Report on field quality in the main LHC dipole collared coils: May-June 2003

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This report gives data relative to field quality measured in collared coils during the period May 1–June 30 2003, 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. **395577**

The dashboard

- Available measurements: 120 collared coils, 81 cold masses, 30 cryodipoles.
- In these two months, 20 collared coils: 6 from Firm 1, 3 from Firm 2 and 11 from Firm 3.

What's new

- **Production rate**: we have the same rate as in the previous two months: 10 collared coils per month. Large increase of production at Firm3, which has produced nearly 2 collared coils per week in June.
- **Length of feedback loop:** The delay between collared coil magnetic measurements and cold test is 15 months (average), and 4.5 months (minimal, obtained for 3002). The delay between between cold mass magnetic measurements at 300 K and cold test is 7 months (average), and 1.5 months (minimal, obtained for 3006). The minimal delay between a cold mass measurement and a collared coil measurement is one month (obtained for 3037, 3038). In principle, the minimal delay between collared coil measurement and cold test could be 2.5 months.
- **Corrective action, integrated main field:** collared coil data show that the systematic difference in integrated main field between Firm3 and Firm1-2 is decreasing. This is due to an increase of integrated main field in Firm1 and Firm2 (see Section 3, pg. 4-5). The overall random component is now at the limit of the specification. Data at cold only partially confirm the systematic difference (see Appendix B). A decision on the corrective action through laminations will be taken after the calibration of the magnetic length and main field of all measuring systems, which is in progress.
- **Corrective action, odd multipoles:** collared coil 2035 has been assembled with 0.125 mm more insulation in the mid-plane at the end of June. This action aims at reducing b_3 b_5 and b_7. The collared coil has been measured on July 14 and therefore data are not included in the plots of this report. Indeed, a anticipation of the results of the measurement is given in Appendix C.
- **Trends in b_3 and b_5 in Firm3**: we observe a decrease of b_5 (0.5 units) and an increase of b_3 (1.5 units) in the last 10-15 collared coils of Firm3 (see Sections 8.1 and 8.2, pg. 12-13).
- **Trends in systematic and random harmonics**: For all other multipoles, new data confirm the previous ones.
- **Field quality variation after a re-collaring**. We have two more cases, one from Firm2 and one from Firm3. Details in Section 10, pg. 16, and on http://lhc-div-mms.web.cern.ch/lhc-div-mms/MMSPAGES/MA/2013.html). Both re-collared coils have been accepted.
- **Open case, assembly fault:** collared coil 2032 showed large spike (up to 10 sigma) in multipoles along the axis. These variations can be obtained from simulations by inner radial movements of 0.5 mm of the inner layer close to the pole. A de-collaring has been asked. More information on http://lhc-div-mms.web.cern.ch/lhc-div-mms/MMSPAGES/MA/2032.html
- **Special experiments**: the dedicated experiment on the effect of the mid-plane insulation on field harmonics has been completed in building 927 under the supervision of D. Tommasini and H. Kummer. Information at http://lhc-div-mms.web.cern.ch/lhc-div-mms/MMSPAGES/MA/mid_ins.html.

1. Measured magnets and assembly data

- 20 'new' collared coils have been measured (collared coils 101st to 120th), plus two old ones (2005 and 3028 that have been re-collared)
  - o 6 of Firm 1 (1040, 1042, 1046, 1047, 1049 and 1050)
  - o 3+1 of Firm 2 (2032, 2034, 2036, plus 2005)
  - o 11+1 of Firm 3 (3026, 3034, 3036-9, 3041-5 plus 3028)

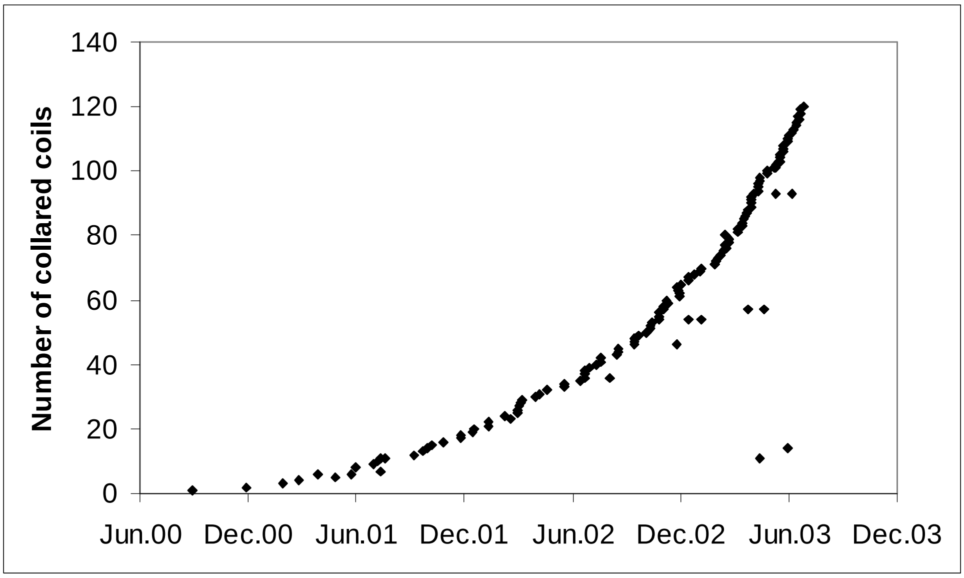


Fig. 1: Number of measured collared coils versus time. Dots out of the main trend are relative to collared coils measured more than one time.

- Cross section: all magnets with cross section 2.
- All shims are nominal, with the exception of two Firm 3 collared coils, featuring 0.05 mm more on the outer layer (outer coil too small) and 0.05 mm less on the inner layer (inner coil too large) respectively [see Fig. 2]. This has a small impact on field quality.

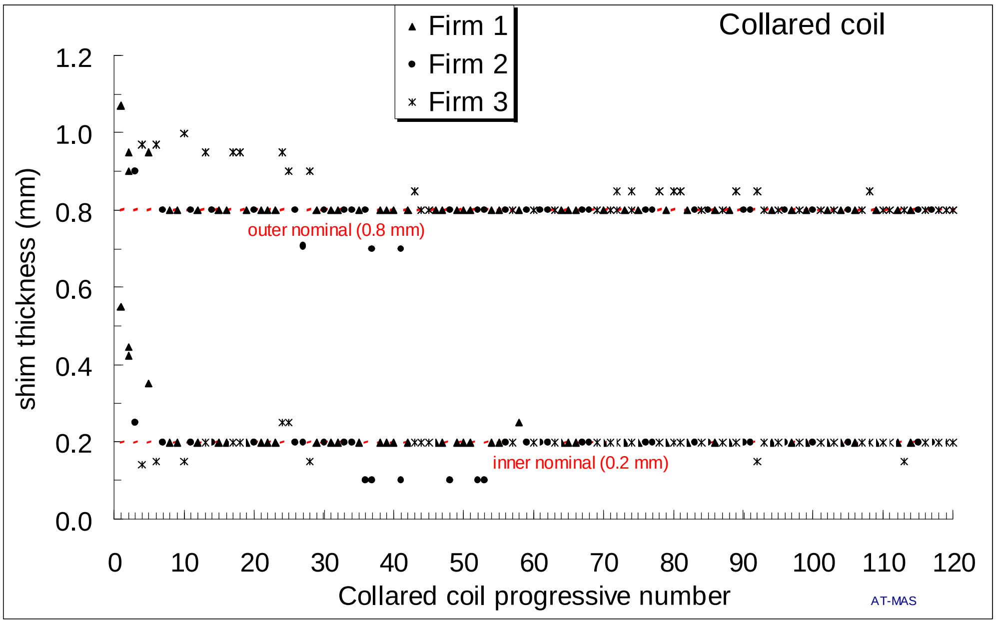


Fig. 2: Thickness of the polar shims used in the collared coils

2. Estimated coil waviness

- Coil waviness estimated from the variation of the multipoles along the axis is below 30 microns. Collared coil 105th (2032) has one aperture with very high waviness (70 microns, see Fig. 3), which is related to an assembly defect. More information in Section 10, page 17.

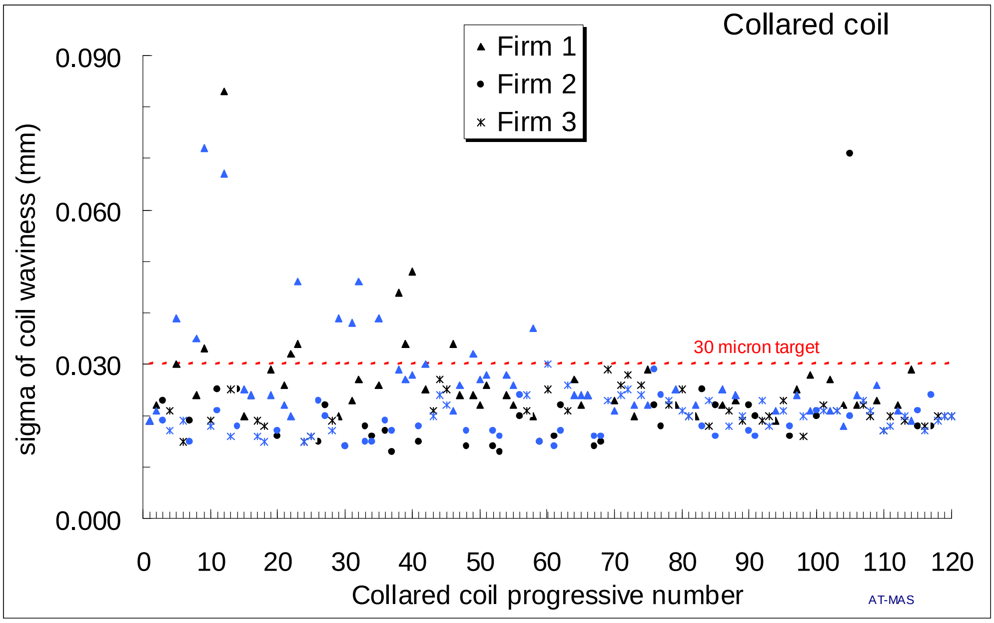


Fig. 3: Estimated coil waviness in the straight part of the measured collared coils (black dots: aperture 1, blue dots: aperture 2).

