Field quality in WP3 magnets – episode I

E. Todesco, L. Fiscarelli
Magnets, Superconductors and Cryostats Group (CERN)

17 June 2019 – WP2 meeting

SUMMARY

- HO correctors
- D2 correctors
- Nested correctors

HO CORRECTORS

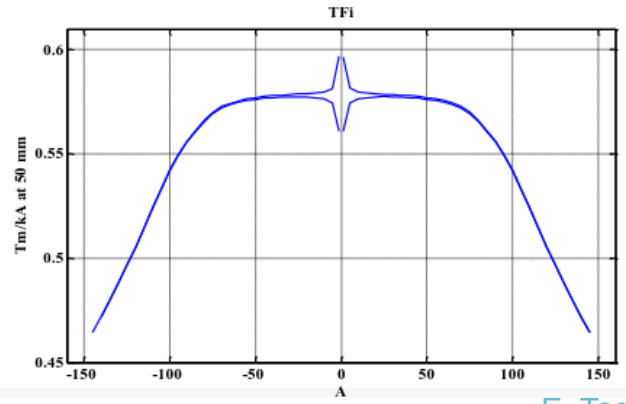
- Test reports
  - https://edms.cern.ch/document/1909064 (sextupole at CERN)
  - https://edms.cern.ch/document/1978472 (octupole and decapole at CERN)
  - Dodecapole is in the pipeline of measurements at SM18 – test in June
  - Skew quadrupole shall be measured at LASA in summer (first magnetic measurements in LASA)

SEXTUPOLE CORRECTOR

- Some iterations in the design from the prototype
  - Increase in integrated strength (50%)
  - Increase in number of turns to decrease current <120 A
- Transfer function within 2%
  - Saturation of 18%
  - Multipoles within target

	300 K		1.9 K	
n	b_n	a_n	b_n	a_n
4	-1.9	-0.8	-4.1	-0.9
5	-0.6	-1.2	-0.1	-0.9
6	-0.2	-0.4	0.3	-1.0
7	-0.1	-0.1	0.0	-0.1
8	0.2	-0.1	0.3	-0.2
9	-3.8	-0.4	-3.1	-0.1
10	-0.3	0.0	-0.1	-0.1
11	0.3	-0.2	0.0	-0.2
12	0.5	0.0	-0.4	0.1
13	0.4	-0.7	0.0	-0.6
14	-0.2	-0.6	-0.1	-0.3
15	-2.2	0.1	0.4	0.0

	T m/kA	T m
50 A	0.578	
135 A	0.475	0.0638
Room temperature	0.55	

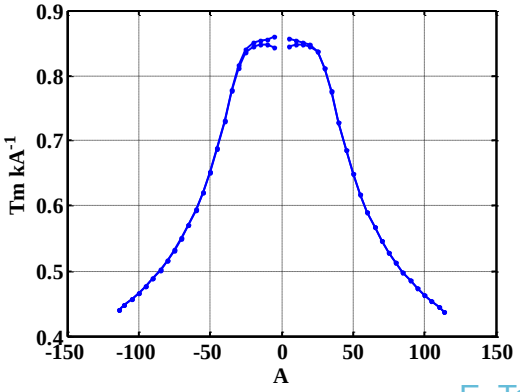


OCTUPOLE CORRECTOR

- One iteration in the design from the prototype
  - Increase in integrated strength (50%)
- Transfer function 3% larger
  - Saturation of 47%
  - Multipoles within target

		Octupole
Nominal current	A	105
Integrated field at nominal	T m	0.0476
Saturation	3	47%
Residual magnetization	T mm	0.032

	Octupole	
Order	bn	an
1	-12	-3
2	-4	-9
3	0	0
4	10000	0
5	-10	8
6	2	2
7	-1	1
8	1	-1
9	1	-2
10	-4	-2
11	-2	-2
12	-10	-

