MCBXF series production at CERN
Update December 2024

Juan Carlos Perez, Jose Ferradas and Gonzalo Hernando
on behalf of the full team!

05/12/2024
HL-LHC WP3

Outline

- MCBXF general status at CERN
- MCBXFB05 assembly
- MCBXFA1 assembly
- MCBXFB06 assembly
- MCBXFB07 assembly
- Components needed for beginning of next year
- Summary and outlook

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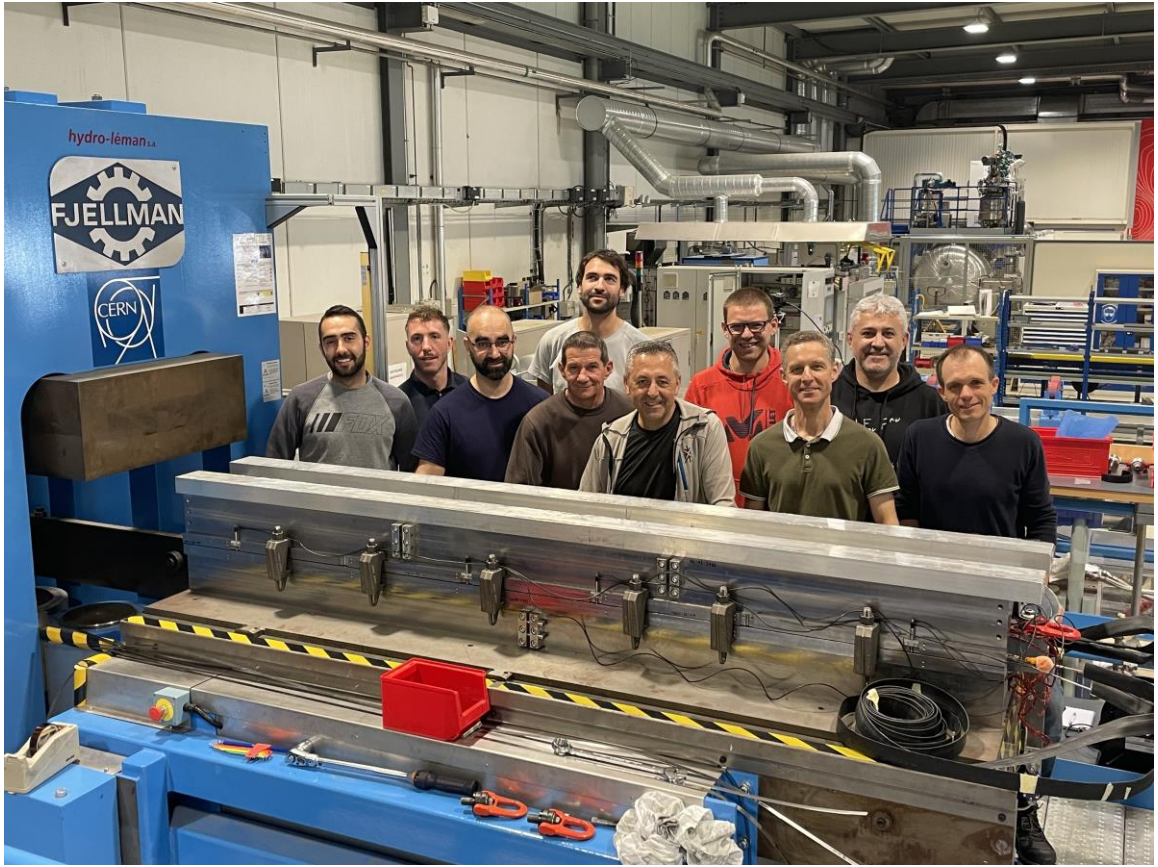

HiLumi HL-LHC PROJECT

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Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

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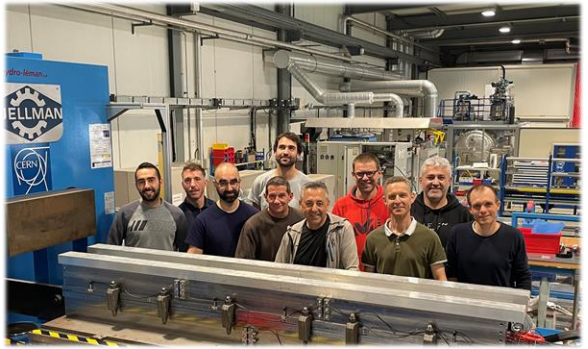
MCBXF status at CERN

