Status of field quality in D1 and D2

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D1 STATUS: MBXF1 MEASUREMENTS AT 12.11 kA

- D1 cross section went through three iterations to cope with stringent targets for b_3 and b_5
- From first to second model (MBXFS1 → MBXFS2)
- From third model to prototype (MBXFS3 → MBXFP1)
- From prototype to first series (MBXFP1 → MBXF1) EDMS 2612909
  - Change made via modification of wedges, b_3 +4 unit, b_5 -5.5 units
  - Note that target range is [-2.9,2.9] units for b_3 and is [-1.5,1.5] units for b_5
- News: first series magnet MBXF1 has been measured at 12.11 kA
  - The increase of b_3 and the reduction of b_5 have been confirmed
  - Integral b_3 measured in the vertical KEK test station: -4.1 units, that projected in the CERN final cryostat gives 2.0 units (to be verified by measurements)
  - Integral b_5 measured in the vertical KEK test station: 1.4 units, that projected in the CERN final cryostat gives 1.7 units (to be verified by measurements)

D1 STATUS: MBXF1 MEASUREMENTS AT 12.11 kA

- In general, multipoles are well within the targets
  - Nearly 4 units of b_2 to be better understood

- As shown in previous slide, these data are measured in KEK cryostat, and not in CERN cryostat – this effect is not negligible and will be measured at CERN with the MBXFP1 (prototype) in October 2023

n	Total	
	an	bn
2	-3.84	0.11
3	1.90	-4.15
4	-0.63	0.55
5	-0.06	1.39
6	0.13	0.14
7	0.28	-0.44
8	0.00	0.27
9	0.09	0.15
10	0.04	0.03
11	0.09	-0.19
12	0.11	-0.40
13	0.09	-0.96
14	0.14	-0.76
15	0.08	-1.31
16	0.08	-0.51
17	-0.03	-0.58
18	-0.05	0.28
19	-0.01	0.37
20	0.00	-0.01

Magnetic measurements (room temperature H and V, 12.11 kA, In the KEK cryostat
[K. Suzuki, T. Nakamoto, M. Sugano]

ROOM TEMPERATURE MEASUREMENTS OF MBFX5

- News: MBXF5 is the second series magnet – it has been completed in April and room temperature measurements give a good indication of the reproducibility
  - Note: these are on a portion of the magnet, full measurements will be made in vertical position
  - Within 1 unit for b_3, and within 0.2 units for b_5: good!

b_3		Opera3D (for series)	MBXFP1	**MBXF1**	MBXF5
Horizontal by portable MM system			-4.87	**1.96**	1.00
Horizontal warm	Central		-4.12	**4.06**	
	SS average			**3.04**	
	Integral			**-7.55**	
Vertical, warm	Central				
	SS average		-4.37	**2.90**	
	Integral		-14.38	**-7.55**	
Vertical, 12.11kA	Central	-2.74	-8.51	**1.19**	
	SS average	1.70	-4.25	**4.48**	
	Integral	-4.72	-12.31	**-4.15**	
CERN (prediction)	Central	3.74	-2.03	**7.67**	
	SS average	7.98	2.03	**10.77**	
	Integral	-1.55 / +1.40	-6.19	**1.97**	

b_5		Opera3D (for series)	MBXFP1	**MBXF1**	MBXF5
Horizontal by portable MM system			2.86	**-2.34**	-2.49
Horizontal warm	Central		2.90	**-2.31**	
	SS average			**-2.49**	
	Integral			**-2.63**	
Vertical, warm	Central				
	SS average		2.85	**-2.43**	
	Integral		2.31	**-2.51**	
Vertical, 12.11kA	Central	0.55	6.72	**1.25**	
	SS average	0.70	6.76	**1.16**	
	Integral	0.63	6.51	**1.39**	
CERN (prediction)	Central	0.77	6.94	**1.47**	
	SS average	0.94	7.01	**1.40**	
	Integral	0.89	6.78	**1.66**	

