Field quality in WP3 magnets

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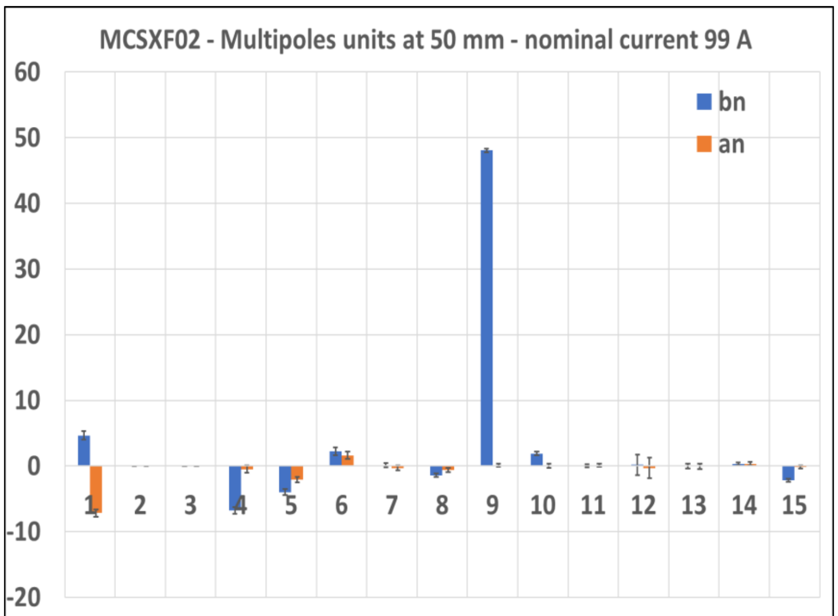
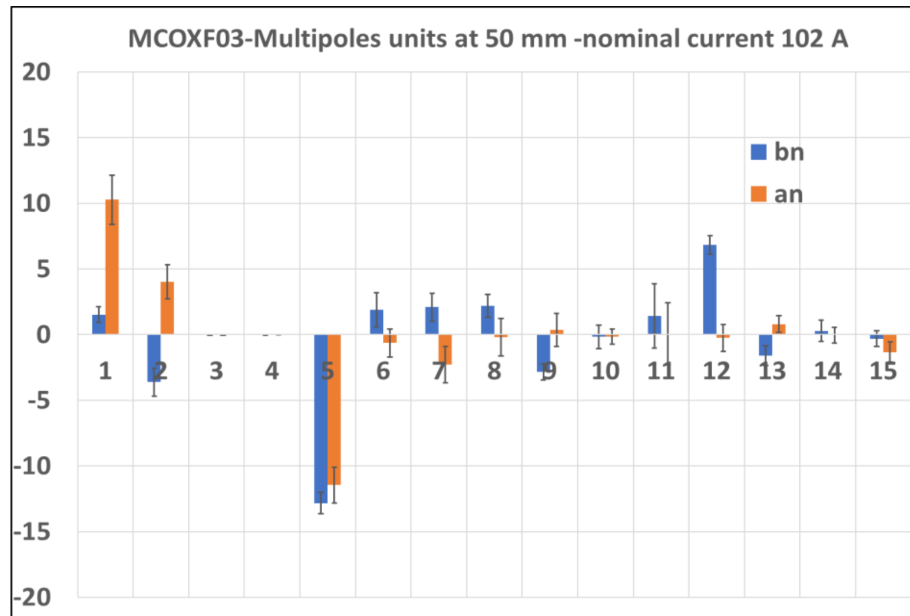
  - MQXFA: transfer function spread

The high order correctors

- Requirement: multipoles within 100 units
  - See acceptance criteria, EDMS 2045901
  - Field quality measured in several magnets, in line with simulations and requirements



