



MBRD coupling strategy

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Status of the Series Magnets

- So far, all the 24 coils have been wound, cured and measured
 - To cope with the different coil sizes, we have studied a specific shimming plan to meet the field quality requirements
- MBRD1 was delivered to CERN in October 2023 and was sent back to ASG the first week of July 2024 for repair
- MBRD2 was delivered to CERN in April 2024 and will be cold-tested in January 2025
- MBRD3 is currently under construction at ASG

<i>oversize of the remaining coils</i>			
<i>Coil type</i>	<i>Min [mm]</i>	<i>Max [mm]</i>	<i>Avg [mm]</i>
AS03	0.56	0.70	0.63
BS03	0.52	0.82	0.65
BS05	0.42	0.68	0.57
AS08	0.34	0.52	0.43
AS09	0.39	0.55	0.45
BS09	0.56	0.81	0.67
AS10	0.37	0.52	0.43
BS10	0.36	0.58	0.46
AS11	0.47	0.62	0.54
BS11	0.37	0.52	0.43
AS12	0.34	0.52	0.43
BS12	0.42	0.57	0.46

<i>Oversize of the collared coils</i>								
<i>Coil type</i>	<i>Min [mm]</i>	<i>Max [mm]</i>	<i>Avg [mm]</i>	<i># Aperture</i>	<i>Shimming scheme</i>	<i># Magnet</i>		
AS01	0.34	0.47	0.41	AP01	Shimming1	MBRD1		
BS01	0.39	0.60	0.48					
AS02	0.47	0.64	0.53	AP02	Shimming2			
BS02	0.31	0.55	0.46					
AS04	0.37	0.61	0.53	AP03	Shimming2	MBRD2		
BS04	0.42	0.60	0.48					
AS06	0.41	0.59	0.49	AP04	Shimming2			
BS06	0.36	0.66	0.50					
AS05	0.42	0.61	0.52	AP05	Shimming2	MBRD3		
BS07	0.42	0.54	0.47					
AS07	0.37	0.55	0.46	AP06	Shimming3			
BS08	0.41	0.59	0.48					

