Report on field quality in the main LHC dipole collared coils: January-February 2004

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This report gives data relative to field quality measured in collared coils during the period January 1– February 29 2004, comparison to beam dynamics targets and status of the holding points. Updated graphs can be found in the LHC-MMS field quality observatory http://lhc-div-mms.web.cern.ch/lhc-div-mms/MMSPAGES/MA/Obs.html.

EDMS n. **459212**

The dashboard

- Available measurements: 319 collared coils, 252 cold masses, 83 cryodipoles[1].
- In these two months, 44 collared coils: 12 from Firm1, 7 from Firm2 and 25 from Firm3.

What's new

- **Second octant** of collared coils has been completed**.**
- **Production rate** has slowed down to 22 collared coils per month. This is mainly due a reduction of production rate in Firm3, which is now at 2.9 collared coils per week. This slow down has been caused by a problem in the procedure of the coil assembly, and it has been solved in early March[2]. Firm1 and Firm2 are at 1.4 and 0.8 collared coils per week respectively.
- **Length of feedback loop:** The minimal delay between collared coil magnetic measurements and cold test is 2.5 months (obtained for 3038).
- **Cold tests:** the rate of magnetic measurements at 1.9 K has considerably slowed down in these two months. This is due not only to the foreseen winter shut-down, but also to the efforts that are being made to recover the backlog of magnets that have still to be tested, which is around 100 units: most of these magnets will not be magnetically measured. Results of last year show that it will not be possible to measure the magnetic field of all dipoles at 1.9 K at CERN. A discussion about the size and the strategy of the sampling has been started. More information can be found in http://fqwg.web.cern.ch/fqwg/hmmm/hmmm.html
- **Coil size:** The situation at Firm1, where large coil sizes had to be compensated by non-nominal shims of larger thickness up to 0.2 mm, is improving. In these two months we only had some cases of shims 0.05 mm thinner in the inner layer.
- **Switch to cross-section 3:** the addition of 0.125 mm insulation (X-section 3) in the coil mid-plane is the baseline, and all manufacturers are producing X-section 3.
- **Trends in main field:** collared coil data of the more recent production confirm that the difference between firms is disappearing, as shown in the previous report.
- **Trends in odd multipoles:** we have small positive trends in b_3 b_5 and b_7.
- **Trends in skews:** the improvement of the situation for the systematic a_4 in Firm2 observed in the previous report is confirmed.
- **Assembly faults:** two collared coils have been de-collared for field anomalies indicating a movement of the upper block of the inner layer (block 6 according to the standard numbering). The expected movement have been found: in the first case (3135) this was due to the outer shim that was sliding between the inner layer and the collars. In the second case (1099) the movement was due to a bad quality of the coil, as it has been observed for 2032. More details in Section 10.

[1] These numbers refer to complete measurements available in Oracle databases
[2] Minutes of the Group Leader Meeting of Accelerator Technology Department, 8th and 22nd March 2004.

1. Measured magnets and assembly data

- 44 new collared coils have been measured (collared coils 276th to 319th), plus 5 'old' ones.
  - 12 of Firm1 (1090-1100, 1104), plus a re-measurement of 1082
  - 7 of Firm2 (2063,2069-73,2081), plus 3 re-measurements: 2032, 2047, 2051
  - 25 of Firm3 (3067, 3102, 3127-45, 3047-49, 3053), plus one re-measurement: 3504
- Among the double measurements, 1082, 2051, 2047 were de-collared for reasons not related to field anomalies, 3504 denotes magnet 3004 after substitution of the damaged aperture, and 2032 has been repaired after the detection of an assembly error thanks to magnetic measurements.

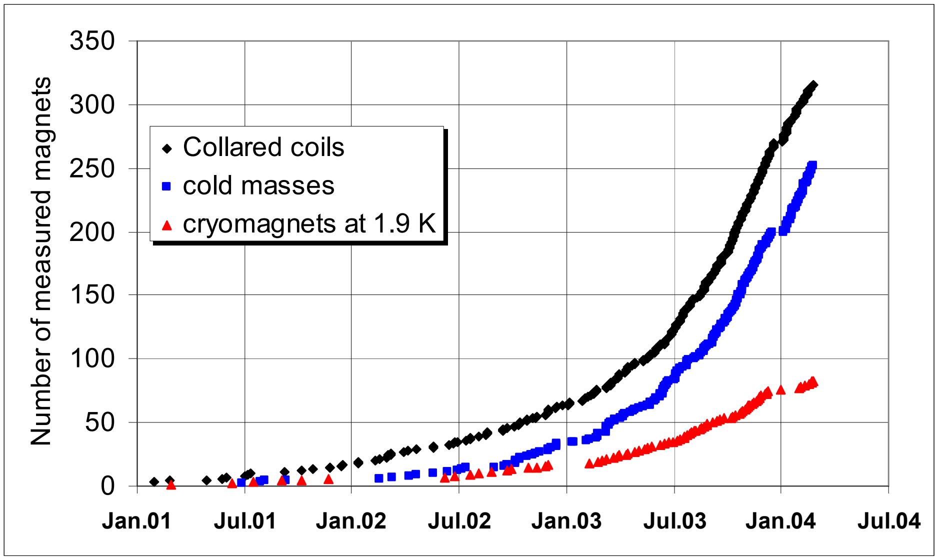

Fig. 1: Number of magnets measured at CERN at 1.9 K and at the manufacturers at room temperature at different stages of assembly procedure

- Cross-section: all the 44 collared coils have X-section 3. Total number of magnets with cross-section 1 and 2 is 34 and 138 respectively, plus one hybrid case[3]: thus, we will have at most 19 magnets with cross-section 2 in the second octant. We have 146 collared coils with X-section 3.
- Shims are nominal in Firm2 and in Firm3. The situation of coil size is improving in Firm1: nominal shims are used for outer layer and thinner shims of 0.05 mm are used for the inner layer.

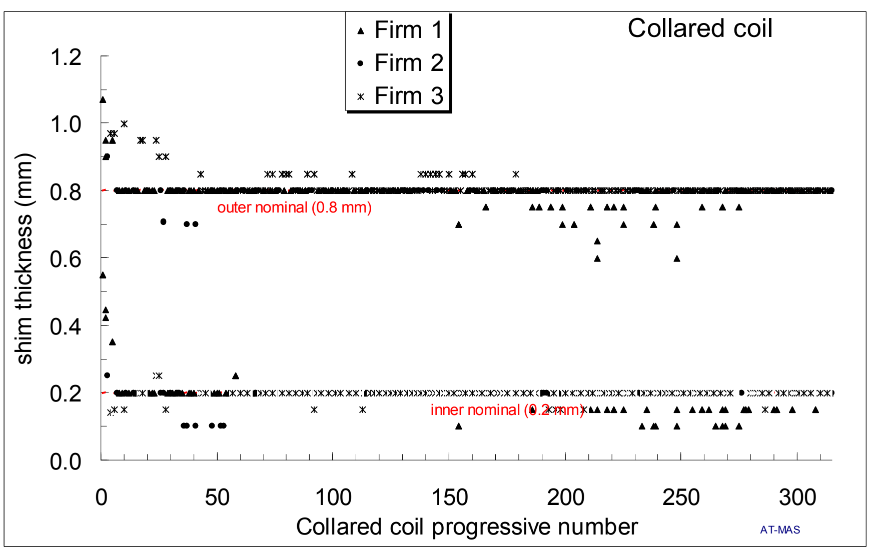

Fig. 2: Thickness of the polar shims used in the collared coils

[3] Magnet 2032, previously cross-section 2, has been de-collared for an assembly error and has been reassembled with mid-plane shim, thus becoming cross-section 3. Magnet 3004, previously cross-section 1, broke during cold test and one aperture has been replaced with cross-section 2 – the magnet name has been changed to 3504.

2. Estimated coil waviness

- Coil waviness estimated from the variation of the multipoles along the axis is below 30 microns. The general situation of this parameter is very good in all firms.

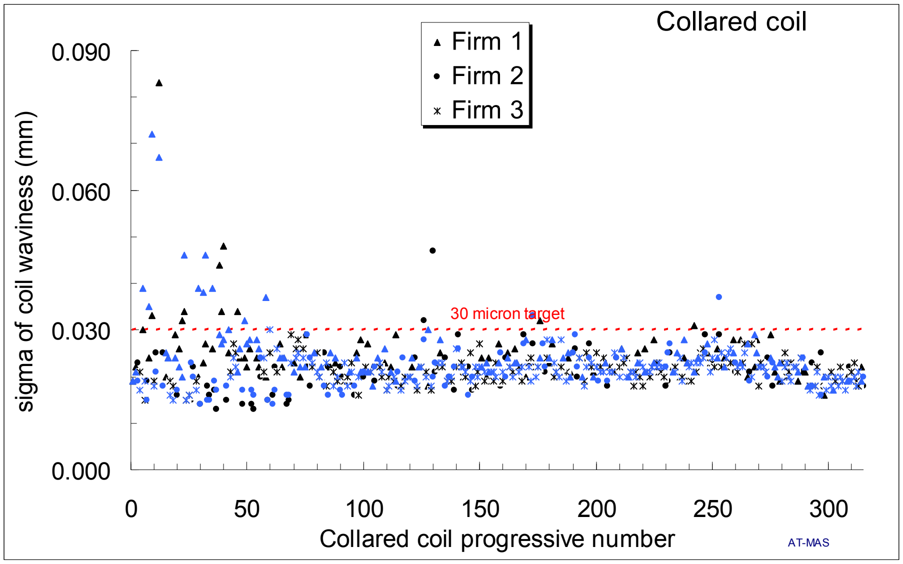

Fig. 3: Estimated coil waviness in the straight part of the measured collared coils (black dots: aperture 1, blue dots: aperture 2).