3. Magnetic length and transfer function

- Magnetic lengths of collared coils 101st to 120th are well within targets (see Fig. 4). The spread in magnetic length is very low.

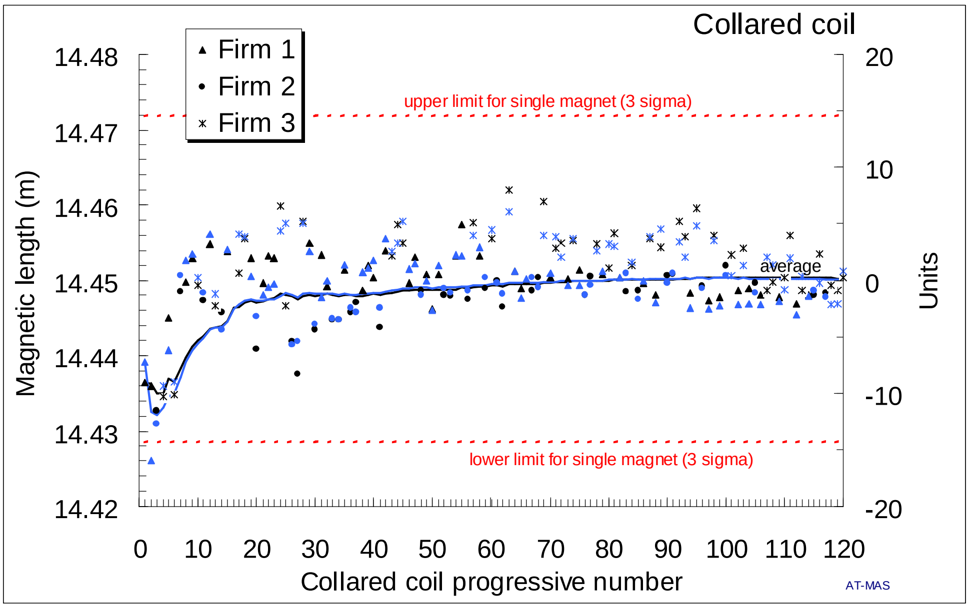


Fig. 4: Magnetic length of the measured collared coils (black dots: aperture 1, blue dots: aperture 2)

- In these two months, Firm3 collared coils have a main field 16 units larger than Firm2 and 12 units larger than Firm1. This previously observed systematic difference between firms is therefore confirmed by latest data.
- The sigma is 9.1 units over all collared coils, and 8.6 units over the last 30 collared coils (10 per manufacturer). This is above the specification (5 units in the cold mass, 6 in the collared coils).
- We remind that the integrated main field (see next page) is the quantity relevant to beam dynamics.

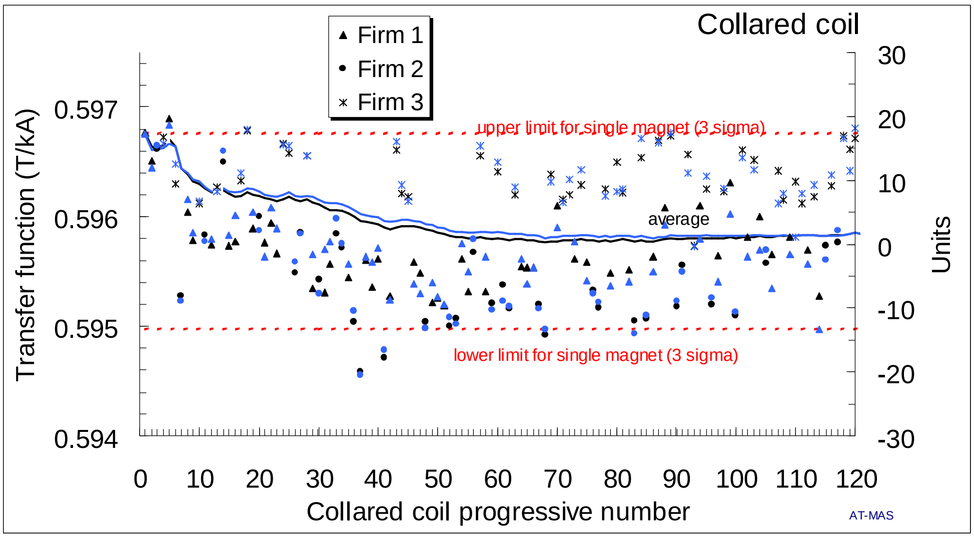


Fig. 5: Main field in the straight part of the collared coils (black dots: aperture 1, blue dots: aperture 2) and average over all collared coils (solid lines).

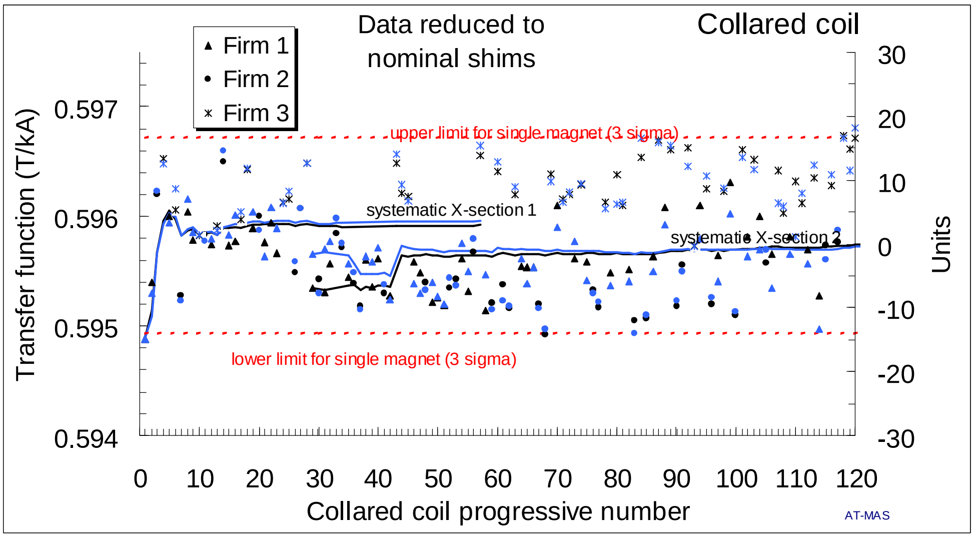


Fig. 6: Main field in the straight part of the collared coils (black dots: aperture 1, blue dots: aperture 2) and best estimate of systematic (solid lines). Data are reduced to nominal shims and separated according to different cross-sections.

- Integrated transfer function in the last 30 collared coils (10 per firm) has a sigma of 9 units. This is within the spec (9.6 in the collared coil, 8 units in the cold mass). Data relative to all collared coils give a sigma of 10.1 units, at the limit of the specification. The situation has improved in the last two months, due to upward trend in Firm1 and Firm2 integrated main field.
- A procedure for adding magnetic laminations in Firms showing low field and reducing their number in Firm3 could correct up to 14 units of systematic difference. The impact of adding ferromagnetic laminations on the magnetic length has been tested on two cold masses at Firm2, confirming the expected results (see web page http://lhc-div-mms.web.cern.ch/lhc-div-mms/MMSPAGES/MA/lamin.html for more information).
- Origins of the problem under analysis. Data at 1.9 K only partially confirm this systematic difference (see Appendix B). For this reason, it has been decided to calibrate all measuring systems in the firms before carrying out the corrective action with ferromagnetic laminations.

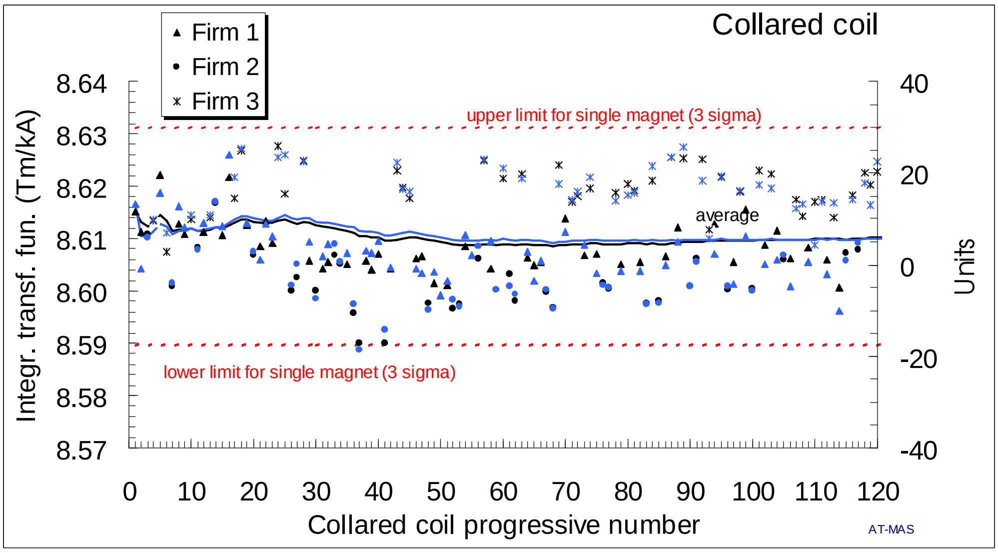


Fig. 7: Integrated transfer function (black dots: aperture 1, blue dots: aperture 2) and average over all collared coils (solid lines)