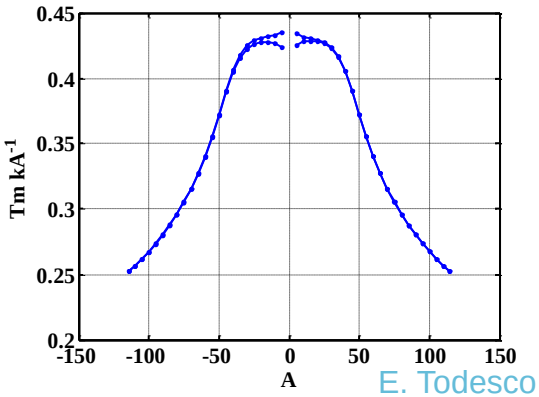


DECAPOLE CORRECTOR

- One iteration in the design from the prototype
  - Increase in integrated strength (50%)
- Transfer function 10% larger
  - Saturation of 39%
  - Multipoles within target

Order	Decapole bn	Decapole an
1	0	-2
2	-23	13
3	4	9
4	0	0
5	10000	0
6	-1	0
7	4	-8
8	-1	2
9	-3	4
10	-3	-3
11	5	14
12	-	-

		Decapole
Nominal current	A	105
Integrated field at nominal	T m	0.0275
Saturation	3	39%
Residual magnetization	T mm	0.022



SUMMARY

- HO correctors
- D2 correctors
- Nested correctors

MCBRD (CCT CORRECTOR)

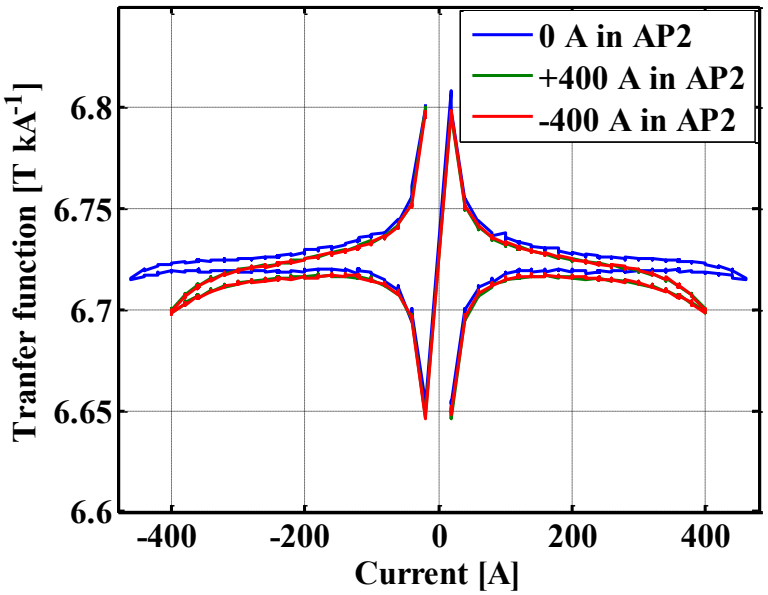
- We first built a short model (MCBRDS1)
  - First a single aperture
  - TF not significant (0.5 m long)
  - Multipoles within target of 10 units
  - https://indico.cern.ch/event/738022/
  - Test report draft
    - https://edms.cern.ch/document/1856625

AP1 vertical field newest-built aperture			
TF			
1.695			T m kA^{-1}
n	bn	an	
2	-4.10	-2.97	units at 35 mm
3	-3.29	-0.74	
4	-0.59	-0.16	
5	-1.09	-0.08	
6	-0.05	-0.16	
7	-0.09	-0.14	
8	0.01	-0.05	
9	-0.06	-0.03	
10	-0.03	-0.02	
at nominal field level and 1.9 K			

AP2 horizontal field first-built aperture			
TF			
1.698			T m kA^{-1}
n	bn	an	
2	-2.05	1.70	units at 35 mm
3	-2.69	-0.01	
4	0.35	1.17	
5	-1.77	0.23	
6	0.54	0.23	
7	0.28	0.09	
8	0.28	0.05	
9	0.01	0.05	
10	0.07	0.01	
at nominal field level and 1.9 K			