3. Magnetic length and transfer function

- Magnetic lengths of collared coils 275th to 319th are well within targets (see Fig. 4). The spread in magnetic length is very low (3 units).
- Firm3 is producing collared coils whose magnetic length is 4 units smaller than Firm1. Firm2 values are in between.

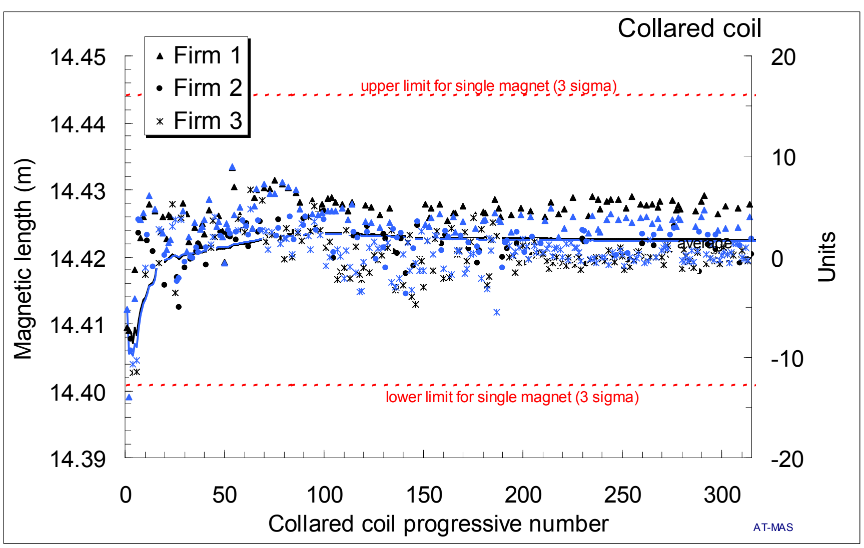

Fig. 4: Magnetic length of the measured collared coils (black dots: aperture 1, blue dots: aperture 2)

- We still have a few collared coils from Firm1 with rather low main field (see Figs. 5 and 6). This is not due to non-nominal shims.
- In the last months, the spread in transfer function between firms is getting smaller.
- The introduction of cross-section 3 has shifted down the main field by less than 5 units.

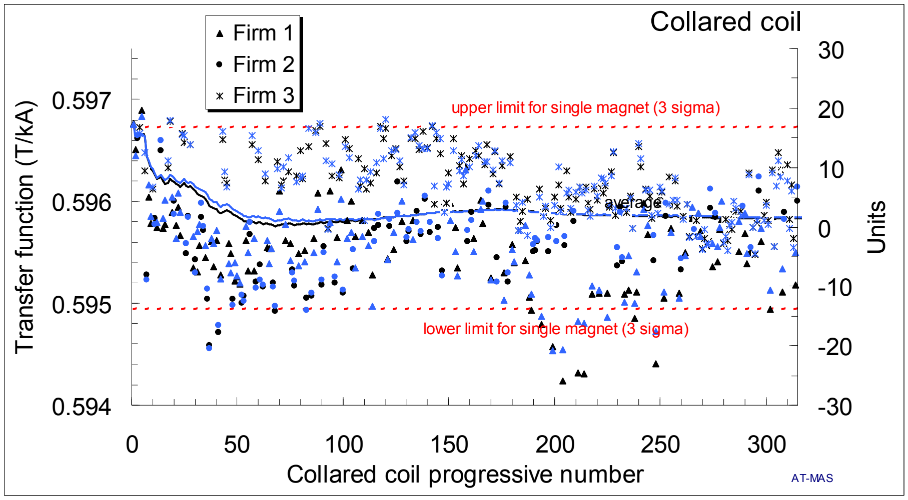

Fig. 5: Main field in the straight part of the collared coils (black dots: aperture 1, blue dots: aperture 2) and average over all collared coils (solid lines).

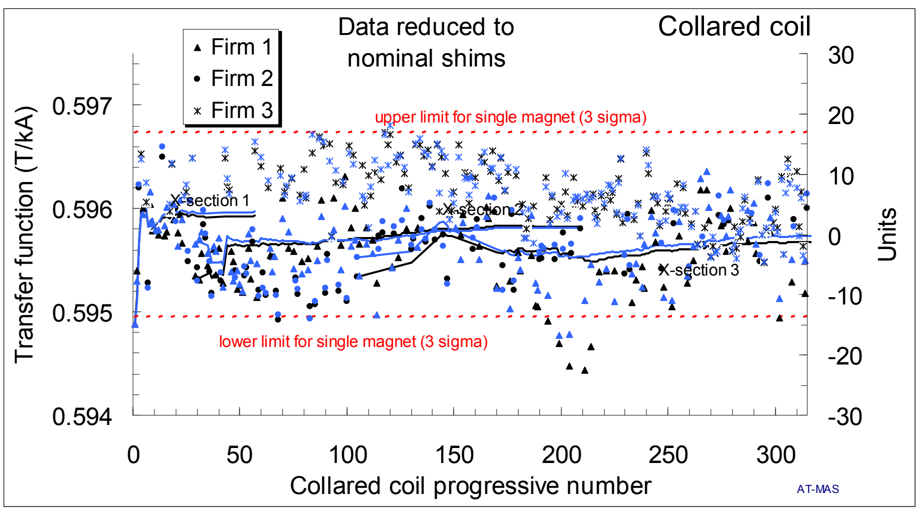

Fig. 6: Main field in the straight part of the collared coils (black dots: aperture 1, blue dots: aperture 2) and best estimate of systematic (solid lines). Data are reduced to nominal shims and separated according to different cross-sections.

- The spread of the integrated transfer function in all collared coils is 7.3 units (one sigma), i.e. within the target of 8 units.
- Cold mass data show that the difference between firms gets smaller after the assembly of the iron yoke (see http://fqwg.web.cern.ch/fqwg/031111/031111.html). This is confirmed by measurements at 1.9 K. Therefore, we can expect that in operational conditions the main field spread is further reduced with respect to the 7.7 units observed in collared coils.

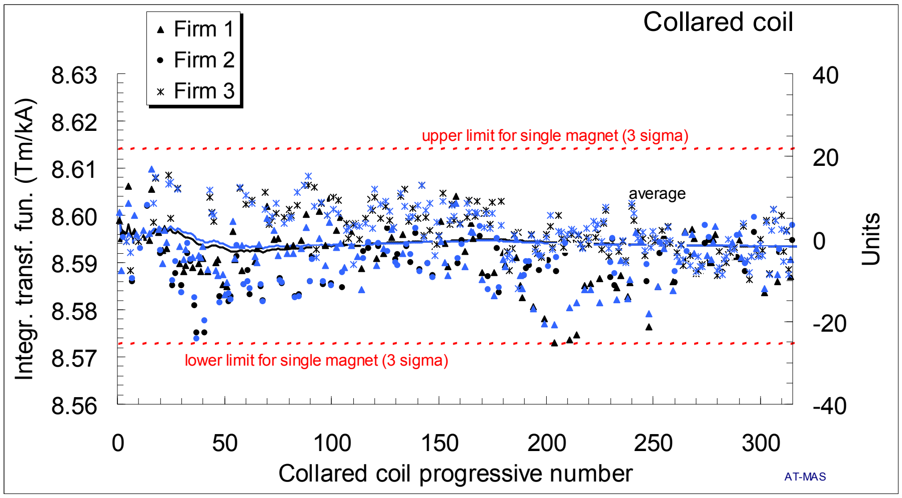

Fig. 7: Integrated transfer function (black dots: aperture 1, blue dots: aperture 2) and average over all collared coils (solid lines)

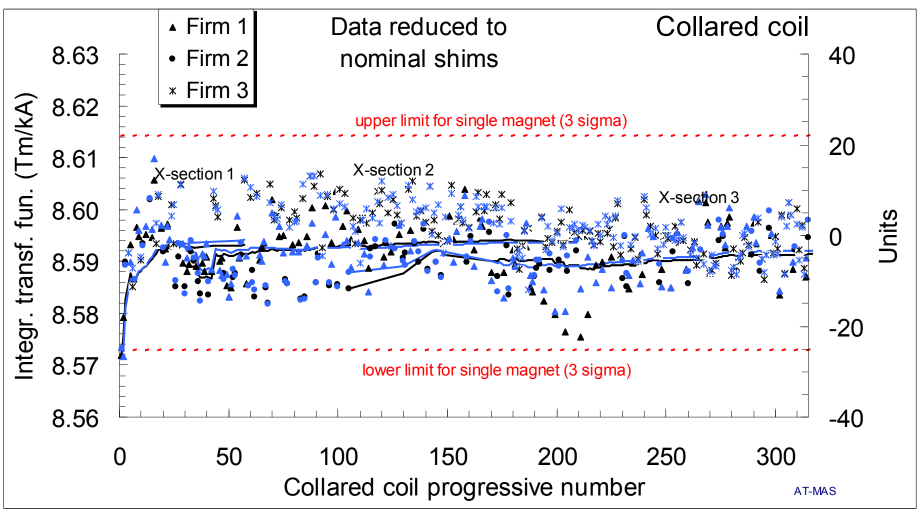

Fig. 8: Integrated transfer function (black dots: aperture 1, blue dots: aperture 2) and best estimate of systematic (solid lines). Data are reduced to nominal shims and separated according to different cross-sections.

