SM18 Test-Facility and Test Plans

Prepared by M. Buzio, S. Russenschuck & F. Savary

on behalf of the SM18 test and magnetic measurement team, and all Groups/Sections involved in the SM18 test bench re-configuration project

Presented by A. Devred

Overview

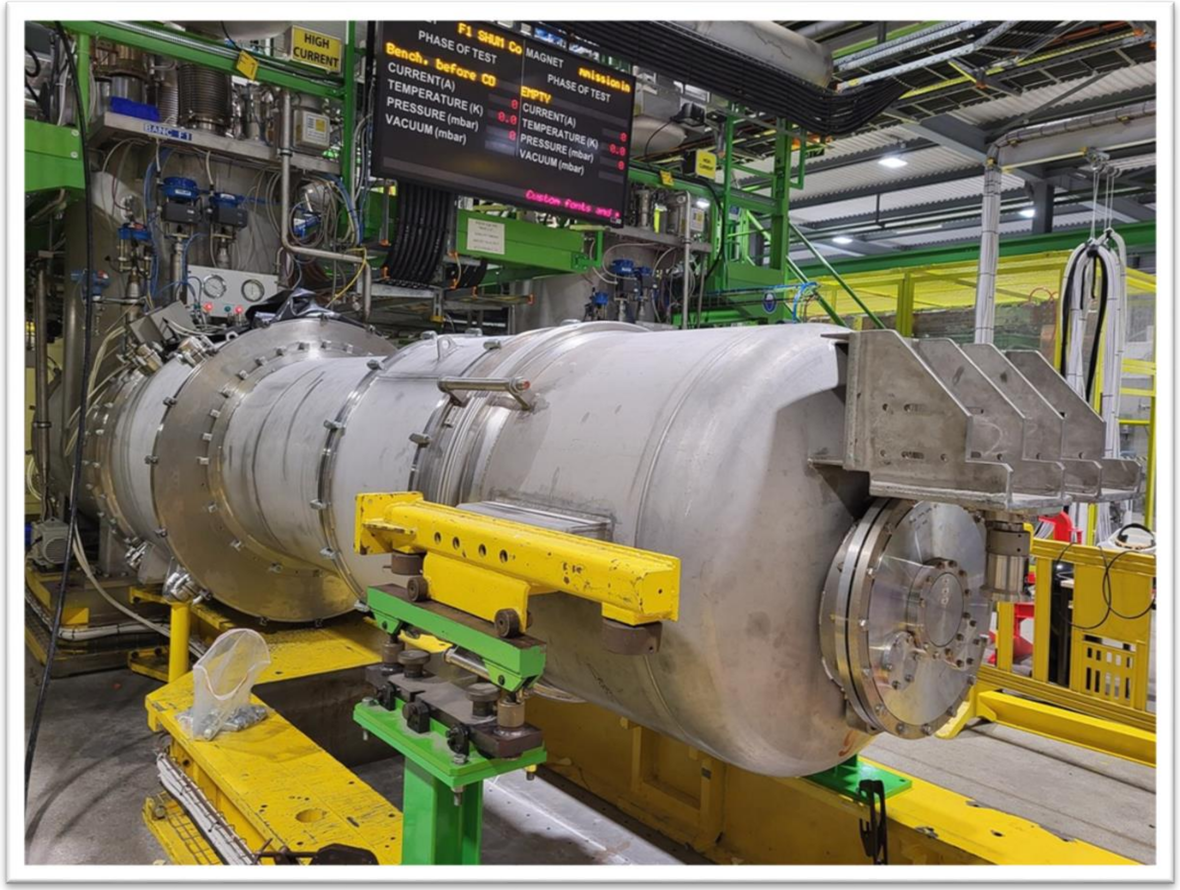
- **Advances in the SM18 test-bench reconfiguration project**
- **Recent results in cryomagnet testing**
  - *See also the presentation by G. Willering*
- **Recent results of magnetic measurements and instrumentation**
  - *See also the presentation by L. Fiscarelli*

Thanks to a large team from other CERN Groups and Sections

- **BE-CEM**
  - uQDS GUI (all benches); DAQ (all benches except F1/2).
- **BE-ICS**
  - Interlock PLC for shuffling module and anticryostat (all benches), software and commissioning.
- **EN-EL**
  - CFB instrumentation cabling, 2 kA cabling of the new polarity switch, AC connections of new aux powering racks, cabling for additional CP instrumentation and CLIQ.
- **EN-MME**
  - Design Office; procurement and/or manufacture of various components for shuffling modules.
- **EN-ACE**
  - Relocation of staircase to the platform; installation of new electronics racks.
- **SY-EPS**
  - Installation of new 2 kA polarity inverting switch; installation and commissioning of 2 kA power supplies; load/polarity inverting switches.
- **TE-CRG**
  - Cryo PLC: complete cabling to DFHX/DFX, I/O test; cold commissioning of the upgraded CFB; modifications of the CFB for the shuffling module; cold commissioning of the shuffling module; modification of the CFB for the new anticryostats.
- **TE-MPE**
  - Commissioning of 2 kA Energy Extraction system; commissioning uQDS current sensors; installation and commissioning of Energy Extraction 2k A/600 A (mobile rack); commissioning of uQDS crates and current sensors (dI/dt computation in firmware).

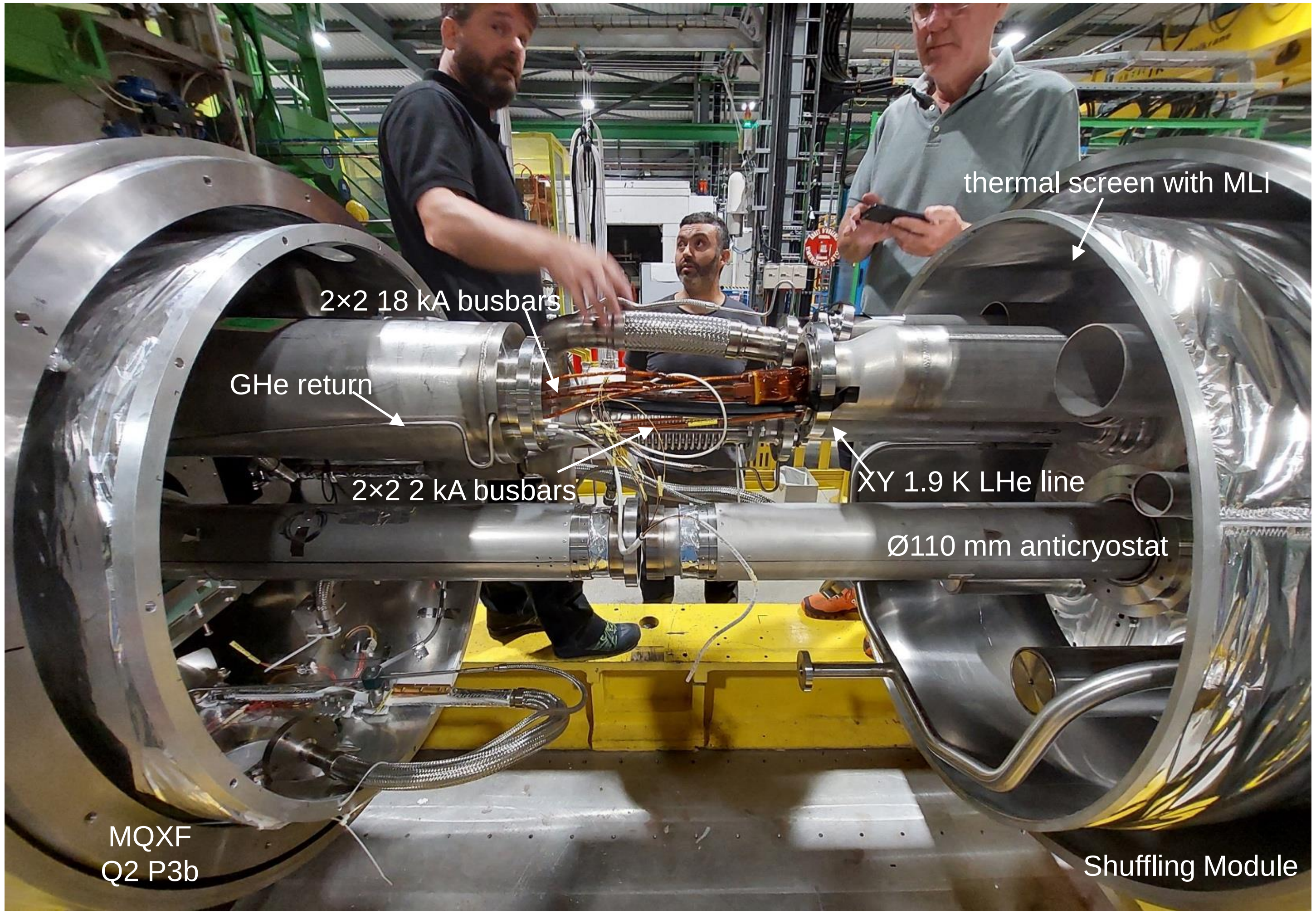
F1: First bench equipped with a shuffling module