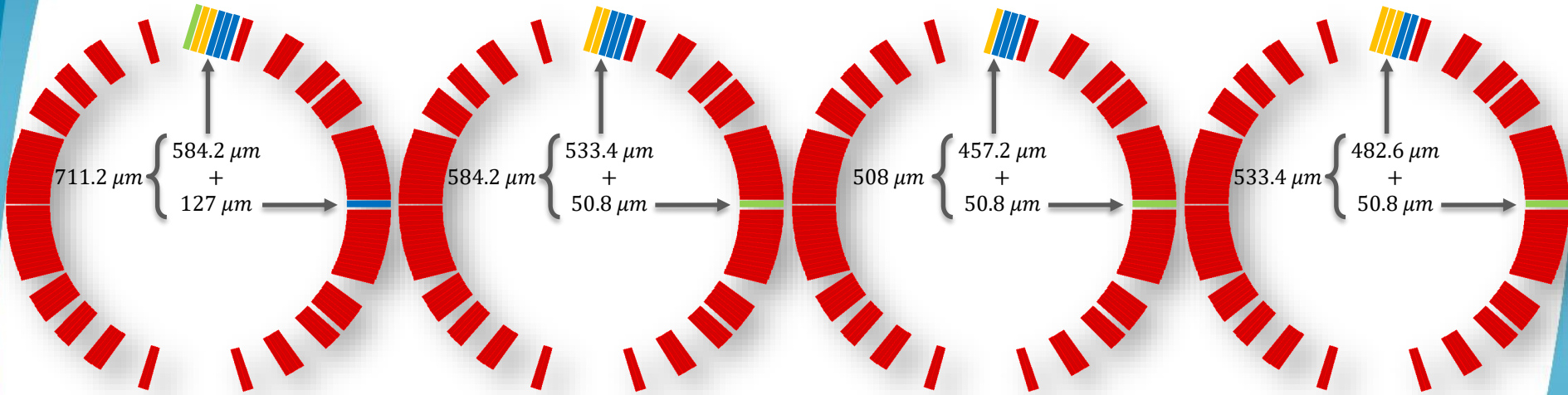
Series Shimming Plans

Baseline

Shimming1

Shimming2

Shimming3



— 50.8 μm — 76.2 μm — 127 μm

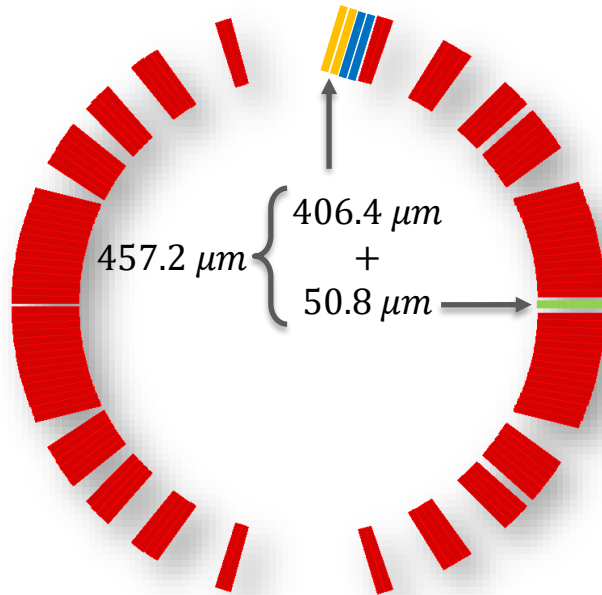
First Coupling Strategy

- This coupling strategy can employ different insulation schemes for the two magnet apertures, ensuring that the largest coils are used only in the last magnet (MBRD6).

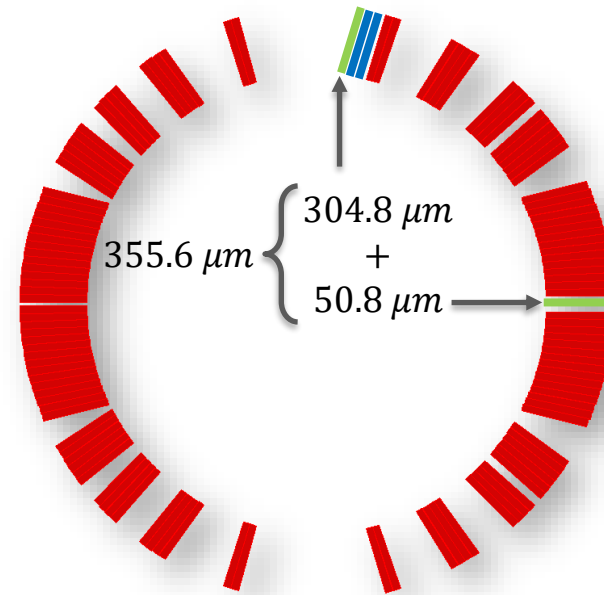
<i>Coil type</i>	<i>Min [mm]</i>	<i>Max [mm]</i>	<i>Avg [mm]</i>	<i># Aperture</i>	<i>Shimming scheme</i>	<i># Magnet</i>
AS09	0.39	0.55	0.45	AP07	Shimming1	MBRD4
BS11	0.37	0.52	0.43			
AS08	0.34	0.52	0.43	AP08	Shimming1	
BS10	0.36	0.58	0.46			
AS10	0.37	0.52	0.43	AP09	Shimming1	MBRD5
BS12	0.42	0.57	0.46			
AS11	0.47	0.62	0.54	AP10	Shimming4	
BS05	0.42	0.68	0.57			
AS03	0.56	0.70	0.63	AP11	Shimming5	MBRD6
BS09	0.56	0.81	0.67			
AS12	0.34	0.52	0.43	AP12	Shimming4	
BS03	0.52	0.82	0.65			