4. Summary of systematics

- Best estimates of skew and even normal systematics are given in Fig. 9, with an error at 95% confidence limit (two sigma). All the multipoles are within specifications. Details are given in sections 6 and 7.

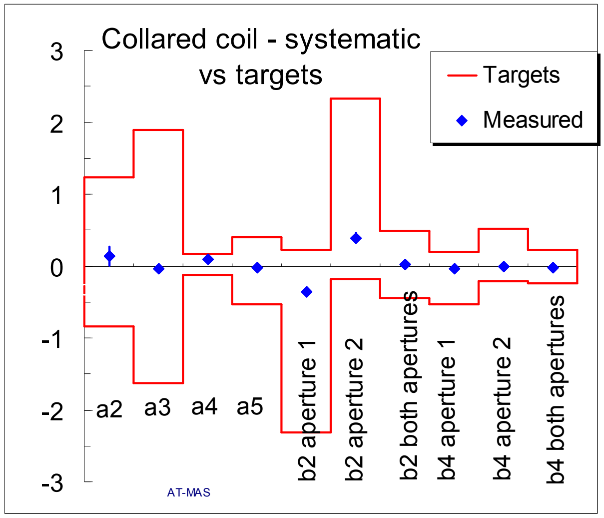

Fig. 9: Best estimate for systematic skew multipoles and even normal multipoles (markers) versus beam dynamics limits (red line). An error of two sigma (95% confidence limit) is associated to the best estimates of systematics.

- Best estimates for systematic odd normal multipoles are shown in Fig. 10. In the left part, raw data are plotted. This gives the actual situation for global values relative to all manufactured collared coils, which are slowly moving towards optimal ranges: b_3 is now at the edge of the target and b_5 is larger than the upper target of 0.3 units.
- In the right part of Fig. 10, data are reduced to nominal shims and separated according to the three cross-sections (34 collared coils have cross-section 1, 138 have cross-section 2, 146 have cross-section 3, plus one hybrid). With cross-section 3, b_3 is within targets, 1.45 units below the upper limit (i.e., 1.85 units at high field), and also b_5 is within targets, 0.11 units below the upper limit (i.e., 1.01 units at injection). Finally, b_7 is 0.25 units larger than the limits (i.e. 0.30 units at injection). A small positive drift is being observed for these three normal odd multipoles, see also Section 8.

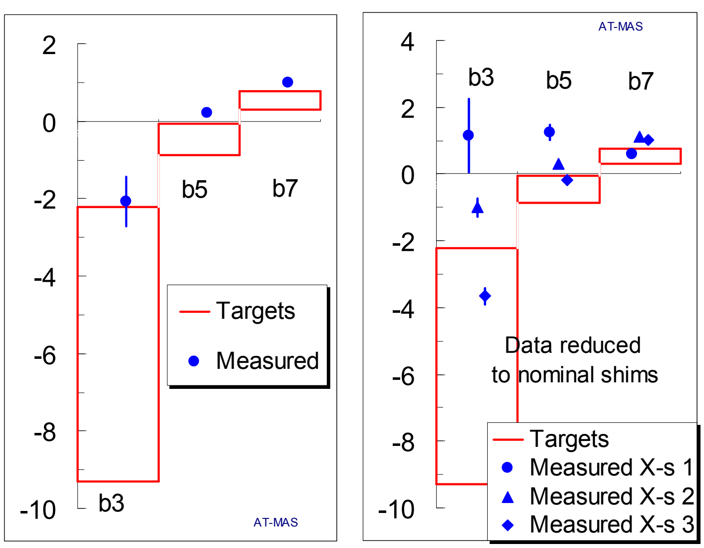

Fig. 10: Best estimate for systematic odd normal multipoles (markers) versus beam dynamics limits (red line). An error of two sigma (95% confidence limit) is associated to the best estimates of systematics. Raw data (left) and data reduced to nominal shims and separated according to different cross-sections (right).

5. Summary of systematic differences between firms

The relevant systematic difference between firms in the main field is disappearing. The more relevant signature of Firms is in b_7.

- Normal 14th pole: b_7 at Firm2 is 0.40 units lower than Firm2 and Firm1. This difference is three to four times the natural sigma within the same manufacturer measured in cross-section 3. Firm2 is within targets, whereas both Firm1 and Firm3 are outside.

We observe a small systematic difference between firms (from one to two times the natural sigma within the same manufacturer) in the following cases.

- Normal decapole b_5: Firm1 has a systematic b_5 of 0.6 units larger than Firm2-3. This difference is two times the natural sigma within the same manufacturer. Firm2 and Firm3 are within targets, whereas Firm1 is outside.
- Skew sextupole a_3: Firm3 has a systematic a_3 of 0.46 units, against –0.41 units in Firm2, Firm1 being at -0.16 units. This difference is two-three times the natural sigma within the same manufacturer. All Firms are within targets
- Skew octupole a_4: Firm2 has a systematic a_4 of 0.34 units, against 0.0 units in Firm2 and Firm1. This difference is equal to the natural sigma within the same manufacturer. Firm1 and Firm3 are within targets, whereas Firm2 is outside.

Systematic differences between firms are small or negligible in a_2, b_2 b_3 and b_4.

6. Systematic skew multipoles

- Systematic skew multipoles a_2, a_3 and a_4 are within beam dynamics limits (see Figs. 11-13). We have a large margin for the a_3, whereas beam dynamics limits are tighter for a_2 and a_4.
- In the production of these two months, the reduction of the a_4 values observed in Firm2 is confirmed (see Fig. 12). The average a_4 in the production of these two months in Firm2 is 0.41 units.
- The introduction of cross-section 3 produced no effect on a_2 and a_4, as expected.

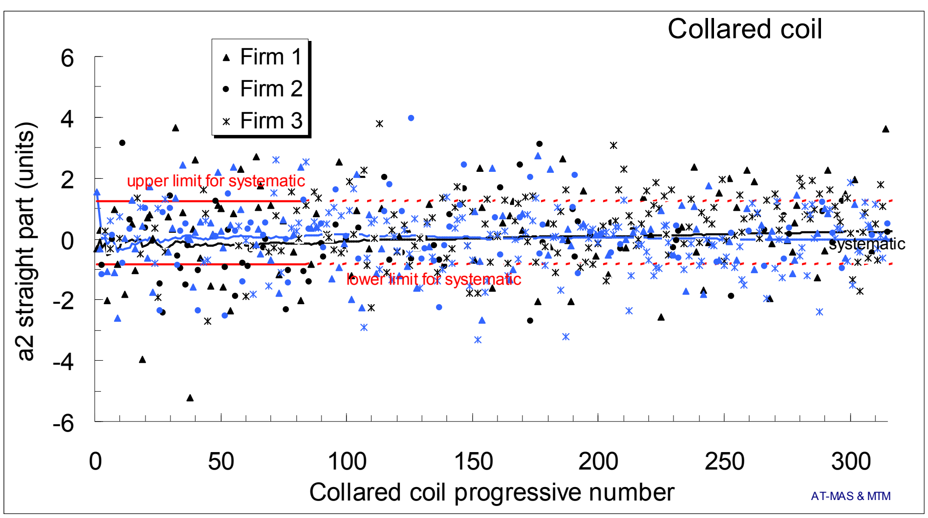

Fig. 11: Average a_2 in the straight part of the collared coils (black dots: aperture 1, blue dots: aperture 2), best estimate for systematic in each aperture (solid lines), and beam dynamics limits for the systematic (red lines) based on correlations with 83 cryodipoles.

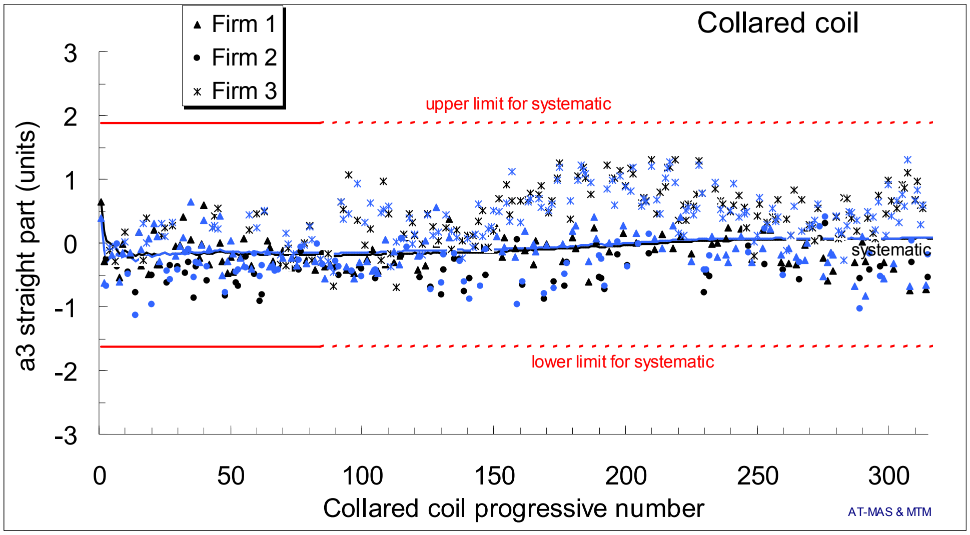

Fig. 12: Average a_3 in the straight part of the collared coils (black dots: aperture 1, blue dots: aperture 2), best estimate for systematic in each aperture (solid lines), and beam dynamics limits for the systematic (red lines) based on correlations with 83 cryodipoles.