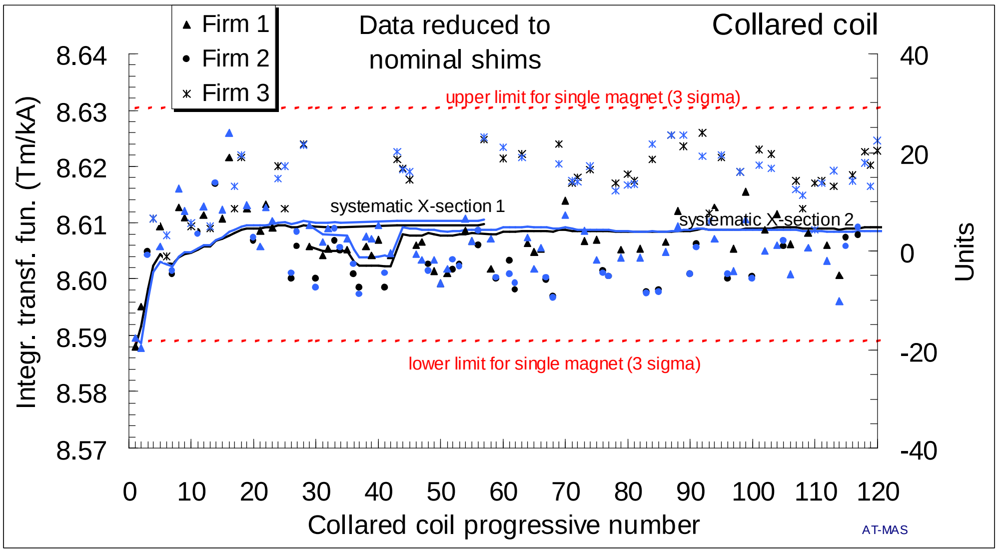


Fig. 8: Integrated transfer function (black dots: aperture 1, blue dots: aperture 2) and best estimate of systematic (solid lines). Data are reduced to nominal shims and separated according to different cross-sections.

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.

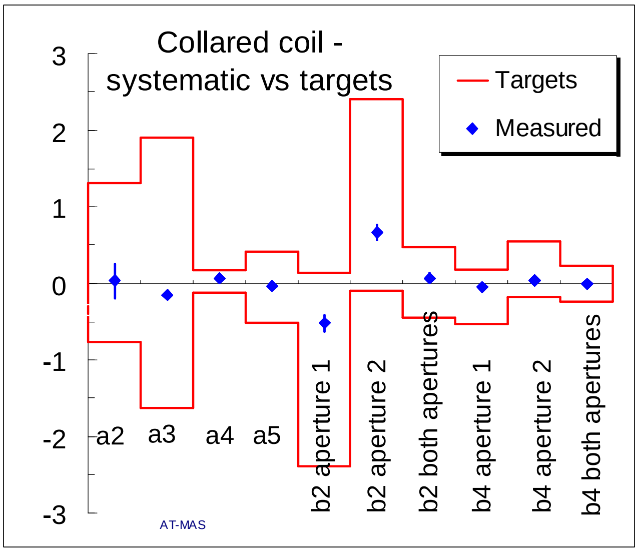
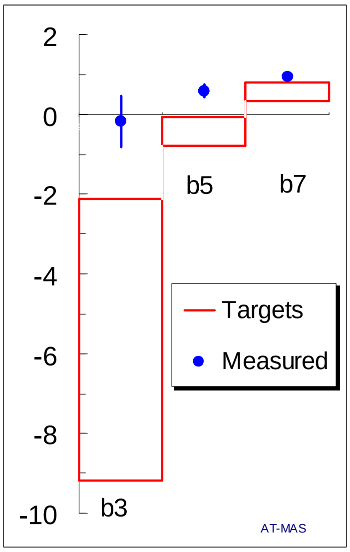


Fig. 9: Best estimate for systematic skew multipoles and even normal multipoles (markers) versus beam dynamics limits (red line). An error of two sigma (95% confidence limit) is associated to the best estimates of systematics.

- Best estimates for systematic odd multipoles are shown in Fig. 10. In the left part, raw data are plotted. This gives the actual situation for the manufactured collared coils: b_3 and b_5 are larger than the upper specifications of 1.9 and 0.64 units respectively.
- In the right part of Fig. 10, data are reduced to nominal shims and separated according the two cross-sections (35 collared coils have cross-section 1, 85 have cross-section 2). With the X-section 2, b_3 b_5 and b_7 are larger than the specification of 1.16, 0.40 and 0.30 units respectively.



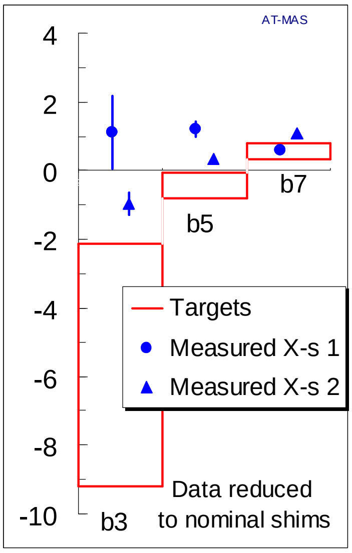


Fig. 10: Best estimate for systematic odd normal multipoles (markers) versus beam dynamics limits (red line). An error of two sigma (95% confidence limit) is associated to the best estimates of systematics. Raw data (left) and data reduced to nominal shims and separated according to different cross-sections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

5. Summary of systematic differences between firms

We observe a relevant systematic difference between firms only for the main field:

- Main field: Firm 3 is higher than Firm 2 of around 20 units, Firm1 being in between (see Fig. 5). The global sigma (i.e. the sigma of all collared coils, with a complete mixing of manufacturers) is 10 units.

In other cases, we observe a small systematic difference between firms.

- Normal decapole: in the last 20 collared coils, Firm 1 is higher than Firm 3 of 1.0 unit, Firm2 being in between. Global sigma: 0.4 units. This systematic difference is not negligible compared to the allowed range (0.7 units).
- Normal 14[th] pole: b_7 at Firm 1 is 0.25 units higher than Firm 2, Firm 3 being in between. Global sigma: 0.14 units. This is rather small if compared to the allowed range (0.5 units).
- Normal sextupole: in the last 20 collared coils, Firm 3 is higher than Firm 2 of 2.0 units, Firm 1 being in between. Global sigma: 1.2 units. This is completely negligible compared to the allowed range (7 units).

No large systematic differences between firms are visible in a_2, a_3, a_4 b_2 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.
- A few collared coils from Firm3 manufactured in the last months have a systematic a_3 of about 0.5 units (see Fig. 12); this is not worrying for beam dynamics since margins are large.

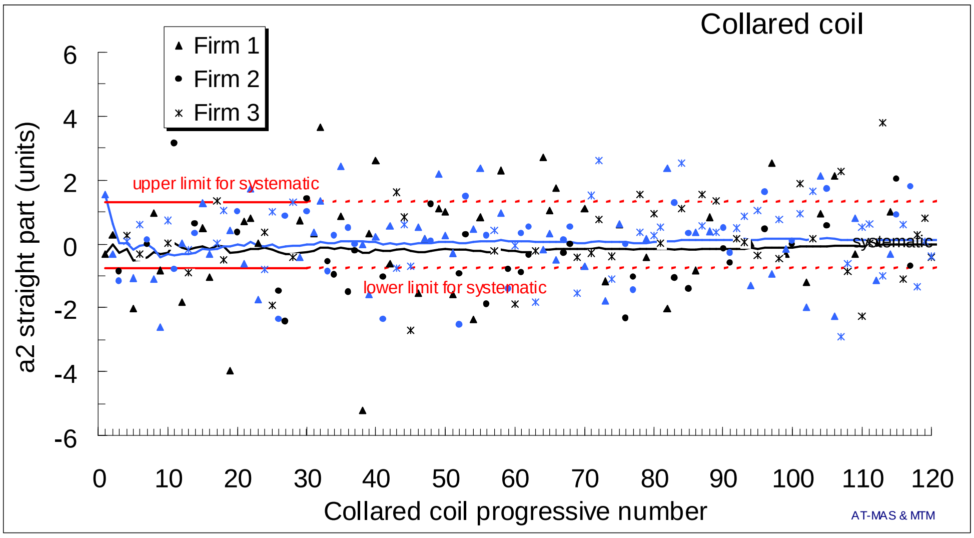


Fig. 11: Average a_2 in the straight part of the collared coils (black dots: aperture 1, blue dots: aperture 2), best estimate for systematic in each aperture (solid lines), and beam dynamics limits for the systematic (red lines) based on correlations with 30 cryodipoles.

