


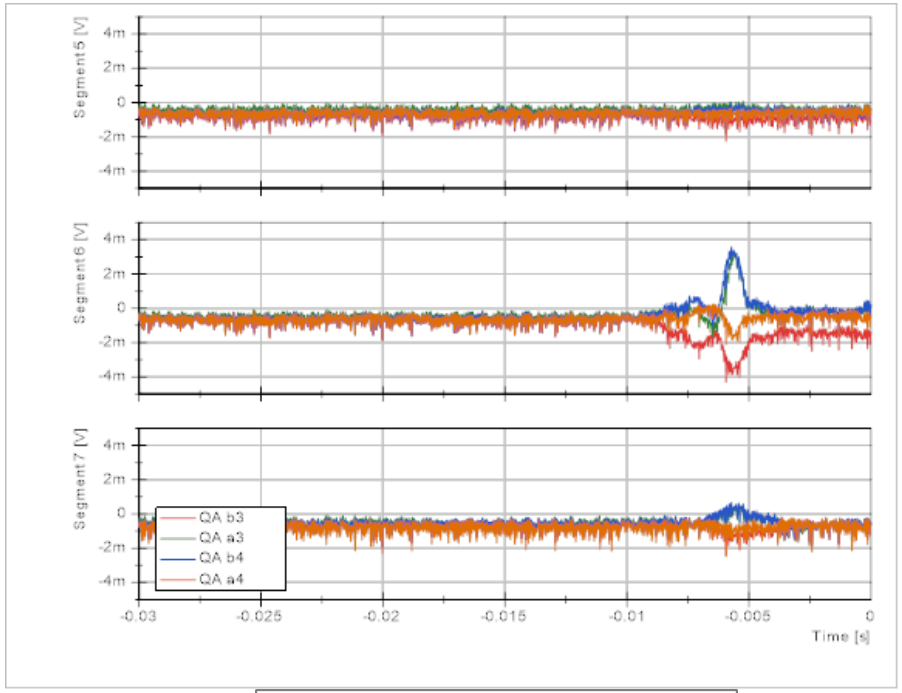
Improved Instrumentation: MQXFBP3 Quench Antenna Results