- **Organization:**

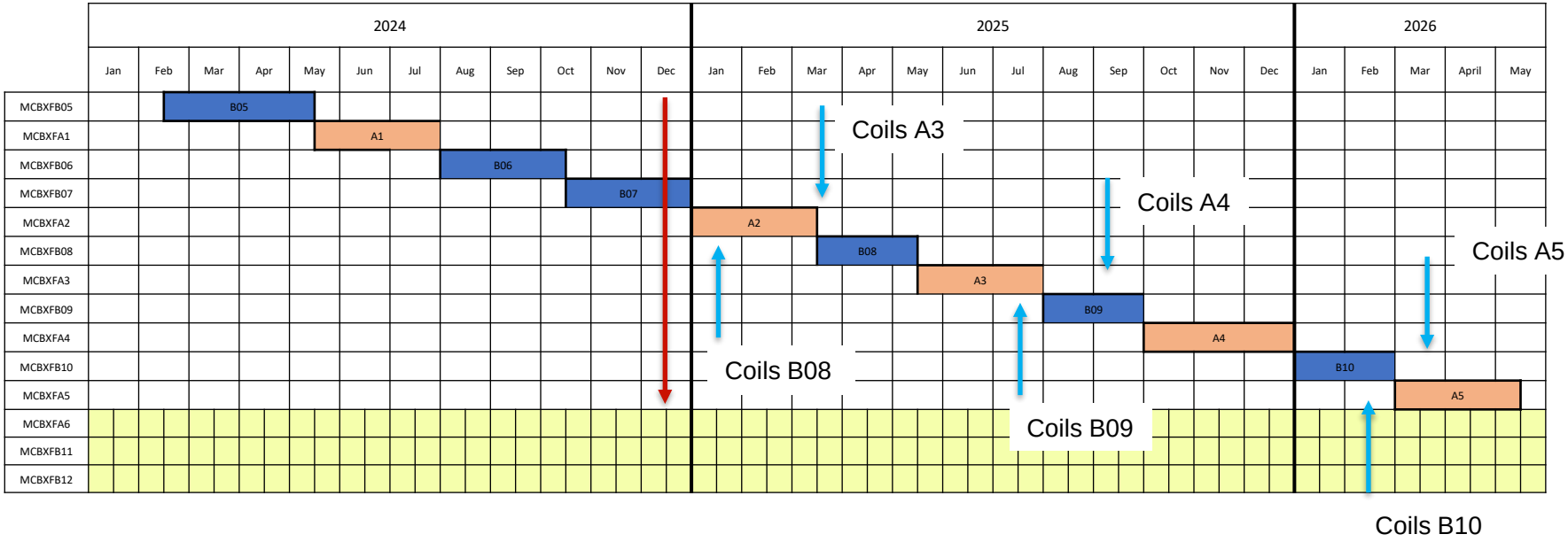


WP3 Project engineer: J.C. Perez

- Magnet assembly activities (including magnetic measurements):
  - Gonzalo Hernando (TE-MSC-SMT)
  - Jose Ferradas (TE-MSC-SMT)
  - Federico Ismail Ben el Caid (TE-MSC-SMT)
  - Sebastien Luzieux (TE-MSC-LMF)
  - Karim Kallat (TE-MSC-LMF)
  - Nicolas Eyraud (TE-MSC-LMF), *in charge of knowledge transfer during MCBXFB05 and MCBXFA1 assembly!*
- Logistics:
  - Steve Becle (TE-MSC-LMF), Laurent (TE-MSC-LMF) and Sylvain Caille (TE-MSC-LMF)
- Mechanical measurements (EN-MME):
  - Sylvain Mugnier and Michael Guinchard
- Additional support from LMF and SMT (machining, electrical and magnetic measurements, etc): Pietro Rizzo, P.A. Contat, Ludovic Grand-Clement, Jeremy Pechiney, Franck Evrard, Piotr Rogacki and Lucio Fiscarelli.

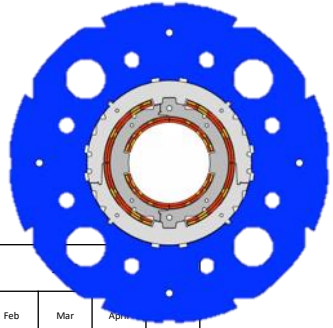
MCBXF status at CERN

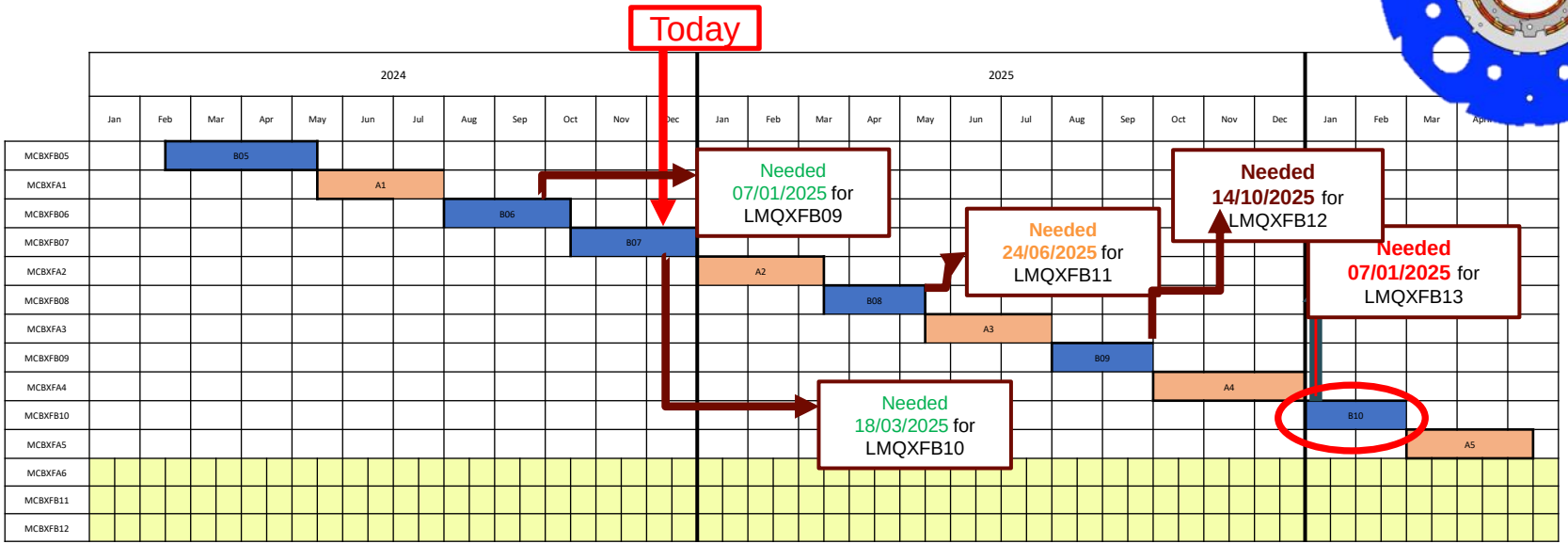
- **Where are we?:**



Assembly activities at CERN are aligned with the planning proposed beginning of the year.
MCBXFB07 assembly has been finished last week (before Christmas break).