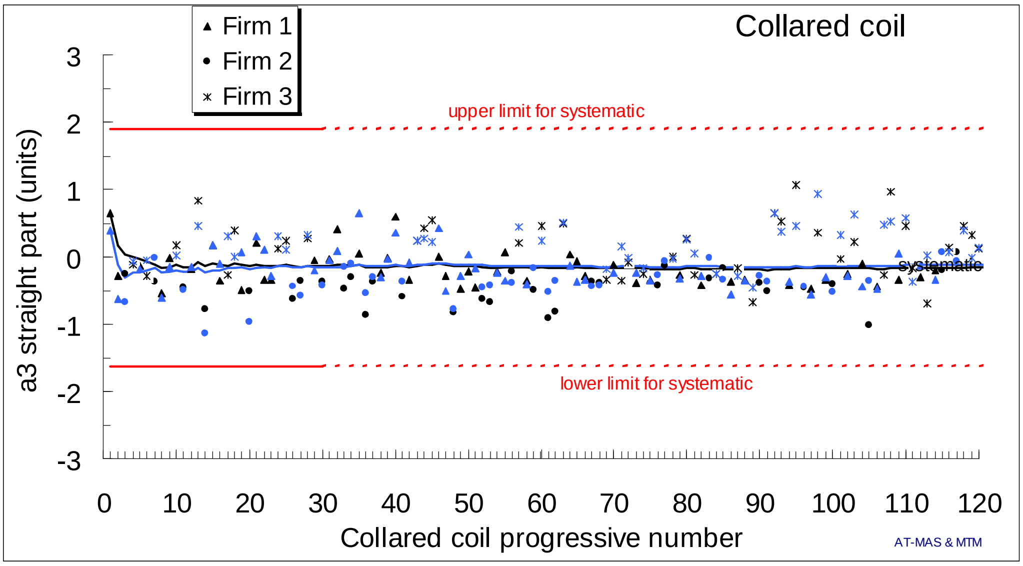


Fig. 12: Average a_3 in the straight part of the collared coils (black dots: aperture 1, blue dots: aperture 2), best estimate for systematic in each aperture (solid lines), and beam dynamics limits for the systematic (red lines) based on correlations with 30 cryodipoles.

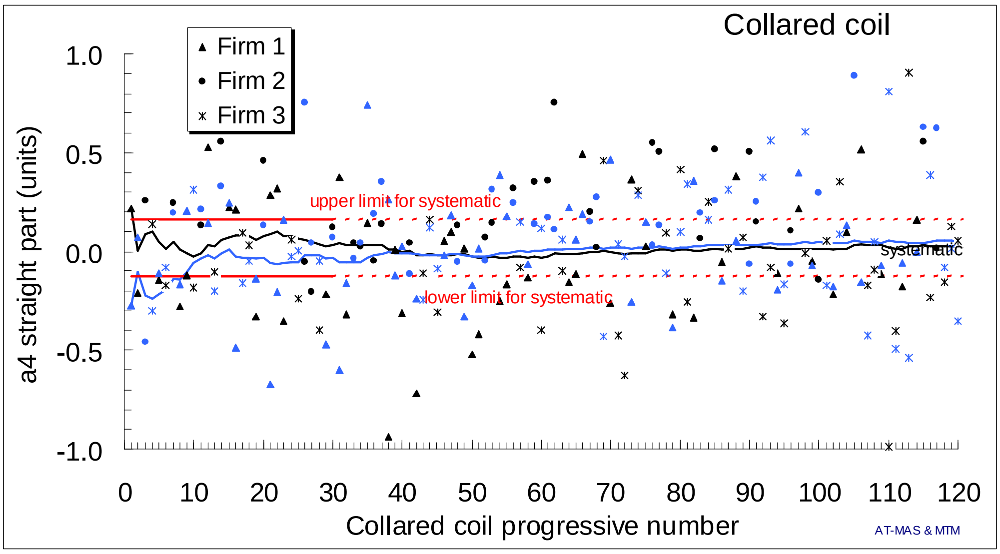


Fig. 13: Average a_4 in the straight part of the collared coils (black dots: aperture 1, blue dots: aperture 2), best estimate for systematic in each aperture (solid lines), and beam dynamics limits for the systematic (red lines) based on correlations with 30 cryodipoles.

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).

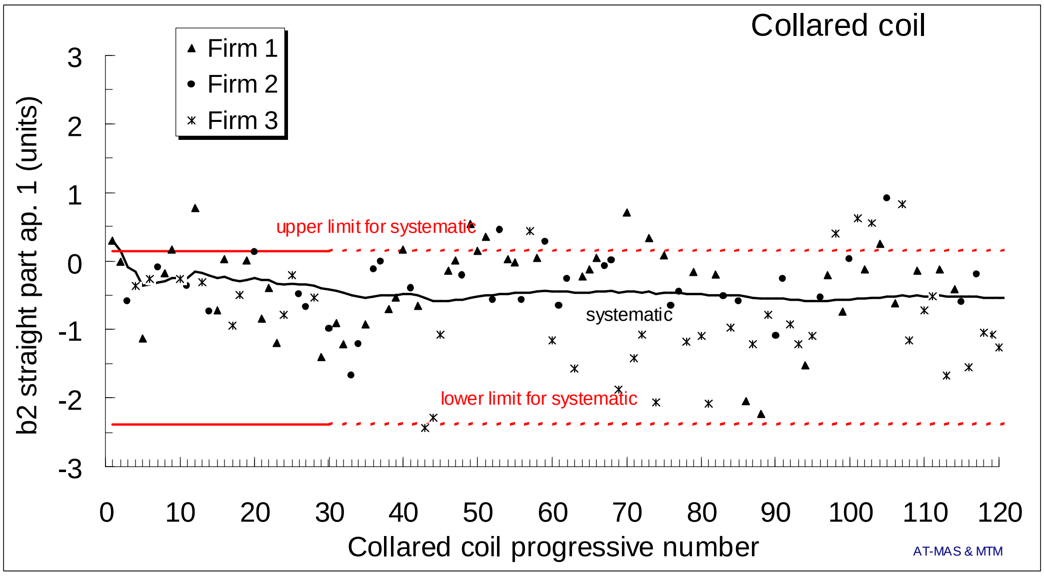


Fig. 14: Average b_2 in the straight part of the aperture 1 collared coils (black dots), best estimate for systematic per aperture (black line), and beam dynamics limits for the systematic (red lines) based on correlations with 30 cryodipoles.

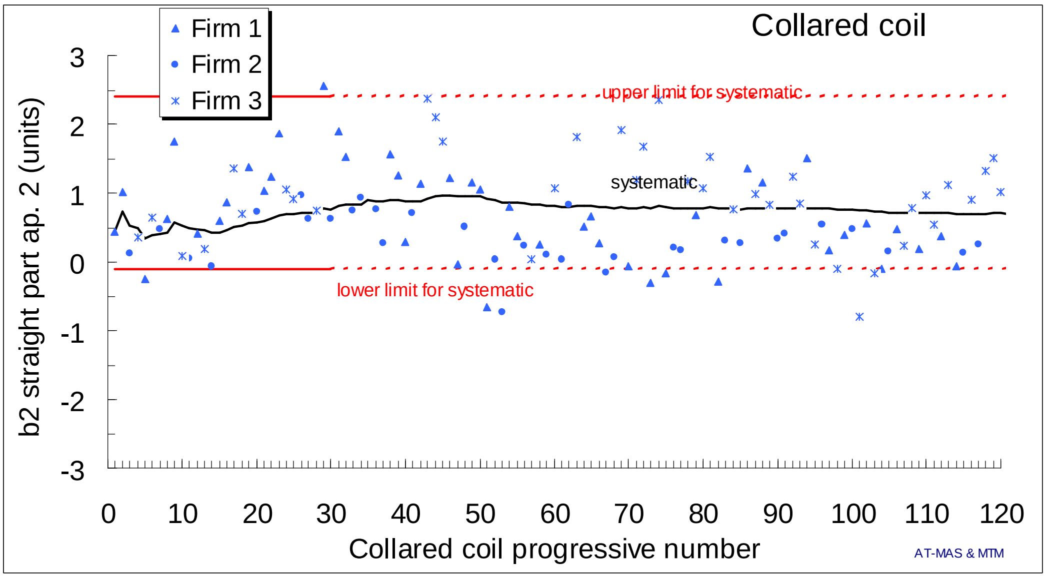


Fig. 15: Average b_2 in the straight part of the aperture 2 collared coils (blue dots), best estimate for systematic per aperture (blue line) and beam dynamics limits for the systematic (red lines) based on correlations with 30 cryodipoles.

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

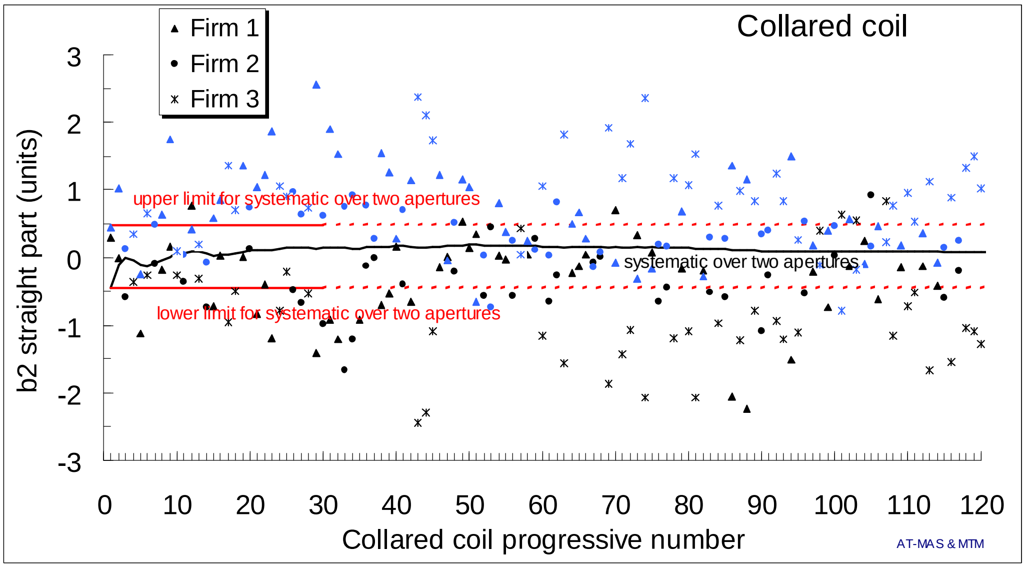


Fig. 16: Average b_2 in the straight part of collared coils ((black dots: aperture 1, blue dots: aperture 2), best estimate for systematic per beam (soild line) and beam dynamics limits for the systematic (red lines) based on correlations with 30 cryodipoles.