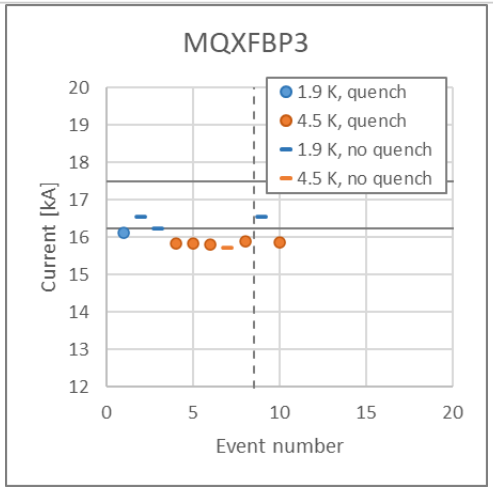






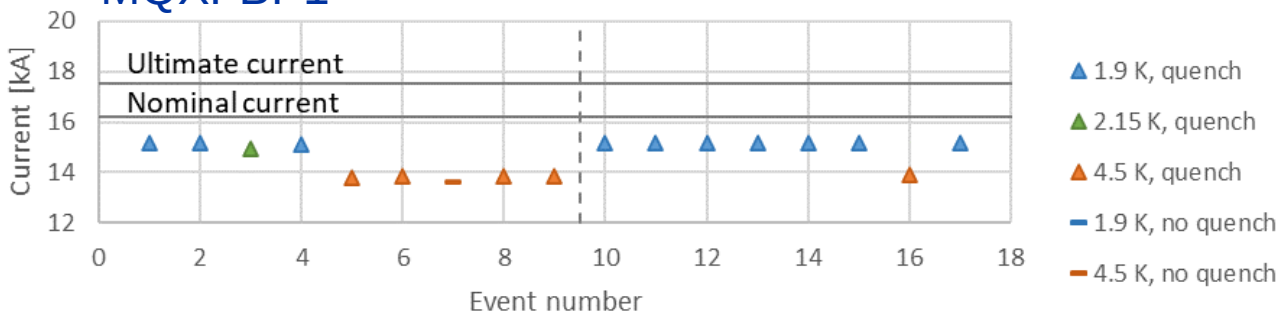






MQXFBPx Quench History

MQXFBP1



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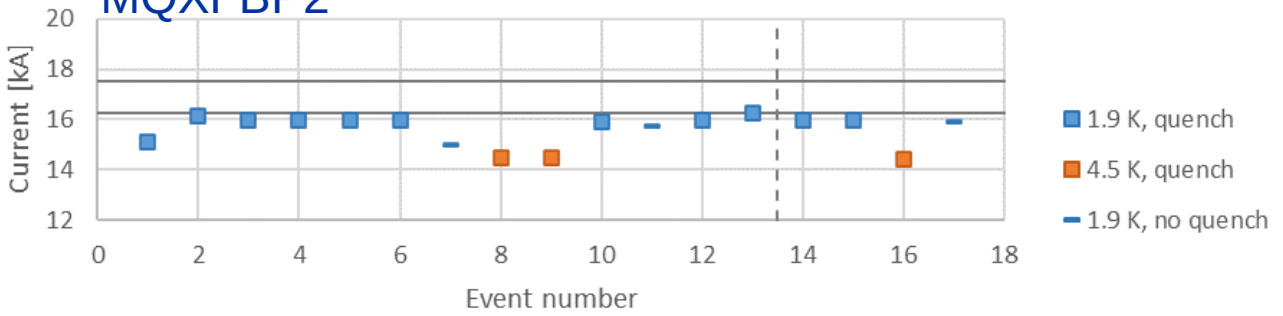