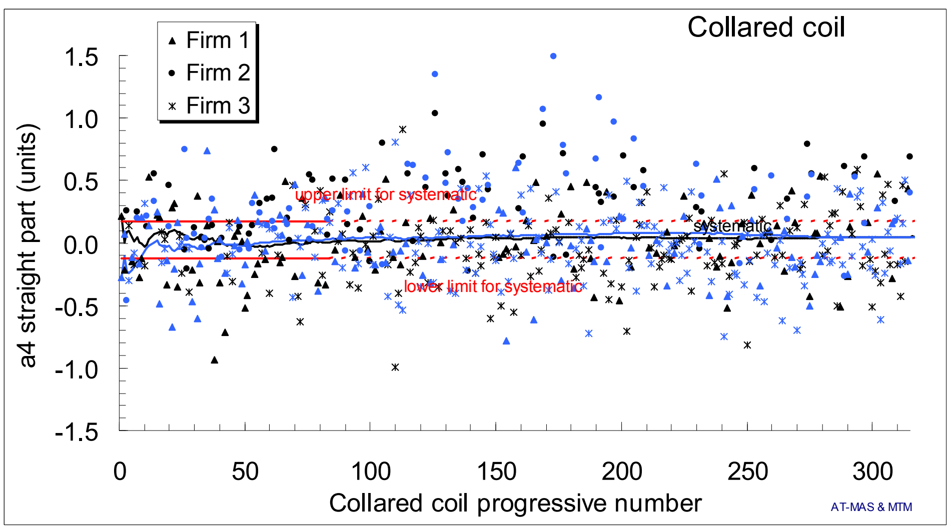

Fig. 13: Average a_4 in the straight part of the collared coils (black dots: aperture 1, blue dots: aperture 2), best estimate for systematic in each aperture (solid lines), and beam dynamics limits for the systematic (red lines) based on correlations with 83 cryodipoles.

7. Systematic even multipoles

For each multipole being subject to beam dynamics specifications, we present two separated plots for the systematic per aperture, plus a plot of the systematic per beam, i.e. the average of both apertures (that should be zero due to two-in-one symmetry).

7.1 Normal quadrupole

- The systematic per aperture is within specifications in both apertures (see Figs. 14 and 15).

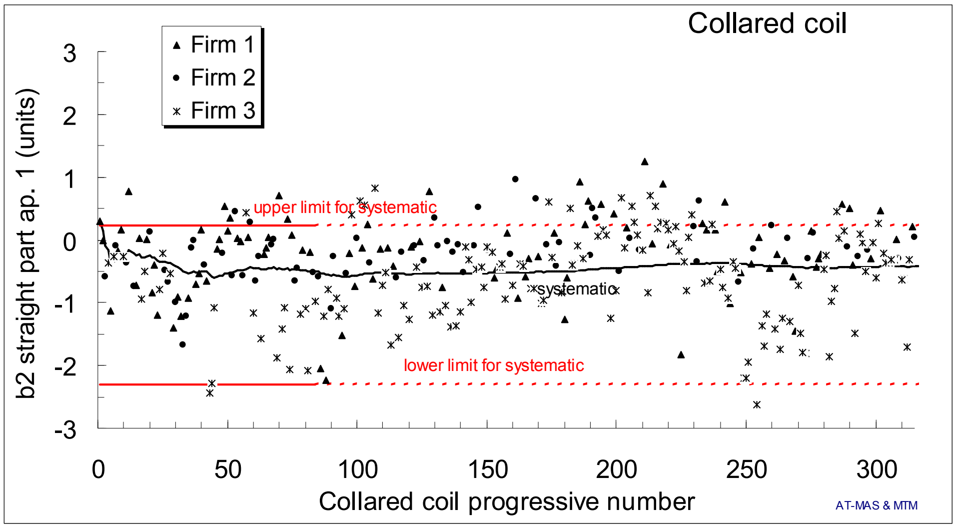

Fig. 14: Average b_2 in the straight part of the aperture 1 collared coils (black dots), best estimate for systematic per aperture (black line), and beam dynamics limits for the systematic (red lines) based on correlations with 83 cryodipoles.

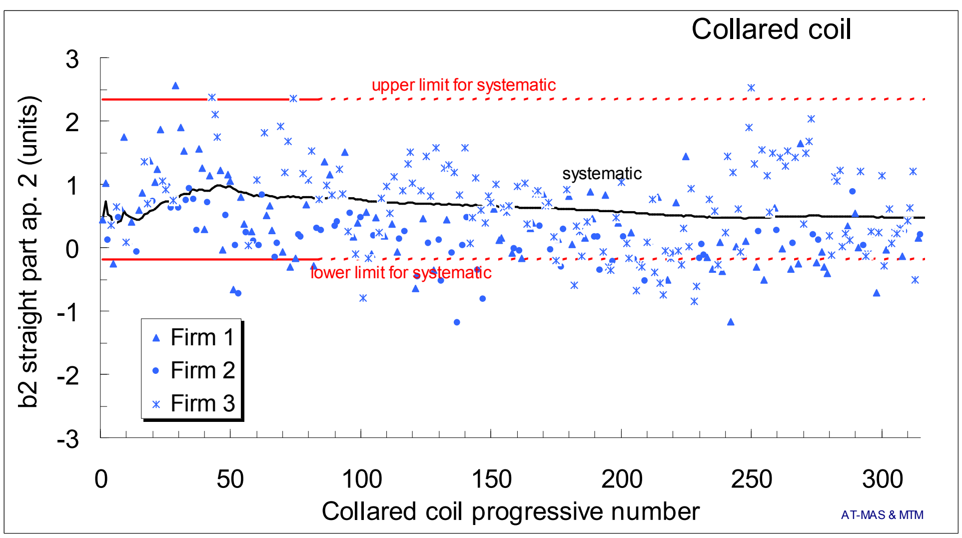

Fig. 15: Average b_2 in the straight part of the aperture 2 collared coils (blue dots), best estimate for systematic per aperture (blue line) and beam dynamics limits for the systematic (red lines) based on correlations with 83 cryodipoles.

- The systematic normal quadrupole per beam is within specifications (see Fig. 16).

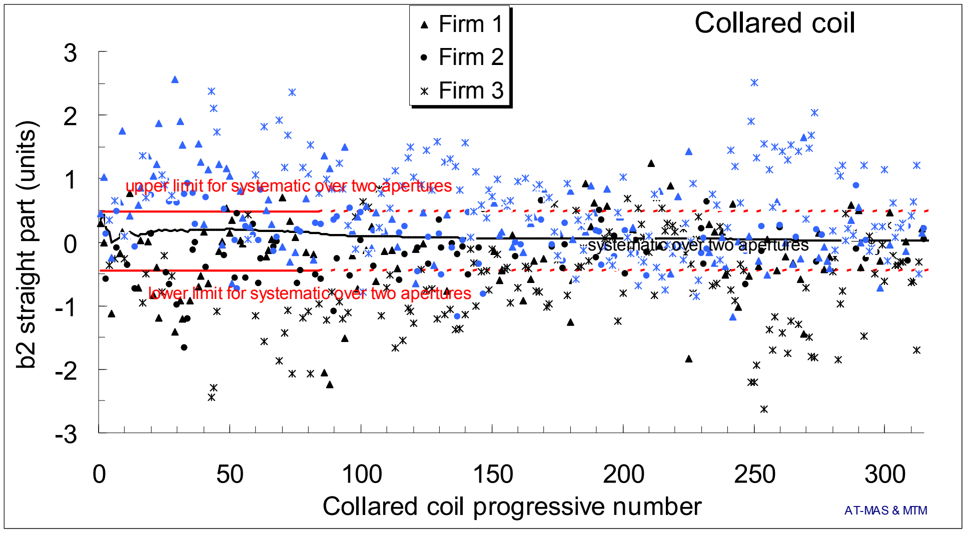

Fig. 16: Average b_2 in the straight part of collared coils ((black dots: aperture 1, blue dots: aperture 2), best estimate for systematic per beam (soild line) and beam dynamics limits for the systematic (red lines) based on correlations with 83 cryodipoles.

7.2 Normal octupole

- The systematic per aperture is within specifications in both apertures (see Figs. 17 and 18).
- The systematic per beam is also within specifications (see Fig. 19).