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).

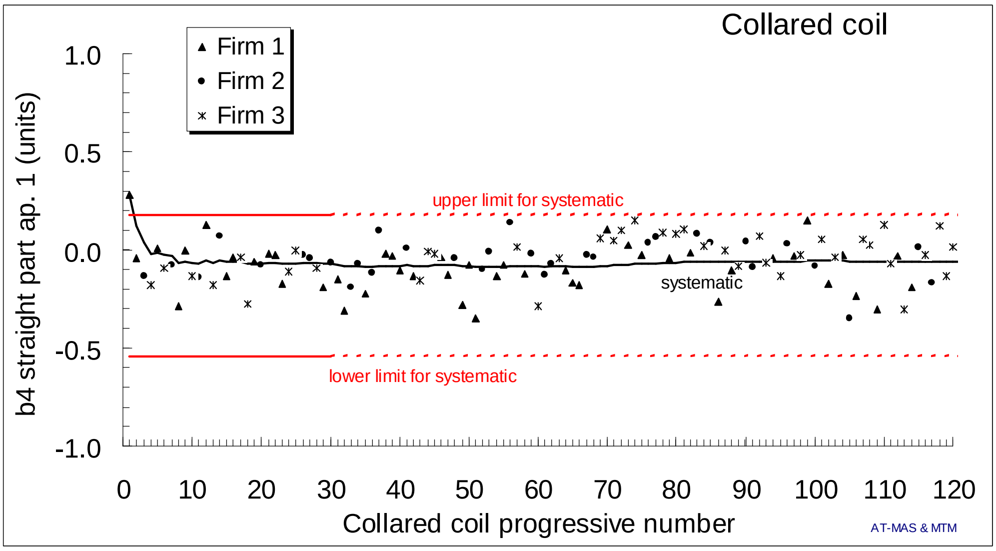


Fig. 17: Average b_4 in the straight part of the aperture 1 collared coils (black dots), best estimate for systematic per aperture (black line), and beam dynamics limits for the systematic (red lines) based on correlations with 30 cryodipoles.

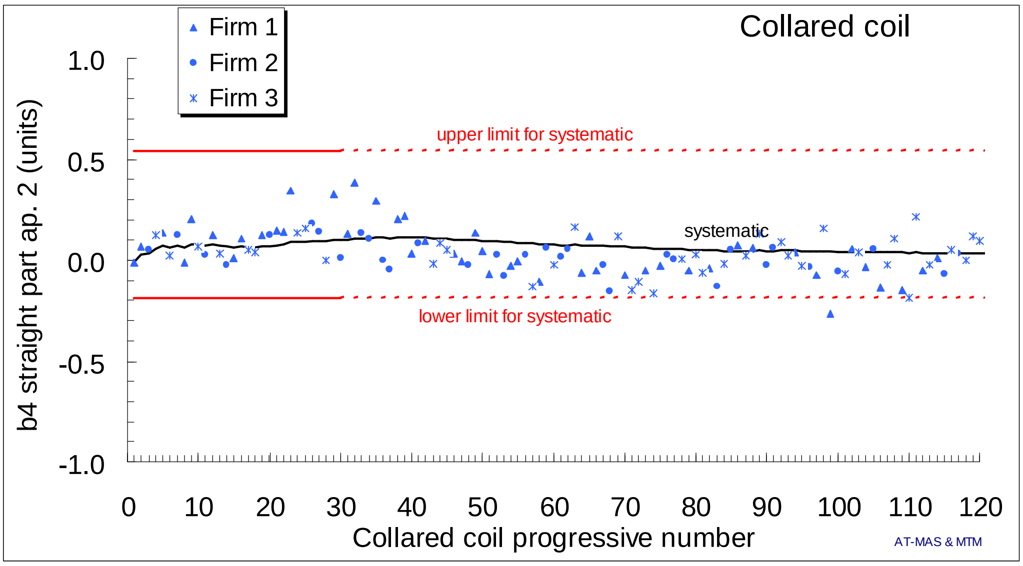


Fig. 18: Average b_4 in the straight part of the aperture 2 collared coils (blue dots), best estimate for systematic per aperture (black line) and beam dynamics limits for the systematic (red lines) based on correlations with 30 cryodipoles.

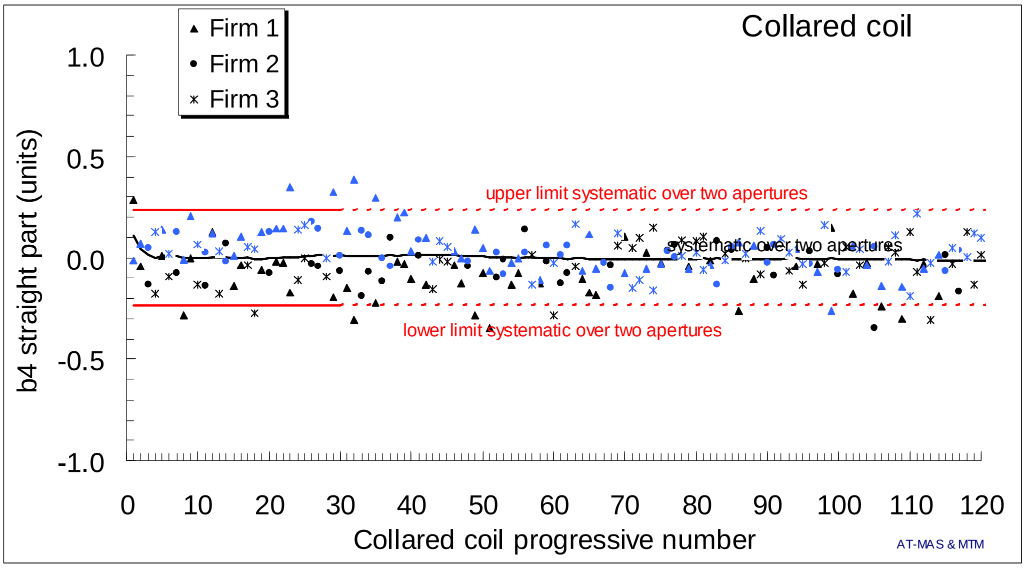


Fig. 19: Average b_4 in the straight part of collared coils (black dots: aperture 1, blue dots: aperture 2), best estimate for systematic per beam (black line) and beam dynamics limits for the systematic (red lines) based on correlations with 30 cryodipoles.

8. Systematic odd multipoles

8.1 Normal sextupole

- New data confirm the previous ones, with a small upward trend: the systematic in X-section 2 is 1.18 units larger than the limit (see fig. 21).
- There is a small positive trend in Firm3: average b_3 has moved from –1.0 units (collared coils between 40[th] and 90[th]) to around 0.5 units (collared coils from 90[th] to 120[th]).
- Systematic differences between firms are small.
- Cryodipoles with the X-section 2 should feature 4.0 units of b_3 at high field; this is outside the specification but within the hard limit of 4.35 units given by the maximum correction of chromaticity.

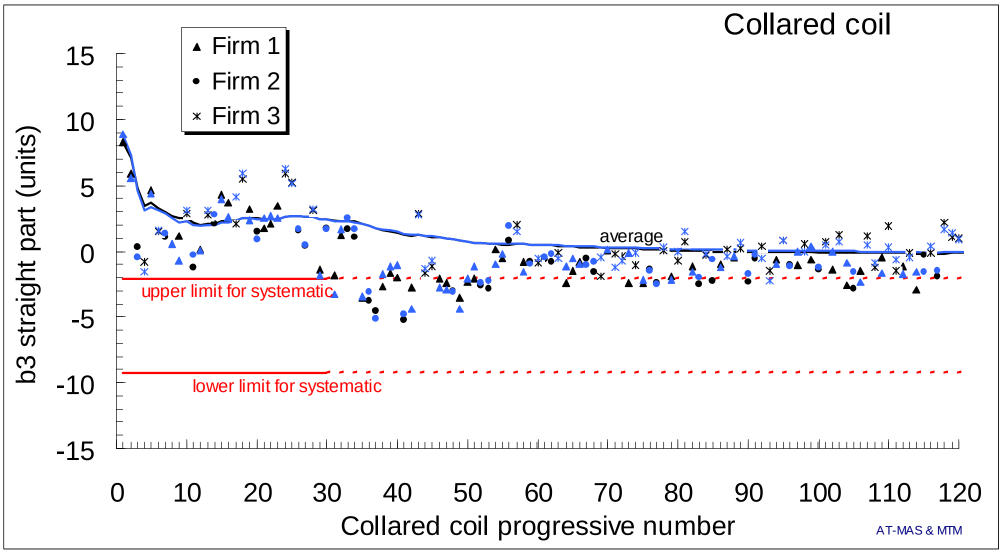


Fig. 20: Average b_3 in the straight part of the collared coils (black dots: aperture 1, blue dots: aperture 2), best estimate for systematic (solid lines), and beam dynamics limits for the systematic (red lines) based on correlations with 30 cryodipoles.