Shimming Plans – First Coupling Strategy

Shimming4



Shimming5



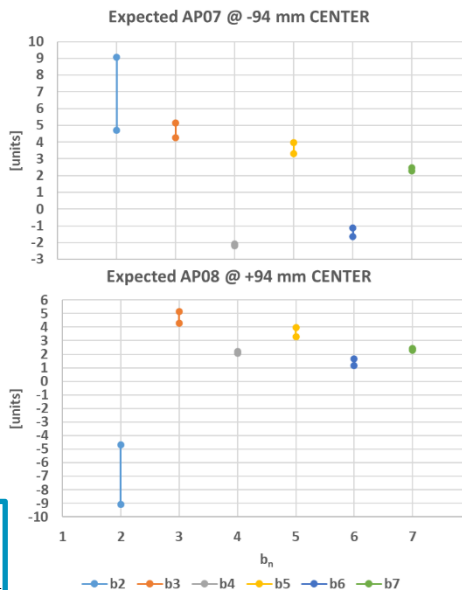
— 50.8 μm — 76.2 μm — 127 μm

MBRD4 – First Coupling Strategy

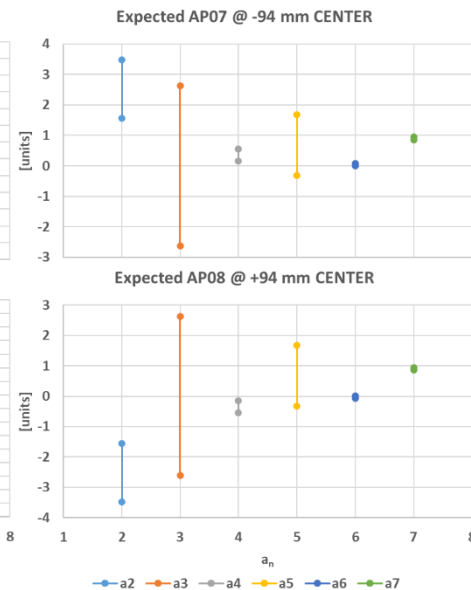
	CENTER					
	AP07 @ -94 mm			AP08 @ +94 mm		
	SIMU	EXPE PROTO	EXPE SERIE	SIMU	EXPE PROTO	EXPE SERIE
b2	5.54	4.70	9.08	-5.54	-4.70	-9.08
b3	-11.09	4.28	5.14	-11.09	4.28	5.14
b4	-1.32	-2.09	-2.20	1.32	2.09	2.20
b5	-1.38	3.30	3.97	-1.38	3.30	3.97
b6	-0.57	-1.64	-1.14	0.57	1.64	1.14
b7	2.49	2.45	2.28	2.49	2.45	2.28
b8	1.06	2.90	0.85	-1.06	-2.90	-0.85
b9	1.55	1.11	1.18	1.55	1.11	1.18
b10	0.15	-2.13	0.79	-0.15	2.13	-0.79
a2	0.00	3.47	1.56	0.00	-3.47	-1.56
a3	0.00	2.63	-2.62	0.00	2.63	-2.62
a4	0.00	0.16	0.55	0.00	-0.16	-0.55
a5	0.00	1.67	-0.32	0.00	1.67	-0.32
a6	0.00	0.08	0.00	0.00	-0.08	0.00
a7	0.00	0.94	0.86	0.00	0.94	0.86
a8	0.00	-1.51	-0.20	0.00	1.51	0.20
a9	0.00	1.57	-0.62	0.00	1.57	-0.62
a10	0.00	2.78	0.13	0.00	-2.78	-0.13

Coil type	Min [mm]	Max [mm]	Avg [mm]	# Aperture	Shimming scheme	# Magnet
AS09	0.39	0.55	0.45	AP07	Shimming1	MBRD4
BS11	0.37	0.52	0.43			
AS08	0.34	0.52	0.43	AP08	Shimming1	
BS10	0.36	0.58	0.46			

Normal harmonic component



Skew harmonic component



$$\Delta_1 = Meas_{PROTO}^{@ I_{nom}} - Simu_{PROTO}^{@ I_{nom}}$$

$$EXPE PROTO = Simu_{SERIE}^{@ I_{nom}} + \Delta_1$$

$$\Delta_2 = Meas_{SERIE}^{iron @ RT} - Simu_{SERIE}^{iron @ RT}$$

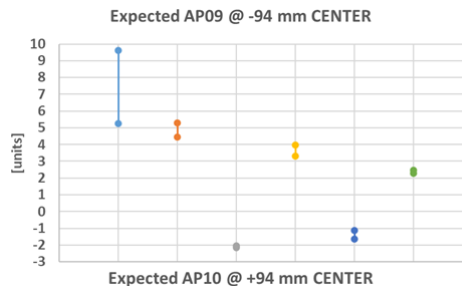
$$EXPE SERIE = Simu_{SERIE}^{@ I_{nom}} + \Delta_2$$