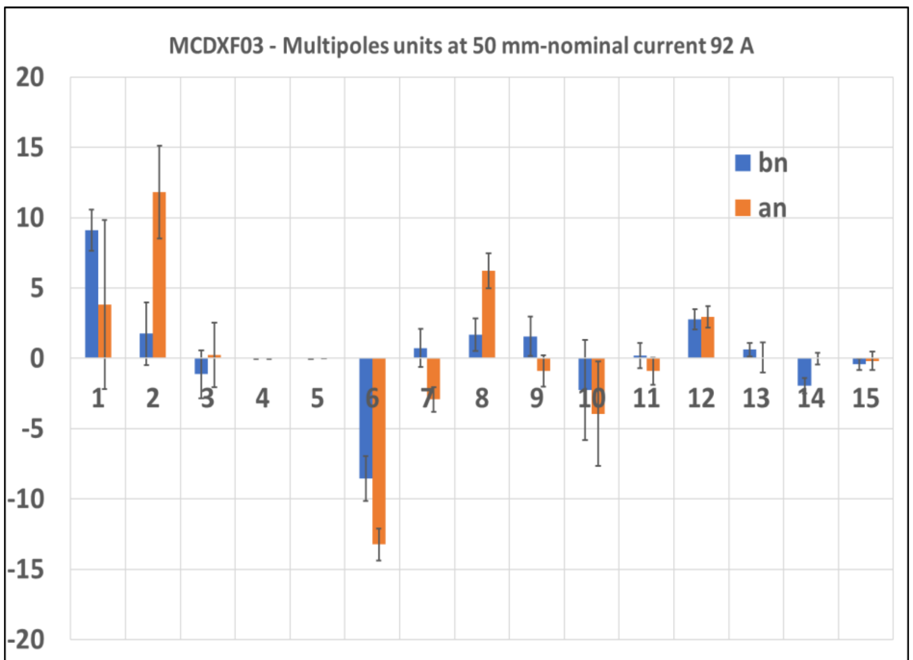


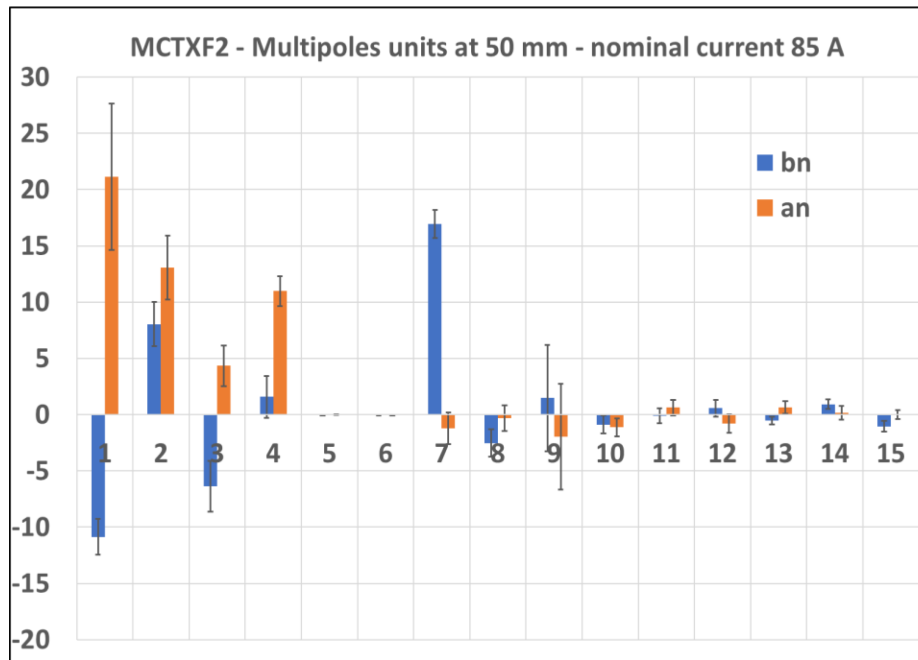
Multipoles measured in 2nd sextupole (left) and in 3rd octupole (right)

(M. Statera, M. Prioli, L. Fiscarelli, et al)

The high order correctors

- Requirement: multipoles within 100 units
  - See acceptance criteria, EDMS 2045901
  - Field quality measured in several magnets, in line with simulations and requirements

