FIELD QUALITY: WHERE WE STAND

G. L. Sabbi, S. Izquierdo Bermudez, E. Todesco, L. Fiscarelli, P. Rogacki, et many al.

21 September 2022 – Uppsala, HL-LHC meeting

Contents

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  - Integrated gradient
  - Integral multipoles
- MQXFB
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- D1-D2
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- HO correctors and MCBRD

Integrated gradient of MQXFA

- Difference in integrated gradient in the two magnets of the same cold mass
  - First cold mass (MQXFA03 and MQXFA04): 0.05%
  - Second cold mass (MQXFA05 and MQXFA06): 0.16%
- Note: MQXFA07, MQXFA08, MQXFA09 being disassembled, are given in the table just to give an indication of the trends
- We see higher values of MQXFA03 and MQXFA04, removing these magnets the stdev on MQXFA05-10 is 0.11%
- Requirement: difference smaller than 0.5 % (EDMS 2031083)

	Int. Gradien (T/kA)	Diff. In CM (%)		Diff. To ave (%)
MQXFA03	37.198	0.05	LQXFA01	-0.31
MQXFA04	37.178			-0.36
MQXFA05	37.350	0.16	LQXFA02	0.10
MQXFA06	37.290			-0.06
MQXFA07	37.334			0.06
MQXFA08	37.366			0.14
MQXFA09	37.394			0.22
MQXFA10	37.395			0.22
Stdev (%)	0.23			
Average	37.313			

b6 CORRECTION

- After initial data on prototypes, a correction of b_6 was implemented in November 2018 to reduce it from -5 to 0 units
  - Corrective action: move a 0.125 sheet from midplane to pole, see EDMS 2019517
  - MQXFA03 will still have old shimming scheme (-4.4 units of b6)
  - All others have the new shimming scheme

Integ (unit)	MQXFA03	MQXFA04	MQXFA05	MQXFA06	MQXFA07	MQXFA08	MQXFA10	ave	stdev
b3	-0.598	1.687	-1.219	-1.870	2.09	-1.77	2.48	0.115	1.90
b4	1.258	0.292	0.293	-0.198	1.31	-0.30	-3.04	-0.055	1.46
b5	1.646	-0.845	-0.745	-1.071	-0.24	-0.09	-1.77	-0.445	1.08
b6	-4.412	-0.773	1.962	1.058	1.06	2.06	-1.06	-0.015	2.29
b7	0.180	-0.064	0.315	-0.663	0.14	-0.37	0.29	-0.026	0.37
b8	-0.104	-0.171	-0.076	-0.031	0.05	0.02	0.06	-0.036	0.09
b9	0.099	-0.117	-0.071	0.130	0.02	-0.01	-0.36	-0.044	0.17
b10	0.123	0.398	0.145	0.149	0.32	0.33	-0.23	0.176	0.21

Integ (unit)	MQXFA03	MQXFA04	MQXFA05	MQXFA06	MQXFA07	MQXFA08	MQXFA10	ave	stdev
a3	0.564	-2.601	1.650	-0.993	3.17	3.18	0.09	0.723	2.13
a4	2.275	2.527	2.750	0.336	3.43	1.94	-2.23	1.575	1.93
a5	1.554	-0.581	-0.494	-1.617	0.41	0.50	-0.40	-0.090	1.01
a6	0.517	1.417	1.009	1.648	0.73	0.23	1.16	0.958	0.50
a7	-0.304	0.220	0.050	1.051	0.30	0.02	-0.62	0.103	0.52
a8	-0.537	-1.453	-0.724	-0.476	-0.03	-0.48	-0.40	-0.587	0.44
a9	0.141	0.123	-0.136	-0.065	0.13	0.11	-0.19	0.016	0.14
a10	0.026	0.075	0.139	0.105	0.04	-0.07	0.08	0.056	0.07

Integral harmonics at nominal current (G. L. Sabbi for AUP)

MQXFA MULTIPOLES

- We have data at nominal of the 7 magnets (5 accepted, two disassembled but included in the statistics)
  - MQXFA03, MQXFA04, MQXFA05, MQXFA06, plus MQXFA07, MQXFA08, MQXFA10 – prototypes not included
  - Caveat: initial part of production usually has a larger spread
  - On MQXFA05, MQXFA06, MQXFA10 and MQXFA11 magnetic shimming was used

Integ (unit)	MQXFA03	MQXFA04	MQXFA05	MQXFA06	MQXFA07	MQXFA08	MQXFA10	ave	stdev
b3	-0.598	1.687	-1.219	-1.870	2.09	-1.77	2.48	0.115	1.90
b4	1.258	0.292	0.293	-0.198	1.31	-0.30	-3.04	-0.055	1.46
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b6	-4.412	-0.773	1.962	1.058	1.06	2.06	-1.06	-0.015	2.29
b7	0.180	-0.064	0.315	-0.663	0.14	-0.37	0.29	-0.026	0.37
b8	-0.104	-0.171	-0.076	-0.031	0.05	0.02	0.06	-0.036	0.09
b9	0.099	-0.117	-0.071	0.130	0.02	-0.01	-0.36	-0.044	0.17
b10	0.123	0.398	0.145	0.149	0.32	0.33	-0.23	0.176	0.21