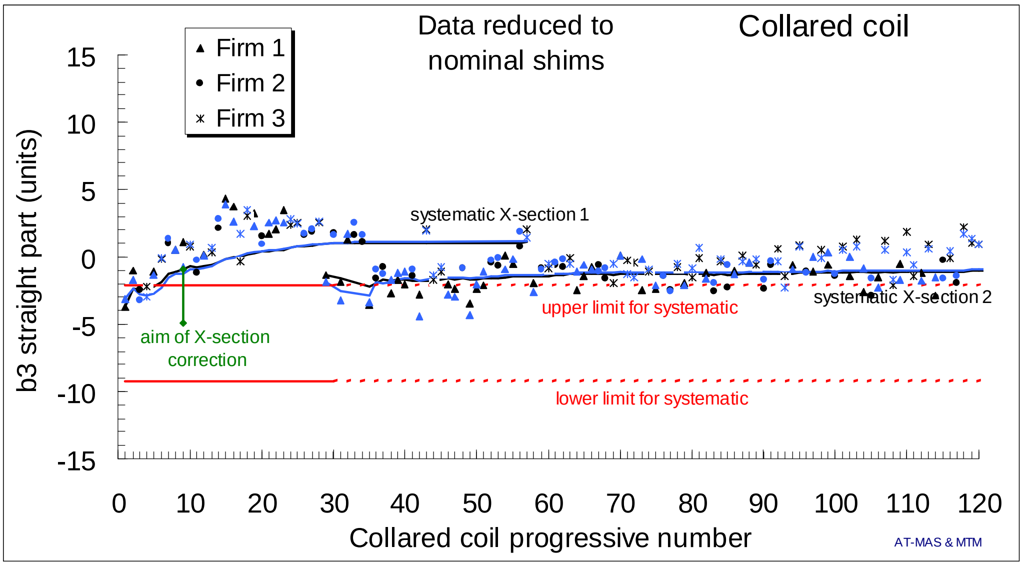


Fig. 21: Average b_3 in the straight part of the collared coils (black dots: aperture 1, blue dots: ap. 2), best estimate for systematic (solid lines), and beam dynamics limits for the systematic (red lines) based on correlations with 30 cryodipoles. Data reduced at nominal shims and separated according to X-section type.

8.2 Normal decapole

- The average normal decapole is stable in Firm1 (around 0.7 units), increasing from around 0.2 to 0.4 units at Firm2, and decreasing from 0.3 to -0.2 units in Firm3. This latest negative trend in Firm3 is rather strong and is going in the right direction: now Firm3 magnets have a normal decapole within targets. This negative trend could be related to the positive trend in normal sextupole (see previous section).
- The best estimate for the systematic is stable at 0.35, i.e. 0.40 more than the limit for the collared coil.

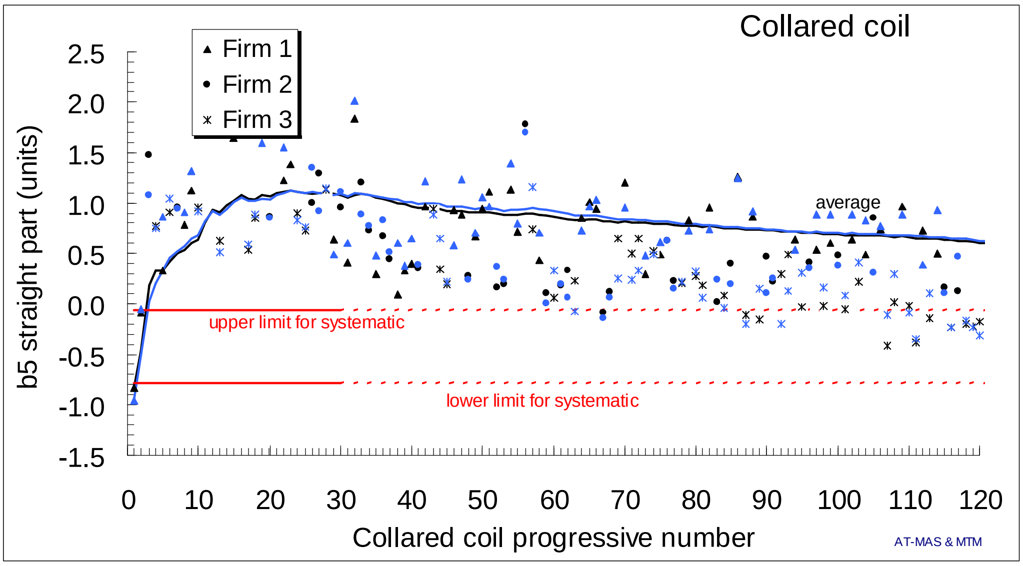


Fig. 22: Average b_5 in the straight part of the collared coils (black dots: aperture 1, blue dots: aperture 2), best estimate for systematic (solid lines), and beam dynamics limits for the systematic (red lines) based on correlations with 30 cryodipoles.

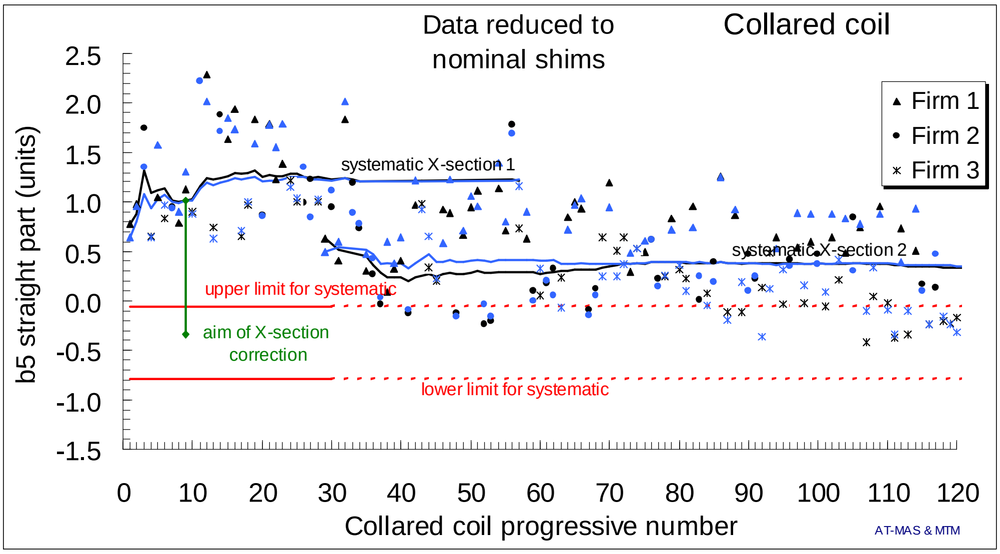


Fig. 23: Average b_5 in the straight part of the collared coil (black dots: aperture 1, blue dots: aperture 2), best estimate for systematic (solid lines), and beam dynamics limits for the systematic (red lines) based on correlations with 30 cryodipoles. Data are reduced to nominal shims and separated according to different cross-sections.

8.3 Normal 14-th pole

- New data confirm previous trends: new X-section collared coils have a systematic b_7 of around 1.1 units, i.e. 0.3 units more than the upper limit. The associated error is small (0.04 units at 95% confidence level, see Fig. 10).
- Firm1 has an average of 1.25 units, but latest coils are between 1.25 and 1.35 units. Firm2 and Firm3 are stable at 1.0 and at 1.1 respectively. The negative trend in Firm2 has disappeared.
- The best estimate for the systematic is 1.10 units, which corresponds to 0.36 units at injection.

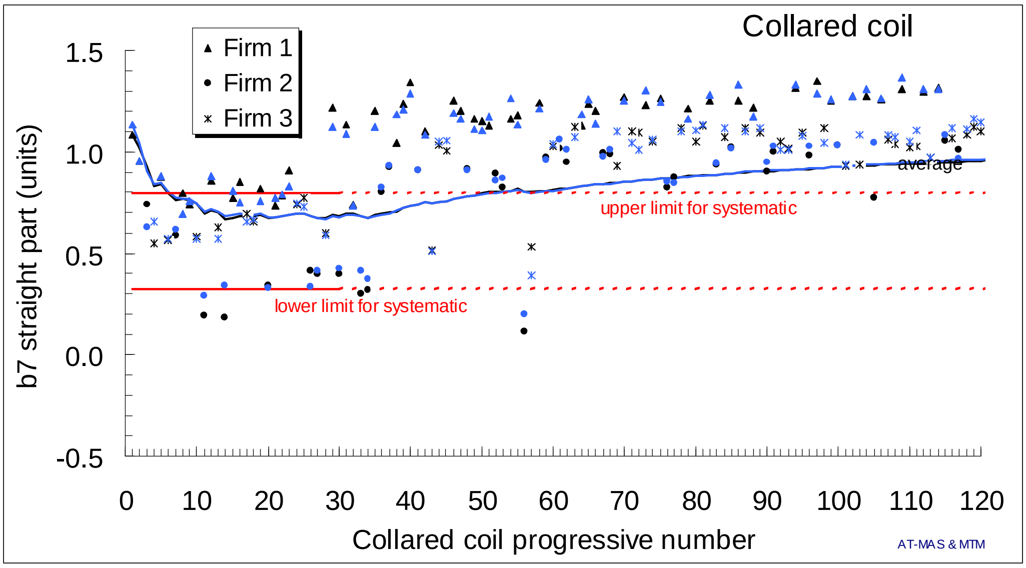


Fig. 30: Average b_7 in the straight part of the collared coils (black dots: aperture 1, blue dots: aperture 2), best estimate for systematic (solid lines), and beam dynamics limits for the systematic (red lines) based on correlations with 30 cryodipoles.