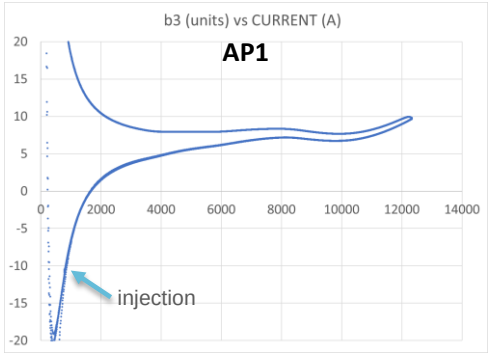
Magnetic measurements (room temperature H and V, 12.11 kA, and projection for final configuration at CERN [K. Suzuki, T. Nakamoto, M. Sugano]

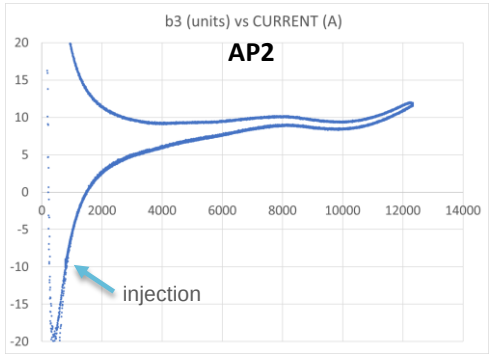
D2 FIELD QUALITY

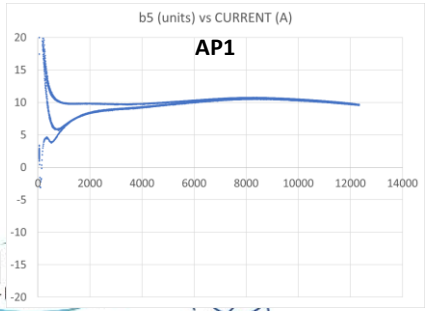
- For D2 there were two iterations on cross section (wedges) from short model to prototype and from prototype to series, to correct b_3 and b_5
- Prototype has been measured in operational conditions at CERN in October last year
  - The problem is simpler than in D1, since impact of saturation is lower, but there is a coupling with the preload/shimming/coil size that has to be dealt with the shimming plan
  - Moreover there is a large discrepancy between simulations and measurements of 10 units of b_3 – not understoood, and applied to the series
- News: in early August 2023, the first series magnet MBRD1 has been measured at room temperature at the end of the magnet assembly https://indico.cern.ch/event/1314538/

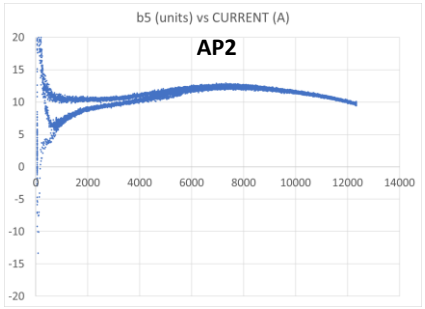
D2 FIELD QUALITY

- Measurements of the prototype MBRDP1 https://indico.cern.ch/event/1286742/
  - b_3: 10 to 12 units
  - b_5: 9 to 10 units









		AP1			AP2	
	n	bn	an	n	bn	an
Injection (790 A)	2	-5.46	4.92	2	2.77	-0.44
	3	-10.63	3.52	3	-9.48	2.06
	4	1.52	-0.44	4	-2.27	-0.39
	5	5.83	2.10	5	6.54	0.87
	6	-1.64	-0.64	6	1.16	-0.59
	7	3.95	1.78	7	4.56	0.05
	8	-		8	-	-
	9	-	-	9	-	-
	10	-	-	10	-	-
	n	bn	an	n	bn	an
Nominal (12330 A)	2	-0.29	5.69	2	-2.65	0.93
	3	9.75	4.57	3	11.76	1.55
	4	-0.09	-0.82	4	-1.98	-0.66
	5	9.63	2.32	5	9.75	0.93
	6	-1.50	-0.50	6	3.13	-0.24
	7	1.56	1.73	7	0.41	0.04
	8	-	-	8	-	-
	9	-	-	9	-	-
	10	-	-	10	-	-