Short-circuit commissioning: **August 10, 2023**

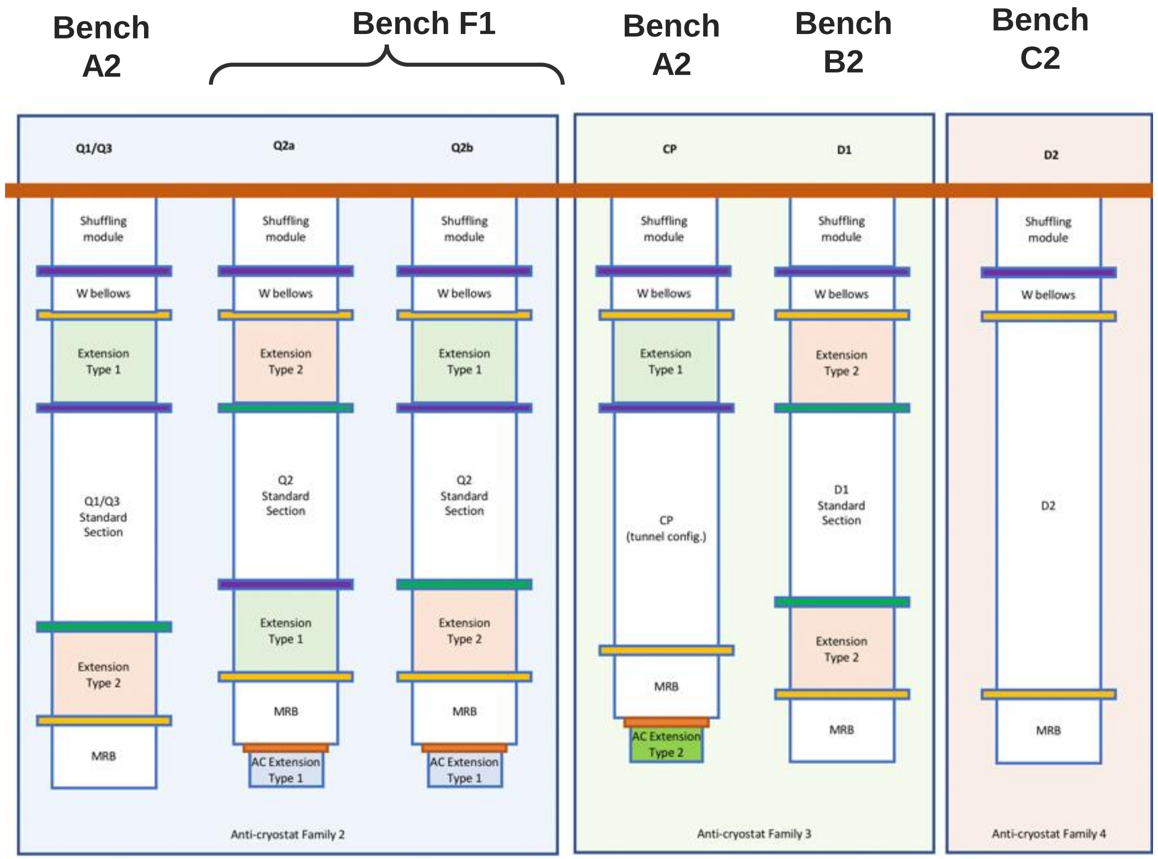


Q2 cryo-magnet connection: **September 14, 2023**

Cryomagnet connection: details

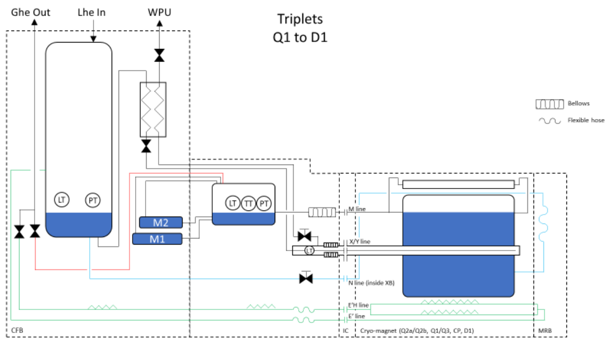


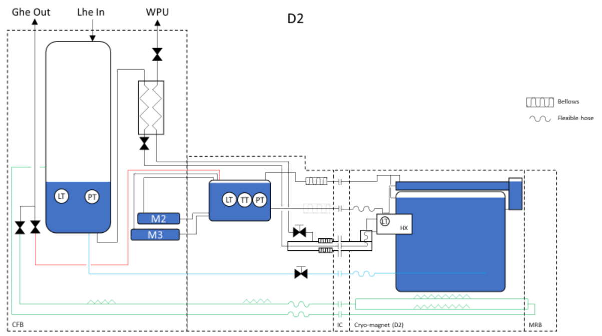
Test-bench compatibility



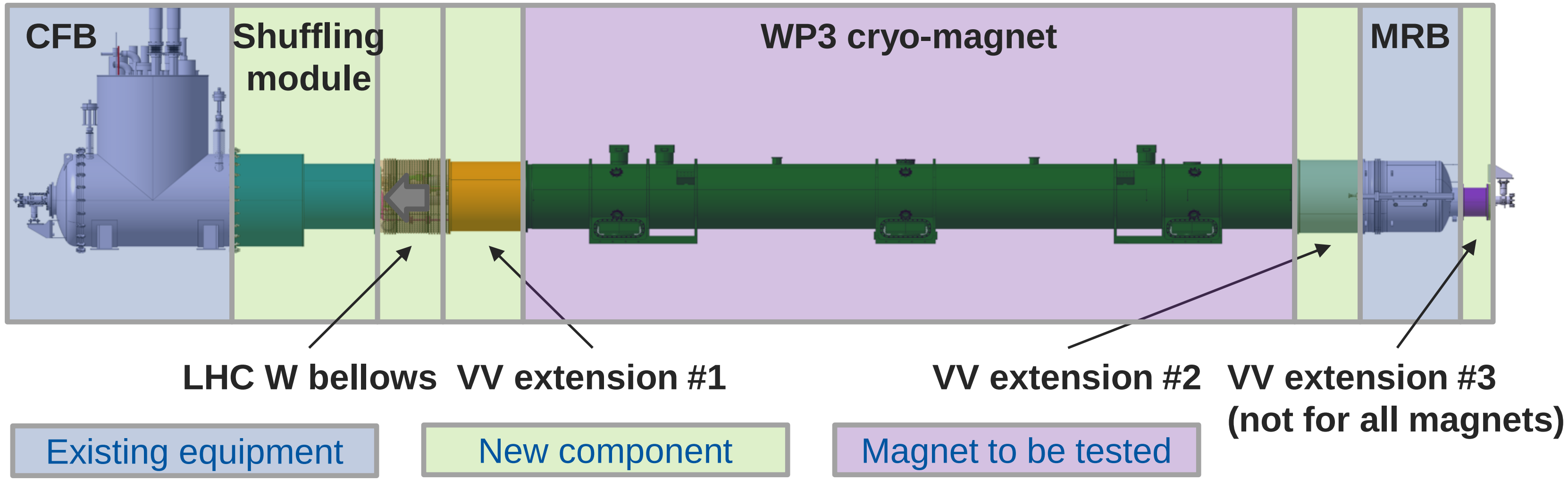
The shuffling module can be made compatible with all WP3 magnets including D2; **3 benches are still to be equipped** for the SM18 upgrade; baseline: one magnet type per bench (except Q1/Q3 and CP on A2).

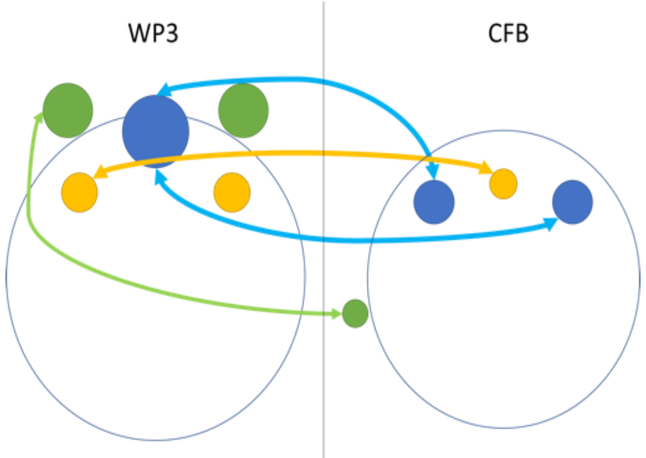
Standardization
as much as possible, in order to limit types of anti-cryostats, shafts for magnetic measurements, and quench antenna.





Good level of standardization albeit with variants



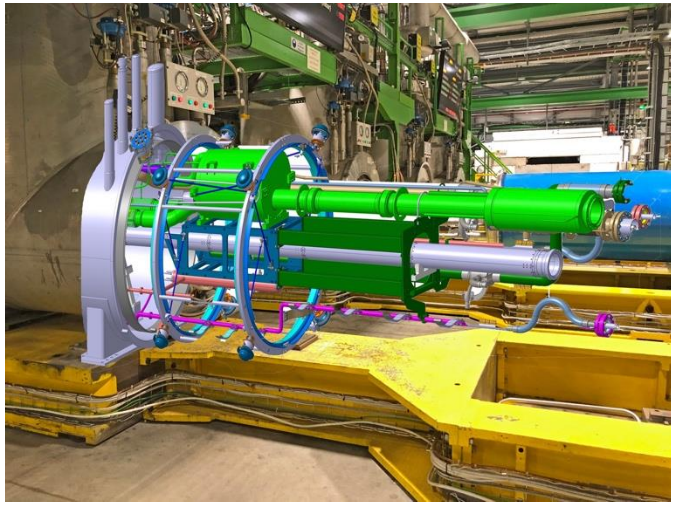


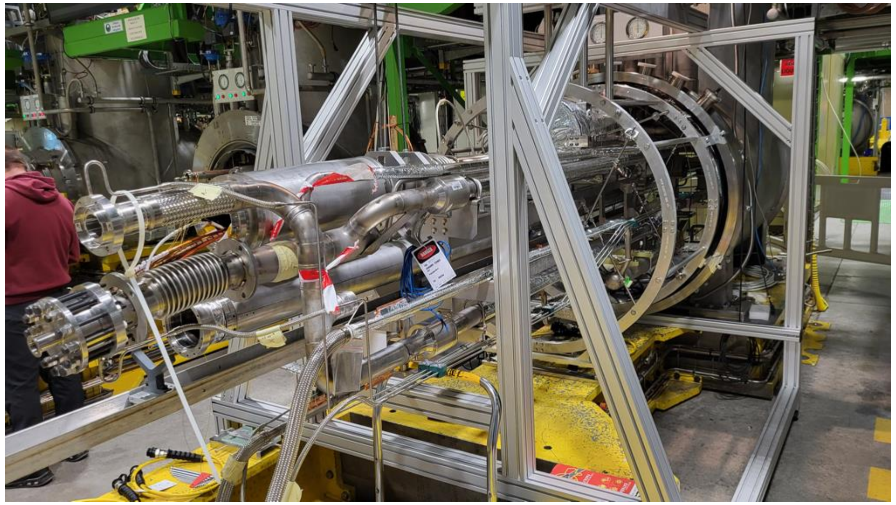
Shuffling Module:

- **Interface between WP3 magnets and CFB.**

Compatibility matrix:

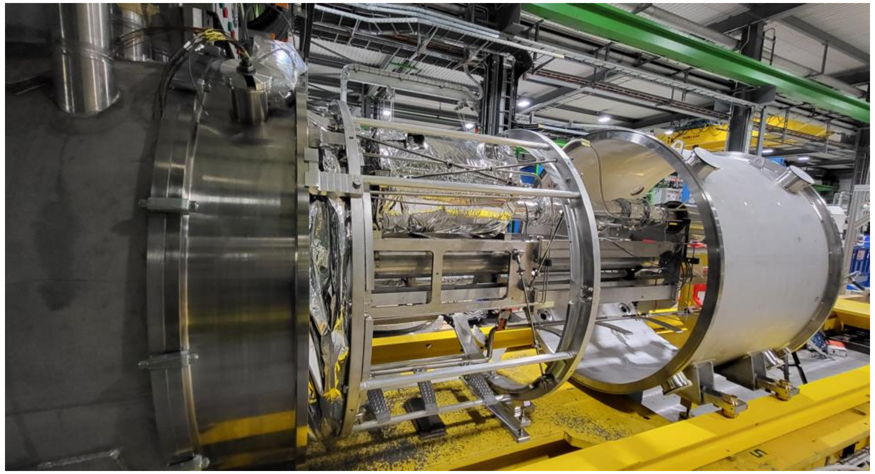
	A2	B2	C2	F1
Q1	X			
Q2a	OK			X
Q2b	OK			X
Q3	X			
D1	OK	X		
CP	X			
D2			X	



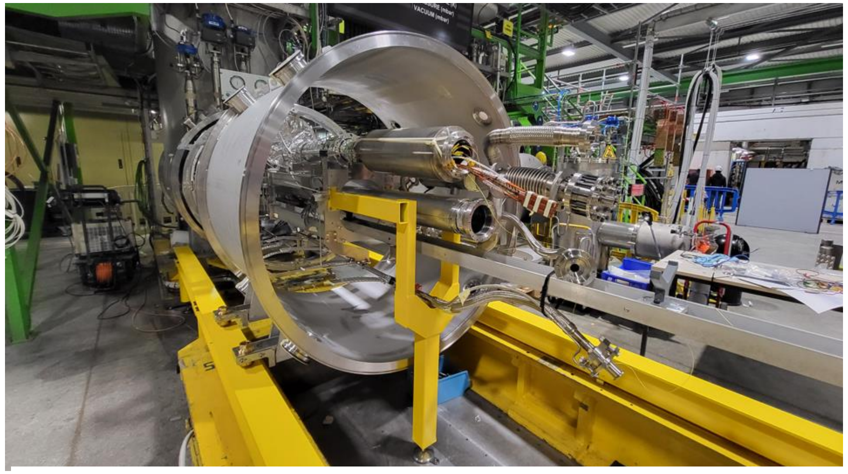


Highlights

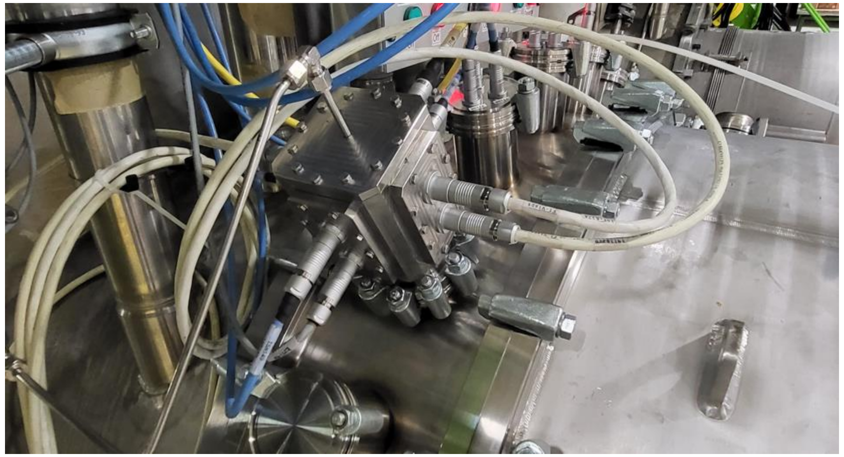
Space frame and cantilever beam to support the He lines in the vacuum vessel



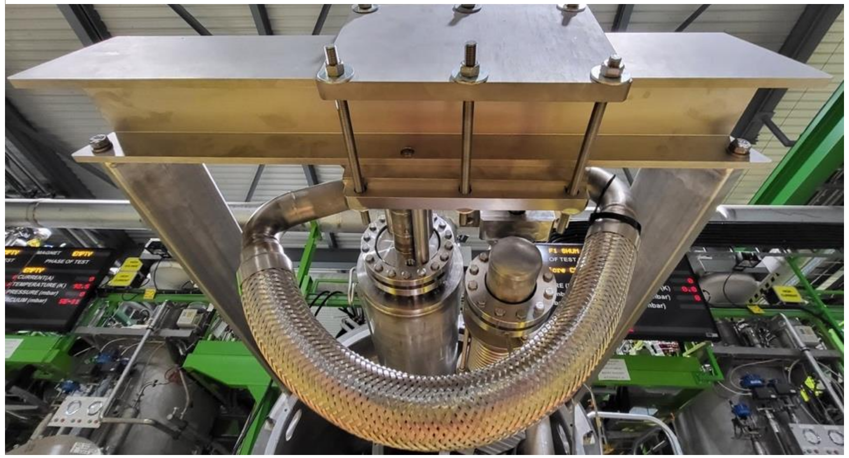
Integration of a short anti-cryostat to house the magnetic measurements shaft



Connector box on the instrumentation VV, extension of the phase separator via IFS capillary

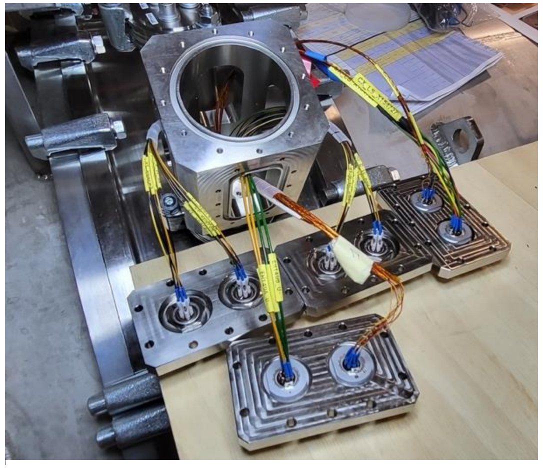


Temporary support structure for global pressure and leak test at end of assembly



Example of challenges: qualification of the connector box

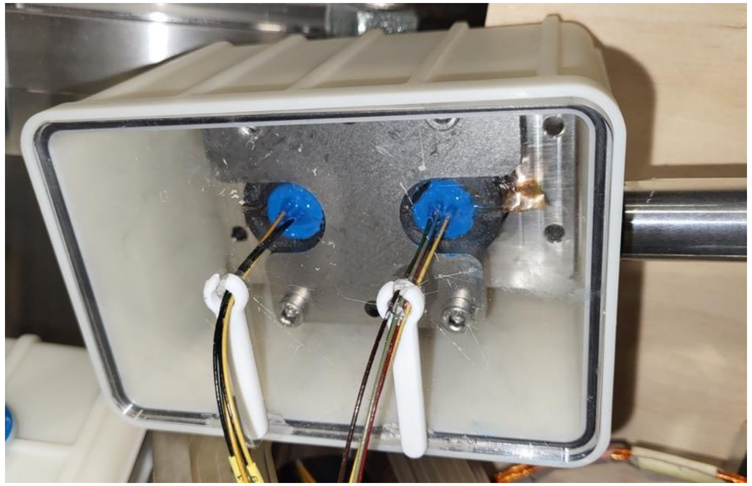
- **The connector box** has undergone **HV insulation tests in air and gaseous He;** the insulation of the connectors was reinforced with resin potting:
  - Breakdown was observed for 2 of 4 tested connectors @4.2 kV and 4.8 kV in gaseous He, providing adequate margin to test HL-LHC magnets.
- Cabling, jointing, and assembly procedures developed during **work on F1.**
- Qualification of the connector box per **PED requirements with HSE** (pressure tested @5 x 20 bars).