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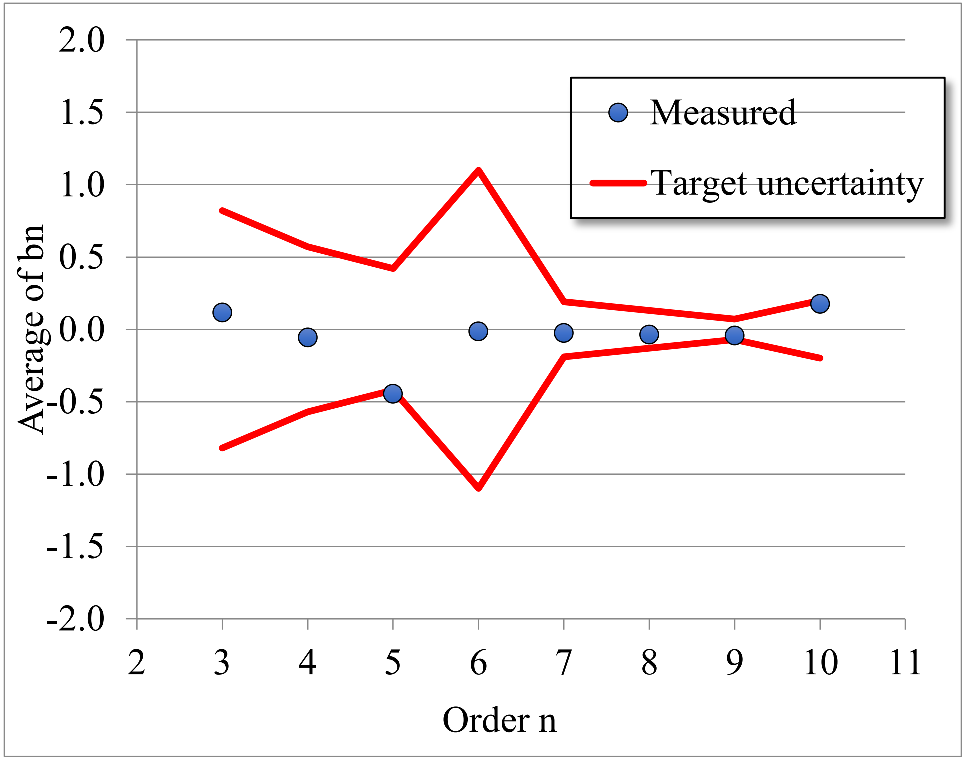
a4	2.275	2.527	2.750	0.336	3.43	1.94	-2.23	1.575	1.93
a5	1.554	-0.581	-0.494	-1.617	0.41	0.50	-0.40	-0.090	1.01
a6	0.517	1.417	1.009	1.648	0.73	0.23	1.16	0.958	0.50
a7	-0.304	0.220	0.050	1.051	0.30	0.02	-0.62	0.103	0.52
a8	-0.537	-1.453	-0.724	-0.476	-0.03	-0.48	-0.40	-0.587	0.44
a9	0.141	0.123	-0.136	-0.065	0.13	0.11	-0.19	0.016	0.14
a10	0.026	0.075	0.139	0.105	0.04	-0.07	0.08	0.056	0.07

Integral harmonics at nominal current (G. L. Sabbi for AUP)

MQXFA MULTIPOLES

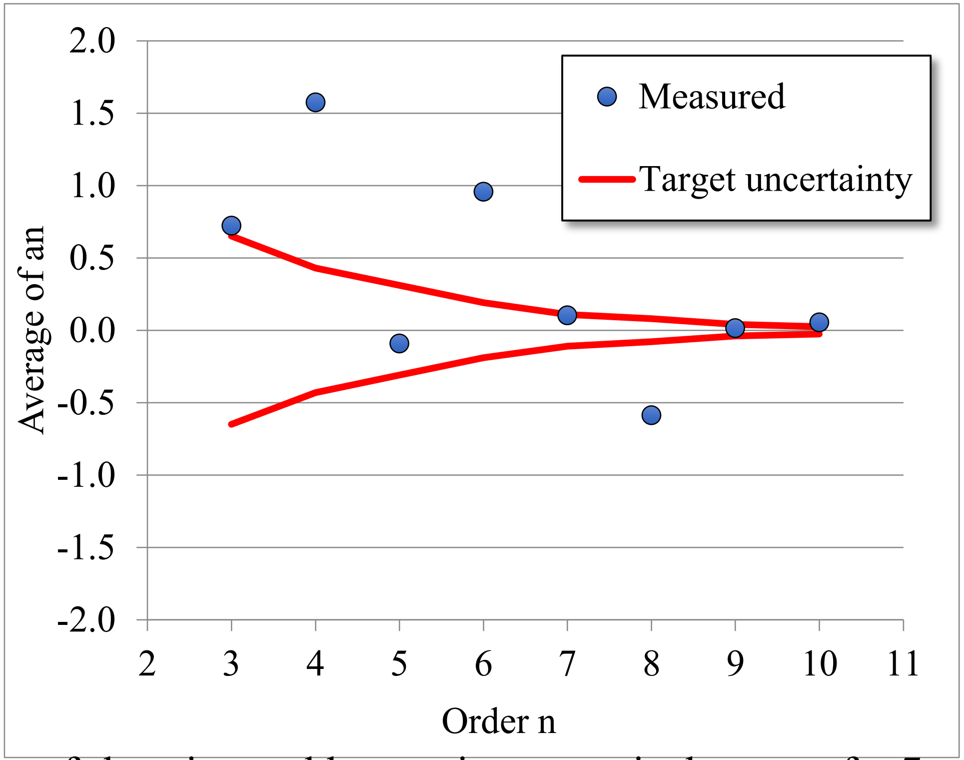
- Average: to be compared to uncertainty (accounting that the average is done over 7 magnets, and when it will be over 20 it will be probably reduced by a factor ~2)
- All averages of normal multipoles are less than 0.5 unit, well within the target uncertainty