MCBXF future activities





MCBXF status at CERN

- **Summary on what has been done this year:**
  - MCBXFB05:
    - Assembly duration: 3 months
    - *Used for transferring the know-how to the new team and setting-up the production line (including ancillary systems like magnetic measurements)*
    - *Field quality: b3 out of range (~1-2 units in combined operation)*
  - MCBXFA1:
    - Assembly duration: 2.5 months
    - *First MCBXFA series magnet. Used for transferring the know-how to the new team*
  - MCBXFB06:
    - Assembly duration: 2.5 months
    - *Field quality: b3 out of range (~1-2 units in combined operation)*
  - MCBXFB07:
    - Assembly duration: 2.5 months
    - *Modified shimming to correct field quality (see next slides)*

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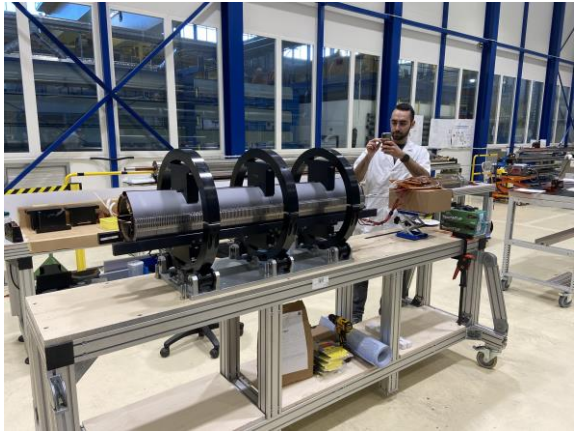
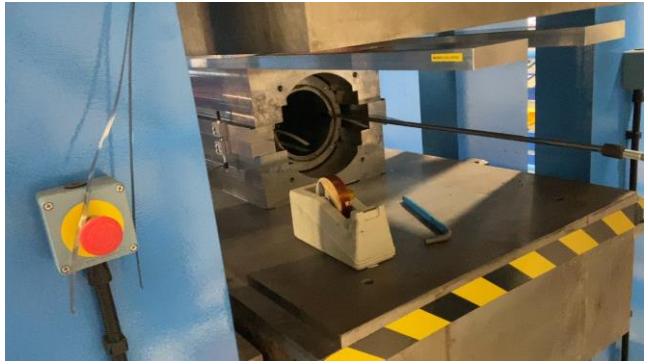
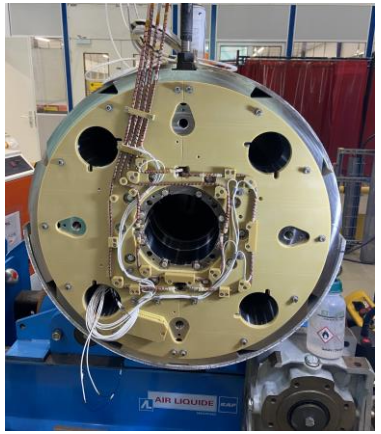
MCBXFB05

- **First magnet for the new production line**
  - Assembly duration / finishing date: 3 months / May 2024
  - 2 inner dipole collaring operations, 1 outer dipole collaring operation
  - Two minor NCR during the assembly process
    - Inner dipole collared twice due to the mispositioning of pole shims: *EDMS 3089268*
    - Minimal damage to one Kapton layer outside the coil (on the ground insulation protruding outside the collars): *EDMS 3088744*
  - Commissioning of the magnetic measurement bench took longer than expected
    - Results cross-checked with TE-MSC-TM using shorter probes
  - Various adjustments in the procedures and tooling according to the new infrastructure and lessons learnt

MCBXFB05







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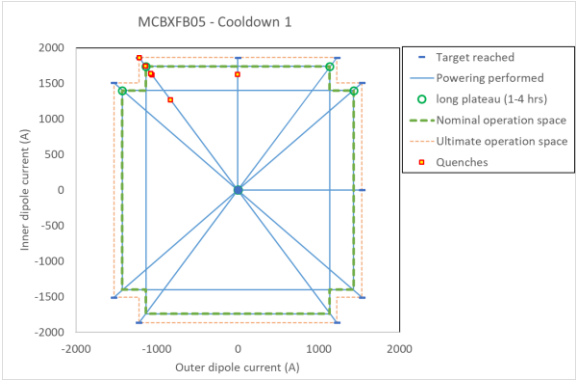
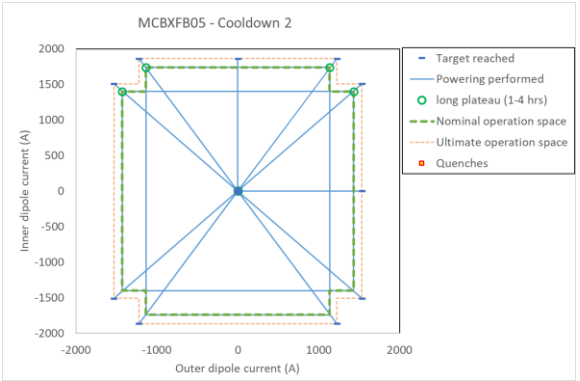
MCBXFB05

- ✓ Mechanical measurements and coil contact homogeneity (FUJI)
  - Consistent with previous magnets
- ✓ All electrical tests successfully passed
  - Consistent with previous magnets
- ✓ Warm magnetic measurements
  - Small difference in b3 and a3 for the inner dipole ~ 5-6 units with respect to previous magnets. **As expected, also present at cold.**
  - Outer dipole in line with previous assemblies
- ✓ Cold test
- ✓ Documentation and EDMS status:
  - Documentation is up to date.



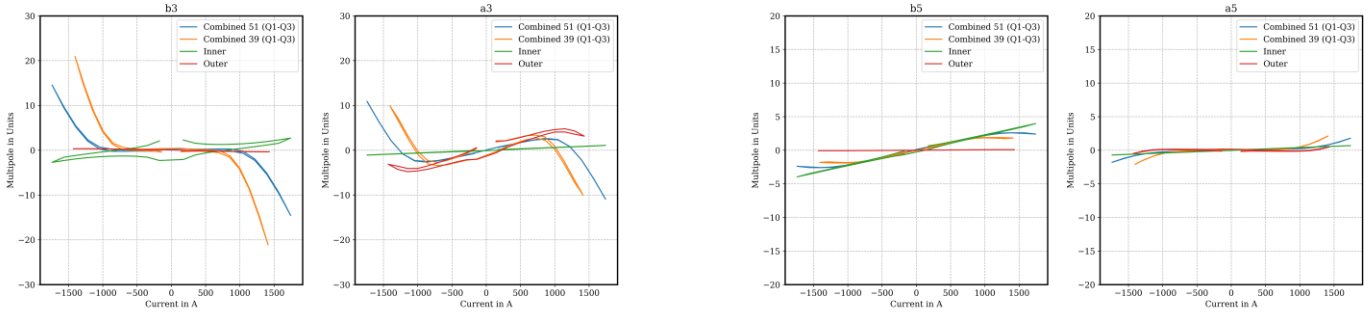


Courtesy of G. Willering et al.