Cabling, jointing and potting on F1 bench

HV test set-up at CERN HV laboratory

Connector box for high pressure test

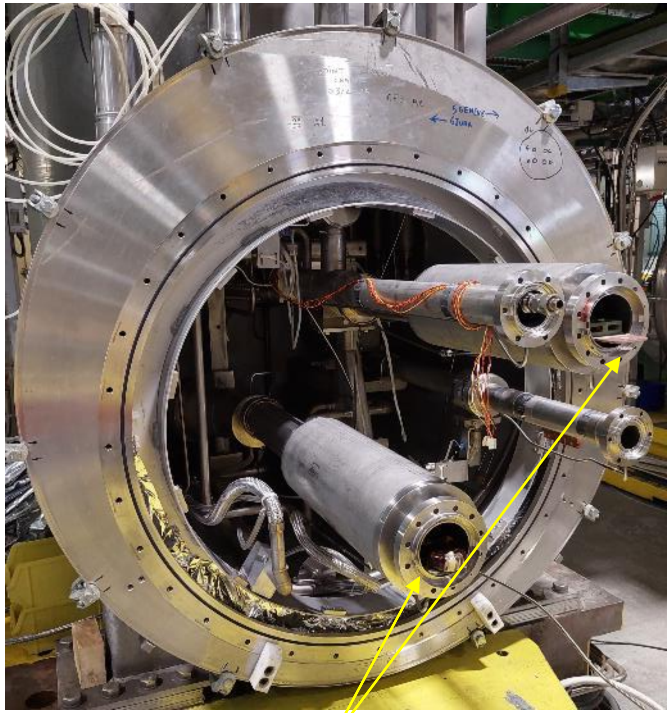


Test bench F2 for SC link: status

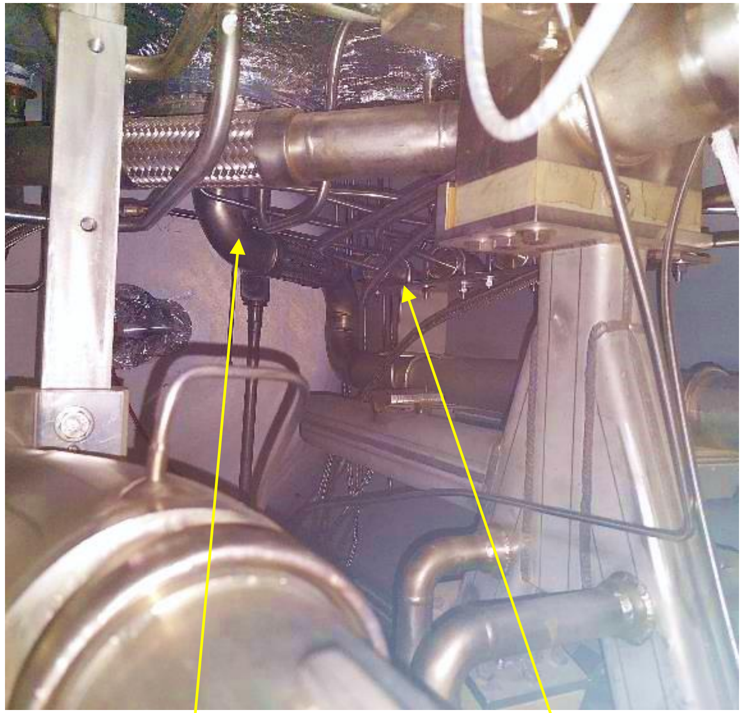
- **Patch Panel Interface (PPI)**
  – commissioned successfully with new 18 kA and 2kA water- and air-cooled power circuits; – 2kA current lead terminations now in preparation with help of String mock-up (temporary configuration with standard rigid 300 mm^2 cable).
- **Instrumentation and cabling**
  – DFHX/DFX cryo instrumentation cabling: preparations ongoing;
  – 20 × new uQDS crates installed and cabled, to be tested.

Test bench A2 for Q1/3 & CP – status

- **Cryo PLC:** process updated (~identical to F1);
- **Aux power circuits:** 2 kA load and polarity switches procured and assembled, ultra-flexible cable ordered;
- **Protections:** 2×uQDS crates for MQXF/MCBXF protection installed; 2 kA/600 A Energy Extraction systems available;
- **Shuffling Module:** essentially identical to F1/B2 unit, all components/electrical connectors available, assembly started in SMI2;
- **Anticryostat:** new short unit type 2/3 available.

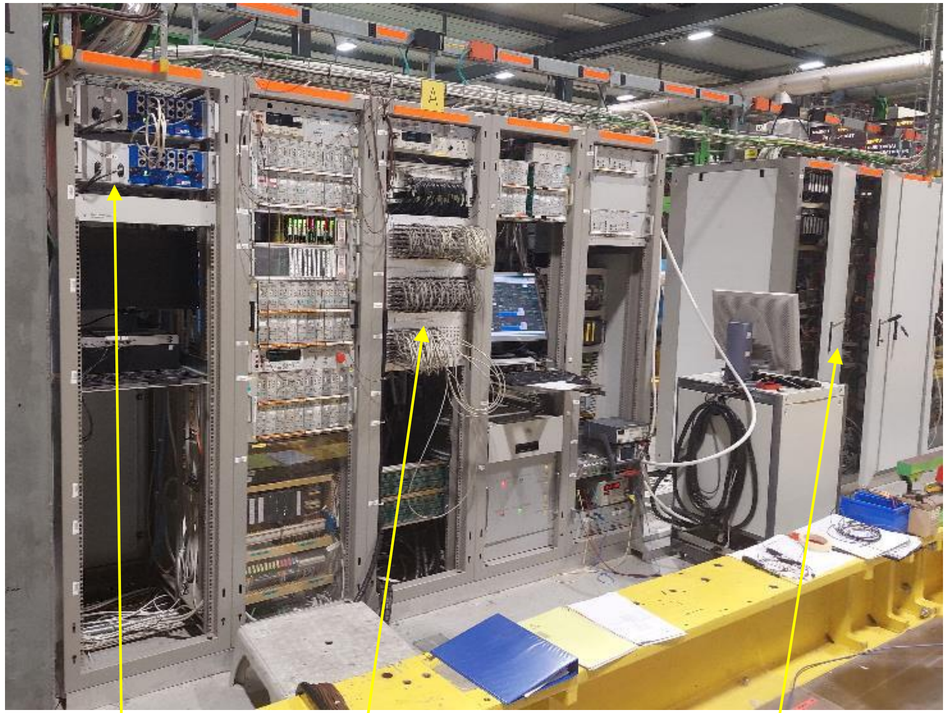


2 kA/18 kA s/c
ready to install "pieuvre"



raised line N
(to be done on B2/C2)

new 2 kA current
leads/plugs



2× uQDS crates

Interlock PLC HW upgraded

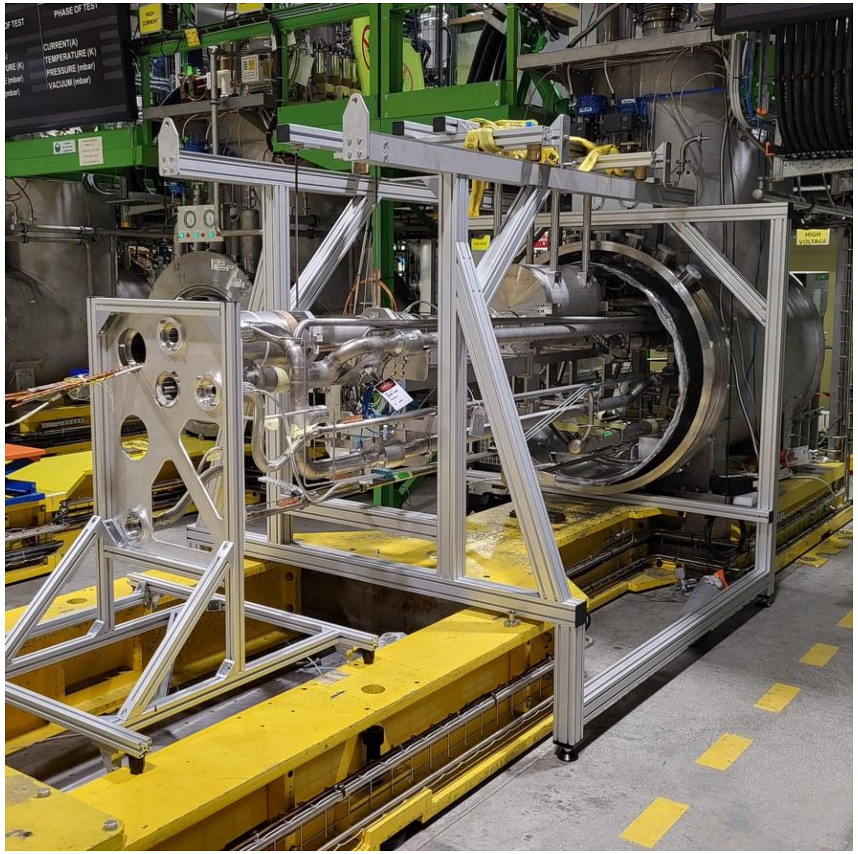
NI DAQ-based instrumentation v.3 (10 kHz)

Challenges: scheduling

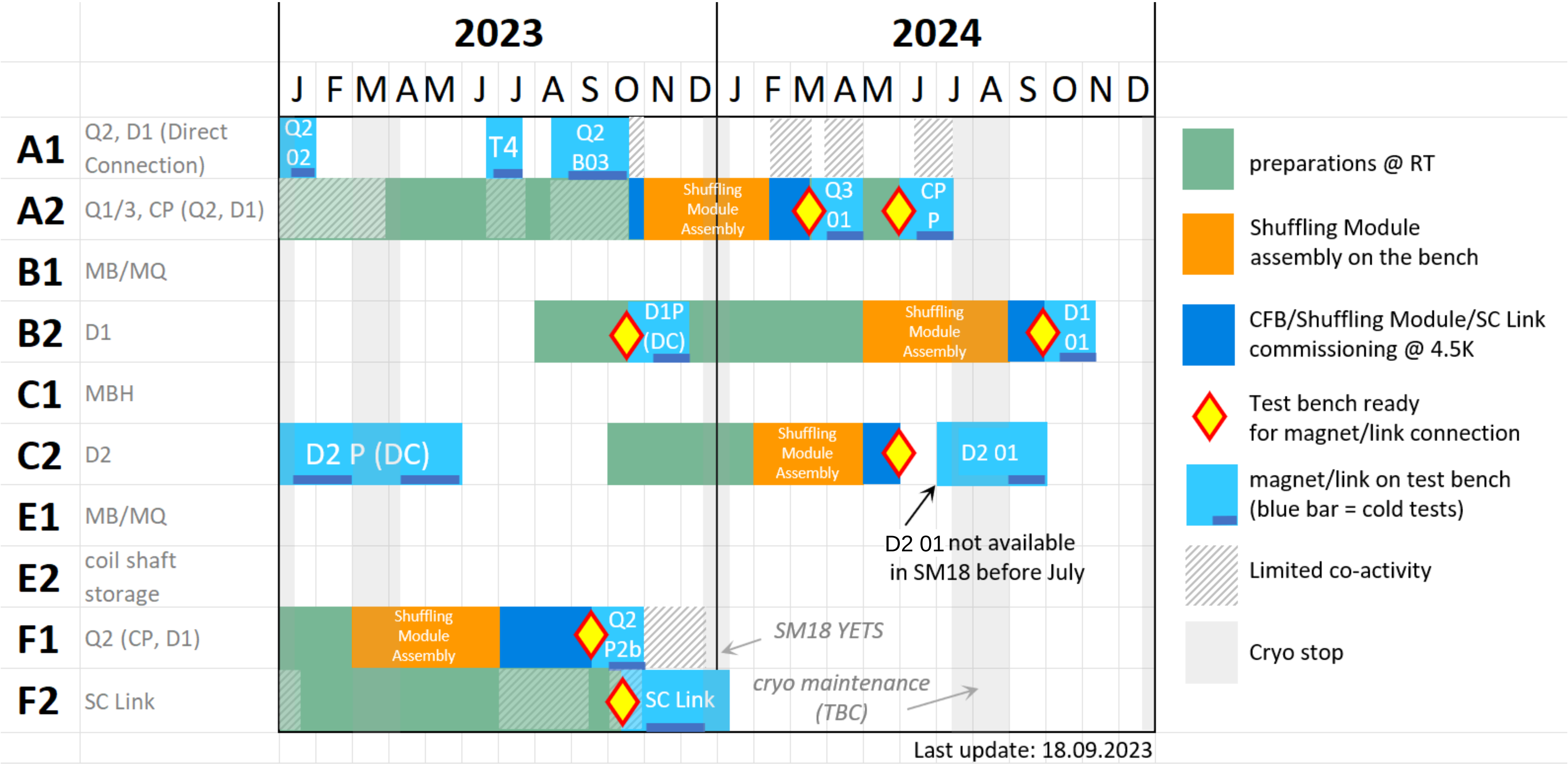
- Schedule requirements for **A2** are still a challenge and attention is required for **C2.**

- Following a **review by TE Department** on 19 September 2023; decision was taken to allocate **additional resources**
  - Fabrication of a second assembly structure to allow work that has to go in parallel on two benches;
  - Determine the best moment to install the new N-line equipped with a new submarine valve (for safety reasons, a one-week cryo-stop is required).

- Following slide presents **baseline schedule** agreed by TE-Department and HL-LHC project.