MCBRD (CCT CORRECTOR)

- We then built a long model (MCBRDP1)
  - https://indico.cern.ch/event/773207/ (1.9 K)
  - Transfer function in line with the model within 1% (after some clarification on the model)



MCBRD (CCT CORRECTOR)

- We then built a long model (MCBRDP1)
  - https://indico.cern.ch/event/773207/ (1.9 K, one aperture)
  - -10 units of b_3/a_3 at room temperature and at 1.9 K

	AP1 at ambient temperature				AP1 at 1.9 K and 430 A			
	NCS	Center	CS	INTEGRAL	pos1	pos2	pos3	
n	b_n							
2	1.37	-0.68	-0.06	-0.18	-2.19	-3.80	-5.12	units
3	-10.13	-9.79	-11.18	-10.11	-10.93	-11.18	-11.19	
4	0.19	0.07	0.07	0.09	-0.17	-0.13	-0.13	
5	2.57	2.26	2.10	2.29	-0.01	0.09	0.19	
6	-0.04	0.02	-0.13	-0.02	-0.06	0.02	-0.06	
7	-0.96	-0.98	-1.20	-1.02	-0.38	-0.31	-0.33	
8	0.07	0.01	-0.02	0.02	-0.02	0.03	-0.02	
9	0.31	0.13	0.42	0.22	-0.02	0.00	0.01	
10	0.00	0.01	0.19	0.04	0.00	0.01	0.00	
n	a_n							
2	13.07	-6.34	-31.48	-7.41	-4.80	-3.23	-4.78	units
3	-4.41	-0.59	2.15	-0.79	-0.18	-0.35	-0.87	
4	-1.33	0.06	1.25	0.02	-0.35	-0.26	-0.28	
5	-0.28	0.25	0.33	0.17	0.17	0.17	0.22	
6	-0.53	-0.26	-0.28	-0.31	-0.06	-0.06	-0.04	
7	-0.08	0.00	-0.01	-0.02	0.04	-0.01	0.01	
8	0.06	0.01	-0.24	-0.02	0.00	0.01	-0.02	
9	-0.06	-0.03	-0.15	-0.06	-0.03	-0.03	-0.04	
10	-0.11	-0.02	0.41	0.04	0.00	0.01	0.00	

MCBRD (CCT CORRECTOR)

- We then built a long model (MCBRDP1)
  - https://indico.cern.ch/event/773207/ (1.9 K, both apertures)
  - a_3 from -10 to -15 units
  - b_3 from -6 to -7 units
  - a_2 of max -11 units
  - Saturation within 0.1%

AP VERTICAL CORRECTOR at nominal level						
other AP	0 A		+393 A		-393 A	
n	bn	an	bn	an	bn	an
1	0.00	10000	0.00	10000	0.00	10000
2	3.95	-5.85	0.06	-11.36	-0.07	-0.56
3	0.43	10.94	-1.44	14.54	2.34	14.57
4	0.17	-0.35	-0.23	-1.14	-0.25	0.4
5	0.13	0.23	0.46	-0.13	-0.2	-0.15
6	-0.08	0.14	-0.08	0.25	-0.08	0.03
7	-0.01	0.4	-0.05	0.43	0.03	0.43
8	-0.01	-0.03	0.01	-0.05	0.01	-0.02
9	-0.04	0.01	-0.03	0.01	-0.04	0.01

AP HORIZONTAL CORRECTOR at nominal level						
other AP	0 A		+393 A		-393 A	
n	bn	an	bn	an	bn	an
1	10000	0.00	10000	0.00	10000	0.00
2	-0.05	3.37	-3.23	5.79	3.23	5.81
3	-7.14	-0.05	-6.35	2.51	-6.10	-2.51
4	0.59	-0.24	0.68	-0.32	0.52	-0.32
5	0.88	0.01	0.69	0.11	0.71	-0.16
6	0.03	-0.09	0.05	-0.06	0.01	-0.06
7	-0.30	-0.06	-0.28	-0.10	-0.30	-0.03
8	-0.01	-0.04	-0.01	-0.05	0.00	-0.04
9	0.02	0.03	0.02	0.04	0.02	0.03