MBRD5 – First Coupling Strategy

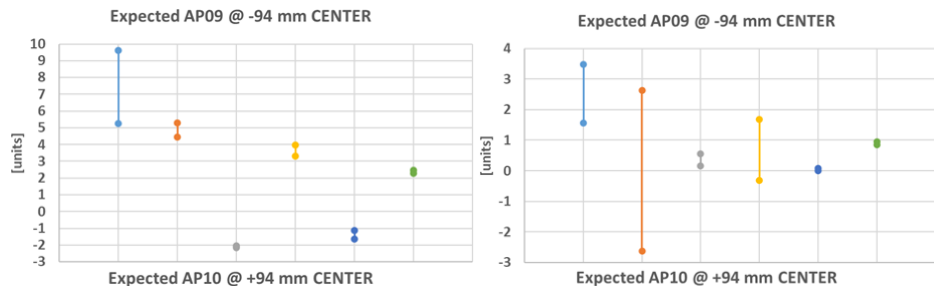
	CENTER					
	AP09 @ -94 mm			AP10 @ +94 mm		
	SIMU	EXPE PROTO	EXPE SERIE	SIMU	EXPE PROTO	EXPE SERIE
b2	6.09	5.26	9.63	-5.73	-4.89	-9.27
b3	-10.93	4.44	5.29	-16.80	-1.43	-0.58
b4	-1.28	-2.04	-2.15	1.76	2.53	2.64
b5	-1.37	3.31	3.98	-0.79	3.89	4.55
b6	-0.57	-1.64	-1.14	0.56	1.63	1.12
b7	2.50	2.46	2.29	2.36	2.32	2.15
b8	1.06	2.90	0.85	-1.03	-2.88	-0.82
b9	1.55	1.10	1.18	1.61	1.16	1.24
b10	0.15	-2.13	0.79	-0.18	2.11	-0.82
a2	0.00	3.47	1.56	0.00	-3.47	-1.56
a3	0.00	2.63	-2.62	0.00	2.63	-2.62
a4	0.00	0.16	0.55	0.00	-0.16	-0.55
a5	0.00	1.67	-0.32	0.00	1.67	-0.32
a6	0.00	0.08	0.00	0.00	-0.08	0.00
a7	0.00	0.94	0.86	0.00	0.94	0.86
a8	0.00	-1.51	-0.20	0.00	1.51	0.20
a9	0.00	1.57	-0.62	0.00	1.57	-0.62
a10	0.00	2.78	0.13	0.00	-2.78	-0.13

Coil type	Min [mm]	Max [mm]	Avg [mm]	# Aperture	Shimming scheme	# Magnet
AS10	0.37	0.52	0.43	AP09	Shimming1	MBRD5
BS12	0.42	0.57	0.46			
AS11	0.47	0.62	0.54	AP10	Shimming4	
BS05	0.42	0.68	0.57			

Normal harmonic component



Skew harmonic component



$$\Delta_1 = Meas_{PROTO}^{@ I_{nom}} - Simu_{PROTO}^{@ I_{nom}}$$

$$EXPE PROTO = Simu_{SERIE}^{@ I_{nom}} + \Delta_1$$

$$\Delta_2 = Meas_{SERIE}^{iron @ RT} - Simu_{SERIE}^{iron @ RT}$$

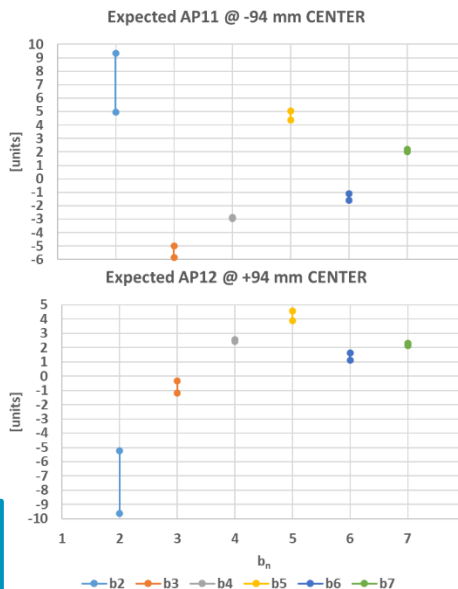
$$EXPE SERIE = Simu_{SERIE}^{@ I_{nom}} + \Delta_2$$