Average of normal integral harmonics at nominal current for 7 magnets versus target uncertainty (G. L. Sabbi for AUP)

MQXFA MULTIPOLES

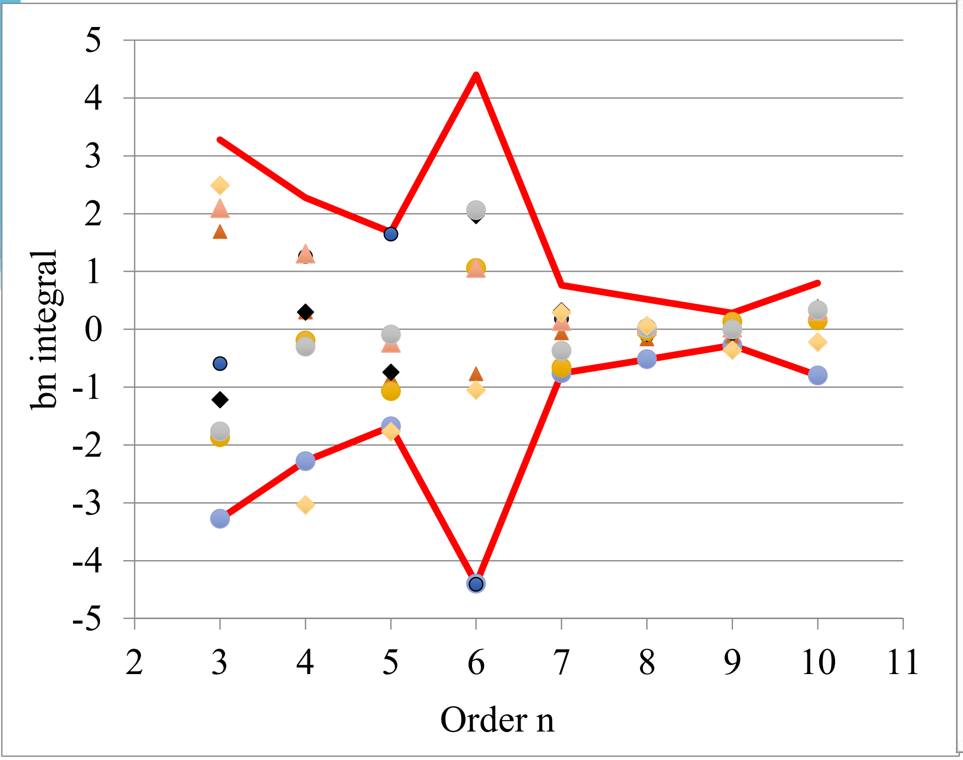
- Average: to be compared to uncertainty (accounting that the average is done over 4 magnets, and when it will be over 20 it will be probably reduced by a factor 2)
- All averages of skew multipoles are less than 0.5 unit, with three exceptions: a_4 (1.5 units), a_6 (1 unit) and a_8 (0.5 unit) – to be carefully monitered

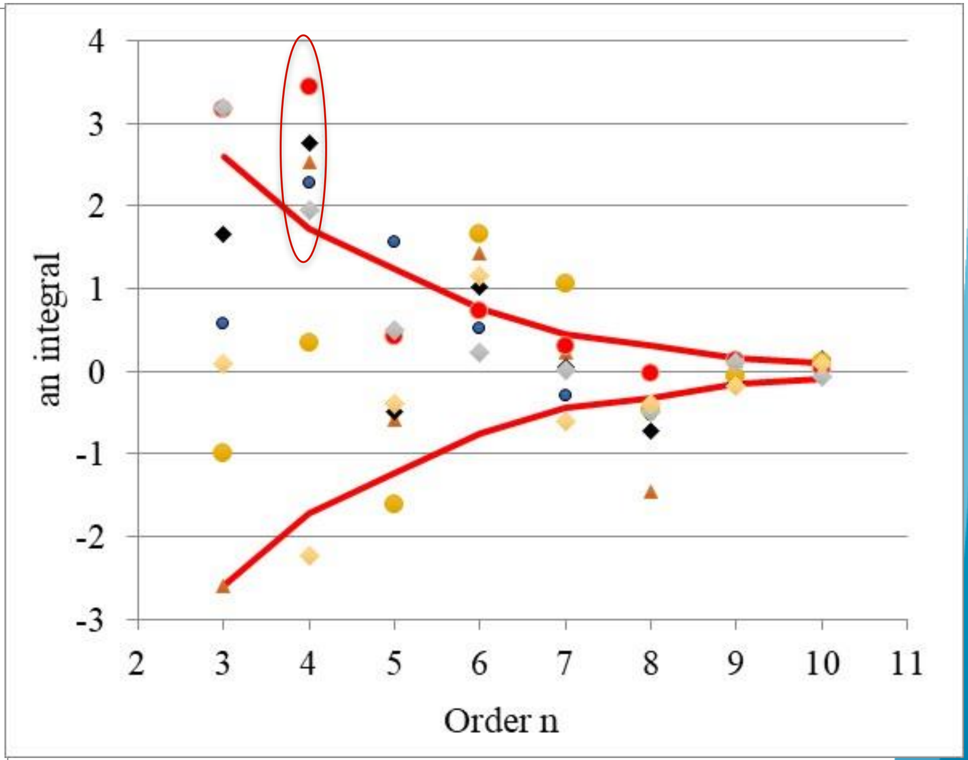


Average of skew integral harmonics at nominal current for 7 magnets versus target uncertainty (G. L. Sabbi for AUP)