- Recent measurements at r.t. without yoke give b_3 at 3 units (alignment slot responsible of large b_3/a_3)

SUMMARY

- HO correctors
- D2 correctors
- Nested correctors

MCBXFB (NESTED CORRECTOR)

- We first built inner dipole (MCBXFBP1)
  - https://edms.cern.ch/document/1856617 (r.t. and 1.9 K)
  - Transfer function 6% larger
  - b_3 about 30 units larger than expected
  - About 20 units explained by 0.6 mm shimming on the pole

	Measurements			Model
	Room temperature	Geometric	Nominal	Nominal Roxie 2D
b_2	-1.36	1.47	1.92	
b_3	21.73	20.06	19.73	-13.0
b_4	-0.55	-0.44	-0.28	
b_5	-3.17	-4.27	-5.30	0.28
b_6	-0.21	-0.01	-0.06	
b_7	1.68	1.63	1.68	1.78
b_8	-0.12	-0.07	-0.04	
b_9	1.80	1.77	1.51	2.58
b_{10}	-0.12	0.17	0.18	
b_{11}	3.56	4.11	4.28	3.09
a_2	-0.95	-2.30	-2.72	
a_3	0.15	0.14	0.00	
a_4	0.29	0.12	0.16	
a_5	0.02	0.13	0.08	
a_6	0.07	-0.27	-0.27	
a_7	0.00	-0.10	-0.11	
a_8	0.07	-0.18	-0.15	
a_9	-0.07	-0.15	-0.18	
a_{10}	0.18	-0.62	-0.65	
a_{11}	-0.08	-0.62	-0.62	

Central part measurements [L. Fiscarelli]

	Measurements			Model
	Room temperature	Geometric	Nominal	Nominal Roxie 3D
b_2	-1.59	0.21	0.66	
b_3	22.16	29.88	29.28	-10.85
b_4	-0.26	-0.60	-0.40	
b_5	-1.13	-1.16	-1.75	-1.64
b_6	0.17	-0.02	-0.04	
b_7	-1.24	-1.55	-1.48	-2.19
b_8	0.01	-0.05	-0.02	
b_9	0.80	0.66	0.47	0.87
b_{10}	-0.19	0.11	0.13	
b_{11}	3.53	2.85	2.99	2.00
a_2	-1.73	-0.95	-0.93	
a_3	0.01	0.55	0.37	
a_4	0.81	-0.45	-0.39	
a_5	-0.06	0.08	0.03	
a_6	0.16	-0.10	-0.09	
a_7	-0.05	0.06	0.05	
a_8	0.17	-0.20	-0.17	
a_9	-0.13	-0.04	-0.03	
a_{10}	0.22	-0.50	-0.51	
a_{11}	-0.21	-0.42	-0.41	

Integral measurements [L. Fiscarelli]

MCBXFB (NESTED CORRECTOR)

- We first built inner dipole (MCBXFBP1)
  - https://edms.cern.ch/document/1856617 (r.t. and 1.9 K)
  - Strange feature of b_3 integral, 10 units increase from r.t. to 1.9 K – being understood
  - All other multipoles within 5 units

	Measurements			Model
	Room temperature	Geometric	Nominal	Nominal Roxie 2D
b_2	-1.36	1.47	1.92	
b_3	21.73	20.06	19.73	-13.0
b_4	-0.55	-0.44	-0.28	
b_5	-3.17	-4.27	-5.30	0.28
b_6	-0.21	-0.01	-0.06	
b_7	1.68	1.63	1.68	1.78
b_8	-0.12	-0.07	-0.04	
b_9	1.80	1.77	1.51	2.58
b_{10}	-0.12	0.17	0.18	
b_{11}	3.56	4.11	4.28	3.09
a_2	-0.95	-2.30	-2.72	
a_3	0.15	0.14	0.00	
a_4	0.29	0.12	0.16	
a_5	0.02	0.13	0.08	
a_6	0.07	-0.27	-0.27	
a_7	0.00	-0.10	-0.11	
a_8	0.07	-0.18	-0.15	
a_9	-0.07	-0.15	-0.18	
a_{10}	0.18	-0.62	-0.65	
a_{11}	-0.08	-0.62	-0.62	