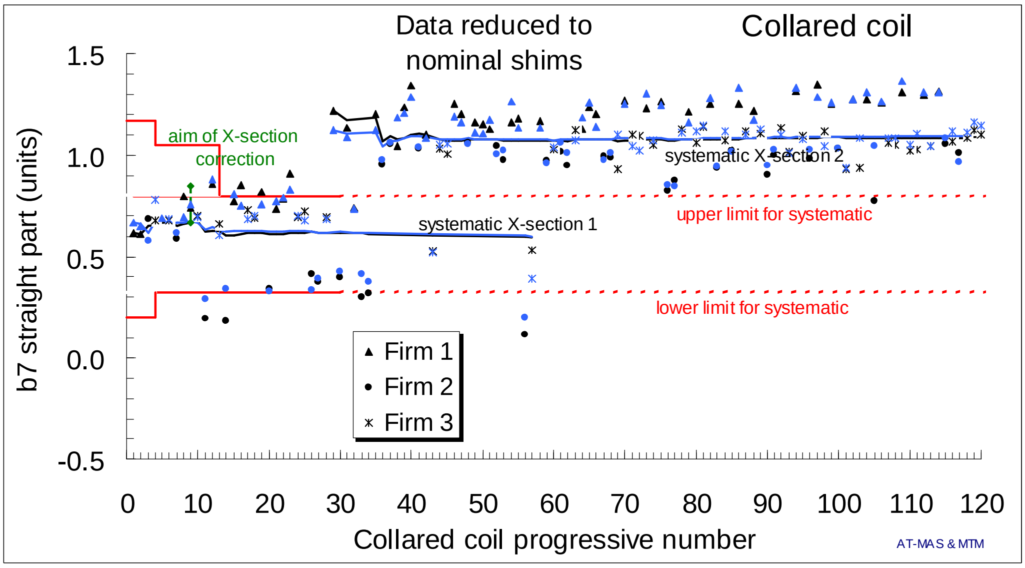


Fig. 25: Average b_7 in the straight part of the collared coils (black dots: aperture 1, blue dots: aperture 2), best estimate for systematic (solid lines), and beam dynamics limits for the systematic (red lines) based on correlations with 30 cryodipoles. Data are reduced to nominal shims and separated according to different cross-sections.

9. Random multipoles

We repeat the same considerations made in the previous report.

- Random per manufacturer and global random (i.e., the standard deviation of the distribution of all magnets) are shown in Figs. 26 and 27.
- Raw data (see Fig. 26) show an out of tolerance for b_3 and b_5. This is mainly due to the change of cross-section that shifted down these multipoles of 3 units and 1 unit respectively. The other parameters are within specifications, also in the hypothesis of a complete mixing.
- When data are reduced to nominal shims and split according to the cross-section type, one observes a random b_3 out of tolerance in the old X-section: this is due to the upward trend (see Section 7.1, Fig. 21). This is the only out of tolerance in the old X-section.
- We now have a good statistics for the new cross-section: all the multipoles are within specifications, global integrated main field BdL being slightly above the specification.

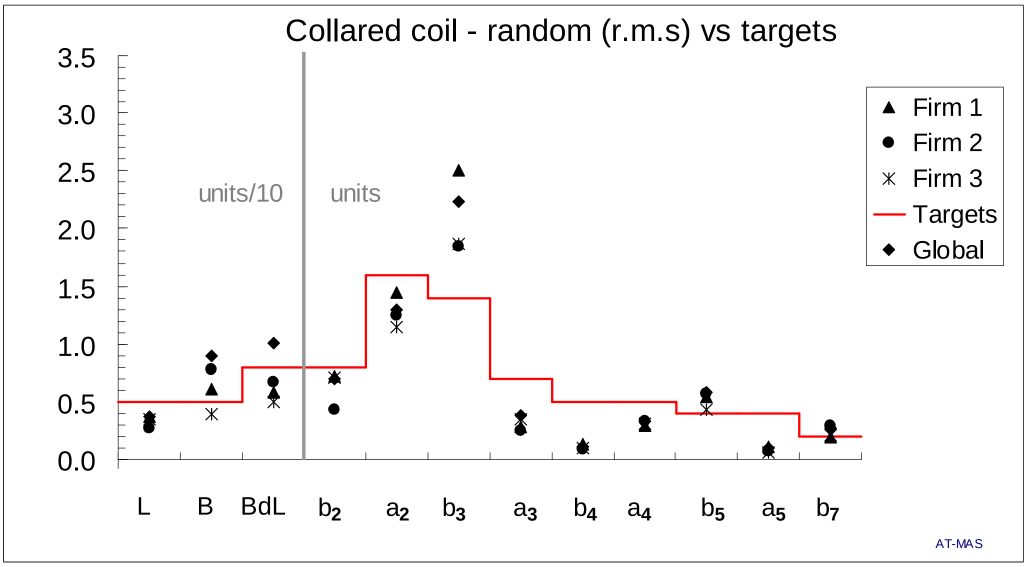


Fig. 26: Random component in the measured collared coils

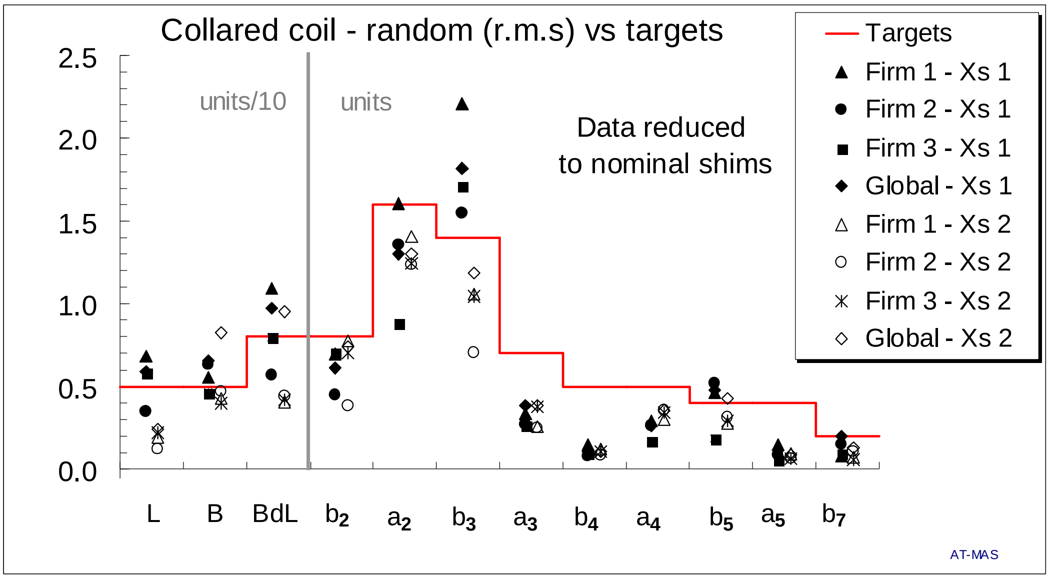


Fig. 27: Random component in the measured collared coils. Data reduced to nominal shims and split according to different cross-sections.

10. Holding point results

Table I: results of the holding point for the measured collared coils

	Magnet name	Collared coil measure	Result	Comments
101st	3034	15/05/03	OK	
102nd	1040	14/05/03	OK	
93rd	3028	14/05/03	NA	Re-measurement before de-collaring
103rd	3036	22/05/03	Ok-W	Expected increase in main field towards coil end (CS) missing, no explanation found
104th	1046	21/05/03	OK	
105th	2032	21/05/03	HOLD	Large variations (more than 8 sigma) of high order multipoles in several positions along the axis - decollaring asked
106th	1042	26/05/03	OK	
107th	3037	26/05/03	OK	Low main field in position 2 as in 3036
108th	1026	27/05/03	OK	
14th	2005	03/06/03	OK-W	Recollared after 1.5 years, higher c1 (+10 units), higher b3 (+1 unit), higher b5 and b7 as in the other recollared magnets
109th	1047	04/06/03	OK-W	Spike in b3 b5 a4 a6 at 5-7 sigma along 1 m in ap. 2 at 3.5 m from CS - could be due to inner radial displ. of 0.2 mm of bl 5 and 6 towards cold bore
110th	3041	03/06/03	OK	
111th	3038	06/06/03	OK	
112th	1049	11/06/03	OK	
93rd	3028	12/06/03	OK	Measurement after re-collaring
113th	3039	13/06/03	OK	Non-nominal shims used in the inner layers of both apertures
114th	1050	19/06/03	OK	
115th	2036	19/06/03	OK	
116th	3042	23/06/03	OK	
117th	2034	20/06/03	OK	
118th	3044	25/06/03	OK	
119th	3043	26/06/03	OK	
120th	3045	30/06/03	OK	

- 2005 has been re-collared after 1.5 years. We observe a field quality variation in b3, b5 and b7 that is in agreement with what was observed in other re-collared magnets. Indeed, a large variation of the main field (10 units) has also been observed (see Table II).
- 3028 has been re-collared. Field quality variations are in agreement with what was previously observed in Firm1 and 2, i.e., an increase on b5 between 0.3 and 0.6 units and a decrease of b7 of 0.10 to 0.30 units. This is the second measured effect of de-collaring on field quality. We recall that the first case (3010) showed no change of harmonics, contrary to the experience of Firm1 and 2.
- Updated summary of the impact of re-collaring on field quality in Table II. Information in http://lhc-div-mms.web.cern.ch/lhc-div-mms/MMSPAGES/MA/1027.html

Table II: Multipole variation due to re-collaring, measurements on 6 cases.