MQXFA MULTIPOLES

- The seven magnets compared to acceptance ranges
  - a_4 is the most critical, and is also the multipole on which we cannot act so much with magnetic shmming
  - a_6, a_8 are as well out



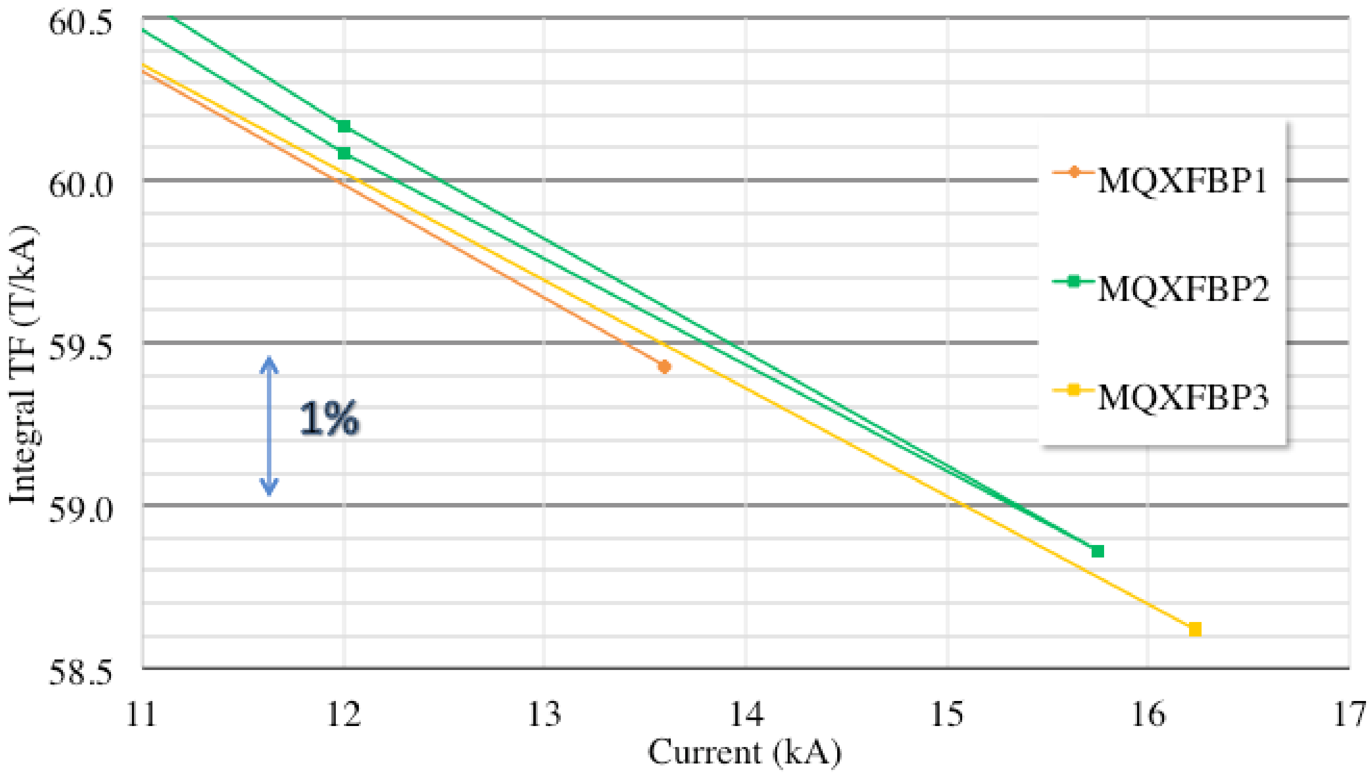


Normal and skew integral harmonics at nominal current for 7 magnets versus acceptance targets (3 sigma plus 1 uncertainty) (G. L. Sabbi for AUP)

Contents

MQXFB INTEGRATED GRADIENT

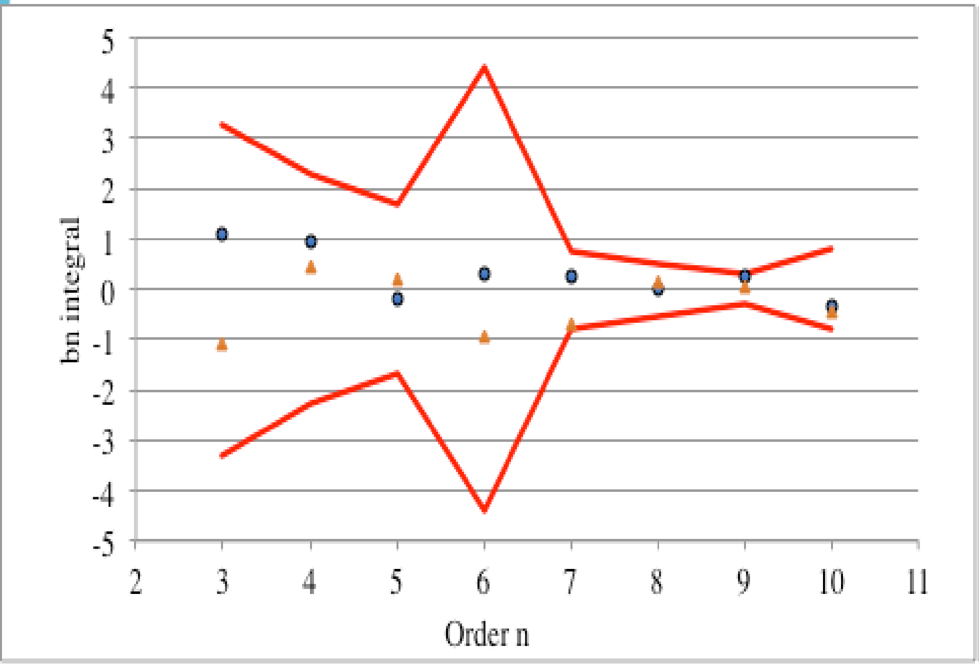
- Integrated gradient of the first three prototypes
  - At nominal current, one can guess it is within a range of 20 units, as required, already in this early phase