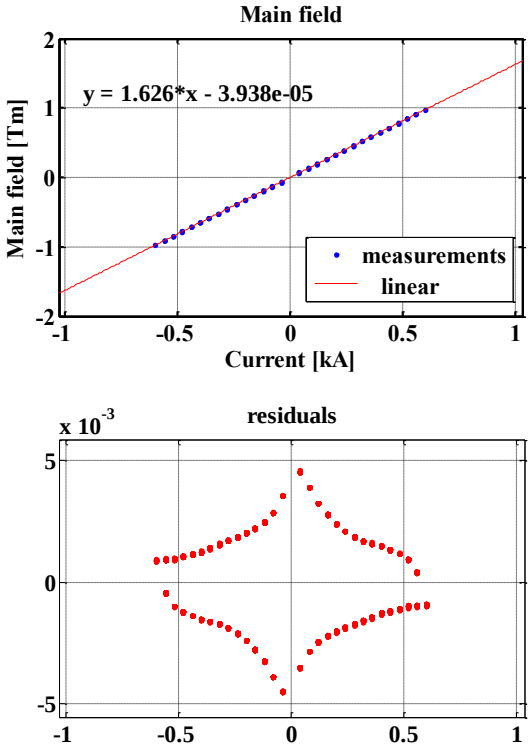
Central part measurements [L. Fiscarelli]

	Measurements			Model
	Room temperature	Geometric	Nominal	Nominal Roxie 3D
b_2	-1.59	0.21	0.66	
b_3	22.16	29.88	29.28	-10.85
b_4	-0.26	-0.60	-0.40	
b_5	-1.13	-1.16	-1.75	-1.64
b_6	0.17	-0.02	-0.04	
b_7	-1.24	-1.55	-1.48	-2.19
b_8	0.01	-0.05	-0.02	
b_9	0.80	0.66	0.47	0.87
b_{10}	-0.19	0.11	0.13	
b_{11}	3.53	2.85	2.99	2.00
a_2	-1.73	-0.95	-0.93	
a_3	0.01	0.55	0.37	
a_4	0.81	-0.45	-0.39	
a_5	-0.06	0.08	0.03	
a_6	0.16	-0.10	-0.09	
a_7	-0.05	0.06	0.05	
a_8	0.17	-0.20	-0.17	
a_9	-0.13	-0.04	-0.03	
a_{10}	0.22	-0.50	-0.51	
a_{11}	-0.21	-0.42	-0.41	

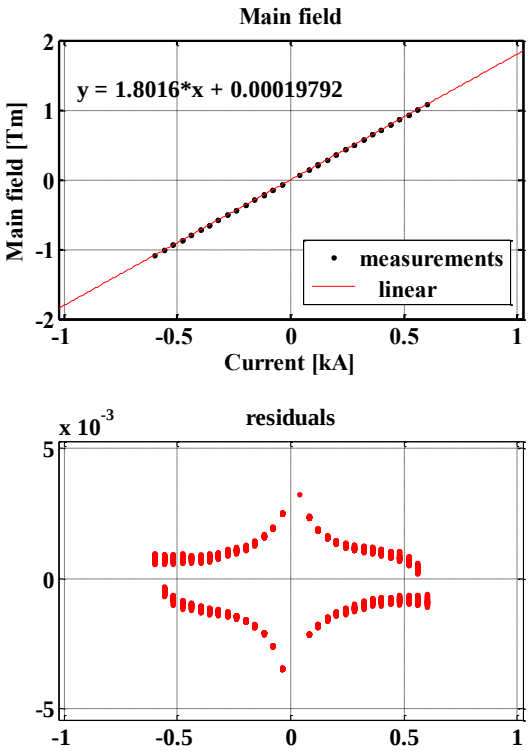
Integral measurements [L. Fiscarelli]