Differences n-(n-1) collaring							
Magnet	decoll.	Ap.	c1	b3	b5	b7	b9
2002 - I	partial	1	-2.4	0.39	0.18	-0.04	-0.005
2002 - I	partial	2	-3.0	0.51	0.14	-0.05	-0.003
2011	complete	1	1.0	-0.80	0.65	-0.28	0.016
2011	complete	2	0.6	-0.67	0.50	-0.23	0.009
2013	complete	1	3.4	-0.63	0.54	-0.09	0.024
2013	complete	2	4.7	-0.38	0.50	-0.11	0.028
1027	complete	1	-0.3	-0.43	0.25	-0.04	0.007
1027	complete	2	0.2	-0.46	0.39	-0.05	0.004
2002 - II	complete	1	-0.2	-0.47	0.63	-0.33	0.085
2002 - II	complete	2	0.3	-0.22	0.36	-0.23	0.076
3010	complete	1	5.5	0.06	-0.07	-0.08	0.010
3010	complete	2	4.2	-0.28	-0.02	-0.11	0.014
2005	complete	1	12.7	1.11	0.56	-0.19	-0.01
2005	complete	2	14.1	1.49	0.32	-0.13	-0.01
3028	complete	1	1.13	-1.96	0.35	-0.10	0.04
3028	complete	2	1.22	-1.84	0.25	-0.07	0.03

- 2032 had several spikes (up to 10 sigma) along the magnet axis in high order multipoles in one aperture. These spikes can be obtained by a movement of block 6 (i.e., the block close to the inner layer pole) in one quadrant of 0.5 mm towards the center of the aperture. It has been asked for a de-collaring.
- 3036 and 3037 do not feature the usual main field increase in position 2 (close to the head connection side). This increase of a few units is due to the coil head. No explanation for this missing increase has been found, and the collared coils have been released.
- 1047 had some spikes of 5 to 7 sigma in b3 b5 a4 a6 along 1 m in aperture 2 at 3.5 m from connection side. Simulations show that these spikes can be obtained by an inner radial displacement of 0.2 mm of blocks 5 and 6 towards the cold bore. The collared coil has been released with a warning.

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Appendix A

The link between the progressive number used in Figures and the official name is given in Table III.

Table III: relation between magnet numbers used in Figs. 2-25 and official names

1st	1001	21st	1010	41st	2014	61st	2015	81st	3022	101st	3034
2nd	1002	22nd	1011	42nd	1021	62nd	2020	82nd	1036	102nd	1040
3rd	2001	23rd	1012	43rd	3011	63rd	3015	83rd	2026	103rd	3036
4th	3001	24th	3007	44th	3012	64th	1020	84th	3023	104th	1046
5th	1003	25th	3008	45th	3013	65th	1030	85th	2027	105th	2032
6th	3002	26th	2008	46th	1026	66th	1031	86th	1037	106th	1042
7th	2003	27th	2007	47th	1022	67th	2021	87th	3024	107th	3037
8th	1004	28th	3009	48th	2016	68th	2022	88th	1038	108th	3026
9th	1005	29th	1013	49th	1023	69th	3016	89th	3025	109th	1047
10th	3003	30th	2006	50th	1024	70th	1032	90th	2028	110th	3041
11th	2002	31st	1014	51st	1025	71st	3018	91st	2029	111th	3038
12th	1006	32nd	1015	52nd	2017	72nd	3017	92nd	3027	112th	1049
13th	3004	33rd	2010	53rd	2018	73rd	1033	93rd	3028	113th	3039
14th	2005	34th	2009	54th	1027	74th	3019	94th	1045	114th	1050
15th	1007	35th	1016	55th	1028	75th	1034	95th	3029	115th	2036
16th	1008	36th	2013	56th	2011	76th	2023	96th	2030	116th	3042
17th	3005	37th	2012	57th	3010	77th	2025	97th	1039	117th	2034
18th	3006	38th	1017	58th	1029	78th	3021	98th	3030	118th	3044
19th	1009	39th	1018	59th	2019	79th	1035	99th	1041	119th	3043
20th	2004	40th	1019	60th	3014	80th	3020	100th	2031	120th	3045

Appendix B

Here we compare the integrated transfer function measured in the collared coil to the sample of magnets tested at 1.9 K[1]. In Fig. 28 we repeat Fig. 7, i.e. the integrated transfer function measured in collared coils, without reduction to nominal shims. In Fig. 29 we plot the measurements at 1.9 K at high field (which is more critical for beam dynamics constraints).

Considering the sample of magnets tested at cold, we observe in the collared coil a difference between Firm3 and Firm2 of 17 units, which should correspond to 14 units at cold: we measure at 1.9 K a difference of 8 units. The difference between Firm1 and Firm3 in the collared coil is 12 units, and should give 10 units difference at cold: we measure at 1.9 K a difference of 5.5 units.

The sigma of the correlation is 5 units: this means that on a single magnet one can easily have changes from warm to cold of up to 10 units. One can conclude that, if the systematic difference between Firms exists, it is less than what has been observed in the collared coils. A calibration of all warm measuring systems is in progress.

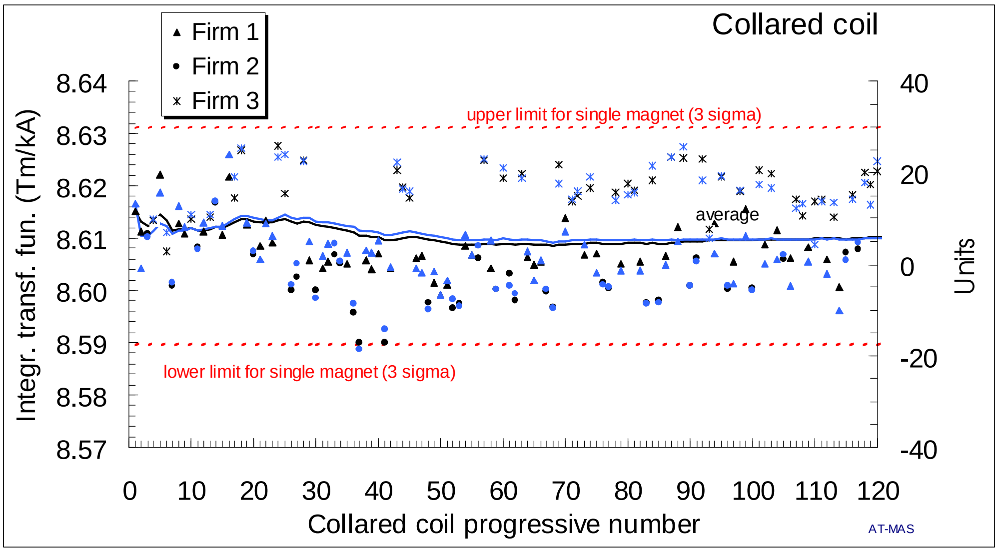

Fig. 28: Integrated transfer function in the collared coil.

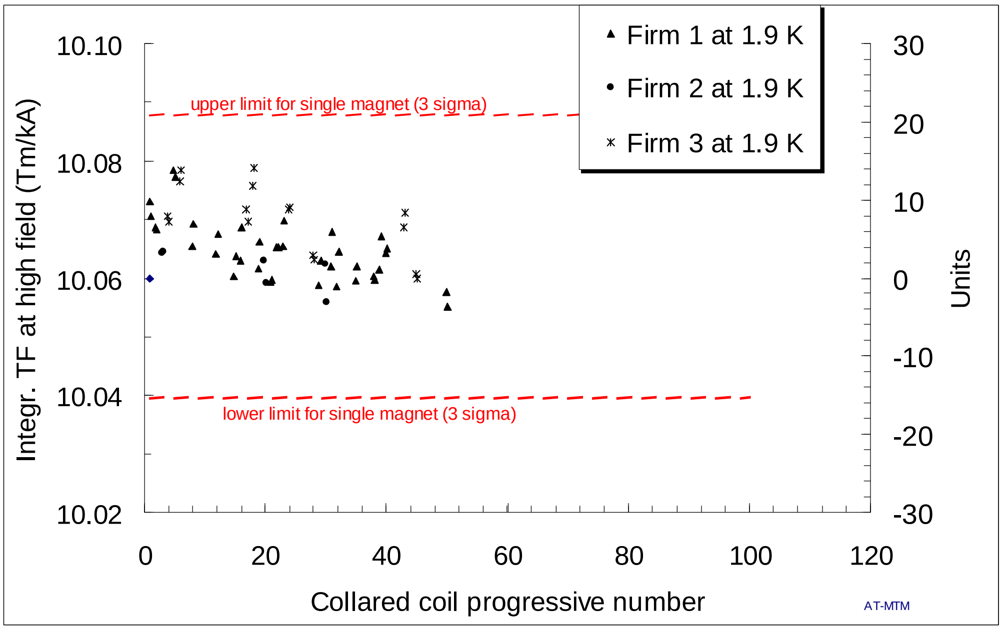

Fig. 29: Integrated transfer function in the cryomagnet, measured at high field (courtesy of AT-MTM).

[1] Data at 1.9 K from AT-MTM group, AS section.

Appendix C

Collared coil 2035 has been collared with 0.125 mm more of insulation in the mid-plane. Results on allowed multipoles and main field are given in Table IV. In the first two rows we give the differences (one per aperture) between 2035 and the average of all Firm2 magnets with cross-section 2. In rows three, four and five we give the expected effect of this change according to a 'rigid' electromagnetic model[2], to a model which includes coil and collar deformations[3], and to the results of the experiment on a short model. In the last row the measured spread over the magnets with cross-section 2 in Firm2 is given (one sigma). The results of the test on the long dipole are in agreement with models and experiment within 2 sigma. No impact on skew multipoles is observed, as in the short model. Eight more magnets (two in Firm2, and three in Firm3 and 1) will be manufactured to have more statistics.

Table IV: Effect of change of midplane insulation measured on short and long dipoles, and models.

	C1	b3	b5	b7
diff 2035 ap 1	-1.0	-2.7	-0.21	-0.23
diff 2035 ap 2	0.7	-2.5	-0.62	-0.10
model rigid	-3.1	-3.2	-0.81	-0.20
model defor	-3.1	-4.0	-0.60	-0.23
experiment	-7.9	-3.5	-0.52	-0.18
sigma (20 coll. coils)	4.5	0.7	0.31	0.10

[2] In this model we consider collars and copper wedges as infinitely rigid, and thus the increase in the midplane insulation is compensated by a uniform azimuthal compression of the coil.
[3] In this model the collar and coil deformations (both azimuthal and radial) are evaluated through a finite element code.