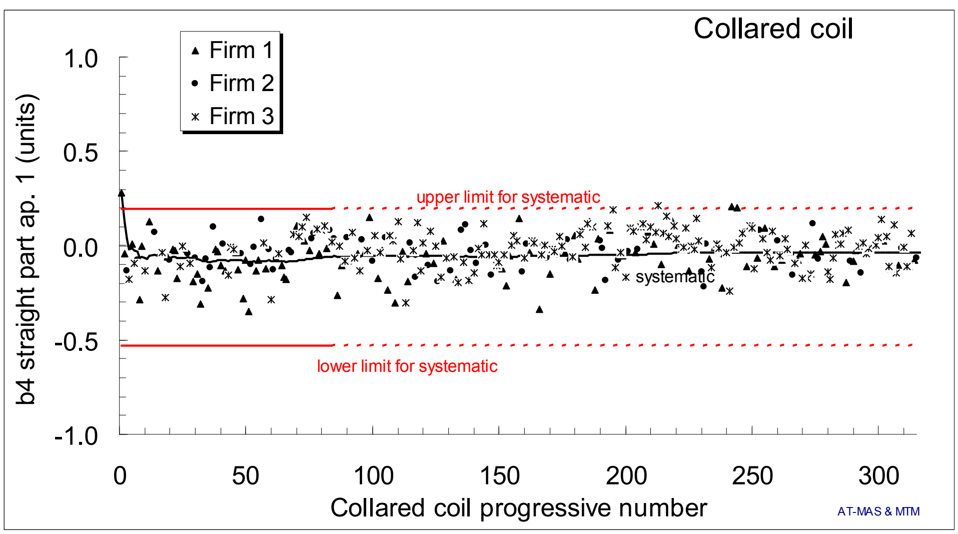

Fig. 17: Average b_4 in the straight part of the aperture 1 collared coils (black dots), best estimate for systematic per aperture (black line), and beam dynamics limits for the systematic (red lines) based on correlations with 83 cryodipoles.

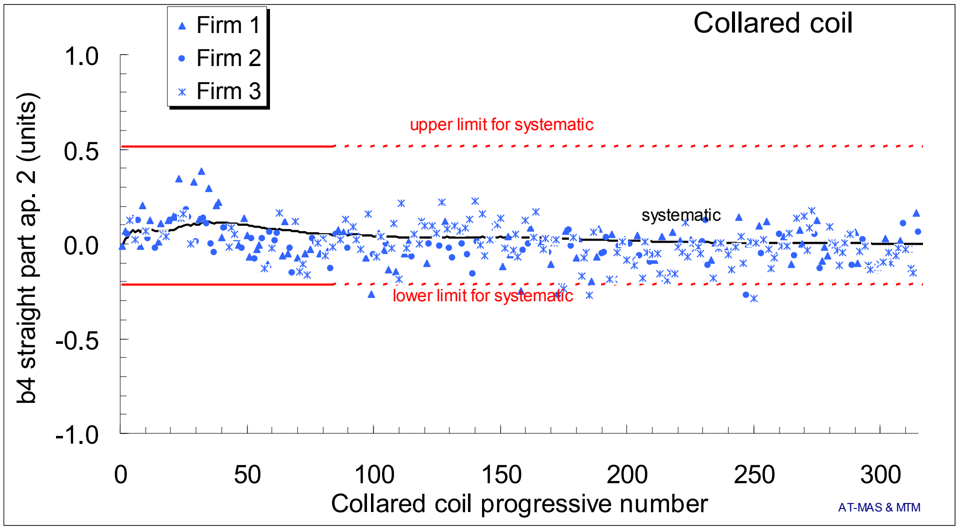

Fig. 18: Average b_4 in the straight part of the aperture 2 collared coils (blue dots), best estimate for systematic per aperture (black line) and beam dynamics limits for the systematic (red lines) based on correlations with 83 cryodipoles.

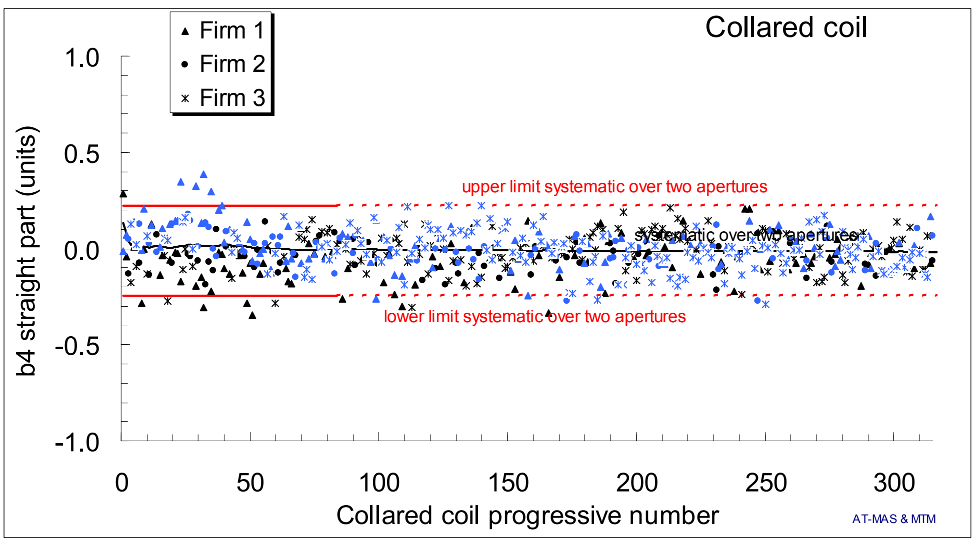

Fig. 19: Average b_4 in the straight part of collared coils (black dots: aperture 1, blue dots: aperture 2), best estimate for systematic per beam (black line) and beam dynamics limits for the systematic (red lines) based on correlations with 83 cryodipoles.

8. Systematic odd multipoles

8.1 Normal sextupole

- Data not reduced to nominal shims and not separated according to different cross-section show a negative trend due to the introduction of cross-section 2 (at collared coil 30th) and 3 (around collared coil 140th, see Fig. 20).
- The introduction of cross-section 3 has brought b_3 in the upper half of the target range (see Fig. 21). Some collared coils of Firm1 feature a rather low b_3 due to non-nominal shims.
- In cross-section 3, b_3 values show a low spread for Firm2 and Firm3 (standard deviation of 0.7 to 0.8 units), whilst for Firm1 data have a larger spread (standard deviation of 1.7 units). The spread in Firm1 is partly due to non-nominal shims: when this effect is subtracted, the standard deviation goes to 1.4 units.
- Average b_3 in cross-section 3 is at -4.0, -4.0 and -3.0 units in Firm1, 2 and 3 respectively (reduced to nominal shims), showing a small difference between Firms.

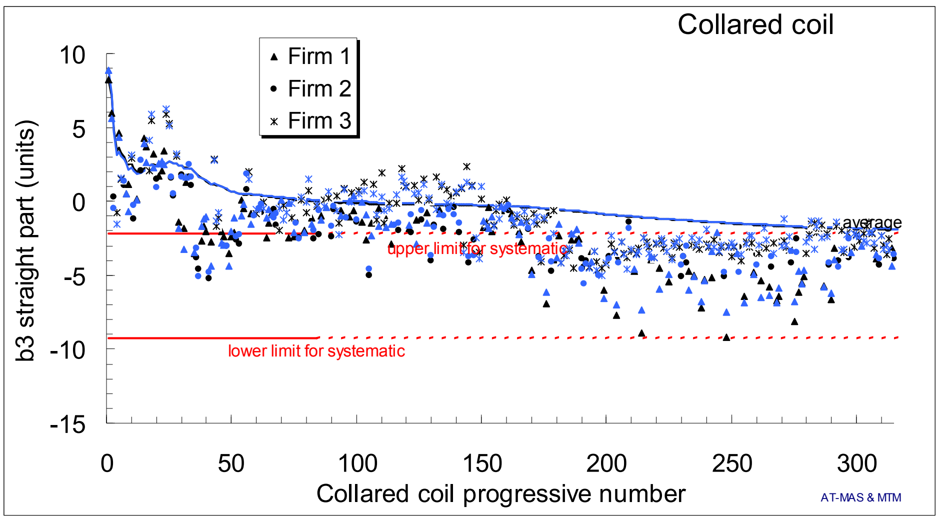

Fig. 20: Average b_3 in the straight part of the collared coils (black dots: aperture 1, blue dots: aperture 2), best estimate for systematic (solid lines), and beam dynamics limits for the systematic (red lines) based on correlations with 83 cryodipoles.