MBRD6 – First Coupling Strategy

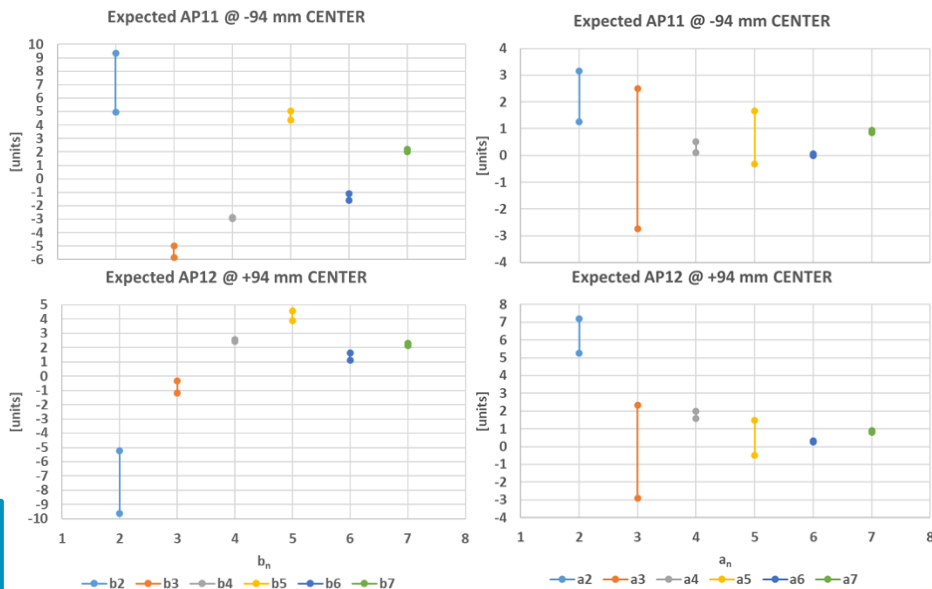
	CENTER					
	AP11 @ -94 mm			AP12 @ +94 mm		
	SIMU	EXPE PROTO	EXPE SERIE	SIMU	EXPE PROTO	EXPE SERIE
b2	5.80	4.96	9.34	-6.09	-5.25	-9.63
b3	-21.22	-5.85	-4.99	-16.55	-1.19	-0.33
b4	-2.08	-2.85	-2.96	1.69	2.46	2.57
b5	-0.30	4.38	5.04	-0.77	3.90	4.57
b6	-0.54	-1.61	-1.10	0.55	1.62	1.12
b7	2.25	2.21	2.04	2.36	2.32	2.14
b8	1.01	2.86	0.80	-1.03	-2.88	-0.82
b9	1.65	1.21	1.28	1.61	1.16	1.24
b10	0.20	-2.08	0.84	-0.18	2.11	-0.82
a2	-0.31	3.16	1.25	8.75	5.27	7.19
a3	-0.12	2.50	-2.74	-0.30	2.33	-2.91
a4	-0.04	0.12	0.51	2.14	1.99	1.59
a5	-0.01	1.66	-0.33	-0.18	1.50	-0.50
a6	0.00	0.07	-0.01	0.33	0.26	0.33
a7	0.00	0.94	0.86	-0.05	0.89	0.80
a8	0.00	-1.51	-0.20	0.05	1.55	0.25
a9	0.00	1.57	-0.62	-0.03	1.54	-0.65
a10	0.00	2.78	0.13	-0.02	-2.80	-0.15

Coil type	Min [mm]	Max [mm]	Avg [mm]	# Aperture	Shimming scheme	# Magnet
AS03	0.56	0.70	0.63	AP11	Shimming5	MBRD6
BS09	0.56	0.81	0.67			
AS12	0.34	0.52	0.43	AP12	Shimming4	
BS03	0.52	0.82	0.65			

Normal harmonic component



Skew harmonic component



$$\Delta_1 = Meas_{PROTO}^{@ I_{nom}} - Simu_{PROTO}^{@ I_{nom}}$$

$$EXPE PROTO = Simu_{SERIE}^{@ I_{nom}} + \Delta_1$$

$$\Delta_2 = Meas_{SERIE}^{iron @ RT} - Simu_{SERIE}^{iron @ RT}$$

$$EXPE SERIE = Simu_{SERIE}^{@ I_{nom}} + \Delta_2$$

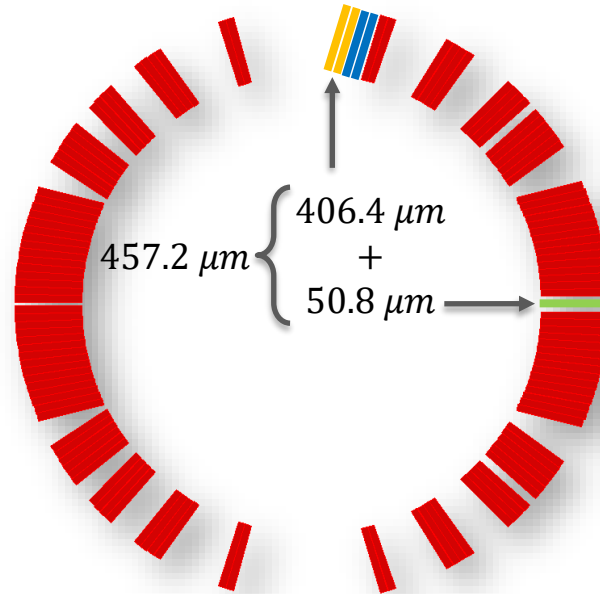
Second Coupling Strategy

- This coupling strategy can employ the same insulation scheme in both apertures, providing consistent field quality and simplifying the fine-tuning with the correctors.