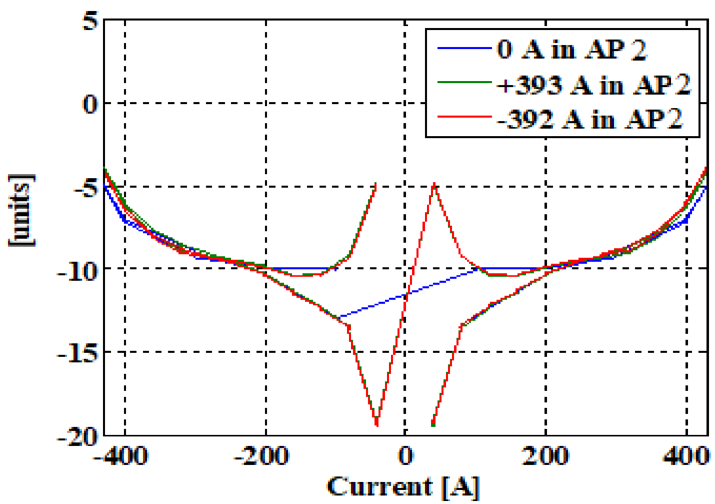


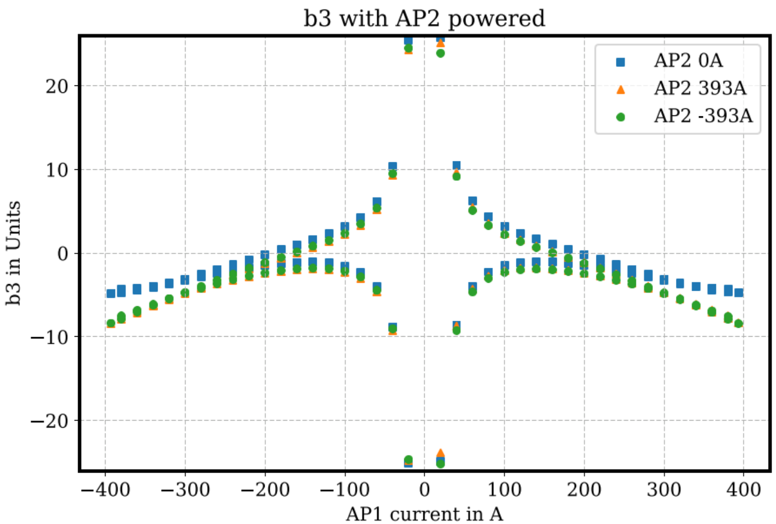


Multipoles measured in 3rd decapole (left) and in 2rd dodecapole (right)
(M. Statera, M. Prioli, L. Fiscarelli, et al)

The D2 corrector

- Requirement: multipoles within ±3 units, b_3 within ±10 units (excluding low field)
  - See acceptance criteria, [EDMS 2051870]
  - Issue with a systematic b_3 observed in prototypes
  - Source found in the keys, see [EDMS 2493641]
  - Problem solved, now all multipoles within requirements

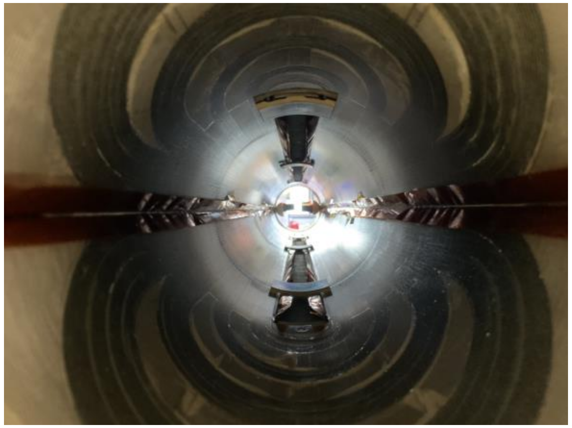


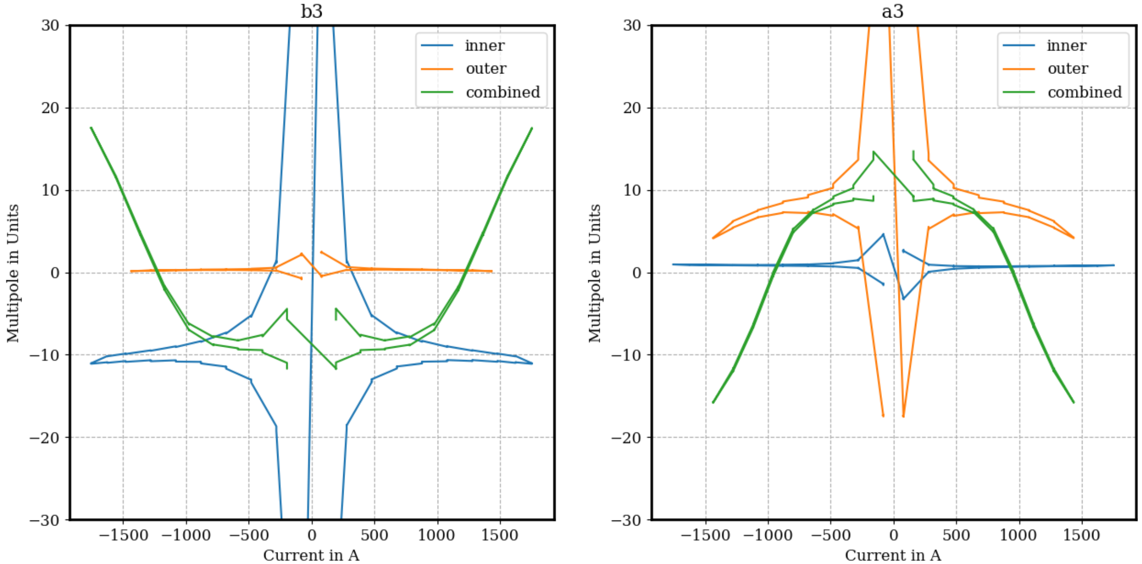


a3 (left) and b3 (right) measured in the MCBRDP3 with improved magnetic design of keys
(L. Fiscarelli, A. Musso, G. Kirby, et al)