MCBXFB05

Table 4. Acceptance criteria for MCBXFB, EDMS 2051311

Requirement	Description	Measurement
Requirement 1	Steady state operation at nominal current in 4 angles at 1 to 4 hours. Steady state operation at ultimate current combinations for 4 hours	OK Not in test plan
Requirement 2	Maximum 1 quench to reach nominal integrated field after thermal cycle in all combinations of signs.	OK
Requirement 3	Field harmonics (except b3, a3, b5, a5) within 5 units Field harmonics b3 and a3 within 20 units Field harmonics b5 and a5 within 7 units	OK b_3 out by 1.8 units OK
Requirement 6	Electrical insulation test passed at reception Electrical insulation test passed at room temperature Electrical insulation test passed at nominal operating conditions	OK OK OK
Requirement 9	The individual splice resistance is lower than 5 nΩ	OK
Requirement A	Satisfy requirement 1 after 100 quenches	Out of scope
Requirement B	Satisfy requirement 1 after 10000 cycles	Out of scope
Requirement C	Satisfy requirement 1 after 10 thermal cycles	Out of scope



Test report: EDMS 3123996

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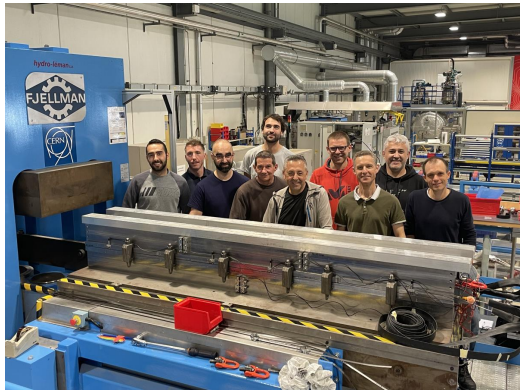
MCBXFA1

- **Second long MCBXF magnet ever built (no units produced at Elytt Energy)**

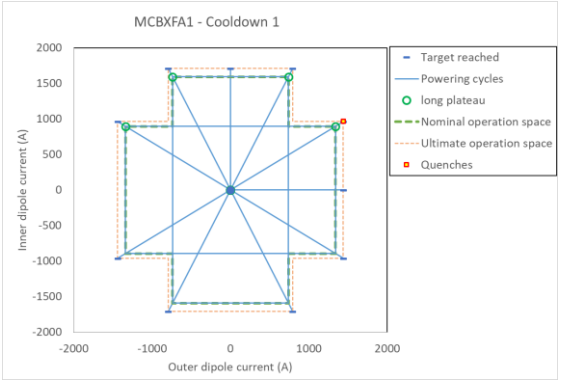
- Assembly duration / finishing date: 2.5 months / August 2024
- 2 inner dipole collaring operations, 1 outer dipole collaring operation
- Two NCRs during the assembly process
  - Inner dipole: broken midplane shim (requiring 2 collaring operations).
  - Magnet tilting: PacMan failure
- As for MCBXFB, various adjustments in the procedures and tooling according to the new infrastructure and lessons learnt.
  - For instance: optimized midplane shimming position after the breakage event

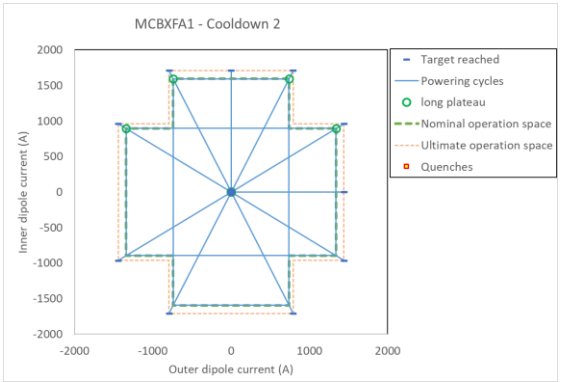
MCBXFA1



MCBXFA1

- ✓ Mechanical measurements and coil contact homogeneity (FUJI)
  - Consistent with previous magnets
- ✓ All electrical tests successfully passed
- ✓ Warm magnetic measurements
- ✓ Cold test
- ✓ Documentation and EDMS status:
  - Documentation is up to date.



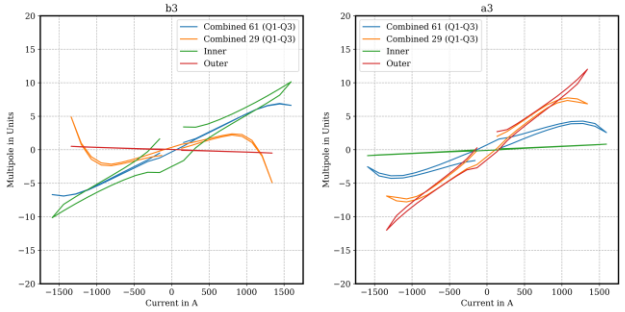


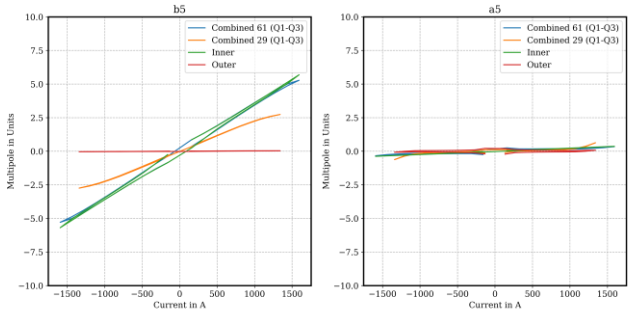
Courtesy of G. Willering et al.