Schedule summary: a consolidated baseline scenario



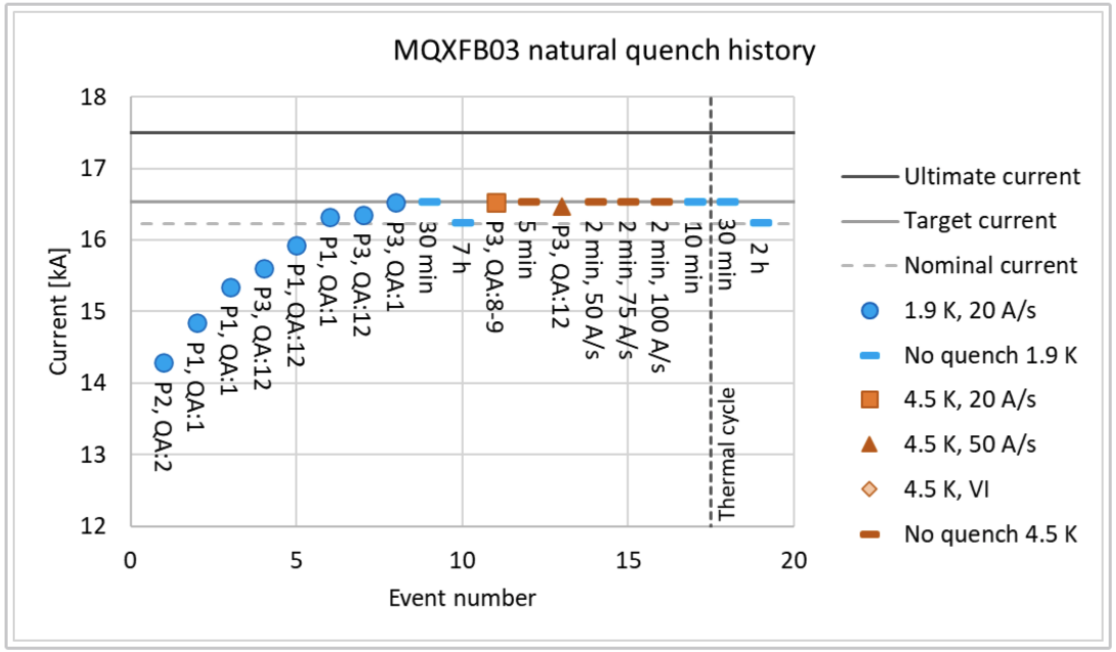
Recent test results: MQXFB03

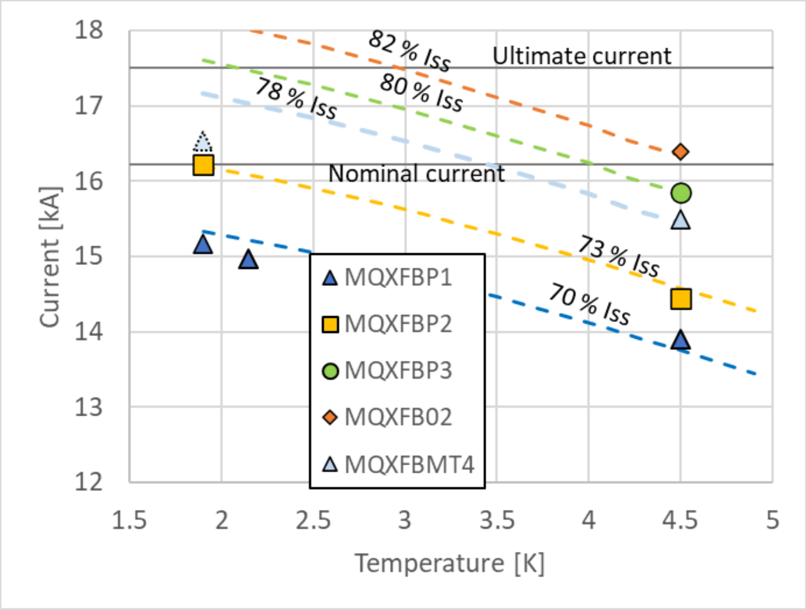
- **3rd magnet of 3-stage recovery strategy,** integrating: (1) improved cold mass assembly and fixed point, (2) improved magnet loading procedure, (3) improved coil manufacturing procedures to remove hump & belly at coil centre.

- Good performance during the first cool down: magnet **reached target current of 16.53 kA at both 1.9 K and 4.5 K;** first 7.2-m-long MQXFB magnet to do so.

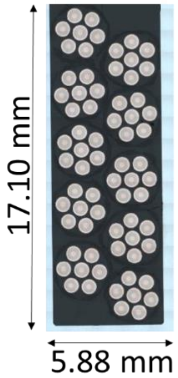
- **No retraining after warm-up/cooldown cycle;** magnet reached target current at 1.9 K; ramp at 4.5 K to be done tomorrow.

- Training quenches are all in **the ends; performance limitation** and phenomenology observed on all previous, full-length, MQXFB magnets in straight section, near magnet centre (at apex of hump & belly) have been **overcome.**

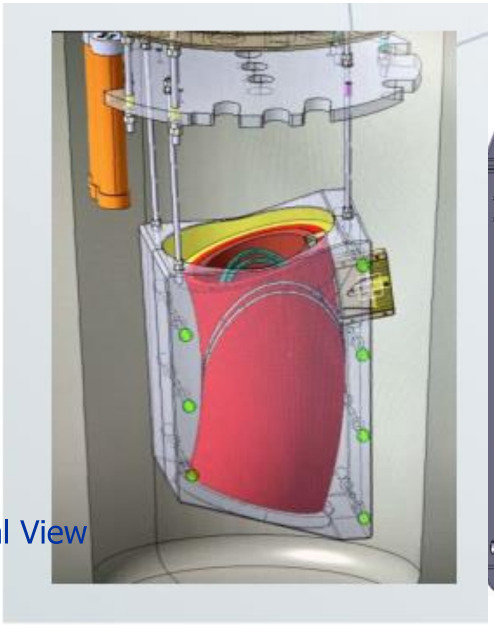


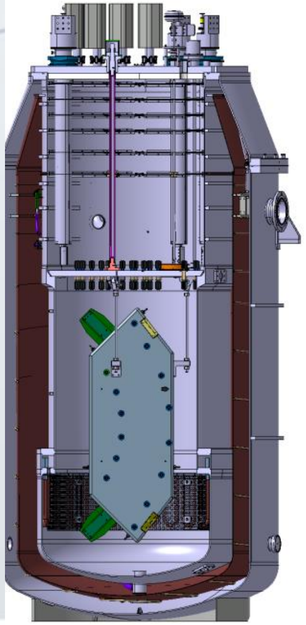


Test and magnetic measurement of FUSILLO sub-scale

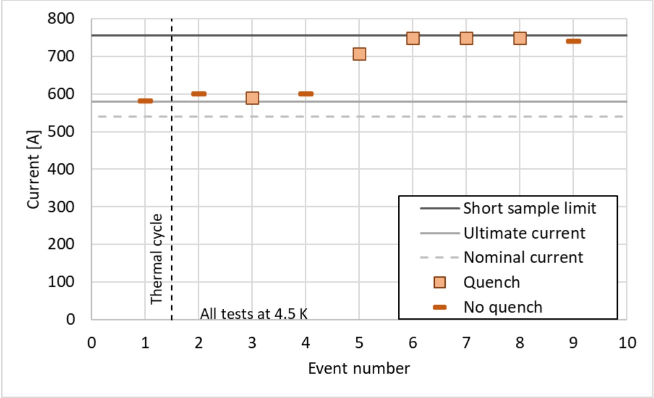


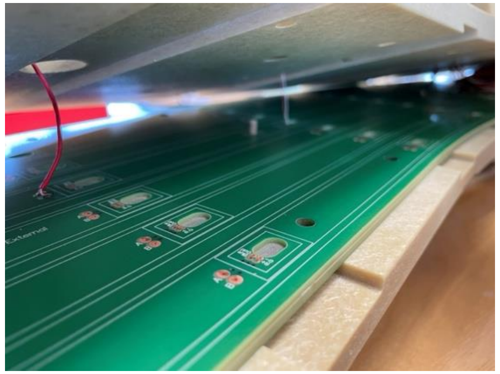
X-Sectional View of Fusillo Winding

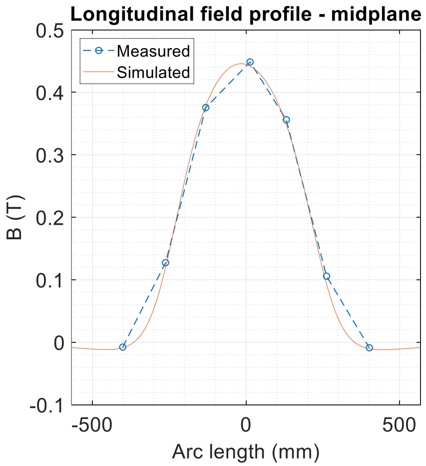


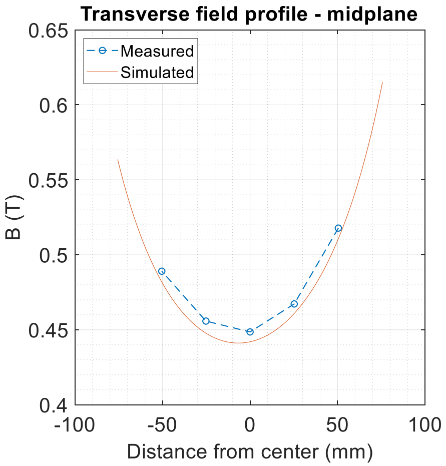


- **FUSILLO** is **a strongly curved Nb–Ti CCT magnet design** derived from MCBRD program (but relying on 6-around-one cable).
- **A sub-scale demonstrator** was built and tested and reached nominal current **without training quench at 4.5 K** and achieved near short sample limit with a few training steps.
- **Magnetic measurements** are in **agreement** with Roxie simulated data.



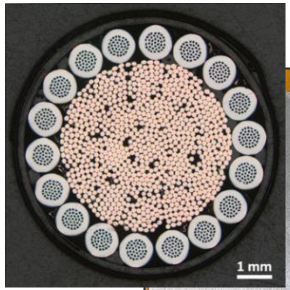






Courtesy of A. Haziot
(CERN/TE-MSC)

Test and Magnetic measurement of EESD magnet demonstrator



MgB_2 Cable (18 Strands Twisted Around Braided Copper Core)

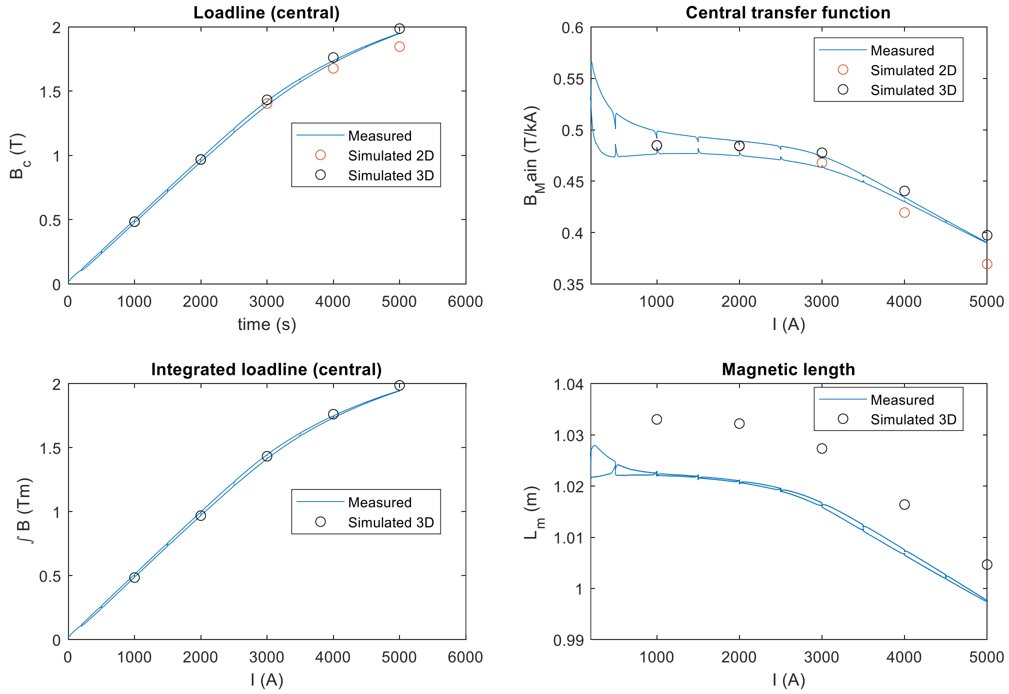
EESD magnet demonstrator

- **Magnetic measurement date** confromed to expectations.

- **20 K test** under preparation.

- **Energy-Efficient Superferic Dipole (EESD)** is an innovative iron-dominated magnet design relying on **the 3-kA MgB_2 cable developed for sc link in WP6a.**

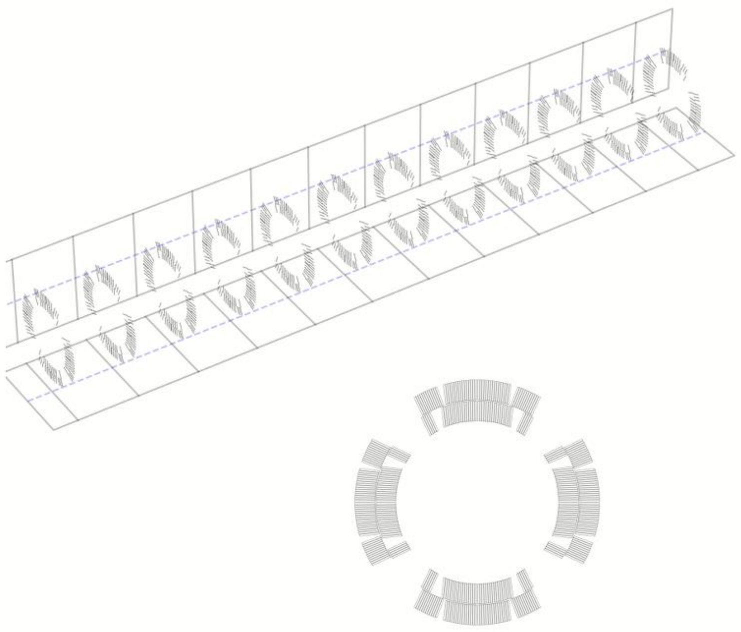
- **A demonstrator** was built and tested, which achieved **5 kA and 1.95 T dipole field at 4.5 K** wihtout quench.