The nested corrector

- Requirement: multipoles within ±5 units, b_3 within ±20 units
  - See acceptance criteria, [EDMS 2051311]
  - Most critical requirement is on b_3 and a_3, whose variation due to saturation is 20 units (10 of these units come from the last 10% of integrated field)



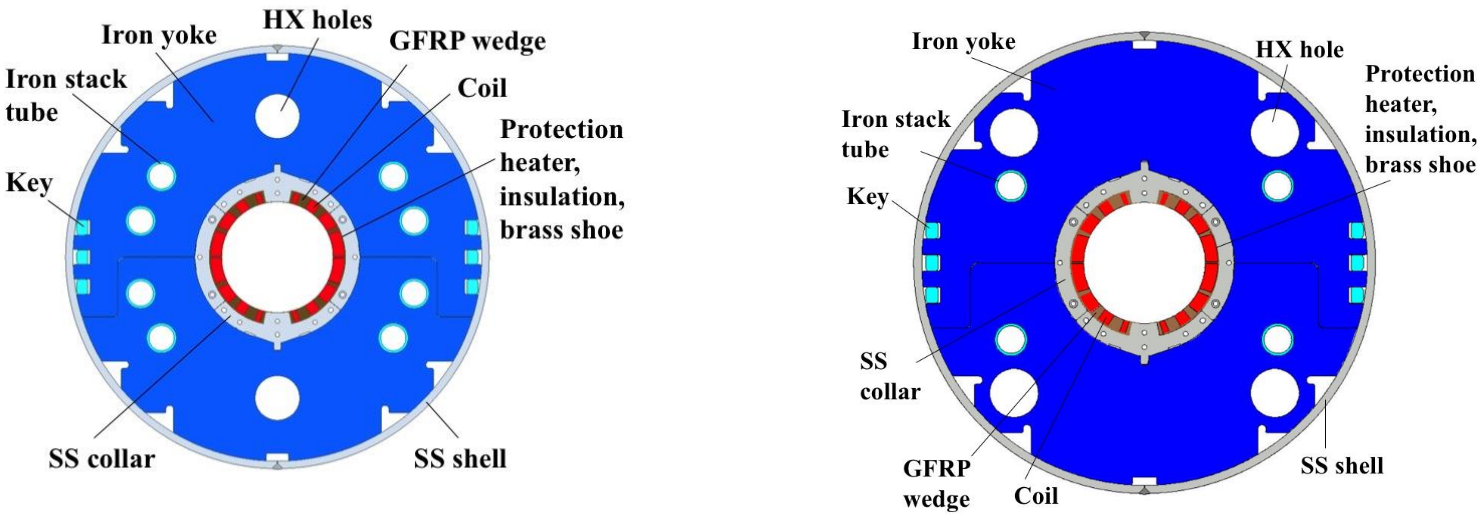


a3 (left) and b3 (right) measured in the MCBXFB01

(L. Fiscarelli, S. Ferradas Troitino, M. Bonora, J. C. Perez, F. Toral, et al)

D1

- D1 had three iterations of the cross-section to match the ±3 units range for b_3 and ±1.5 unit for b_5
  - From first to second short model, to account of the change of the iron shape and holes
    - Third short model with about 20 units of b_3 and b_5 within targets



Iron and cross-section modification from first to second short model
(T. Nakamoto, M Sugano, K. Suzuki, et al)

D1

- D1 had three iterations of the cross-section to match the ±3 units range for b_3 and ±1.5 unit for b_5
  - From the third short model to the prototype, to account for the impact of unexpected iron saturation and wedge compensation to match coil size (see technical meeting on July 2019 https://indico.cern.ch/event/833498/)
  - Prototype expected to have at nominal current 4 units of b_3 and -5 units of b_5
  - This will be measured at CERN at 1.9 K in August 2022 (including verification of cryostat contribution

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D1

- D1 had three iterations of the cross-section to match the ±3 units range for b_3 and ±1.5 unit for b_5
  - From the prototype to the series see EDMS 2612909, to make the final fine tuning
    - Minor change of the wedges by less than 0.3 mm