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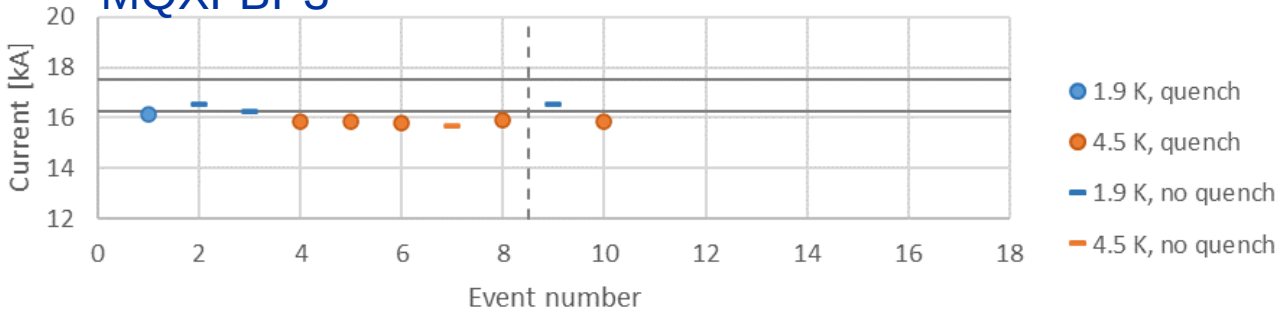
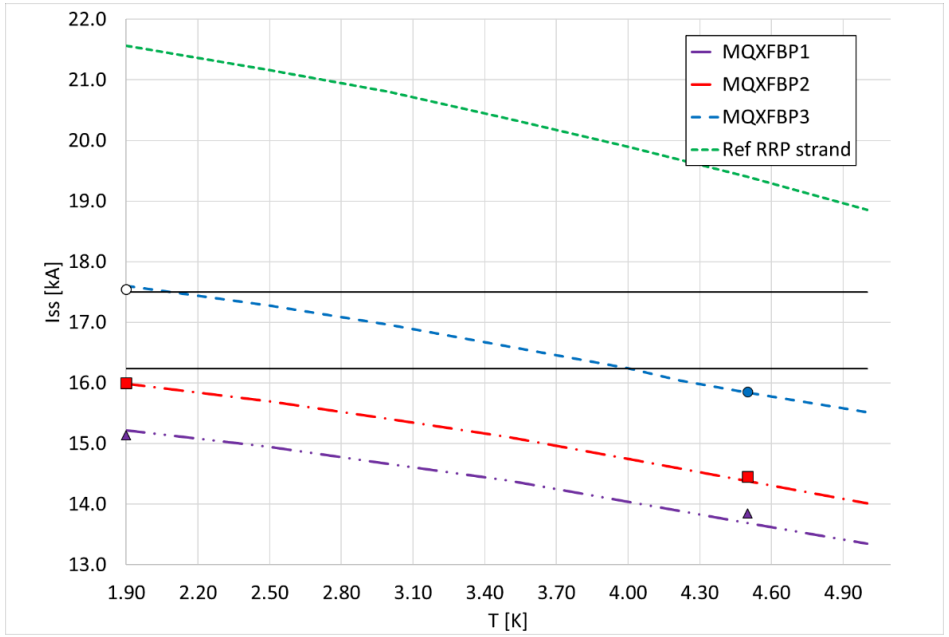
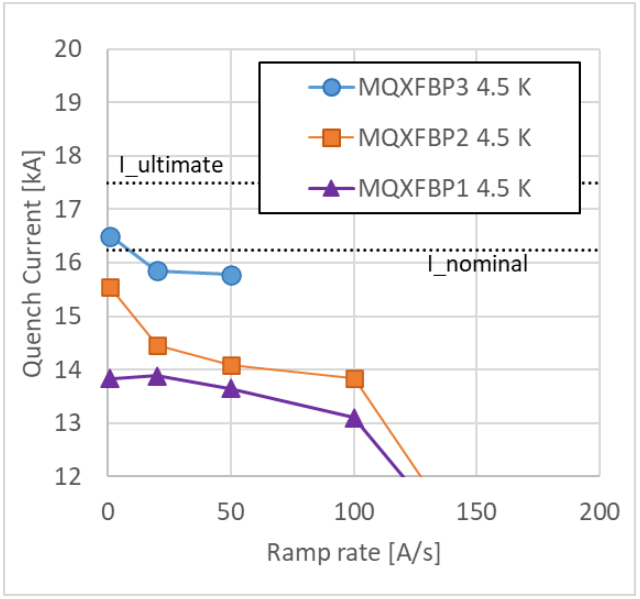
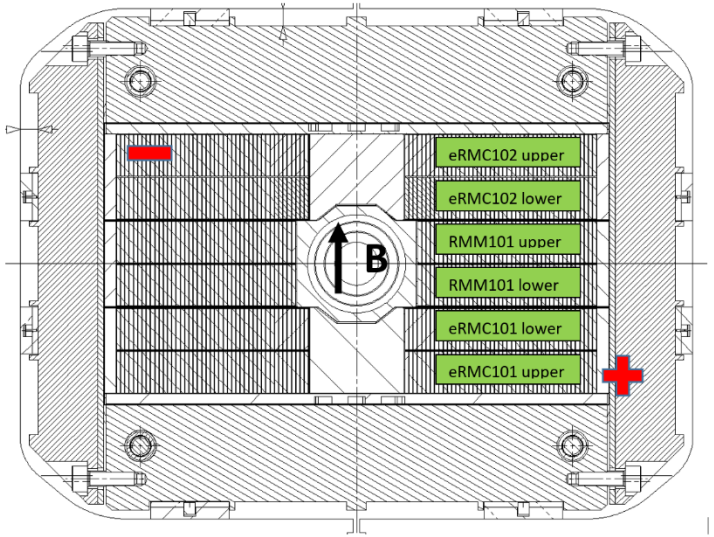