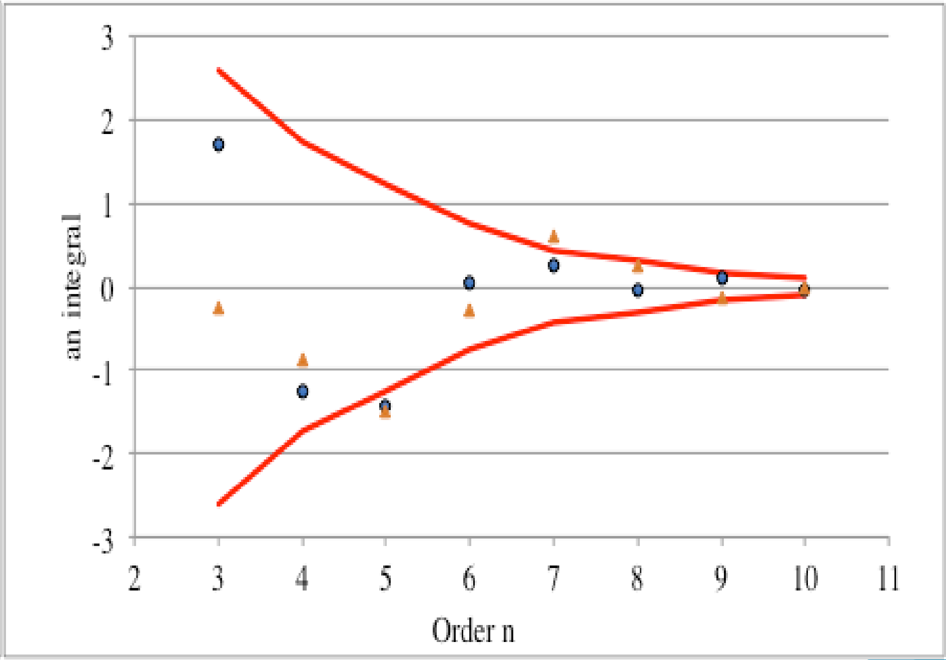


Detail of integrated transfer function of three prototypes
(S. Iqzuierdo Bermudez, L. Fiscarelli et al.)

MQXFB MULTIPOLES

- Only two magnets available at nominal current: MQXFBP2 and MQXFBP3 (first magnet not magnetically measured at 1.9 K)
  - Magnetic shimming used in MQXFBP2
  - So far, looks very good





Normal and skew integral harmonics at nominal current for 7 magnets versus acceptance targets (3 sigma plus 1 uncertainty) (L. Fiscarelli, S. Izquierdo Bermudez et al.)

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D1

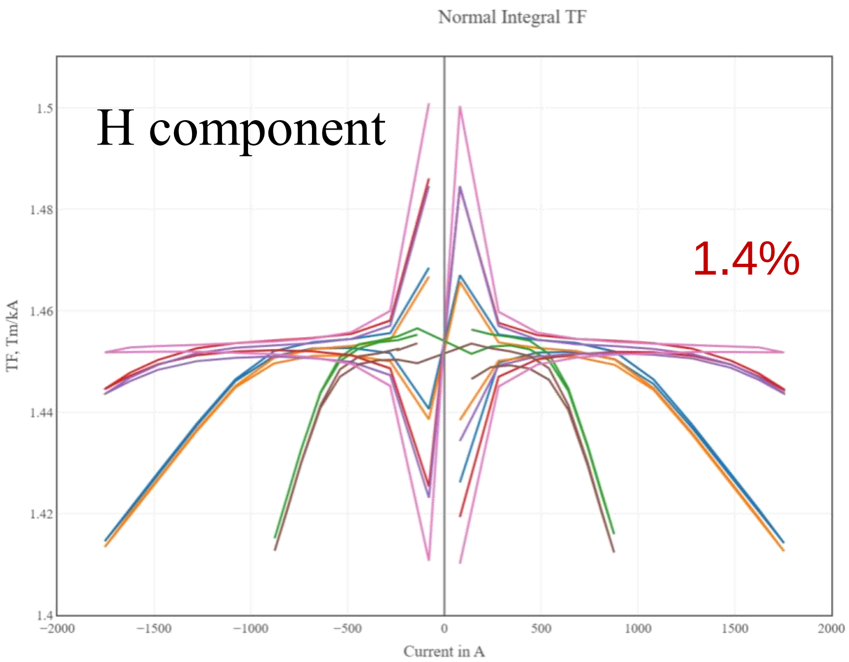
- D1 has a challenging field quality in terms of systematic multipoles (b_3 and b_5)
  - A cross-section modification was done from prototype to first series magnet (EDMS 2612909) – order of magnitude of the correction is 5 units of b_3 and b_5 (much larger than acceptance range)
  - Therefore magnetic measurements of the first series magnet are fundamental to assess the field quality of the series – they will be available in December for MBXF5 and March for MBXF1