<i>Coil type</i>	<i>Min [mm]</i>	<i>Max [mm]</i>	<i>Avg [mm]</i>	<i># Aperture</i>	<i>Shimming scheme</i>	<i># Magnet</i>
AS08	0.34	0.52	0.43	AP07	Shimming1	MBRD4
BS11	0.37	0.52	0.43			
AS10	0.37	0.52	0.43	AP08	Shimming1	
BS10	0.36	0.58	0.46			
AS12	0.34	0.52	0.43	AP09	Shimming4	MBRD5
BS09	0.56	0.81	0.67			
AS09	0.39	0.55	0.45	AP10	Shimming4	
BS03	0.52	0.82	0.65			
AS11	0.47	0.62	0.54	AP11	Shimming4	MBRD6
BS05	0.42	0.68	0.57			
AS03	0.56	0.70	0.63	AP12	Shimming4	
BS12	0.42	0.57	0.46			

Shimming Plans – Second Coupling Strategy

Shimming4



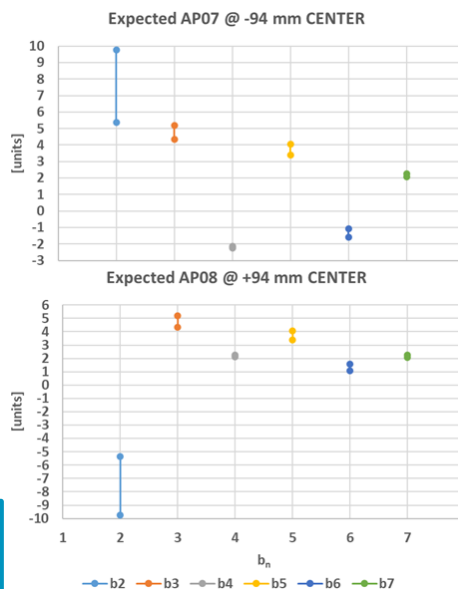
— 50.8 μm — 76.2 μm — 127 μm

MBRD4 – Second Coupling Strategy

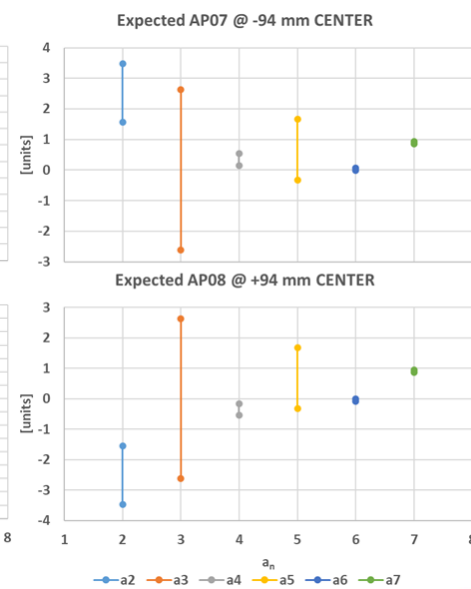
	CENTER					
	AP07 @ -94 mm			AP08 @ +94 mm		
	SIMU	EXPE PROTO	EXPE SERIE	SIMU	EXPE PROTO	EXPE SERIE
b2	6.21	5.37	9.75	-6.21	-5.37	-9.75
b3	-11.02	4.35	5.20	-11.02	4.35	5.20
b4	-1.36	-2.13	-2.24	1.36	2.13	2.24
b5	-1.29	3.39	4.06	-1.29	3.39	4.06
b6	-0.51	-1.59	-1.08	0.51	1.59	1.08
b7	2.30	2.26	2.09	2.30	2.26	2.09
b8	1.00	2.84	0.78	-1.00	-2.84	-0.78
b9	1.74	1.29	1.37	1.74	1.29	1.37
b10	0.20	-2.09	0.84	-0.20	2.09	-0.84
a2	0.00	3.47	1.56	0.00	-3.47	-1.56
a3	0.00	2.63	-2.62	0.00	2.63	-2.62
a4	0.00	0.16	0.55	0.00	-0.16	-0.55
a5	0.00	1.67	-0.32	0.00	1.67	-0.32
a6	0.00	0.08	0.00	0.00	-0.08	0.00
a7	0.00	0.94	0.86	0.00	0.94	0.86
a8	0.00	-1.51	-0.20	0.00	1.51	0.20
a9	0.00	1.57	-0.62	0.00	1.57	-0.62
a10	0.00	2.78	0.13	0.00	-2.78	-0.13

Coil type	Min [mm]	Max [mm]	Avg [mm]	# Aperture	Shimming scheme	# Magnet
AS08	0.34	0.52	0.43	AP07	Shimming1	MBRD4
BS11	0.37	0.52	0.43			
AS10	0.37	0.52	0.43			
BS10	0.36	0.58	0.46	AP08	Shimming1	