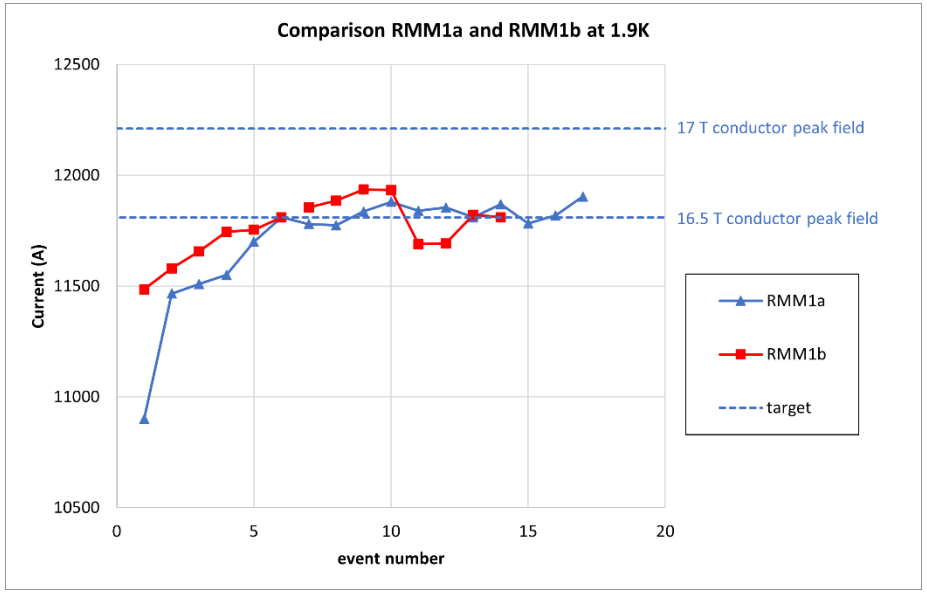


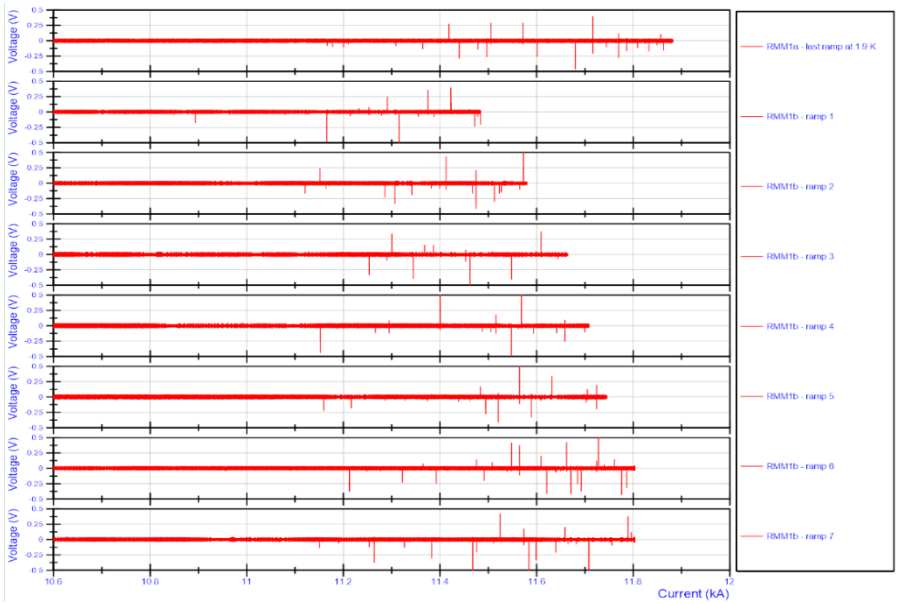


RMM Test Results

- RMM1 is a demonstrator magnet made up of a **stack of 3 double-pancake, racetrack-type coils;** it was tested twice (RMM1a & b) with some modifications on longitudinal rods between the 2 versions.
- **RMM1b** reached a record **16.7 T conductor peak-field** after ~10 quenches.
- The ***V-I*** measurements show **no apparent voltage.**
- From 11.2 kA, **mechanical vibrations** (possible precursors) are observed in the coil voltage signals of all current ramps, indicating that further mechanical stabilization may still enable to improve performance.