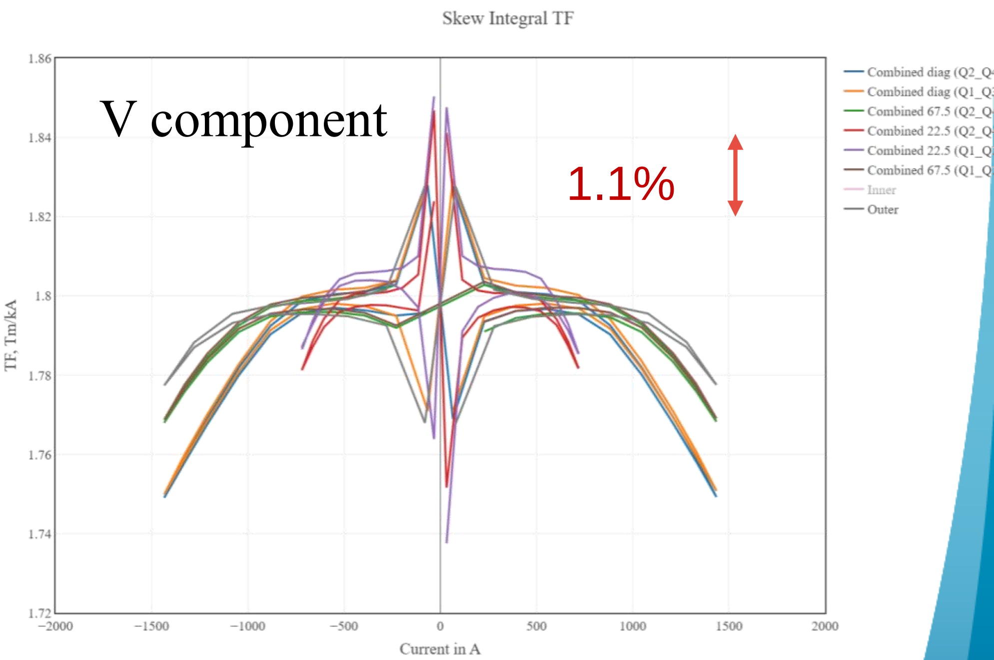
D2

- D2 has a challenging field quality in terms of systematic multipoles (mainly b_3)
  - First cross-section modification from model to prototype (EDMS 2472430) order of magnitude of the correction is 4 units of b_3 and b_5
  - One cross-section modification was done from prototype to first series magnet
  - Therefore magnetic measurements of the first series magnet are fundamental to assess the field quality of the series – they will be available in March 2023 for MBRD1

MCBXF

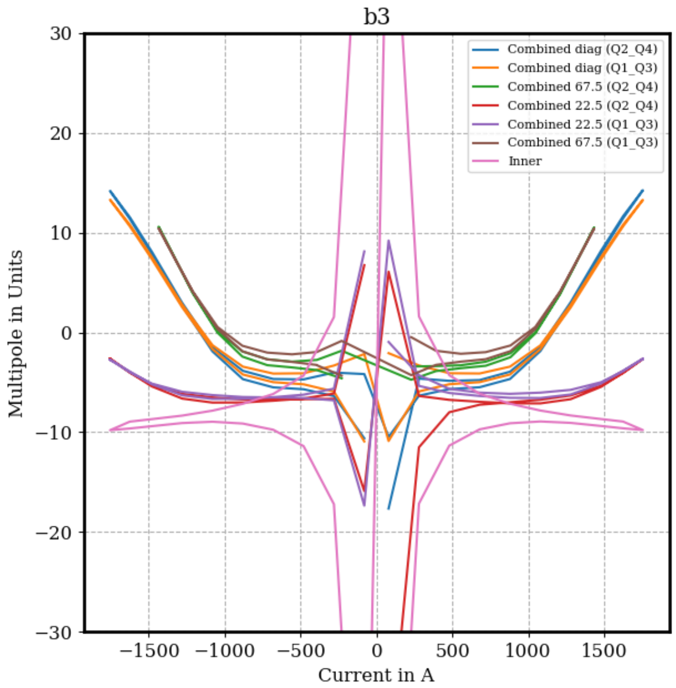
- Complex magnet with two powering parameters
  - Normalization is not trivial and should spelled in DMR between WP2 and WP3
- Saturation of TF will probably need modeling in FiDeHL

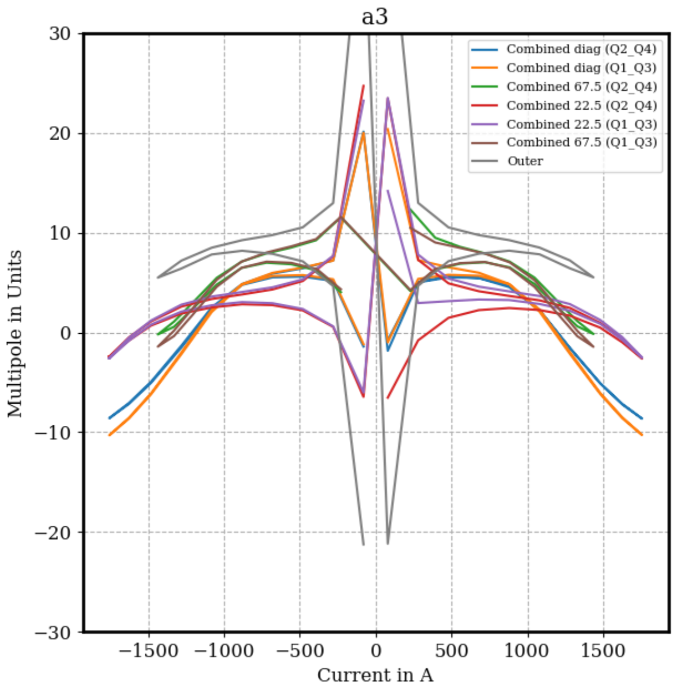




MCBXF

- Complex magnet with two powering parameters
  - b_3 and a_3 are the critical multipoles – the geometric multipoles are carefully placed on the optimal value via shimming of the coil
  - In MCBXFBP2c, within the 20 units requirement – not more than 10 units in half of the range (see plot)