MCBXFA1

Table 4. Acceptance criteria for MCBXFA, EDMS 2051311

Requirement	Description	Measurement
Requirement 1	Steady state operation at nominal current in 4 angles at 1 to 4 hours. Steady state operation at ultimate current combinations for 4 hours	OK Not in test plan
Requirement 2	Maximum 1 quench to reach nominal integrated field after thermal cycle in all combinations of signs.	OK
Requirement 3	Field harmonics (except b3, a3, b5, a5) within 5 units Field harmonics b3 and a3 within 20 units Field harmonics b5 and a5 within 7 units	OK OK OK
Requirement 6	Electrical insulation test passed at reception Electrical insulation test passed at room temperature Electrical insulation test passed at nominal operating conditions	OK OK OK
Requirement 9	The individual splice resistance is lower than 5 nΩ	OK
Requirement A	Satisfy requirement 1 after 100 quenches	Out of scope
Requirement B	Satisfy requirement 1 after 10000 cycles	Out of scope
Requirement C	Satisfy requirement 1 after 10 thermal cycles	Out of scope





Test report: EDMS 3162193

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- **MCBXFB06 assembly**
- MCBXFB07 assembly
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MCBXFB06

- Assembly duration / finishing date: 2.5 months / October 2024
- 2 inner dipole collaring operations, 1 outer dipole collaring operation (in two days)
- High strain values during the first inner dipole collaring
  - For the second ID collaring: shimming (pole and midplane) reduced by 100 µm - 125 µm
  - Understood based on coil geometry measurements (CMM)
- Outer dipole collared in two days (to allow analysis of strain data)
  - Values were in the upper limit during the first day

MCBXFB06

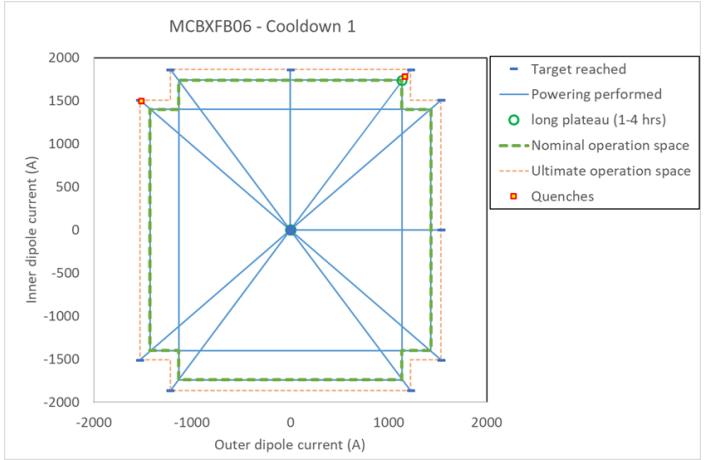
All electrical tests successfully passed

Warm magnetic measurements

- As for MCBXFB05, we see a difference in b3 / a3 compared to the first magnets.
- Outer dipole in line with previous assemblies

Cold test

- **On-going!**
- Issue with energy extraction during CD1
- We miss the 4-hour plateaus and most of magnetic measurement cycles.
- Thermal cycle launched to intervene in the EE system



Courtesy of G. Willering et al.

Outline

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MCBXFB07

- Assembly duration / finishing date: 2.5 months / December 2024
- Modified shimming trying to correct the small field quality deviation in B05 & B06.
- 1 inner dipole collaring operations, 2 outer dipole collaring operation
- For the inner dipole, heads are slightly less pre-loaded w.r.t. previous magnets. Straight section is close to maximum values.
- Strain values above our targets during the first OD collaring (not really understood based on coil geometrical measurements):
  - *Outer dipole shimming modified: only midplane shimming decreased by 0.1 mm (to reduce ~ 100 µstr, 20 MPa)*

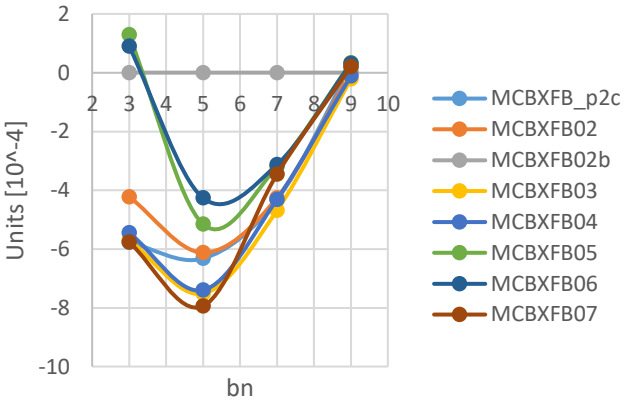
MCBXFB07

✓ All electrical tests successfully passed

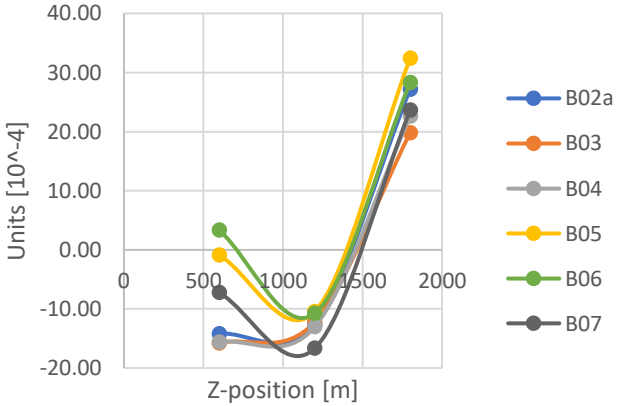
✓ Warm magnetic measurements

- Shape of field harmonics (along the magnet longitudinal axis) is similar to B05 & B06.
- With the new shimming we have shifted the integrated harmonics back to the values of the first series magnets.
- Outer dipole in line with previous assemblies