Conclusion

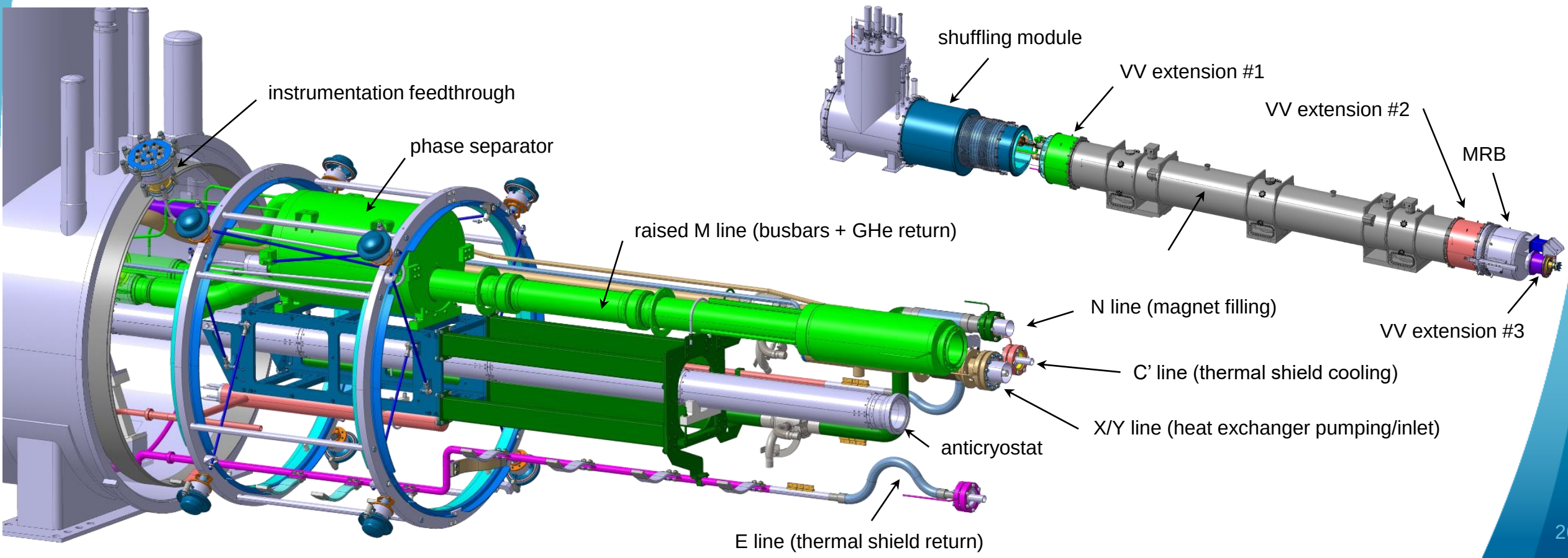
- **The horizontal test bench reconfiguration project is now well underway**, with suitable monitoring and reporting tools; **safety issues** have been addressed; particular care provided to **management of interfaces.**
- All test benches expected to be **ready before HL-LHC components delivery** to SM18 (SM18 upgrade is not on critical path anymore).
- No showstoppers in sight, but **tight margins** for the first two benches
  – 1 month for Q2P2 on **bench F1;**
  – no margin for SC Link prototype on **bench F2.**
  Coordination with TE-CRG Group is instrumental.
- **Shuffling Module** experience on F1 important to **validate schedule on other benches;** same applies to anti-cryostats, 2 kA plugs and magnetic measurement shafts.
- Improved **diagnostic tools and procedures to** enable better interpretation of test results, in particular, for series magnets with **limited instrumentation.**

Annex: Test Bench Status

Shuffling Module

Main functions:

- Extend and “shuffle” cryogenic lines from CFB to HL-LHC magnets
- Add a phase separator to control LHe level and temperature (4.5 K tests)
- Add 400 W heaters to pre-load He control system (increased ramp losses)
- Add instrumentation



Procurement through EN-MME (as of May 2022)

Component		Status	Delivery date
Vacuum vessels			
	Batch #1 (F1 and extensions for Q2a or Q2b)	Delivered	April 2022
	Batch #2 (remainders)	On-going	June 2022
	Extension vessel (for all benches)	Delivered	April 2022
Pressure bearing components			
	Batch #1 (F1 bench)	On-going	End-April 2022
	Batch #2 (A2 and B2 benches)	On-going	End-May 2022
Mechanical components and thermal shields			
	Batch #1 (F1 bench)	Delivery started	End-April 2022
	Batch #2 (A2 and B2 benches)	On-going	End-May 2022