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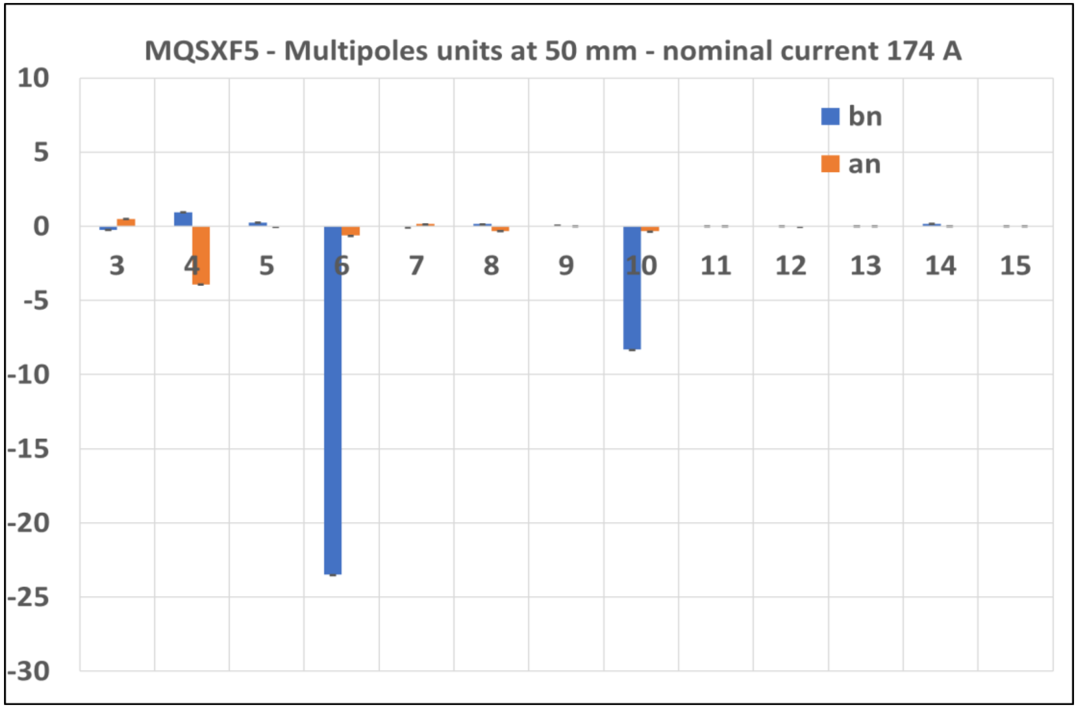
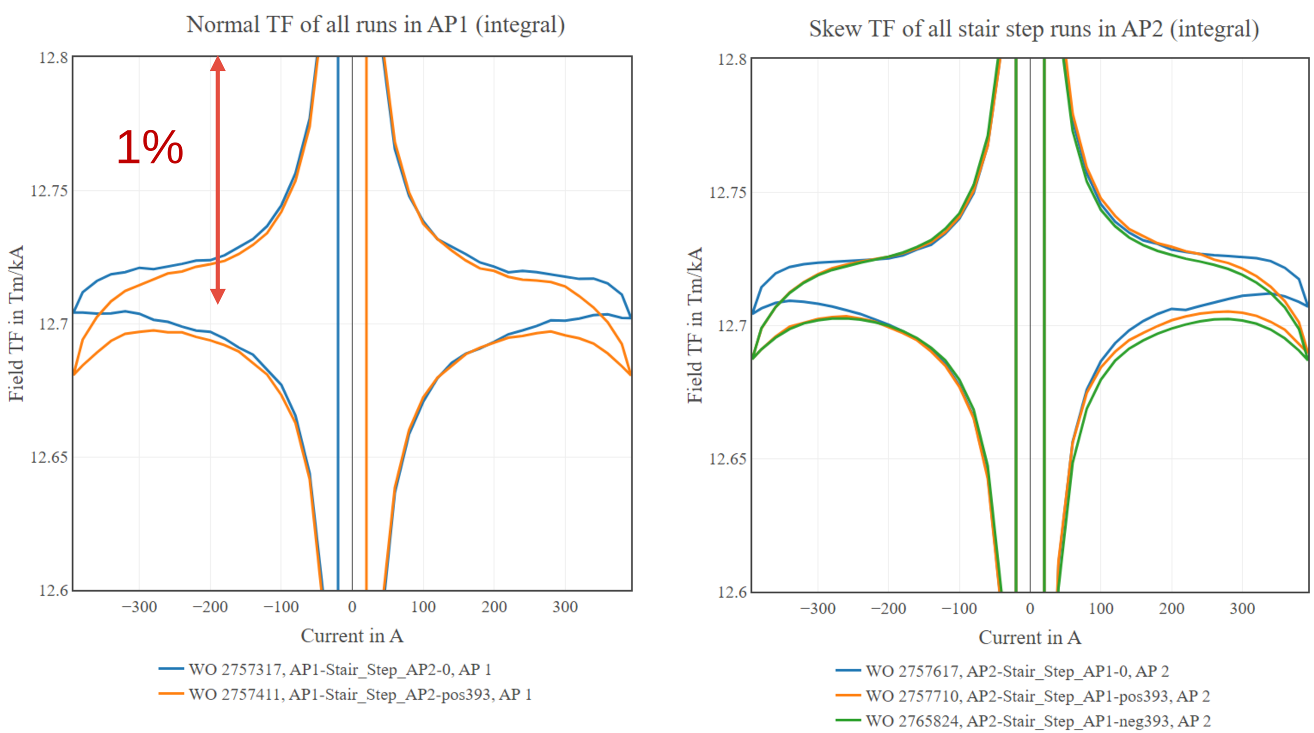
HO correctors