Integrated harmonics – Inner dipole collared



b3 profile – Inner dipole collared



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Status on components

- Today, we have for MCBXFA2
  - 5 lamination boxes (not all of them)
  - Connection and Return End Plate (not the Arc Pushers with the Duratron)
  - Yoke Rods
  - Beam Pipe centering parts
  - Yoking Pins (Not enough)
  - Connection Plate
  - Collaring shoes (inner till A4, outer till A8)
- We need for MCBXFA2
  - Remaining laminations
  - Arc Pushers with the Duratron
  - Yoking pins (80 mm)
- We have 3 MCBXFA coils in stock
  - ICA2
  - OCAS04, OCAS03
- Today, we have for MCBXFB08
  - Yoke Rods (8 + 16)
  - Beam Pipe centering parts (4 units, not enough)
  - Connection Plate (all for MCBXB magnets)
  - Collaring shoes (last ones)
- We need for MCBXFB08
  - Yoke laminations
  - Connection and Return End Plate
  - Arc Pushers with the Duratron
  - Yoking pins (80 mm)
  - Beam Pipe centering parts (2 units at least)
- We have 4 MCBXFB coils in stock
  - ICBS08, ICBS09
  - OCBS18, OCBS19

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The logic behind the field quality correction in B07

- Following the field quality results for MCBXFB05 & MCBXFB06, we launched an investigation to try to understand the source of the deviation w.r.t. first series magnets.

- A suspicious feature was detected at the coil geometrical measurements: there is a step of about 0.1 mm in the measurements of the cable arc length, at the end of the pole window.
  - The arc length is about 0.1 mm larger than nominal.

- It could be explained because for **these ID coils (B05, B06 & B07 on) the impregnation mould has been closed controlling the applied torque on the M20 screws (80 Nm)**.
  - Potentially, there could be a small gap between the pole turn and the closing 0.2-mm-thick sheet, so the main posts could be pushed upwards, which finally yield an arc length larger than nominal. In that situation, the extra thickness of the resin around the pole window could be also present at the coil heads, creating an excessive pressure when the coils are collared. Since the return side coil head is stiffer (the end-spacers of the connection side head are split), the cable blocks closer to midplane would feel this extra pressure, estimated around 20 MPa (arc length could be about 0.15 mm above nominal). When the cable blocks are moved towards the midplane, both b3 and b5 shift towards positive values.

The logic behind the field quality correction in B07

- The thickness of the coils has been measured (Table below). ICBS20 has more resin excess at the pole turns than ICBS19.
  - Based on the CMM and thickness measurements, the shimming thickness will be reduced by 100 microns at the end of the pole window.

	Midplane		Pole turn		Difference
	Layer jump	Non-layer jump	Layer jump	Non-layer jump	
ICBS10	10.243	10.224	10.313	10.253	0.050
ICBS19	10.257	10.242	10.289	10.299	0.045
ICBS20	10.210	10.251	10.334	10.312	0.093
OCBS16	10.303	10.325	10.404	10.450	0.113
OCBS15	10.313	10.319	10.294	10.317	-0.011

Table III. Coil thickness at different points. ICBS10 impregnation mould was closed without torque control, for comparison.

- For information, a midplane shimming variation of 25 microns translates into a b3 variation of 2 units and a change in b5 of 0.3 units. Sensitivity is high.

The logic behind the field quality correction in B07

MCBXFB07 ID

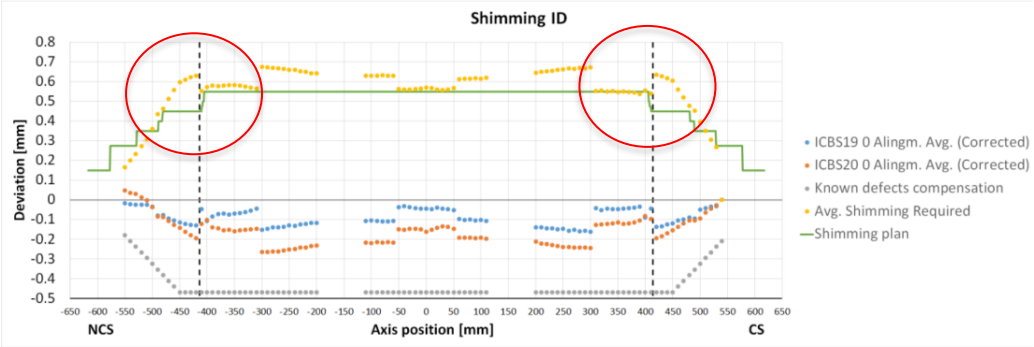


Figure 4. Shimming estimation for MCBXFB07 inner dipole.