MCBXFB (NESTED CORRECTOR)

- We then built inner ad outer dipole (MCBXFBP1b)
  - https://indico.cern.ch/event/810843/ (r.t. and 1.9 K)
  - Transfer function: 6% larger for both in/out dipoles



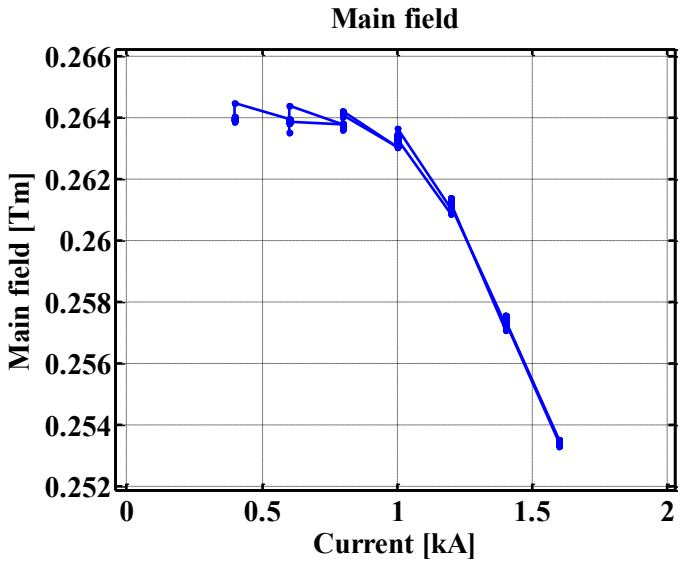
Inner dipole measurements [L. Fiscarelli]



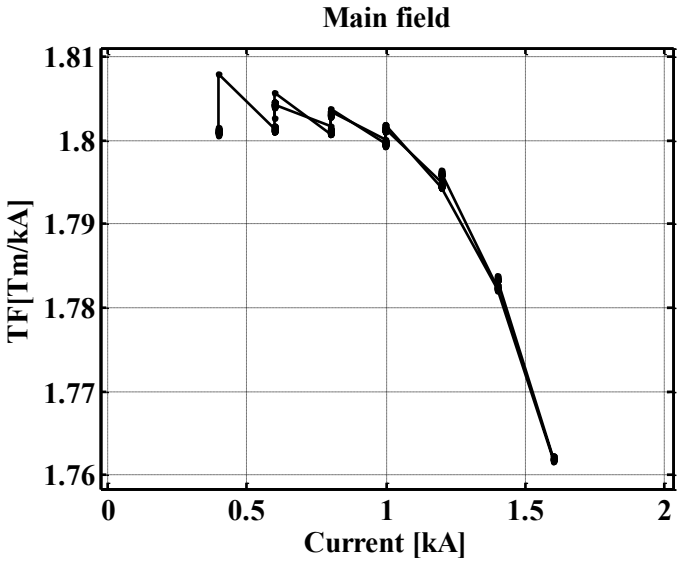
Outer dipole measurements [L. Fiscarelli]

MCBXFB (NESTED CORRECTOR)

- We then built inner ad outer dipole (MCBXFBP1b)
  - https://indico.cern.ch/event/810843/ (r.t. and 1.9 K)
  - Transfer function saturation: 4% for inner dipole, 3% for outer dipole



Inner dipole measurements [L. Fiscarelli]



Outer dipole measurements [L. Fiscarelli]

MCBXFB (NESTED CORRECTOR)