Normal harmonic component



Skew harmonic component



$$\Delta_1 = Meas_{PROTO}^{@ I_{nom}} - Simu_{PROTO}^{@ I_{nom}}$$

$$EXPE PROTO = Simu_{SERIE}^{@ I_{nom}} + \Delta_1$$

$$\Delta_2 = Meas_{SERIE}^{iron @ RT} - Simu_{SERIE}^{iron @ RT}$$

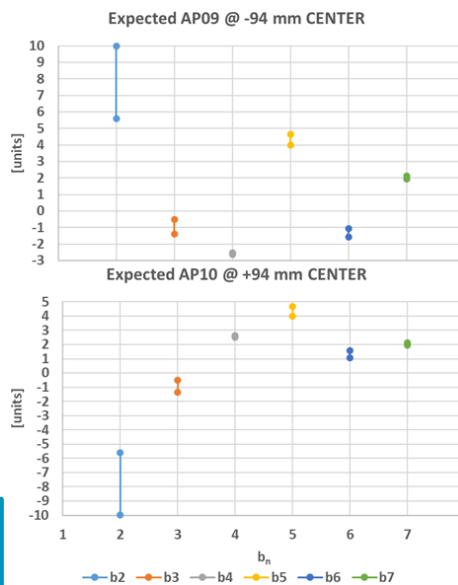
$$EXPE SERIE = Simu_{SERIE}^{@ I_{nom}} + \Delta_2$$

MBRD5 – Second Coupling Strategy

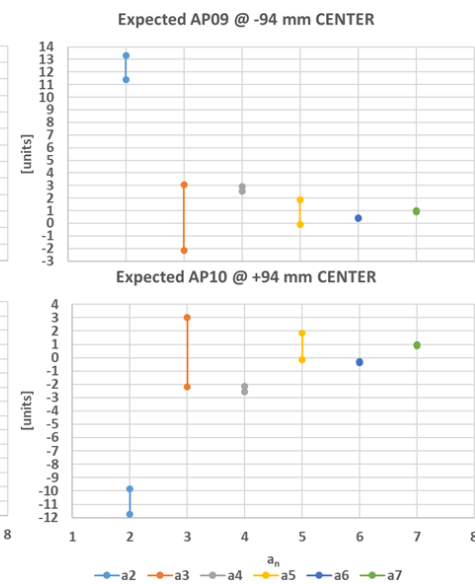
	CENTER					
	AP09 @ -94 mm			AP10 @ +94 mm		
	SIMU	EXPE PROTO	EXPE SERIE	SIMU	EXPE PROTO	EXPE SERIE
b2	6.43	5.59	9.97	-6.43	-5.59	-9.97
b3	-16.75	-1.38	-0.52	-16.74	-1.37	-0.51
b4	-1.75	-2.52	-2.63	1.75	2.52	2.63
b5	-0.69	3.99	4.66	-0.69	3.99	4.66
b6	-0.49	-1.56	-1.06	0.49	1.56	1.06
b7	2.16	2.12	1.95	2.16	2.12	1.95
b8	0.97	2.82	0.76	-0.97	-2.82	-0.76
b9	1.79	1.35	1.43	1.79	1.35	1.43
b10	0.23	-2.06	0.86	-0.23	2.06	-0.86
a2	9.82	13.30	11.38	-8.29	-11.77	-9.85
a3	0.44	3.07	-2.17	0.41	3.04	-2.21
a4	2.37	2.53	2.92	-2.00	-2.15	-2.55
a5	0.21	1.88	-0.11	0.18	1.85	-0.14
a6	0.36	0.44	0.36	-0.31	-0.38	-0.30
a7	0.06	1.00	0.92	0.05	0.99	0.91
a8	0.05	-1.45	-0.15	-0.05	1.46	0.16
a9	0.03	1.60	-0.59	0.03	1.60	-0.59
a10	-0.02	2.76	0.11	0.02	-2.76	-0.11

Coil type	Min [mm]	Max [mm]	Avg [mm]	# Aperture	Shimming scheme	# Magnet
AS12	0.34	0.52	0.43	AP09	Shimming4	MBRD5
BS09	0.56	0.81	0.67			
AS09	0.39	0.55	0.45	AP10	Shimming4	
BS03	0.52	0.82	0.65			

Normal harmonic component



Skew harmonic component



$$\Delta_1 = Meas_{PROTO}^{@ I_{nom}} - Simu_{PROTO}^{@ I_{nom}}$$

$$EXPE PROTO = Simu_{SERIE}^{@ I_{nom}} + \Delta_1$$

$$\Delta_2 = Meas_{SERIE}^{iron @ RT} - Simu_{SERIE}^{iron @ RT}$$

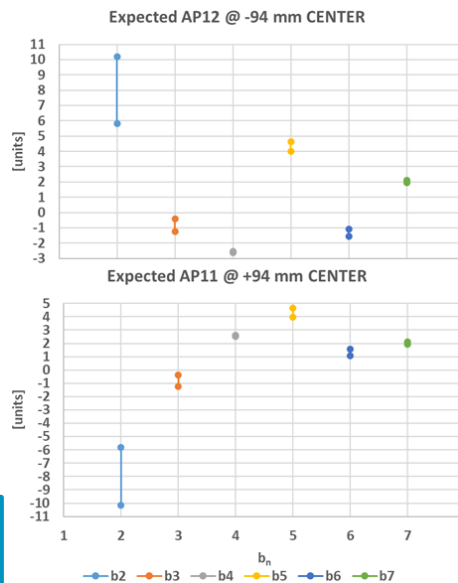
$$EXPE SERIE = Simu_{SERIE}^{@ I_{nom}} + \Delta_2$$