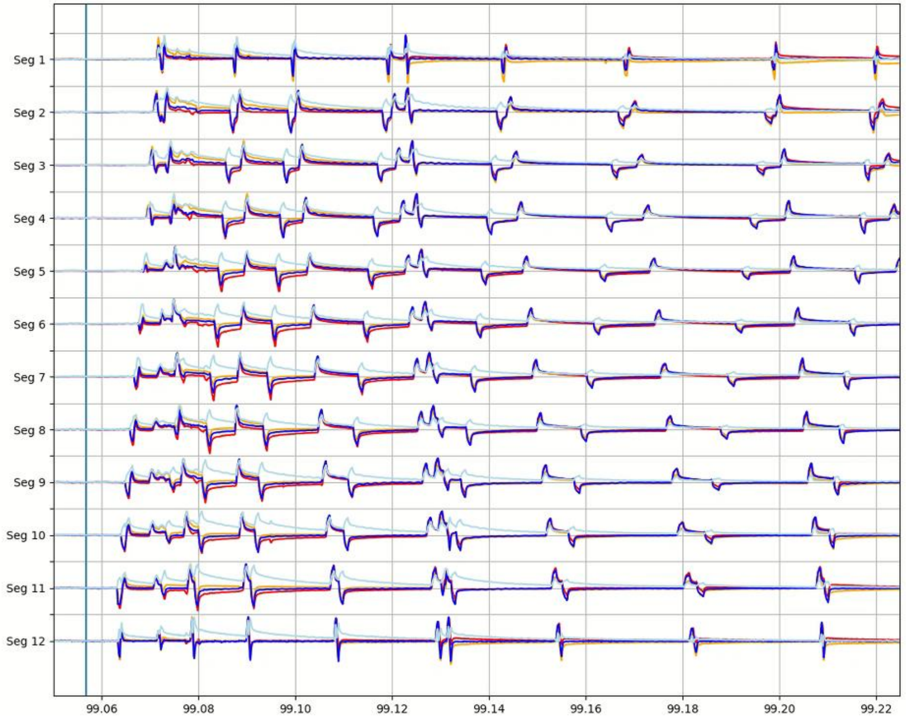


Courtesy of A. Devred, A. Ballarino, N. Bourcey, F. Mangiarotti, A. Milanese, C. Petrone (CERN/TE-MSC)

Flux-jump signals in new quench antenna

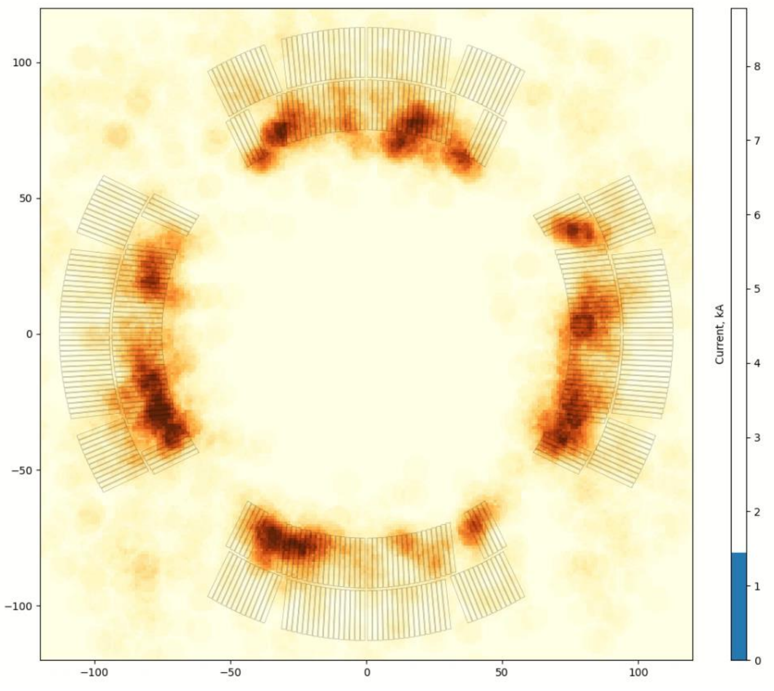
Propagation speed of the order of ~700->350 m/s at 1.9 K, ~900->500 m/s at 4.5 K.



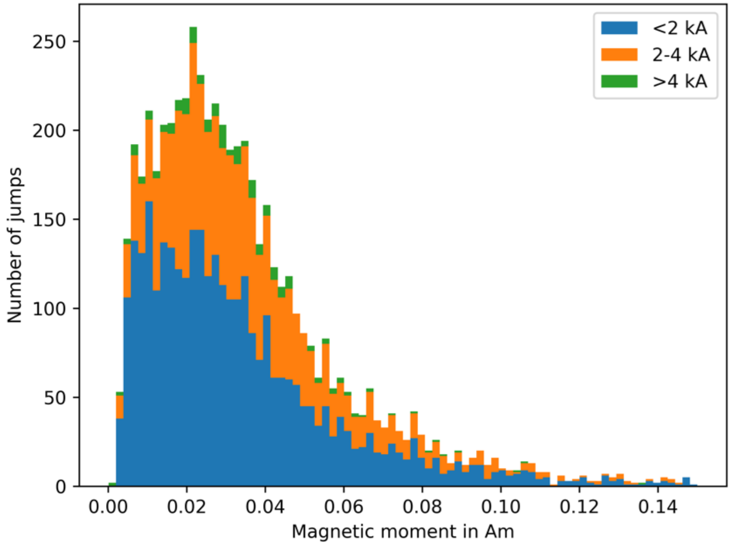


Automatic parameter extraction for flux-jump signals

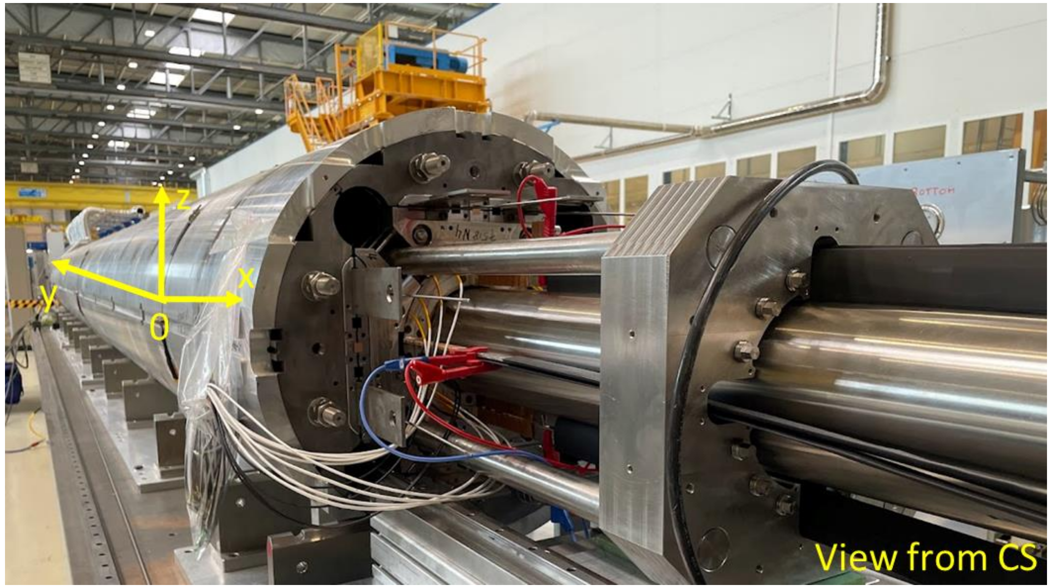
4.5 K



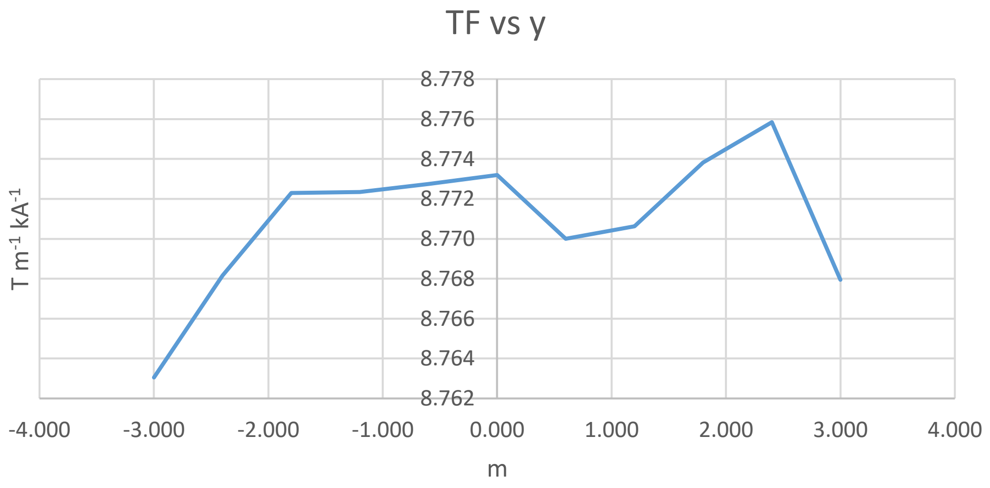
4.5 K

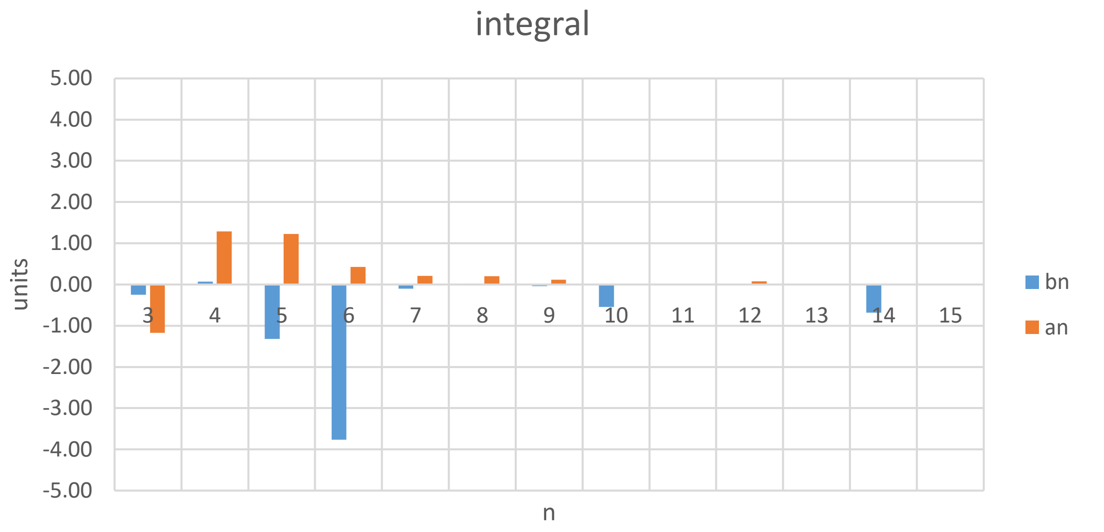


Magnetic measurement of LMQXFB03 after coil-pack insertion



- Magnetic measurement of new series MQXFB magnet, performed by rotating coil scanner (RCS)
- Measurements performed after coil pack insertion (before loading).
- New rotating-coil scanner commissioned





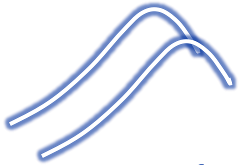
Conclusions

- Important milestones reached in benches F1/F2.
- Result of the hard and dedicated work of many staff in TE-MSC and other CERN Groups and Sections, showing skill and adaptability
- Commissioning tests serve their purpose and point out necessary improvements; issues found cause delays but should be considered natural steps in the development of such a unique and complex test station.
- The schedule consolidated with the experience acquired shows that bench A2 is on the critical path; additional resources committed by TE Department to ensure timely readiness.
- MQXB03 is first 7.2-m-long to achieve achieve target currents at both 1.9 and 4.5 K.
- Good test results on diversification programs spun off from HL-LHC (*e.g.*, FUSILLO and EESD), preparing the path for after HL-LHC activities.

Additional Slides

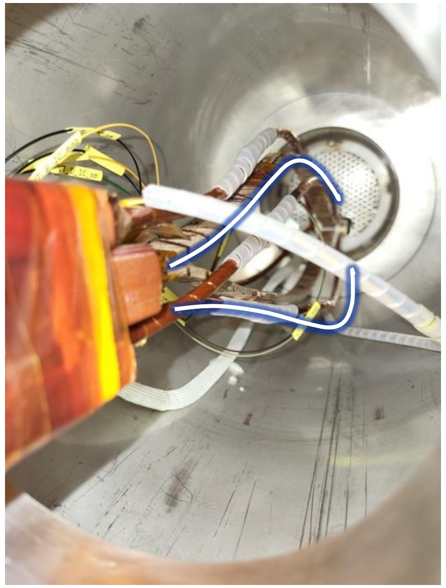
Challenges (2/2): busbar routing and support

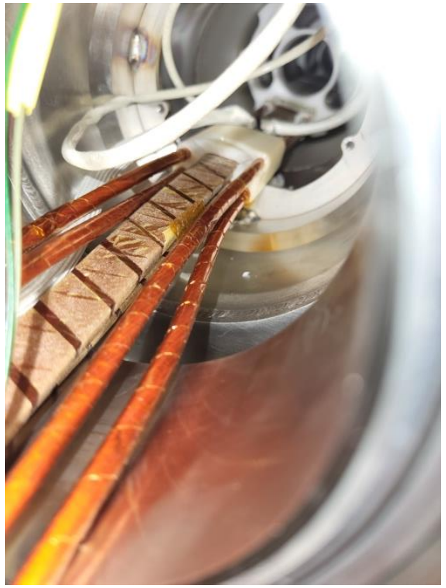
- Both 18 kA and 2 kA busbars were found deformed between the electrical joints (at the very end of the bus bars) and the position of the helium filter where all the bus bars are put together in a non-metallic flange/support.
- The bus bars have repelled each other when powered leading to ”training” quenches; additional supports have been added.