Busbar line being manufactured in main workshop

Instrumentation vessel

Batch #1 of vacuum vessels

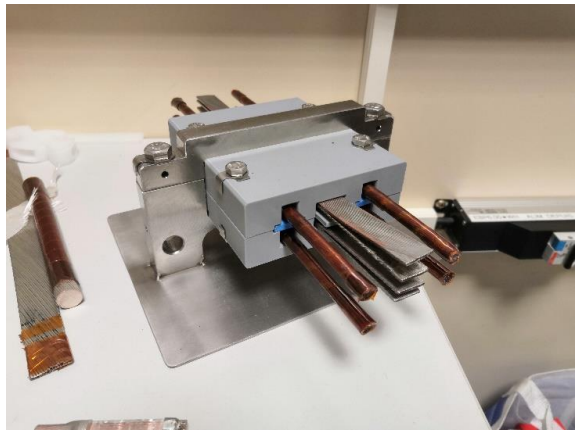
Space-frame Thermal shield for all benches

Fabrication within MSC (as of May 2022)

Component	Status	Delivery date	Note
IFS (CMI)			
Prototype	On-going	April 2022	Prototyping on-going to define correct procedure and geometry
Series for F1 bench	-	End-April 2022	Level gauges may be a bottleneck, solution being studied with CRG
Series for A2 bench	-	August 2022	
Series for B2 bench	-	November 2022	
Series for C2 bench	-	February 2023	
Busbars (LMF)			
F1 bench	On-going	End-April 2022	Busbars available, supports and splice components being manufactured
A2 bench	On-going	August 2022	
B2 bench	On-going	November 2022	
C2 bench	-	TBD	

Prototype of IFS

Prototype of sliding busbar support



Prototype of busbar fixed point

Test Bench A1

In use for MQXF tests in direct connection

Q2 P3 currently under test

New flexi PCB-based quench antenna

Test bench A2

Ready by April 2023, (Q1 expected Jun 2023, CP prototype Nov 2023)

Critical Path Tasks	Due by	Remarks
2kA Energy Extraction	Dec 22	Based on estimated delivery end Nov 22 (to be confirmed).
Mechanical CFB modifications by TE-CRG	Nov 22	As per EDMS 2165739 (TBC)
Shuffling Module connection to CFB	Feb 23	Two months estimated (to be reviewed after F1)
Shuffling Module commissioning	Mar 23	One month estimated (to be reviewed after F1)

New 11T type DQHDS
quench heater power supplies
delivered (output voltage to
be adapted in-situ)

Aux power circuit layout still under discussion.
2kA cabling demand to EN/EL pending.
NB: external procurement of 2kA switch.

3 new racks to be integrated
(2kA PC + energy extraction)
(mobile 600A PC rack under discussion)
impacts cabling demand

Test bench B2

Ready for direct connection in Feb 2023, with shuffling module in Oct 2023 (D1 prototype in direct connection expected Feb 2023, D1 series in June 2024)

Critical Path Task	Due by	Remarks
Assembly new short Ø110 mm anticryostat	Dec 22	Special Family 2 anticryostat needed for high precision magnetic measurements, shorter to allow test w/o Shuffling Module

Functional specification of Cryo PLC/Safety Interlock PLC upgrade pending (minor changes foreseen)

uQDS to be adapted for dI/dt protection

The B2 bench is still being used for LHC magnets.
CFB modifications by TE-CRG planned to start Dec 22