D2

- D2 had two iterations of the cross-section to match the ±3 units range for b_3
  - b_5 range was extended to ±5 units after verifications via tracking (F. v. der Veken, M. Giovannozzi)
  - From short model to prototype, to account of the large differences in the coil azimuthal size
    - Prototype expected to have 8 units of b_3 11 units of b_5 within targets (to be measured at 1.9 K in April 2022)
  - From the prototype to the series see EDMS 2472430, to make the final fine tuning
    - Minor change in the wedges by less than 0.3 mm

MQXF

- One of the most critical quantities is the spread of the transfer function
  - For the Q1/3 difference should be smaller than 3 T m- well within

Gradient and magnetic length summary A04/5/6

MQXFA04	Unit	16.47 kA	16.23 kA (+)
Central Gradient (*)	T/m	134.64	132.68
Integrated Gradient	T	567.64	559.37
Magnetic length	m	4.216	4.216

(*) Average along the magnet straight section.
(+) Linear scaling from measurements at 16.47 kA

At 16.23 kA	Unit	MQXFA04 (#)	MQXFA05 (#)	MQXFA06 (#)
Central Gradient (*)	T/m	132.68 (+)	133.16	132.90
Integrated Gradient	T	559.37 (+)	561.48	560.32
Magnetic length	m	4.216	4.216	4.216

(*) Average along the magnet straight section.
(+) Linear scaling from measurements at 16.47 kA
(#) MQXFA04 has 1 coil with b6 correction; MQXFA05-06 have 4 coils with b6 correction

- Expected gradient increase from A04 to A05/A06 due to 3 additional coils with b6 correction: 12 units (about +0.16 T/m i.e. from 132.68 T/m to 132.84; or about 0.66 T from 559.37 T to 560.03 T)
- Acceptance criteria for IG: magnets with same x-sec within 3T, magnets with different x-sec within 6T
- Acceptance criteria for ML: difference between any pair of magnets < 10 mm

Measured integral transfer function in MQXFA
(A. Ben Yahia, et al)

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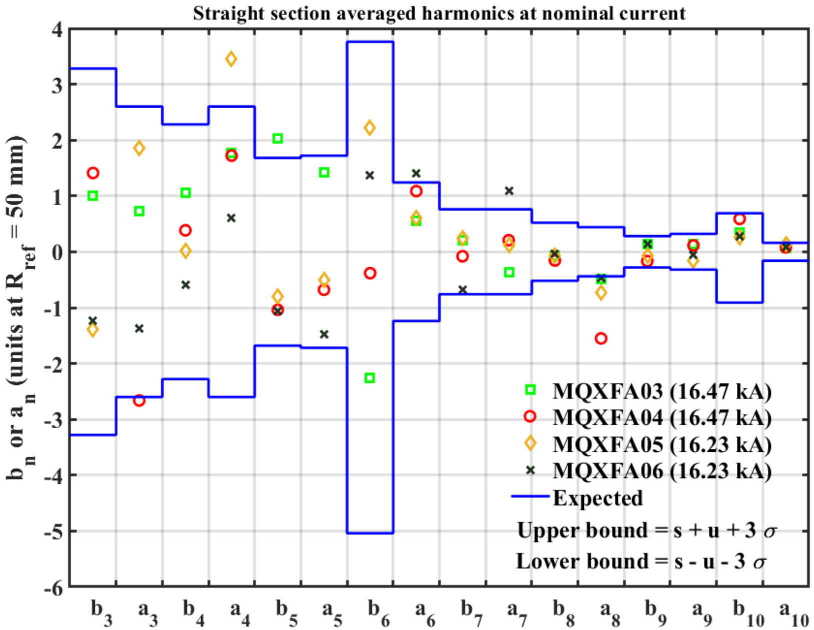
MQXF

- The b_6 correction carried out in November 2018
  - (see EDMS 2019517) Correction effective, multipole average well within the ±3 units range
  - Non allowed multipoles well within targets
  - Magnetic shimming used in MQXFA05 and MQXFA06



Measured integral multipoles in MQXFA
(A. Ben Yahia, et al)

CONCLUSION

- Since the beginning of HL-LHC, seven corrective actions for field quality have been carried out
  - Fine tuning of 4 units of systematic b_6 in MQXF to better center the zero average
  - Change of material of keys to avoid 10 systematic units of b_3 in MCBRD
  - Three fine tuning of cross-section in D1 to better center b_3 and b_5
  - Two fine tuning of cross-section in D2 to better center b_3 and b_5
- Most critical part at the moment is the b_3 and b_5 steering in D1 and D2
  - Fine tuning of cross-section are usually needed to match the stringent requirements (two were done in the LHC dipoles)
  - Here the challenge is that we have very litte time for reaction (short series)
  - In 2022 we will have the main validation of these actions