Original shape of all cables before powering tests

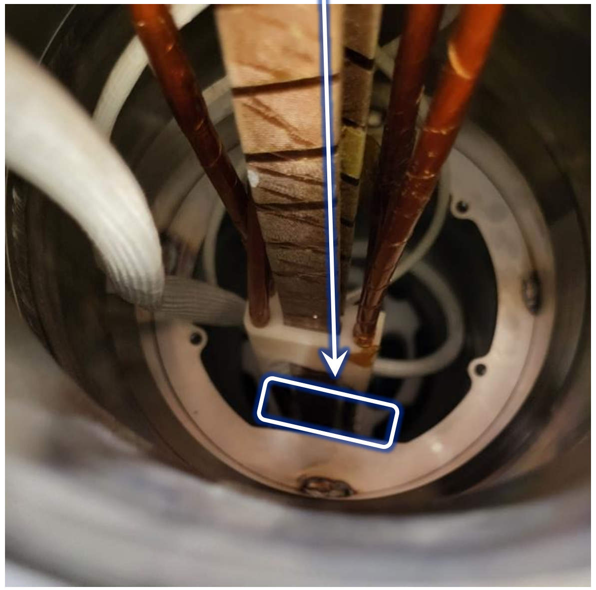
Here after powering tests





Support (at He filter position) broken at top by bus bar pushing outwards when powered and deformed

Support (at He filter position) broken at bottom likely during assembly and adjustment of its position

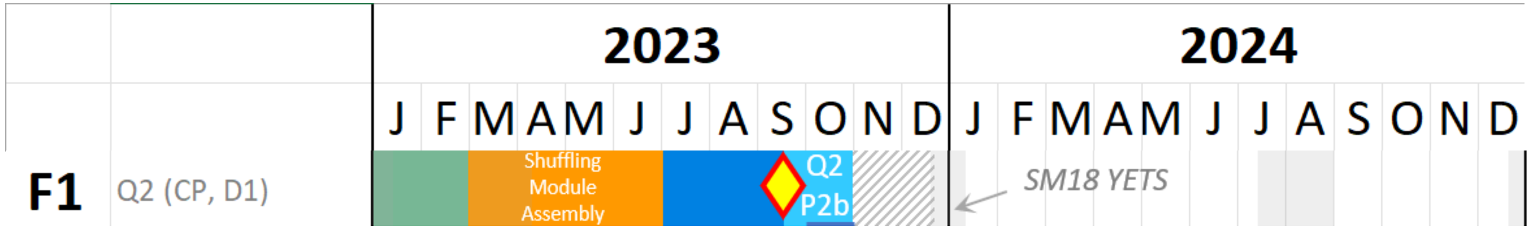


Lessons learned from F1

- Missing components: some required to be designed, and some required simple modifications.
  - Octopus parts for the global pressure and leak test, including thermal screen segments.
  - Various additional supports for the helium lines.
- Additional components:
  - Cold pressure sensor on the N-line, which necessitated modifying the N-line.
  - Mechanical shielding for the connector box.
- Tooling to be designed and manufactured:
  - Set of clamshells for local leak tests of welded joints.
- Qualification of the connector box at both RT and cold conditions @ 5x20 bar.
- Global pressure and leak test not successful
  - XY-line, M-line and N-line found deformed.
  - Octopus parts and supports had to be modified.
- Busbar support:
  - Insufficient support at some locations to take up repelling e.m. force when current circulating
  - Modifications will be put in place for the shuffling modules of the other 3 benches A2, B2 and C2, and also for the bench F1 at the extremity of the bus bars that is accessible (magnet side).

Test bench F1 - coming next

- **Components to be commissioned with first magnet**
  – Dedicated part of the PLC interlock system
  – Protection equipment: new PDSU
  – uQDS: new GUI still to be tested, incl. file saving in TDMS format to be completed.



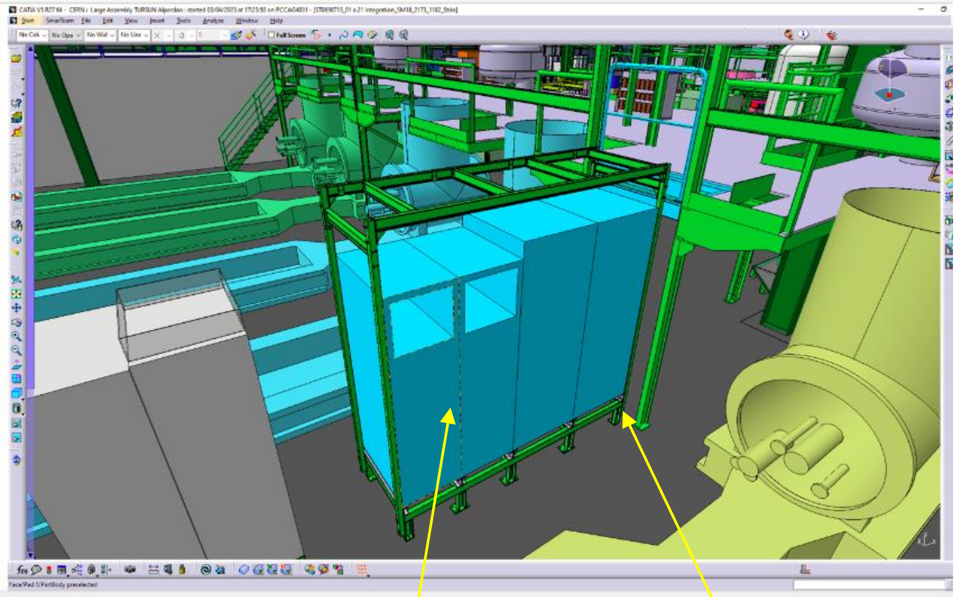
Challenges	Risk	Mitigation
Shuffling Module-related challenges		
Missing redundant Phase Separator LHe level gage	Operation not possible in case of fault of the remaining gage	Repair at the level of the Instrumentation Box can be carried out with magnet @ RT in about ~1 week
R_{GND} = 70 MΩ in the 2kA CL heaters (vs ~ 80 GΩ expct.) *Applies also to bench A2*.	The heaters must be disconnected during HV tests	Installation of insulation transformers upstream (space in the Cryo cabinet TBC).
V≤1.5 kV @4.5 K in 2kA circuits *Applies also to bench A2*.	Non-standard operational procedure. No impact on magnet testing	• Follow detailed HV test procedure with checklist • Improved leads/plugs might be considered for long-term consolidation after HL-LHC campaign
2kA EE incompatible with PC in absence of inductive load *Applies also to bench A2*.	In case of a quench, a 530 V surge will destroy PC diodes	Follow detailed procedure including manual s/c the EE switch in case of future s/c tests
uQDS firmware updates closely coupled to software/operation *Applies to all benches*.	Update/debug cycle may engender delays	• Tight coordination between teams (normally the case !) • Provide test crates to BE-CEM
Co-activity with F2	• Tower structure to lower the link onto DFX + scaffolding for operators represent a risk of falling objects on the magnet (esp. fragile IFS boxes). • Electrical interference/operator safety	• Prevent simultaneous cold operation of F1/DFX installation (impossible to complete commissioning of F1 and F2 in 2023) *and/or* install additional protections • No concurrent powering/HV tests (TBD)

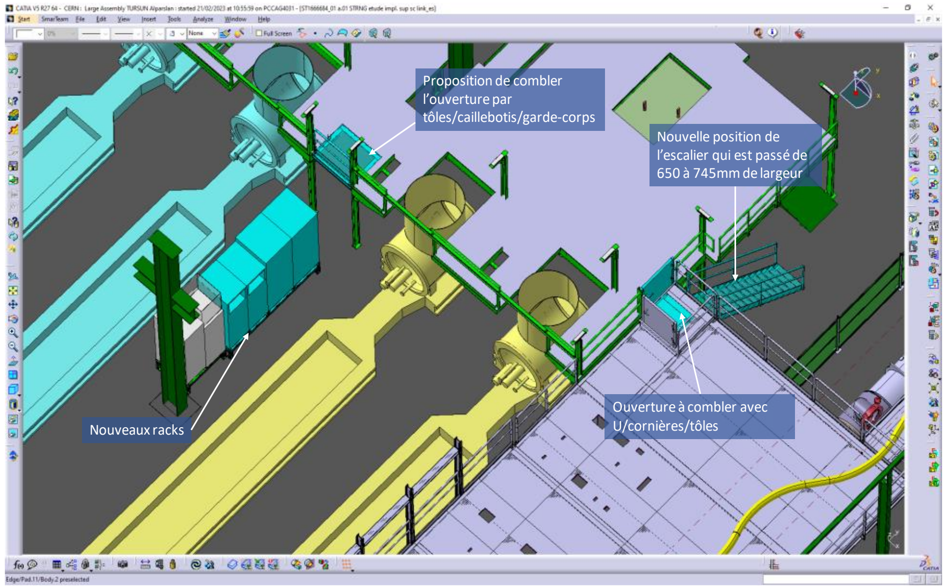
Test bench A2 - coming next

- **Aux power circuits**
  – preparation ongoing for CFB commissioning
  – installation of final electronics in place of the existing staircase
  (2× 2 kA load switches, 2×2 kA polarity switches)
  – final 2 kA circuit to be partially made with Class 6 cablr

- **Cryogenic equipment**
  – Refurbishment of main busbar end plates with SnAg
  – Shuffling module: assembly on test bench

- **Instrumentation and Protection**
  – Finalization of signal cabling for CP, cabling for CLIQ
  – Interlock PLC I/O commissioning in the different bench configurations
  – 2 kA/600 A Energy Extraction systems installation and commissioning
  – uQDS systems: doubling up the number of crates to simplify
  reconfiguration CP ↔ Q2
  – Cryo PLC: commissioning of the CL instrumentation (heater, splitting
  box)





Test bench C2 for D2 – status

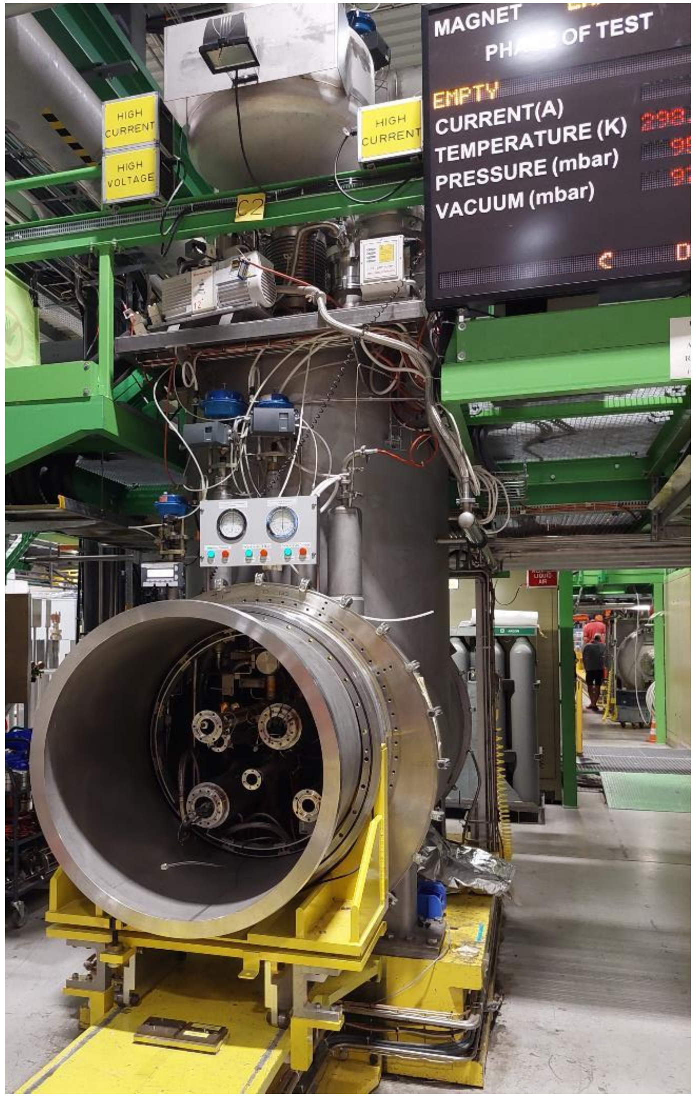
Bench already configured and used to test D2 prototype in Direct Connection

- **Power circuits**
  – Main 15kA/aux 600A ready (except. SnAg refurbishment of main leads)

- **Shuffling module**
  – Significatively different than F1, A2, B2 units due to double aperture magnet
  – Design completed, all components in common with others are procured. Fabrication of differing ones is being launched.