- Inner dipole only: 24 units b_3, rest < 5 units

Outer	0 A		±600 A		1400 A	
Inner	±600 A		0 A		160 A	
	Central field (422 mm)					
n	bn	an	bn	an	bn	an
1	10000	1	7	10000	980	10000
2	2.44	-0.86	0.09	-0.41	1.13	-0.48
3	23.35	-0.89	-0.67	-7.32	4.58	-11.66
4	-0.41	-0.61	0.26	0.46	0.14	0.47
5	-4.50	-0.27	0.20	0.30	0.04	0.81
6	0.32	0.16	0.47	-0.68	0.53	-0.67
7	1.88	-0.24	-0.36	-3.89	-0.14	-3.98
8	0.26	0.32	-0.12	0.15	-0.11	0.19
9	1.81	-0.04	0.11	0.77	0.30	0.80
10	1.09	0.82	0.00	0.01	0.09	0.07
11	4.20	-0.89	0.00	-0.05	0.41	-0.07
	Integral field (2113 mm)					
n	bn	an	bn	an	bn	an
1	10000	1	12	10000	1032	10000
2	1.95	0.01	1.32	1.48	12.28	40.27
3	24.44	-0.69	-0.39	-12.19	3.52	-21.90
4	-0.36	-0.91	-0.10	0.31	-0.39	0.75
5	-1.46	-0.30	0.16	1.41	0.26	2.82
6	-0.13	-0.39	0.37	-0.50	-0.17	-1.05
7	-1.25	-0.06	-0.25	-2.85	-0.44	-2.57
8	0.09	0.02	-0.09	0.10	0.17	0.20
9	0.72	0.06	0.07	0.57	0.34	0.09
10	0.79	0.53	-0.01	0.02	-0.67	-0.72
11	2.91	-0.67	0.02	0.02	1.69	-0.13

Field quality measurements [L. Fiscarelli]

MCBXFB (NESTED CORRECTOR)

- Outer dipole only: 12 units a_3, rest < 5 units

Outer	0 A		±600 A		1400 A	
Inner	±600 A		0 A		160 A	
Central field (422 mm)						
n	bn	an	bn	an	bn	an
1	10000	1	7	10000	980	10000
2	2.44	-0.86	0.09	-0.41	1.13	-0.48
3	23.35	-0.89	-0.67	-7.32	4.58	-11.66
4	-0.41	-0.61	0.26	0.46	0.14	0.47
5	-4.50	-0.27	0.20	0.30	0.04	0.81
6	0.32	0.16	0.47	-0.68	0.53	-0.67
7	1.88	-0.24	-0.36	-3.89	-0.14	-3.98
8	0.26	0.32	-0.12	0.15	-0.11	0.19
9	1.81	-0.04	0.11	0.77	0.30	0.80
10	1.09	0.82	0.00	0.01	0.09	0.07
11	4.20	-0.89	0.00	-0.05	0.41	-0.07
Integral field (2113 mm)						
n	bn	an	bn	an	bn	an
1	10000	1	12	10000	1032	10000
2	1.95	0.01	1.32	1.48	12.28	40.27
3	24.44	-0.69	-0.39	-12.19	3.52	-21.90
4	-0.36	-0.91	-0.10	0.31	-0.39	0.75
5	-1.46	-0.30	0.16	1.41	0.26	2.82
6	-0.13	-0.39	0.37	-0.50	-0.17	-1.05
7	-1.25	-0.06	-0.25	-2.85	-0.44	-2.57
8	0.09	0.02	-0.09	0.10	0.17	0.20
9	0.72	0.06	0.07	0.57	0.34	0.09
10	0.79	0.53	-0.01	0.02	-0.67	-0.72
11	2.91	-0.67	0.02	0.02	1.69	-0.13

Field quality measurements [L. Fiscarelli]

CONCLUSIONS

- HO correctors
  - Field quality ok
  - We have to find the match of TF model vs measurements within 1%
- D2 correctors
  - Field quality at the limit, but understood (comong from iron)
  - Good match of TF
- Nested correctors
  - Field quality ok except b_3 (due to shimming)
  - We have to find the match of TF model vs measurements within 1%