D2 FIELD QUALITY

- First series measured at room temperature – first aperture
  - b_3: -3.2 b_5:4.0

AP01 SERIES MEASUREMENTS – Normal harmonics				
Position	CS	CENTER	NCS	INTEGRATED
Positions	*1-2*	*3-9*	*10-11*	\
Polarity	AVG	AVG	AVG	\
Average Current (A)	18.17	18.11	18.15	18.08
B1	0.0063	0.0073	0.0062	0.0069
b2	-14.73	-1.27	-13.48	-5.19
b3	-7.45	-1.84	-5.99	-3.26
b4	-0.82	0.30	1.12	0.24
b5	4.79	4.90	0.98	4.01
b6	1.64	1.32	1.51	1.33
b7	0.21	1.61	-0.86	0.92
b8	-0.06	0.44	0.06	0.28
b9	0.38	1.12	0.21	0.80
b10	-0.23	-0.75	-0.19	-0.54
b11	-0.92	-0.05	-0.49	-0.25
b12	3.19	2.15	2.88	2.31
b13	-0.49	-0.13	-0.36	-0.21
b14	1.90	1.44	1.70	1.47
b15	-0.44	-0.46	-0.68	-0.47

AP01 SERIES MEASUREMENTS – Skew harmonics				
Position	CS	CENTER	NCS	INTEGRATED
Positions	*1-2*	*3-9*	*10-11*	\
Polarity	AVG	AVG	AVG	\
Average Current (A)	18.17	18.11	18.15	18.08
a1	\	\	\	\
a2	10.06	5.39	6.51	6.00
a3	-6.99	-4.56	-3.08	-4.46
a4	-0.19	0.20	1.00	0.25
a5	-2.20	-1.79	-1.21	-1.67
a6	1.81	0.64	1.68	0.95
a7	0.18	-0.11	-0.10	-0.06
a8	0.10	-0.38	0.07	-0.21
a9	-1.22	-0.47	-1.16	-0.67
a10	1.15	0.13	0.87	0.40
a11	-3.71	-2.30	-3.27	-2.55
a12	1.49	0.92	1.69	1.08
a13	-1.10	-0.67	-0.98	-0.75
a14	1.67	1.56	1.77	1.53
a15	1.28	1.17	1.31	1.14

D2 FIELD QUALITY

- First series measured at room temperature – second aperture
  - b_3: -0.9 b_5: 3.6

AP02 SERIES MEASUREMENTS – Normal harmonics				
Position	CS	CENTER	NCS	INTEGRATED
Positions	*1-2*	*3-9*	*10-11*	\
Polarity	AVG	AVG	AVG	\
Average Current (A)	17.99	18.05	18.05	18.04
B1	0.0062	0.0073	0.0062	0.0069
b2	13.34	1.32	14.68	5.17
b3	-5.59	1.35	-5.59	-0.87
b4	1.41	2.08	0.79	1.66
b5	4.80	4.23	1.14	3.61
b6	0.27	0.45	-0.06	0.32
b7	0.68	0.73	-1.58	0.32
b8	-1.95	-2.03	-1.99	-1.90
b9	0.55	2.13	1.89	1.73
b10	0.41	1.72	2.15	1.49
b11	0.41	2.02	2.66	1.76
b12	0.44	1.49	2.05	1.33
b13	0.28	1.01	1.20	0.87
b14	-0.35	-0.42	-0.32	-0.37
b15	-0.40	-0.11	-0.26	-0.17