- **Instrumentation and Protections**
  – 2 × uQDS crates installed to protect MCBRD correctors
  – Protection of D2 main dipole with legacy PotAim cards

2× uQDS crates   Safety Matrix   NI DAQ v3   Quench Heaters   Aux Power Converters/Switches

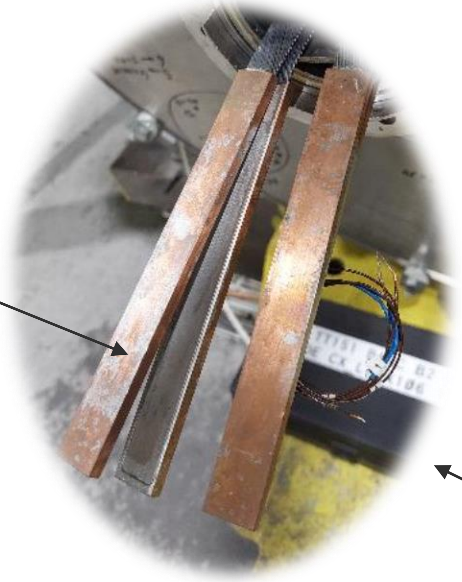


Test bench B2 for D1 – status

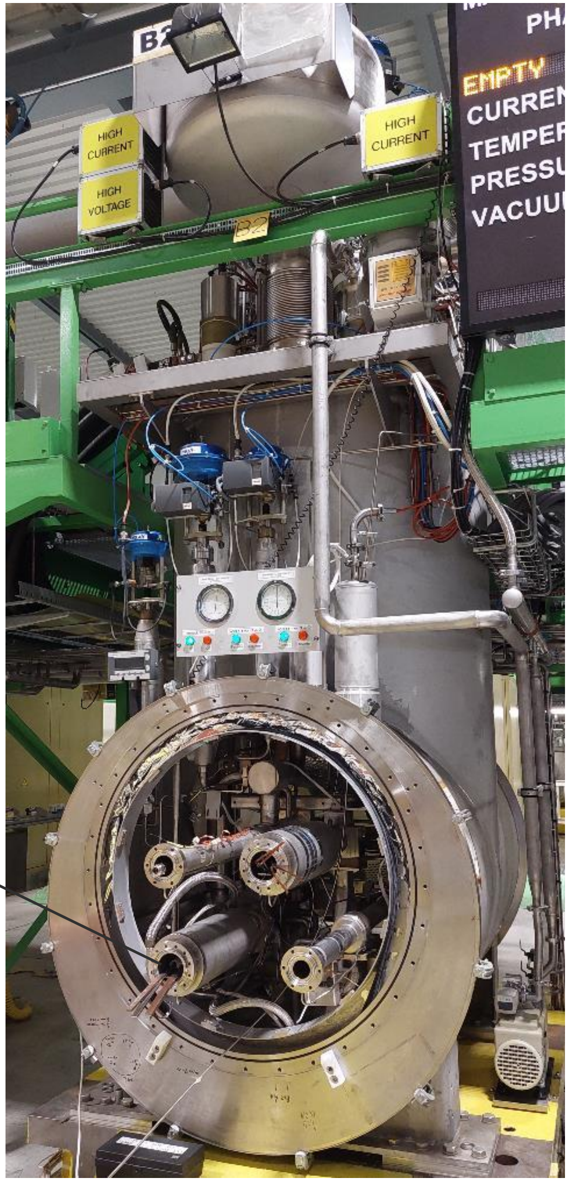
- **Bench configured for D1 Prototype (Direct Connection)**
  – Main 15 kA/600 Auxiliary power circuits [not needed] operational
  – Main magnet protection with legacy PotAim cards
  – Acquisition with improved PXI NI-based DAQ v. 3 (10 kHz)
  – New ∅109 mm short and long antivryostats Type 2/3 ready
- **Shuffling module for D1 Series**
  – All components are procured (identical to F1/A2 units)

Anticryostat installation ongoing

New ∅110 mm
anticryostat support

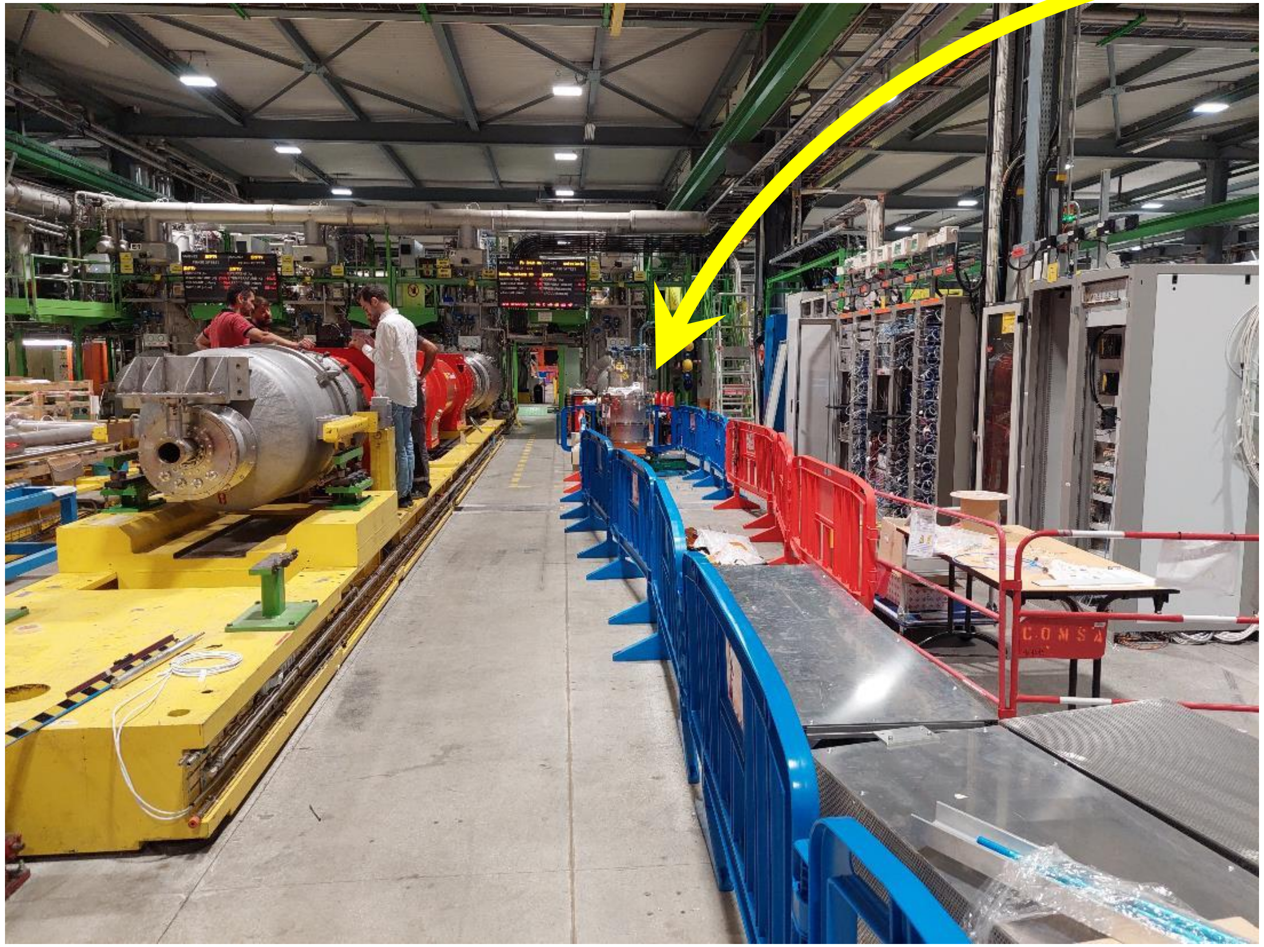


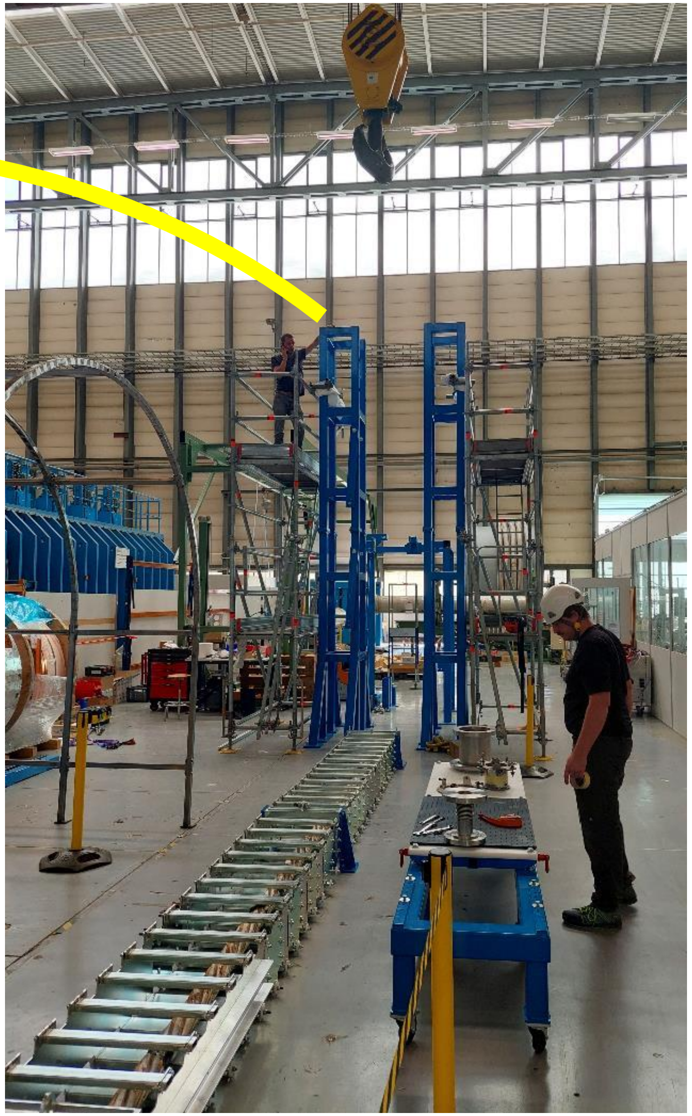
Main busbar terminations
to be refurbished with SnAg



Ready now to connect D1 Prototype

Challenges: co-activity





Risk Analysis of co-activity ongoing

Availability of magnets for test benches

Negative margin: magnet ready before test bench (Critical path)

Magnet to be tested	Bench	Availability for cold test	Test bench readiness	Margins on test bench readiness
Q3 01	A2	26/02/2024	15/03/2024	-3 weeks
Q1 02	No Cold test foreseen	/	/	/
Q2 P2b	Currently on F1	/	/	/
Q2 P3a	F1	11/10/2023	24/11/2023	-2 weeks
CP P	A2	30/01/2024	22/05/2024	-4 months
D1 P	Done. Tested on B2	/	/	/
D2 01	C2	10/07/2024	30/05/2024	6 weeks
D1 01	B2	20/12/2024	30/09/2024	6 weeks

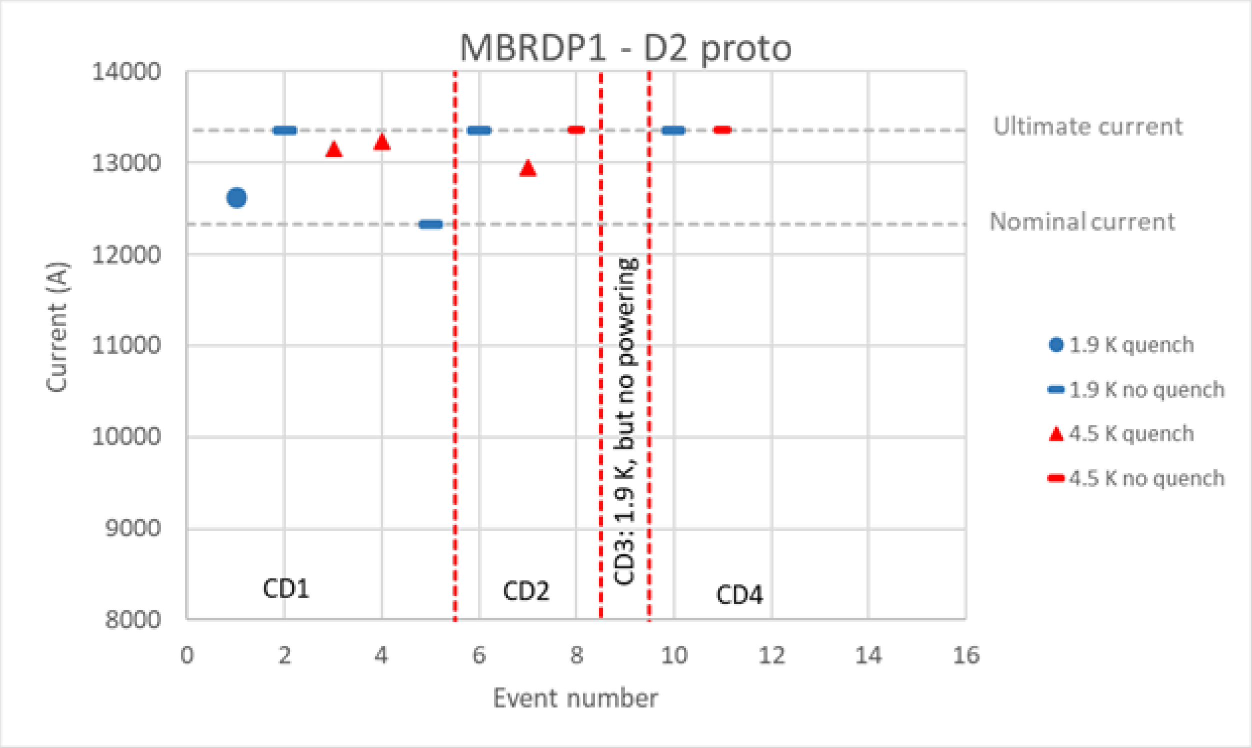
Margin for first serie D2 and D1

Cold tested in the US

Q2P2b before Q2 P3a

Q3 01 tests before + 1 month work for CP P on A2 bench

Recent test results: D2 prototype



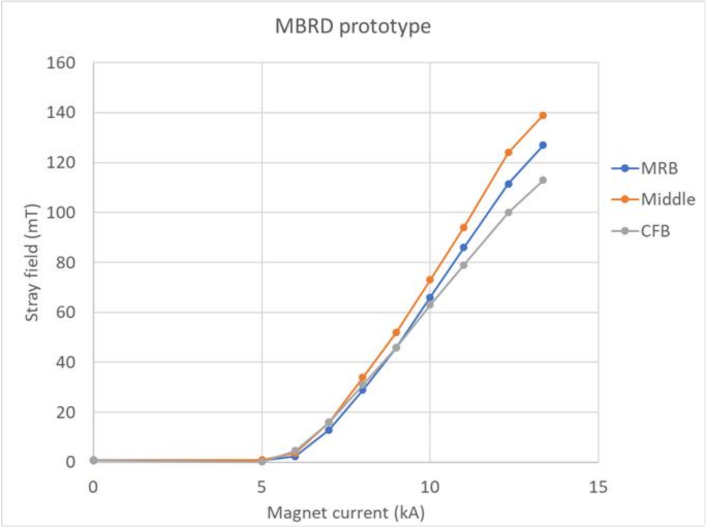
4th cooldown, 3rd cooldown without powering.