MBRD6 – Second Coupling Strategy

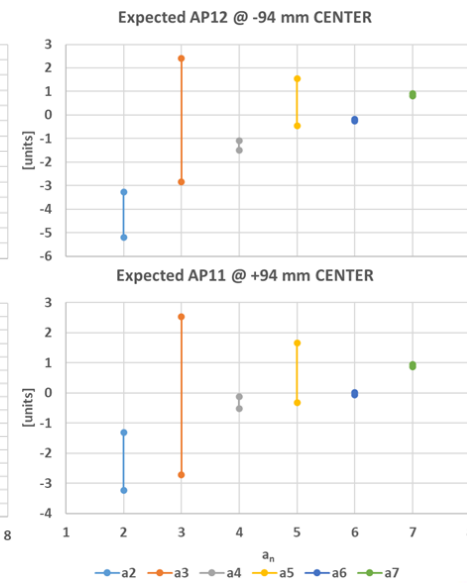
	CENTER					
	AP12 @ -94 mm			AP11 @ +94 mm		
	SIMU	EXPE PROTO	EXPE SERIE	SIMU	EXPE PROTO	EXPE SERIE
b2	6.64	5.80	10.18	-6.64	-5.81	-10.18
b3	-16.63	-1.26	-0.40	-16.62	-1.25	-0.39
b4	-1.76	-2.53	-2.64	1.76	2.53	2.63
b5	-0.69	3.99	4.65	-0.69	3.99	4.66
b6	-0.49	-1.56	-1.06	0.49	1.56	1.06
b7	2.16	2.12	1.95	2.16	2.12	1.95
b8	0.97	2.82	0.76	-0.97	-2.82	-0.76
b9	1.79	1.35	1.43	1.80	1.35	1.43
b10	0.23	-2.06	0.86	-0.23	2.06	-0.86
a2	-6.76	-3.28	-5.20	0.24	-3.23	-1.32
a3	-0.23	2.40	-2.85	-0.10	2.53	-2.71
a4	-1.65	-1.49	-1.10	0.03	-0.12	-0.52
a5	-0.14	1.54	-0.46	-0.01	1.66	-0.33
a6	-0.26	-0.18	-0.26	0.00	-0.07	0.00
a7	-0.04	0.90	0.82	0.00	0.94	0.86
a8	-0.04	-1.54	-0.24	0.00	1.51	0.20
a9	-0.02	1.55	-0.64	0.00	1.57	-0.62
a10	0.02	2.80	0.15	0.00	-2.78	-0.13

Coil type	Min [mm]	Max [mm]	Avg [mm]	# Aperture	Shimming scheme	# Magnet
AS11	0.47	0.62	0.54	AP11	Shimming4	MBRD6
BS05	0.42	0.68	0.57			
AS03	0.56	0.70	0.63			
BS12	0.42	0.57	0.46	AP12	Shimming4	

Normal harmonic component



Skew harmonic component



$$\Delta_1 = Meas_{PROTO}^{@ I_{nom}} - Simu_{PROTO}^{@ I_{nom}}$$

$$EXPE PROTO = Simu_{SERIE}^{@ I_{nom}} + \Delta_1$$

$$\Delta_2 = Meas_{SERIE}^{iron @ RT} - Simu_{SERIE}^{iron @ RT}$$

$$EXPE SERIE = Simu_{SERIE}^{@ I_{nom}} + \Delta_2$$

Conclusion

- MBRD1 was delivered to CERN in October 2023 and was sent back to ASG the first week of July 2024 for repair
- MBRD2 was delivered to CERN in April 2024 and will be cold-tested in January 2025
- MBRD3 is currently under construction at ASG
- Two possible coupling strategies were analysed for the construction of the last three series magnets
 - The first coupling strategy can employ different insulation schemes for the two magnet apertures, ensuring that the largest coils are used only in the last magnet
 - The second coupling strategy can employ the same insulation scheme in both apertures, providing consistent field quality and simplifying the fine-tuning with the correctors
- It was decided to use the first coupling strategy to build the last three series magnets



MBRD coupling strategy

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