MCBXFB06 ID

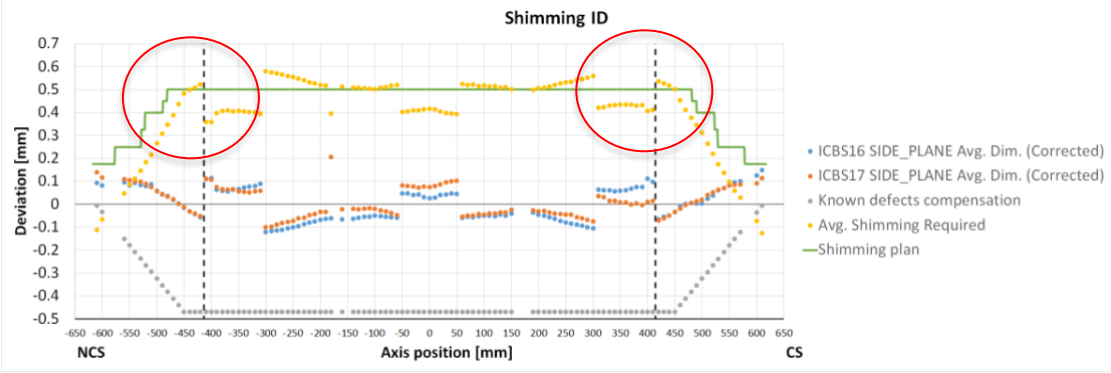
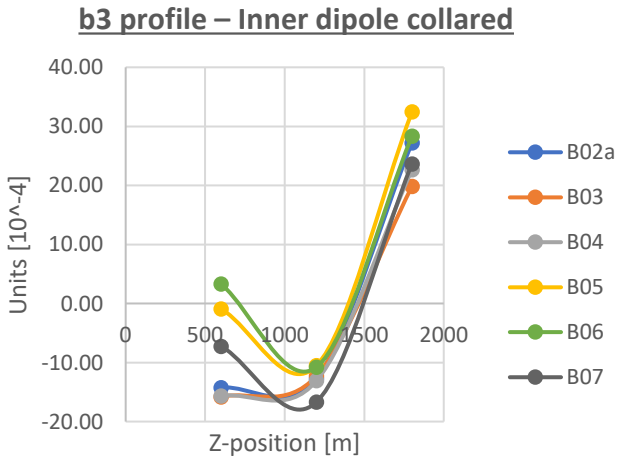
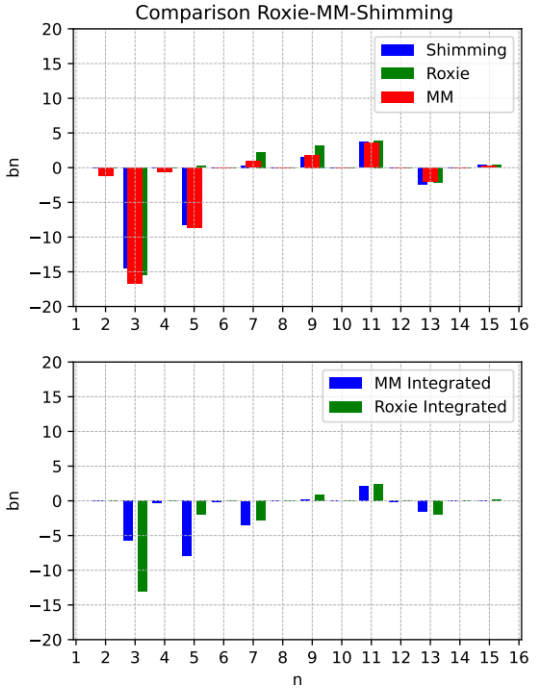


Figure 2. Shimming estimation for MCBXFB06 inner dipole.

The logic behind the field quality correction in B07

- As we saw, the b3 profile after the shimming change is still similar to B05 & B06.
- Values in the central section are lower by 4 units w.r.t. previous magnets (50 microns mid-plane difference), however the shimming there is the same as previous MCBXFB. On the contrary, now we're in good agreement with ROXIE predictions.





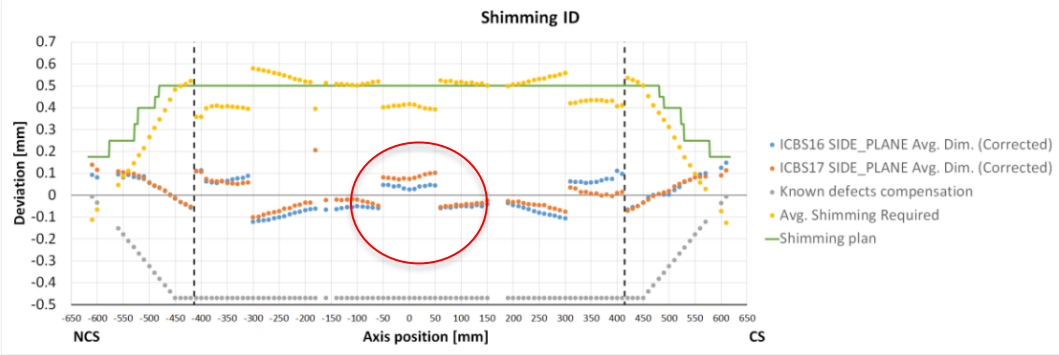
Some notes on high strain values during B06 & B0 collaring

- The inner dipole collaring for MCBXFB06 was done twice. High strain values were quickly identified since the beginning of the instrumented collaring operation.
  - As already mentioned, the source for the high strain values was understood based on coil geometrical measurements (next slide). Indeed, we were aware of it, but we privileged having a shimming plan close to all previous magnets (also due to some uncertainties on the CMM measurements).
  - Shimming (pole and midplane) reduced by 100 µm - 125 µm

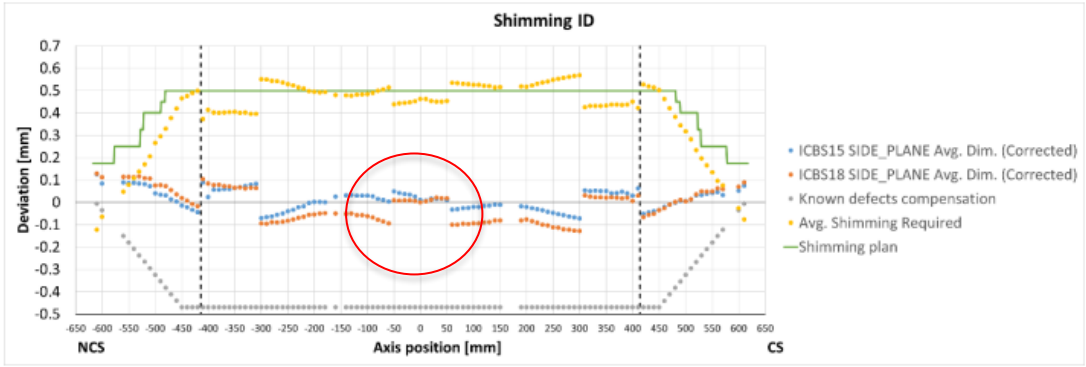
- Similarly, the outer dipole collaring for MCBXFB07 was also done twice due to high strain values.
  - In this case, we could not clearly identify the source for the issue. **Interestingly, this is the first magnet on which the impregnation mold for the outer coils was also closed with a controlled torque. Coil thickness may be larger for these coils, however, we do not have CMM measurements on the coil outer radius.**
  - To avoid fully dismantling the outer dipole, only the midplane shimming for the OD was modified. Expected impact on b3 is +2 units, but we did not really see it!