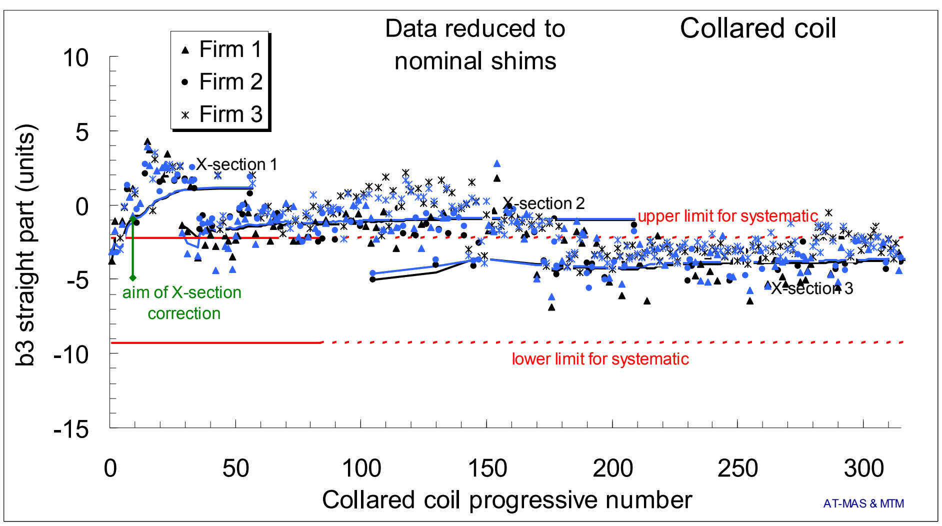

Fig. 21: Average b_3 in the straight part of the collared coils (black dots: aperture 1, blue dots: ap. 2), best estimate for systematic (solid lines), and beam dynamics limits for the systematic (red lines) based on correlations with 83 cryodipoles. Data reduced at nominal shims and separated according to cross-section type.

8.2 Normal decapole

- Data not reduced to nominal shims and not separated according to different cross-sections show a negative trend due to introduction of cross-section 2 (see Fig. 22, from 35th to 140th) and then due to the introduction of cross-section 3 (same Figure, after 140th).
- Indeed, when data are separated according to cross-sections and reduced to nominal shims, one finds that the average b_5 in all cross-sections is stable after a transient due to low statistics (see Fig. 23); there is a small positive trend in the data of last months (collared coils 200th to 318th, see Fig. 23, where average b_5 increased of 0.12 units).
- Magnets with the cross-section 3 should feature 1.02 units of b_5 at injection. This places b_5 on the upper edge of the target range.
- Spread of b_5 for cross-section 3 is between 0.23 and 0.32 units, i.e. well within the specification.
- Average b_5 for cross-section 3 is at 0.39, -0.38 and –0.33 units in Firm1, 2 and 3 respectively. Therefore, the high value of this multipole in Firm1 is confirmed: this feature was present already in cross-section 1 and 2.

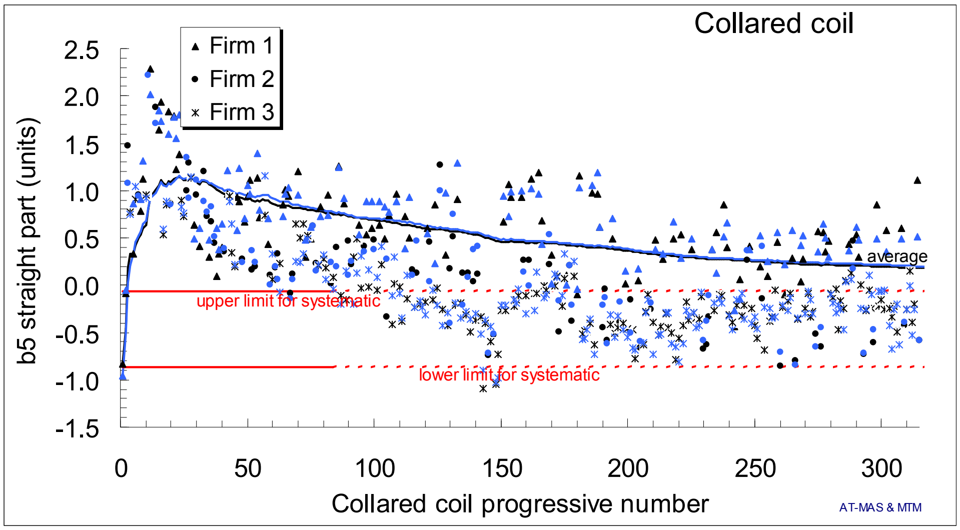

Fig. 22: Average b_5 in the straight part of the collared coils (black dots: aperture 1, blue dots: aperture 2), best estimate for systematic (solid lines), and beam dynamics limits for the systematic (red lines) based on correlations with 83 cryodipoles.

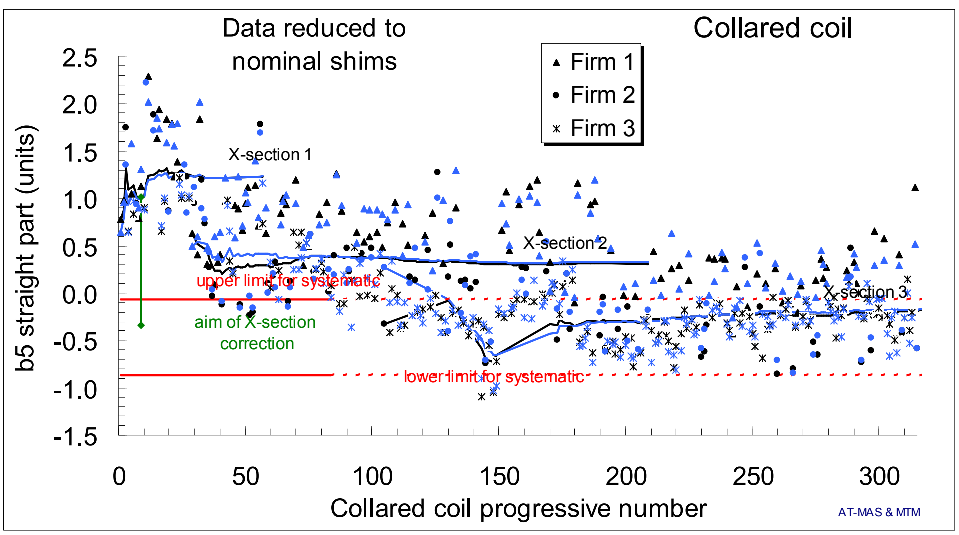

Fig. 23: Average b_5 in the straight part of the collared coil (black dots: aperture 1, blue dots: aperture 2), best estimate for systematic (solid lines), and beam dynamics limits for the systematic (red lines) based on correlations with 83 cryodipoles. Data are reduced to nominal shims and separated according to different cross-sections.

8.3 Normal 14-th pole

- Firm2 has a very low average b_7 (0.74 units, i.e. 0.40 units less than Firm1 and Firm3) and a rather high spread, as it is observed in cross-section 2: this is one of the few cases where a non-negligible difference between Firms is observed. Indeed, Firm2 is the only Firm producing collared coils with b_7 within targets.
- Cryodipoles with the cross-section 3 should feature 0.30 units of b_7 at injection. This would place b_7 above the target, at the limit of the previous target (see Fig. 31).

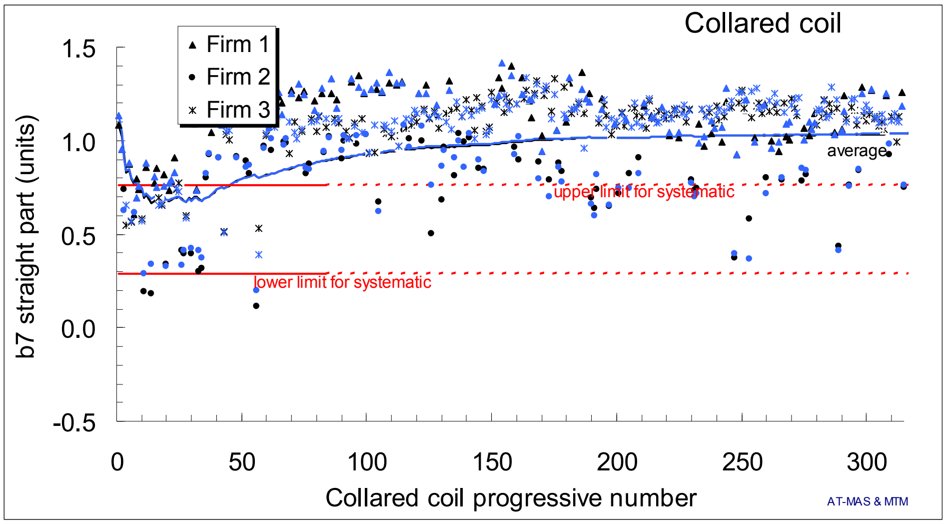

Fig. 24: Average b_7 in the straight part of the collared coils (black dots: aperture 1, blue dots: aperture 2), best estimate for systematic (solid lines), and beam dynamics limits for the systematic (red lines) based on correlations with 83 cryodipoles.