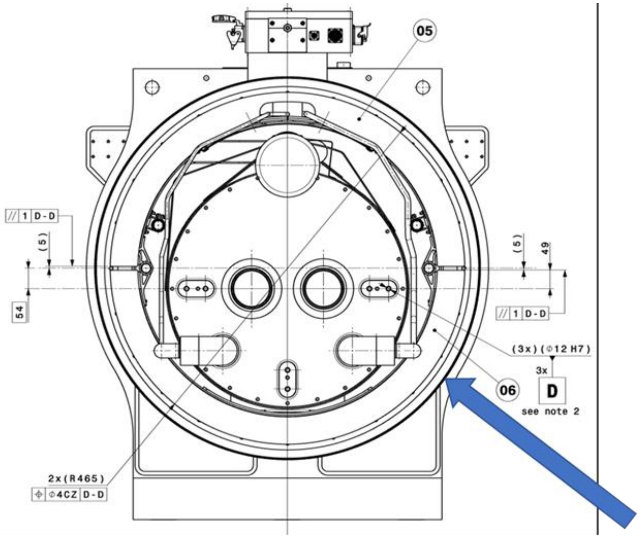
Zero quenches of the main magnet at 1.9 K and 4.5 K up to ultimate current.

Combined powering 1st corrector magnet (MCBRDP1b)+main magnet (MBRDP1) OK up to ultimate current.

Magnetic measurements ongoing for coupling between the corrector and main magnet

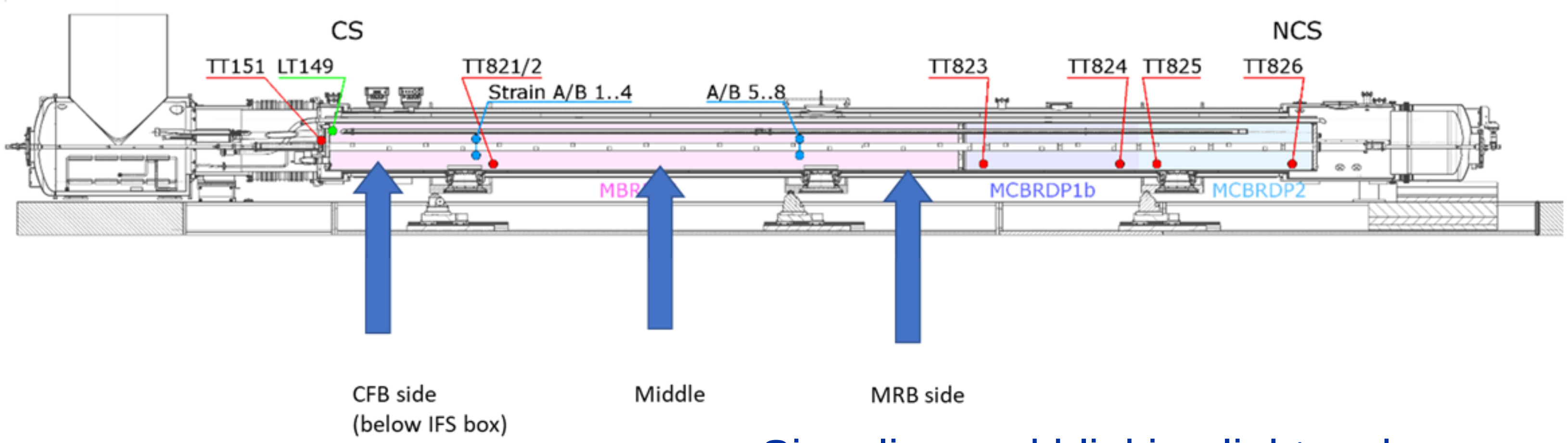
D2 prototype stray field

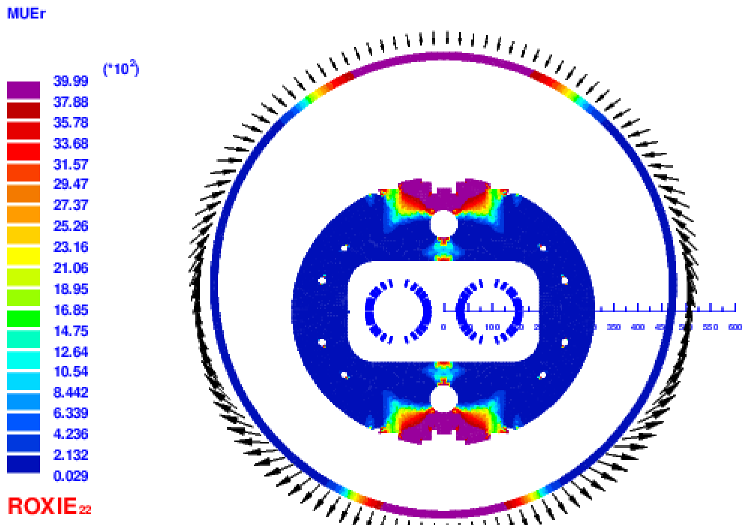




High stray field in D2 magnets because field in both apertures in same direction.

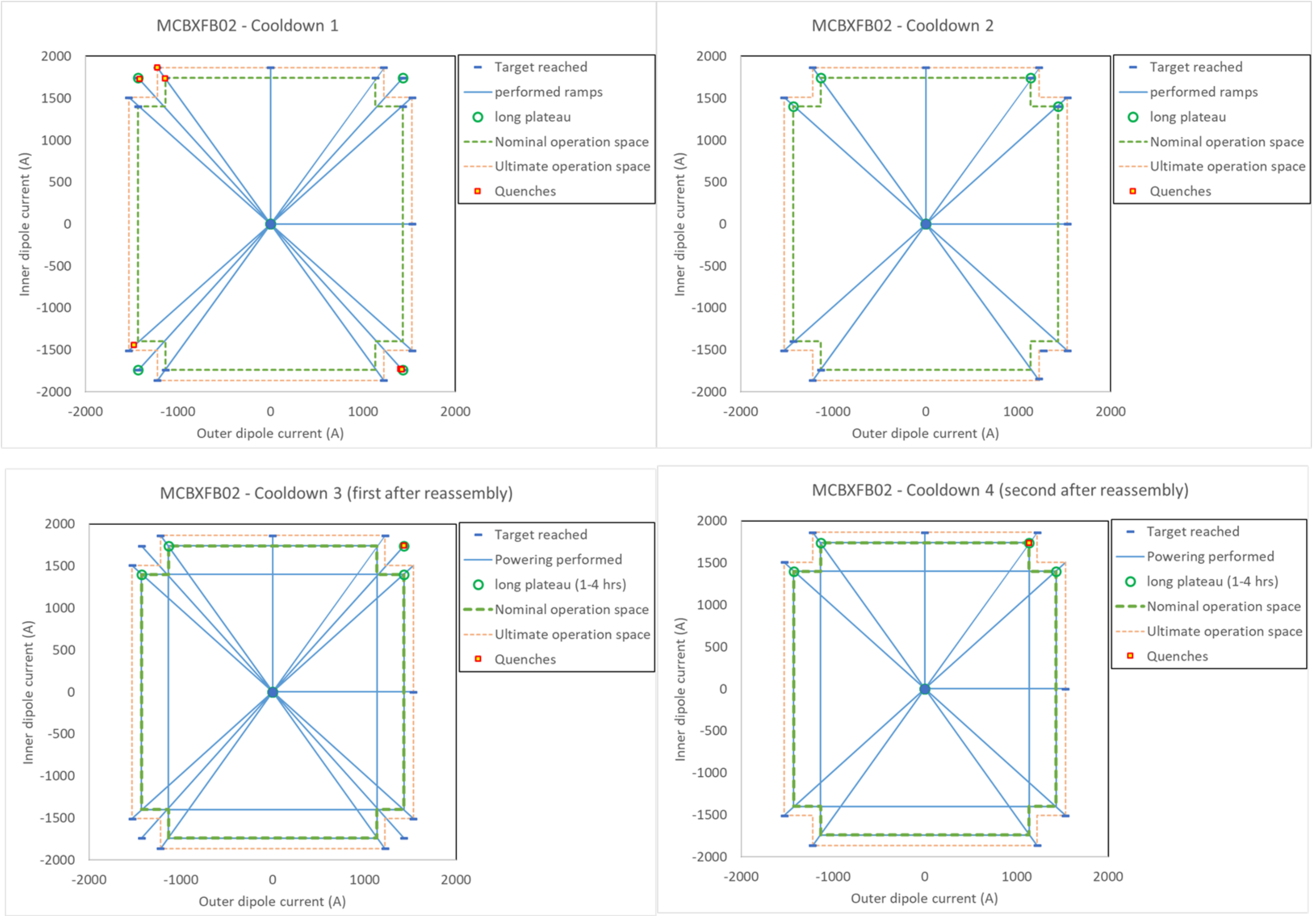
The new 3 mT limit for ferromagnetic tiool manipulation (implemented in summer) asks for derogation with Risk Assessment document.





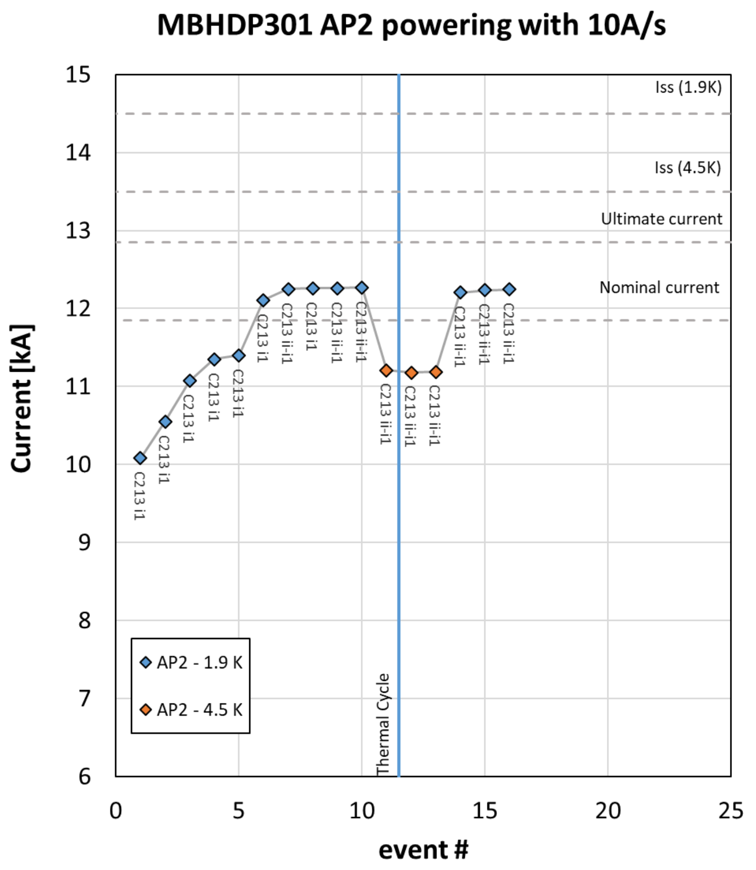
Signaling and blinking lights o.k.

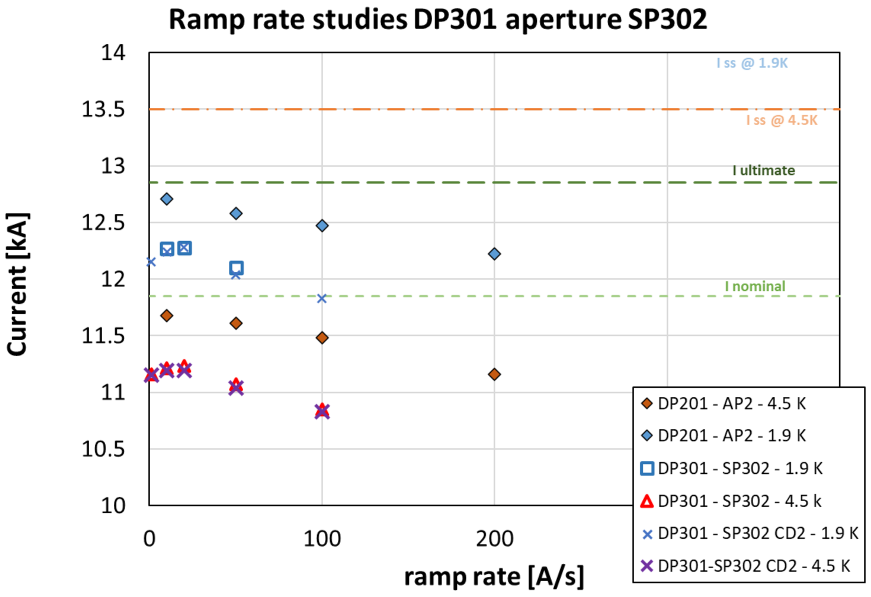
MCBXFB02

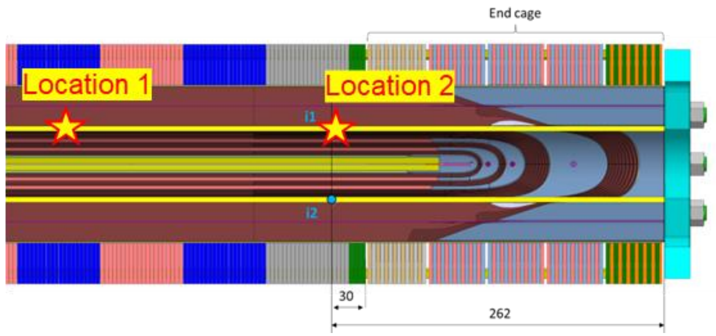


In the 4 cool downs (two before reassembly, two after), there were only 2 quenches in the nominal operating space (one in CD1 and one in CD4), 2 quenches in the ultimate operating space (both in CD1) and 3 beyond the ultimate operating space (two in CD1 and one in CD3).

MBHDP301 – 11T model with end cage







The aperture with end cage reached above nominal current but showed a reduction of coil limit by about 500 A compared to the previous test of this coil in a different assembly. The V-I measurements showed a significant voltage build-up

The aperture without end cage had a quench heater failure and could not be powered.