AP02 SERIES MEASUREMENTS – Skew harmonics				
Position	CS	CENTER	NCS	INTEGRATED
Positions	*1-2*	*3-9*	*10-11*	\
Polarity	AVG	AVG	AVG	\
Average Current (A)	17.99	18.05	18.05	18.04
a1	\	\	\	\
a2	3.89	3.89	3.81	3.66
a3	-6.46	-3.04	-1.37	-3.15
a4	-0.23	-2.01	-0.10	-1.33
a5	-0.35	0.15	0.79	0.16
a6	0.83	-0.64	1.72	-0.01
a7	1.61	1.95	2.02	1.80
a8	-0.21	-2.20	-1.69	-1.69
a9	-0.61	-1.38	-1.35	-1.18
a10	0.37	0.16	0.53	0.24
a11	0.45	0.90	1.20	0.82
a12	1.52	2.06	2.65	1.95
a13	1.63	2.37	2.88	2.20
a14	1.94	2.17	2.53	2.07
a15	1.17	1.31	1.74	1.28

D2 FIELD QUALITY

- First series projected at nominal current
  - Two ways of projecting, little data available on correlations → forecast on b_3 is affected by a large error
  - b_3: between -0.5 and 4 (ap. 1) and between -4 and 0.5 (ap. 2)
  - b_5: between 2.5 and 3 (both apertures)

Double aperture at nominal operation												
SIMULATIONS (S) & EXPECTED (E)												
Position	CENTER						INTEGRATED					
Notes	S AP01	E AP01 Δ_{SERIES}	E AP01 Δ_{PROTO}	S AP02	E AP02 Δ_{SERIES}	E AP02 Δ_{PROTO}	S AP01	E AP01 Δ_{SERIES}	E AP01 Δ_{PROTO}	S AP02	E AP02 Δ_{SERIES}	E AP02 Δ_{PROTO}
b2	6.36	1.79	6.01	-6.42	-1.86	-6.08	-2.86	-4.84	-3.82	2.90	4.88	3.85
b3	-11.92	0.73	3.46	-15.31	-2.66	0.07	-11.62	-0.63	3.88	15.03	-4.03	0.47
b4	-1.41	-0.78	-2.26	1.71	1.09	2.56	-0.78	-0.47	-1.76	1.08	0.76	2.06
b5	-1.27	3.57	3.15	-0.93	3.91	3.49	-2.54	2.65	2.22	-2.21	2.98	2.55
b6	-0.56	0.17	-1.61	0.56	-0.18	1.60	-0.42	0.28	-1.62	0.41	-0.29	1.61
b7	2.47	1.78	2.67	2.39	1.69	2.59	2.11	1.13	1.86	2.03	1.04	1.77
b8	1.05	1.41	2.87	-1.04	-1.40	-2.86	1.08	1.24	3.24	-1.07	-1.23	-3.22
b9	1.56	1.64	0.84	1.59	1.67	0.87	1.29	1.29	0.64	1.33	1.33	0.67
b10	0.15	-1.27	-2.02	-0.17	1.25	2.00	0.19	-1.03	-2.48	-0.20	1.02	2.47

  - We will have second order components of the order of 5 units
  - Magnet will arrive at CERN in September, then assembly of cold mass and cryostating → measurements of MBRD1 will be available in second half of 2024
- Second magnet MBRD2 will be completed in November, and magnetic measurements at room temperature will be available before the end of 2023

CONCLUSIONS

- Both D1 and D2 present challenges for the steering of b_3 and b_5 field quality
  - Several cross sections iterations have been done, and initial values of b_3 and b_5 were above 10 units
- For the first series magnets, both D1 and D2 indications are positive, with b_3 and b_5 within 5 units
  - D1 first series: b_3 and b_5 within 3 units
  - D2 first series: b_3 within 4 units, b_5 at 3 units
  - These are indirect measurements (at room temperature for D2, and not in the final cryostat for D1)
  - Final validation for D1 will arrive with measurements at CERN (within 2023)
  - Final validation for D2 will arrive in the second half of 2024
- Reproducibility
  - For D1, we have measurements of the second series magnet (MBXF5) confirming the reproducibility
  - For D2, measurements of second series magnet MBRD2 will be available at the end of the year
- No additional iterations on field quality are foreseen
  - For D2 there will be a careful selection of shimming plan, based on the coil size, that could give higher b5 to control b3