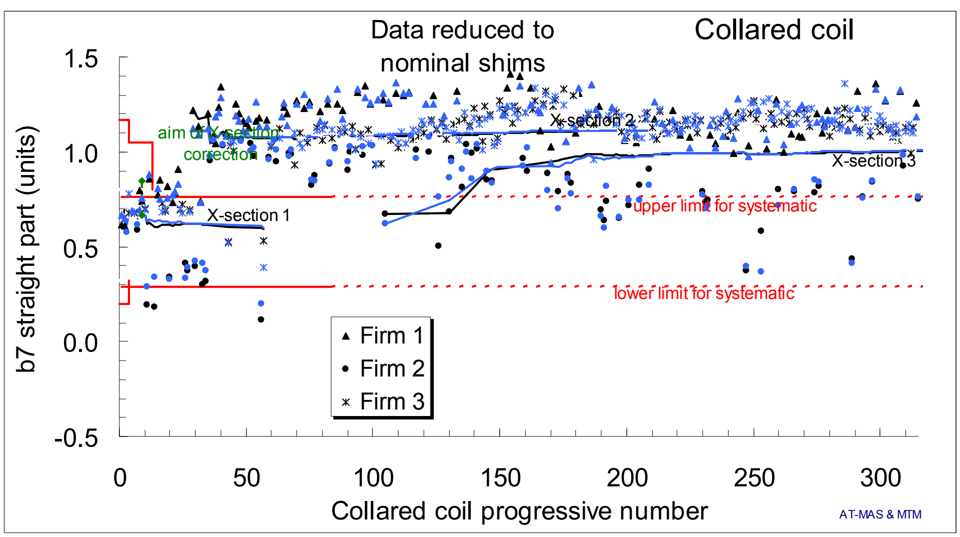

Fig. 25: Average b_7 in the straight part of the collared coils (black dots: aperture 1, blue dots: aperture 2), best estimate for systematic (solid lines), and beam dynamics limits for the systematic (red lines) based on correlations with 83 cryodipoles. Data are reduced to nominal shims and separated according to different cross-sections.

9. Random multipoles

- The standard deviation of magnetic length, main field, bending strength, and multipoles are shown in Fig. 26. They are separated according to the three cross-sections. We repeat considerations made in the previous report: one can observe that cross-section 1 showed an important out of target in b_3 and b_5, whereas cross-section 2 and 3 are all within tolerances. Please note that these data are not reduced to nominal shims. In general, the spread in cross-section 3 is similar to the spread in cross-section 2.
- In cross-section 3, the spread in b_3 is of 1.4 units but goes down to 1.05 units when the contribution of non-nominal shims is taken out.

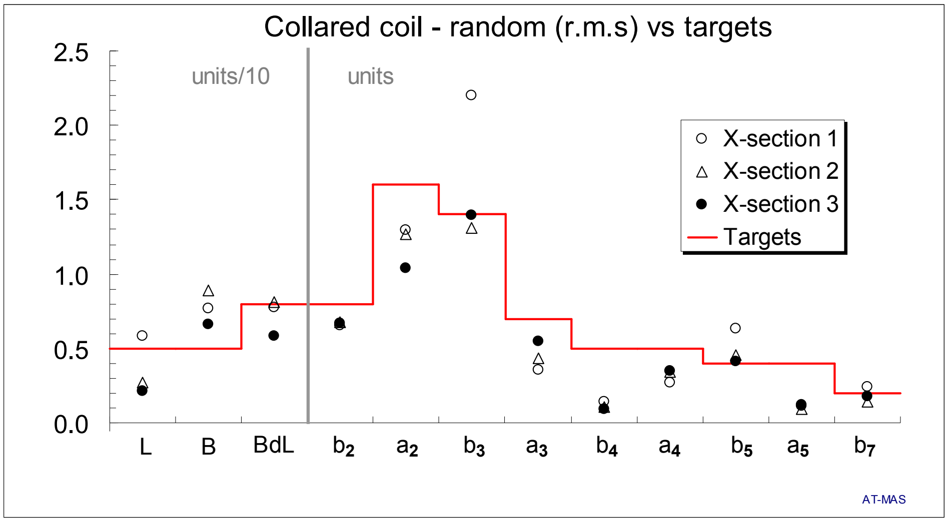

Fig. 26: Random component in the measured collared coils, separated according to different cross-sections.

- We give an estimate of the actual spread due to the geometric component in the first two arcs. We assume that the first arc is made up with X-section 1 and 2, and that the second arc is made up with cross-section 3 plus 20 magnets with X-section 2 of Firm3 (see Fig. 27). Random b_3 is 2.1 and 1.75 units in the first and in the second arc respectively. The second value has bettered with respect to the estimate given in the previous report (1.9 units). It must be pointed out that the random strongly depends on the selection of the magnets to be installed in the arc.
- These values are reduced by 18% when the yoke is assembled, and then one has to add the random components due to persistent currents (0.5 units). Summing in quadrature, one obtains 1.55 units in the second arc, not far from the target of 1.4 units.
- All the other random components are safely within targets.

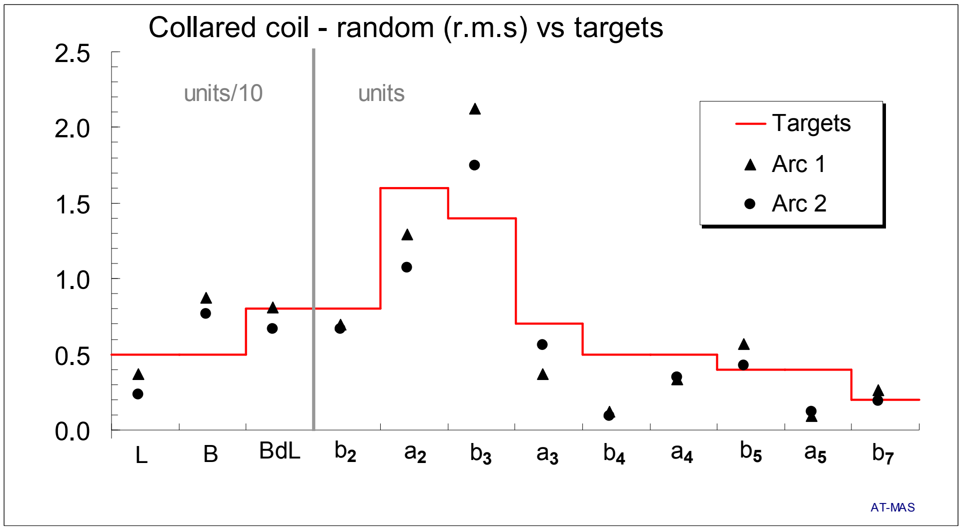

Fig. 27: Estimate of random component in the first and second arc **due to collared coils**.

10. Holding point results

In these two months, two collared coils have been not approved and de-collaring has been asked for assembly faults.

10.1 The folded shim in 3135

Collared coil 3135 has shown anomalies in high order multipoles of a few tenths of units, but corresponding to 4 to 8 sigma (yellow alarms), in position 19 and 20 (i.e., the head non-connection side and the straight part close to it). A measurements with the short mole 125 mm long has shown that the field anomaly was due to a section 375 mm long, therefore corresponding to larger anomalies in multipoles with respect to what observed with the 750 mm mole. The analysis of the inverse problem has shown that this anomaly could be due to an inner movement of block 5 and 6 of 0.5 mm and 1.0 mm respectively.

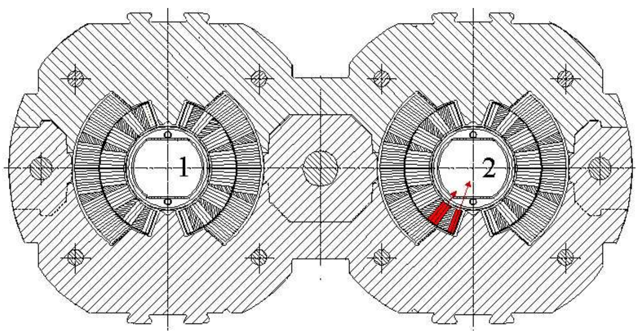

Fig. 28: Expected movements of block 5 and 6 in collared coil 3135 in the section showing field anomalies.

A de-collaring has been asked, and it has been found that in that section showing field anomalies the outer shim was sliding between the inner pole and the collars, thus pushing block 6 inward of 0.8 mm (see Fig. 29). Since the coil was correctly glued, the adjacent block 5 was partially following this movement, as suggested by the magnetic measurements. More details are given in the visit report AT/MAS 7324 by E. Todesco and C. Vollinger and in the crisis unit web site http://lhc-div-mms.web.cern.ch/lhc-div-mms/MMSPAGES/MA/crisis.html This is the fourth assembly error detected with magnetic measurements.

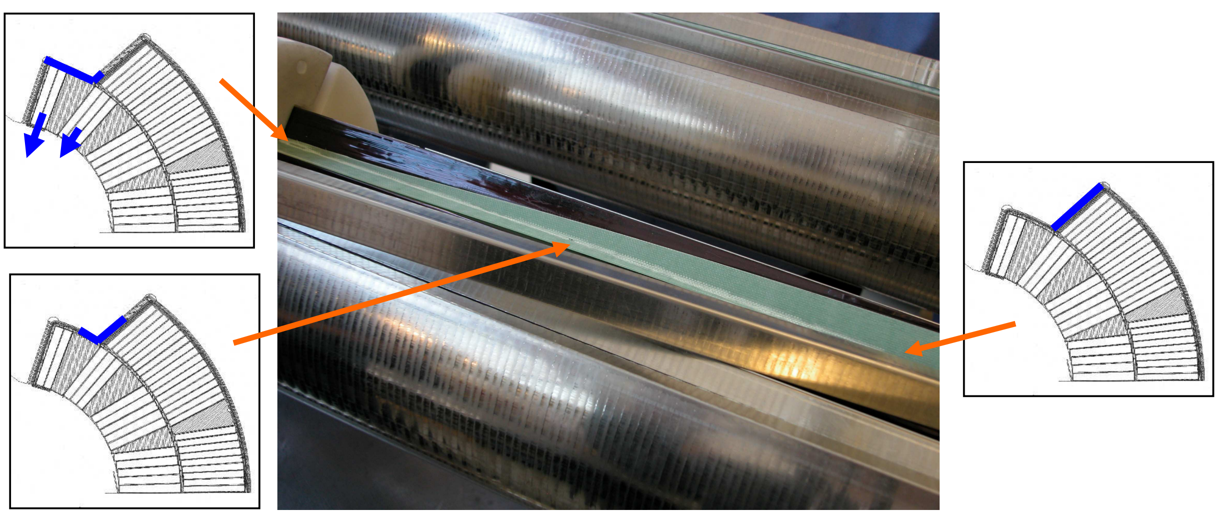

Fig. 29: Sliding of the outer shim between inner layer and collars and effect on block 5 and 6.