Some notes on high strain values during B06 & B0 collaring

MCBXFB06 ID



MCBXFB05 ID



Summary and outlook

- Setting the starting date for the new production line on mid-February (instead of the initially considered early-January due to late availability of the assembly area), activities are following the established planning

- Minor Non-Conformities during the inner dipole assembly both for MCBXFB05 and MCBXFA1
  - Corrective actions and improvements have been already implemented
  - After those NCRs, assembly activities continued extremely smoothly.

- Non-Conformities regarding the Inner Dipole field quality for MCBXFB05 & MCBXFB06 still need to be prepared. We were waiting for the results of MCBXFB07 and to better understand what's happening.

- We suspect that coil geometry variations (mainly due to the way we close the impregnation mold) are creating the field quality and strain differences among magnets. Nevertheless, the CMM data available nowadays does not allow us to fully study the issue.
  - It would be interesting to discuss about what we could do / incorporate during CMM measurements to try to close this open question.

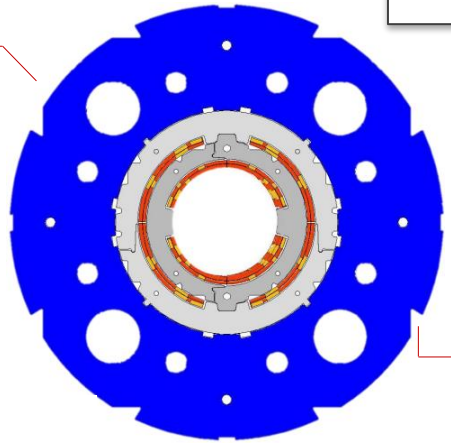
ANNEX

Summary of initial activities

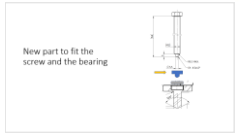
- Initial activities structured in 3 main axes:

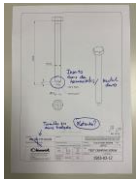
Identification, control and storage of the magnet components. Documentation!

Setup of the required infrastructure in B.180 and B.927. Planning!



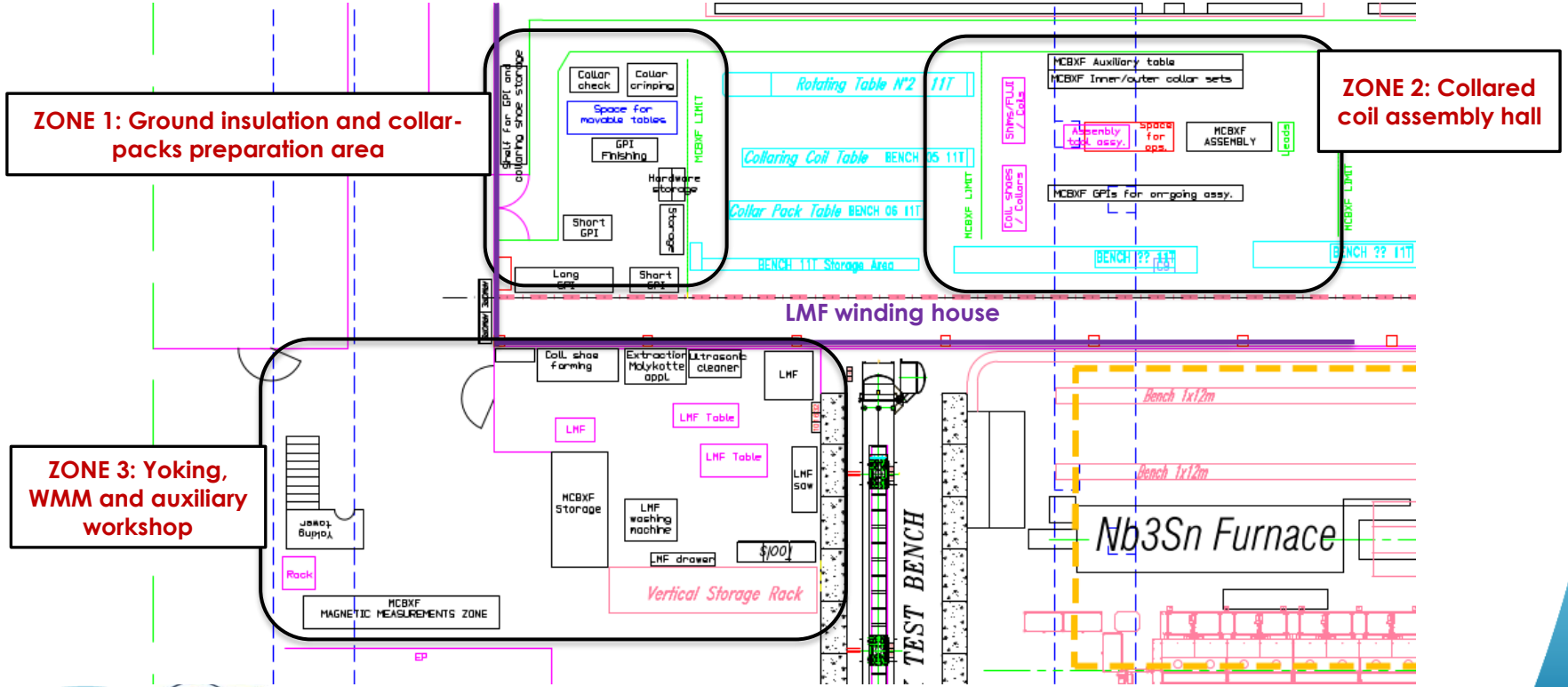
Repairs and modifications on assembly tooling (based on previous exp.). Design of new required tooling.





Setup of the required infrastructure

- All assembly operations but the Collaring are performed in building 180: 3 zones for MCBXF.



Setup of the required infrastructure

ZONE 1: Ground insulation and collar-packs preparation area

ZONE 2: Collared coil assembly hall

HiLumi HL-LHC PROJECT

CERN

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Setup of the required infrastructure

ZONE 3: Yoking, WMM and auxiliary workshop

Setup of the required infrastructure

ZONE 4: Collaring press and assembly area at B.927