Test bench C2

Used for direct connection (D2 prototype installed, test planned end Sep 22)

new 600A Energy Extraction for corrector protection

Safety Interlock PLC upgraded with additional quench heater channels

CFB modified for Direct Connection

Modified MRB

Eccentric thermal shield

Eccentric VV flange

Bench ready

Vacuum vessel extension

Modified CFB

Bench extension

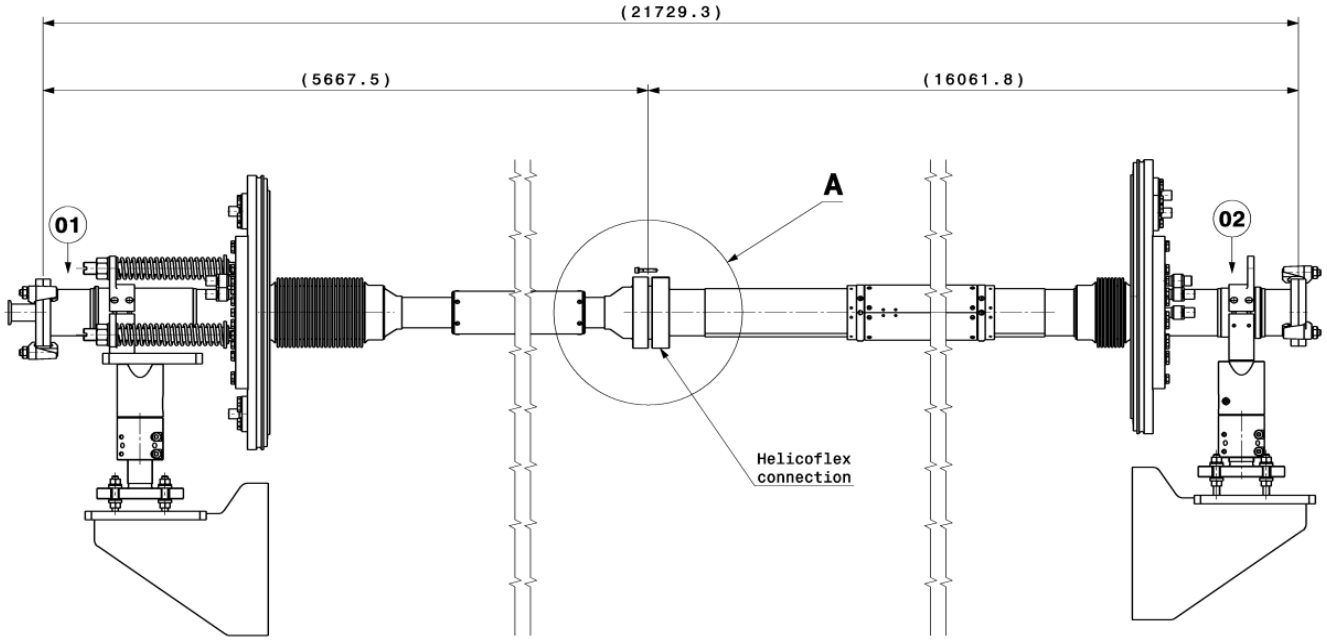
Sliding support for measurement coil shafts

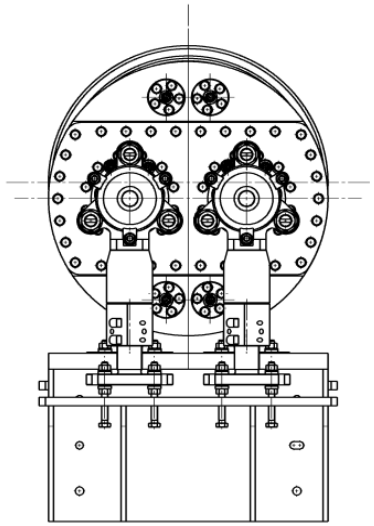
Prototype D2 tested magnetically with ∅40mm LHC coil shafts anticryostat installed in a specially made fake cold bore

Test bench C2

Ready with shuffling module by end June 2023 (D2 series expected Nov 2023)

WBS	Critical Path Task	Contact	Due by	Remarks
1.4.4.3	Assembly short anticryostats ACF4S.01-02	C Solano	end Mar 23	If needed, this task may be decoupled from the Shuffling Module connection, via a novel anticryostat insertion tool (design ongoing).
4.3.8.4	Shuffling Module Connection to CFB	A Vande Craen	end May 23	Two months estimated (to be reviewed after F1)
4.3.8.5	Shuffling Module commissioning	A Vande Craen	end Jun 23	One month estimated (to be reviewed after F1)





double-aperture anticryostat, specially tapered for mechanical compatibility with the CFB

Workflow optimization at P18