10.2 Bad curing in 1099

Collared coil 1099 showed field anomalies of about 5 sigma in a6, b8 and other higher order multipoles. Since the pattern was very similar to what observed in 2032 and 3135 (inner radial shift of block 6), a measurement with the short mole has been performed. Results have shown that the field anomaly was covering at most 125 mm of the longitudinal length (i.e. one position of the short mole), and it could be due to an inward shift of block 6 of 0.5 mm. A second zone with field anomalies has been detected towards the non-connection end.

Fig. 30: Detachment of block 6 in coil 1099.

A de-collaring has been asked, and it has been verified that in the foreseen longitudinal position the two conductors of block 6 were not glued to the copper wedge (see Fig. 30). This case is therefore very similar to the 2032 case. More details can be found in the visit report by C. Vollinger AT-MAS 7365. This is the fifth assembly defect found through magnetic measurements.

11. Acknowledgements

Magnetic measurements have been taken through instrumentation of the AT-MTM-IF section, and are now performed by firm personnel. Measuring system developed by D. Cote, P. Galbraith, D. Giloteaux, V. Remondino, J. Billan. Data at 1.9 K have been taken and made available by the AT-MTM-OP and AT-MTM-AS sections. We wish to acknowledge L. Bottura, V. Chohan, L. Rossi, S. Sanfilippo, W. Scandale, for valuable help and discussions. Thanks to C. Vollinger, E. Wildner and V. Remondino for data analysis. We acknowledge P. Hagen and C. Vollinger for useful comments on the manuscript.

Appendix A: collared coil assembly data

Table I: Magnet number, collared coil progressive number used in figures, and cross-section (data available on April 1 2004) for Firm1 and Firm2.

magnet	cc number	X-section	magnet	cc number	X-section	magnet	cc number	X-section	magnet	cc number	X-section
1001	1	1	1071	214	3	2001	3	1	2071	315	3
1002	2	1	1072	238	3	2002	11	1	2072	276	3
1003	5	1	1073	239	3	2003	7	1	2073	297	3
1004	8	1	1074	218	3	2004	20	1	2074	321	3
1005	9	1	1075	221	3	2005	14	1	2075	352	3
1006	12	1	1076	248	3	2006	30	1	2076	346	3
1007	15	1	1077	225	3	2007	27	1	2077	328	3
1008	16	1	1078	235	3	2008	26	1	2078	329	3
1009	19	1	1079	233	3	2009	34	1	2081	309	3
1010	21	1	1081	244	3	2010	33	1	2082	345	3
1011	22	1	1082	252	3	2011	56	1			
1012	23	1	1083	259	3	2012	37	2			
1013	29	2	1084	255	3	2013	36	2			
1014	31	2	1085	262	3	2014	41	2			
1015	32	1	1086	265	3	2015	61	2			
1016	35	2	1087	268	3	2016	48	2			
1017	38	2	1088	269	3	2017	52	2			
1018	39	2	1089	275	3	2018	53	2			
1019	40	2	1090	277	3	2019	59	2			
1020	64	2	1091	279	3	2020	62	2			
1021	42	2	1092	278	3	2021	67	2			
1022	47	2	1093	287	3	2022	68	2			
1023	49	2	1094	290	3	2023	76	2			
1024	50	2	1095	291	3	2024	126	2			
1025	51	2	1096	298	3	2025	77	2			
1026	46	2	1097	308	3	2026	83	2			
1027	54	2	1098	302	3	2027	85	2			
1028	55	2	1099	316	3	2028	90	2			
1029	58	2	1100	314	3	2029	91	2			
1030	65	2	1101	325	3	2030	96	2			
1031	66	2	1104	319	3	2031	100	2			
1032	70	2	1105	326	3	2032	105	3			
1033	73	2	1106	343	3	2033	131	2			
1034	75	2	1109	338	3	2034	117	2			
1035	79	2	1110	320	3	2035	130	3			
1036	82	2	1111	333	3	2036	115	2			
1037	86	2	1112	339	3	2037	122	2			
1038	88	2	1113	330	3	2038	137	2			
1039	97	2	1114	340	3	2039	141	2			
1040	102	2	1115	349	3	2040	145	3			
1041	99	2	1116	348	3	2041	139	2			
1042	106	2	1117	351	3	2042	135	2			
1043	186	2	1119	354	3	2043	147	3			
1044	121	2				2044	159	2			
1045	94	2				2045	201	3			
1046	104	2				2046	253	3			
1047	109	2				2047	232	3			
1048	158	2				2048	161	2			
1049	112	2				2049	190	3			
1050	114	2				2050	177	2			
1051	154	2				2051	247	3			
1052	124	2				2052	169	2			
1053	153	2				2053	178	3			
1054	162	2				2054	173	3			
1055	133	2				2055	191	3			
1056	181	2				2056	209	2			
1057	128	2				2057	192	3			
1058	165	2				2058	197	3			
1059	151	2				2059	231	3			
1060	166	2				2060	260	3			
1061	170	3				2061	205	3			
1062	188	2				2062	230	3			
1063	176	3				2063	289	3			
1064	180	3				2064	266	3			
1065	242	3				2065	336	3			
1066	189	2				2066	274	3			
1067	211	3				2067	322	3			
1068	194	2				2069	293	3			
1069	204	3				2070	318	3			
1070	199	3									

Table II: Magnet number, collared coil progressive number used in figures, and cross-section (data available on April 1 2004) for Firm3.

magnet	cc number	X-section	magnet	cc number	X-section	magnet	cc number	X-section
3001	4	1	3071	179	2	3140	294	3
3002	6	1	3072	168	2	3141	299	3
3003	10	1	3073	171	2	3142	300	3
3005	17	1	3074	172	2	3143	301	3
3006	18	1	3075	174	3	3144	303	3
3007	24	1	3076	175	2	3145	306	3
3008	25	1	3077	200	3	3147	311	3
3009	28	1	3078	184	3	3148	310	3
3010	57	1	3079	183	3	3149	317	3
3011	43	1	3080	182	3	3150	331	3
3012	44	2	3081	195	3	3151	332	3
3013	45	2	3082	213	3	3153	313	3
3014	60	2	3083	185	3	3154	350	3
3015	63	2	3084	193	3	3155	324	3
3016	69	2	3085	196	3	3156	323	3
3017	72	2	3086	198	3	3157	337	3
3018	71	2	3087	207	3	3158	342	3
3019	74	2	3088	208	3	3160	327	3
3020	80	2	3089	210	3	3161	334	3
3021	78	2	3090	212	3	3162	344	3
3022	81	2	3091	215	3	3163	335	3
3023	84	2	3092	216	3	3164	341	3
3024	87	2	3093	217	3	3165	353	3
3025	89	2	3094	219	3	3166	355	3
3026	108	2	3095	220	3	3504	13	1
3027	92	2	3096	222	3			
3028	93	2	3097	224	3			
3029	95	2	3098	223	3			
3030	98	2	3099	226	3			
3031	202	3	3100	227	3			
3032	203	3	3101	228	3			
3033	206	3	3102	307	3			
3034	101	2	3103	229	3			
3035	347	3	3104	234	3			
3036	103	2	3105	236	3			
3037	107	2	3106	237	3			
3038	111	2	3107	240	3			
3039	113	2	3108	241	3			
3040	187	3	3109	243	3			
3041	110	2	3110	245	3			
3042	116	2	3111	246	3			
3043	119	2	3112	249	3			
3044	118	2	3113	250	3			
3045	120	2	3114	251	3			
3046	123	2	3115	254	3			
3047	125	2	3116	256	3			
3048	127	2	3117	257	3			
3049	129	2	3118	258	3			
3050	132	2	3119	261	3			
3051	134	2	3120	263	3			
3052	136	2	3121	264	3			
3053	138	2	3122	267	3			
3054	140	2	3123	273	3			
3055	142	2	3124	272	3			
3056	143	3	3125	270	3			
3057	144	2	3126	271	3			
3058	146	2	3127	280	3			
3059	148	3	3128	281	3			
3060	149	3	3129	282	3			
3061	150	2	3130	283	3			
3062	152	2	3131	284	3			
3063	155	2	3132	285	3			
3064	156	2	3133	286	3			
3065	157	2	3134	288	3			
3066	160	2	3135	295	3			
3067	312	3	3136	292	3			
3068	163	2	3137	296	3			
3069	164	2	3138	305	3			
3070	167	2	3139	304	3			