- HO correctors have multipoles within specifications (less than 50 units)
- Magnetic model activities are starting – main challenge is geometric TF
  - We will model the TF, with a saturation term



D2 correctors

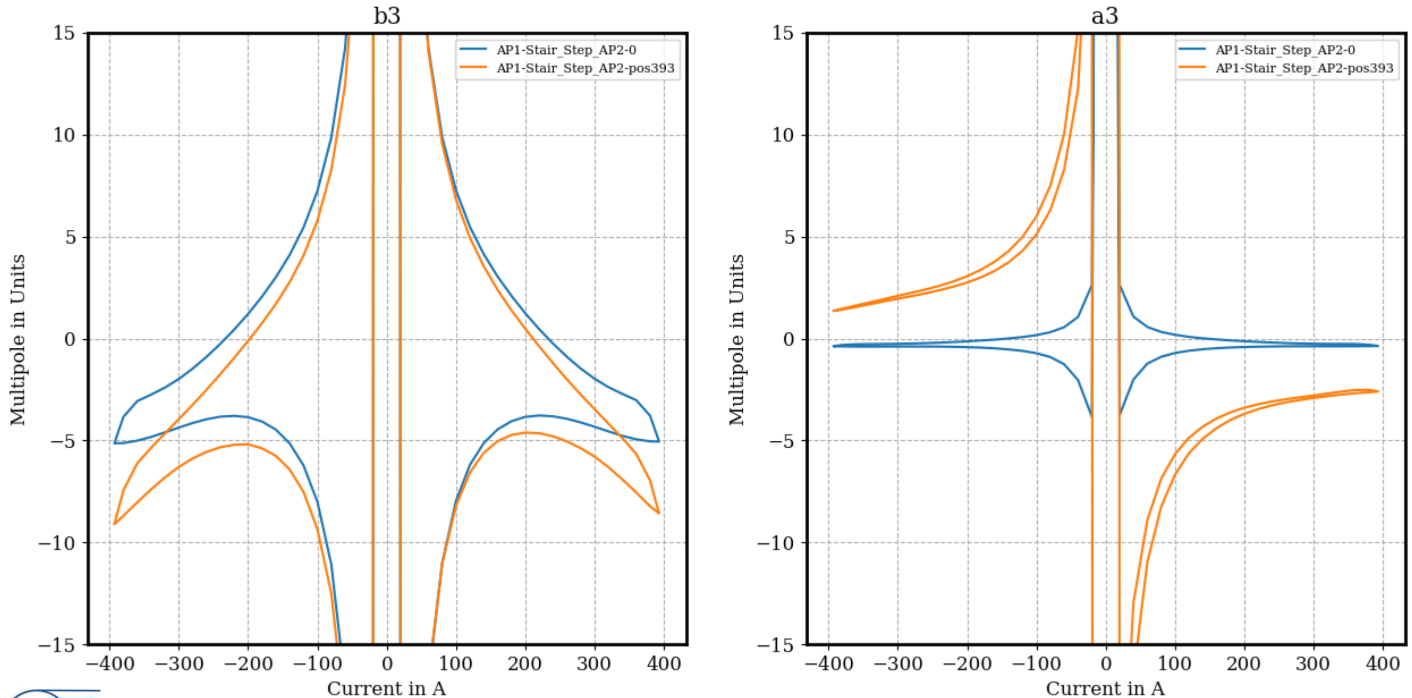
- D2 correctors had a b3 larger than the 10 units requirements
  - The issue was identified and cured after MCBRDP2
  - This does not prevent using MCBRDP1 and MCBRDP2 for HL-LHC
- Small contribution of saturation to transfer function, probably not needed in FiDeHL



Integrated transfer function of MCBRD01 (Q. Xu, P. Rogacki, et al)

D2 correctors

- D2 correctors had a b3 larger than the 10 units requirements
  - The issue was identified and cured after MCBRDP2
  - This does not prevent using MCBRDP1 and MCBRDP2 for HL-LHC
- B3 within 10 units in magnets after second prototype



Integrated b3 of MCBRD01 (Q. Xu, P. Rogacki, et al)

CONCLUSIONS

- First outlook of the field quality, based on early production
  - With all caveats relative to the available data
- MQXFA and MQXFB field quality is in line with requirements
  - Shimming applied in MQXFA to minimize some components
  - b_6 correction effective
  - Spread in integrated gradient is well below requirements
- For D1 and D2, fine tuning of cross-section is ongoing from prototypes to first series
  - First results will be available in March to finally assess where are we with systematic b_3 and b_5
- Nested corrector has large b3/a3 when fully powered
  - As agreed in design phase – FiDeHL modeling is ongoing
- D2 corrector and HO corrector present no issues