Report on field quality in the main LHC dipole collared coils: July-August 2003

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This report gives data relative to field quality measured in collared coils during the period July 1–August 31 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. **404650**

The dashboard

- Available measurements: 163 collared coils, 104 cold masses, 49 cryodipoles.
- In these two months, 43 collared coils: 9 from Firm1, 12 from Firm2 and 22 from Firm3.

What's new

- **Production rate**: notwithstanding the summer holidays, we had a large increase of production rate: around 20 collared coils per month. Firm3 has reached 2.5 collared coils per week, and has produced as much as Firm1 and Firm2 together.
- **Length of feedback loop:** The delay between collared coil magnetic measurements and cold test went down from 15 to 12 months (in average), and from 4.5 to 2 months (minimal, obtained for 3038). The delay between cold mass magnetic measurements at 300 K and cold test went down from 7 to 5.5 months (in average), and from 45 to 36 days (minimal, obtained for 3038).
- **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 at the limit of the target. The 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 has been completed in August.
- **Corrective action, odd multipoles:** six collared coils have been assembled with 0.125 mm more in mid-plane insulation. Results are consistent with simulations, and systematic b_3 and b_5 are within targets. The Field Quality Working Group of 2nd September has advised to implement this change on all magnets as soon as possible, and the Main Ring Committee of 17th September has approved the change of baseline. More details in Section 8, pg. 12-14 and Appendix B, pg. 17-18. Updated results also at the end of the mid-plane insulation experiment page in http://lhc-div-mms.web.cern.ch/lhc-div-mms/MMSPAGES/MA/mid_ins.html.
- **Trends in b_3, b_5 and b_7 in Firm3**: we continue to observe trends in odd normal multipoles in Firm3. More information in Section 8, pg. 12-14.
- **Trends in systematic and random harmonics**: For all other multipoles, new data confirm the previous ones.
- **Open case, assembly fault:** collared coil 2035 showed large spikes (up to 10 sigma) in multipoles along the axis. These variations can be obtained from simulations by inner radial movements of 0.5 to 0.8 mm of the inner layer close to the pole, such as for 2032. The collared coil is therefore held. More information in Section 10, pg. 16.

1. Measured magnets and assembly data

- 43 'new' collared coils have been measured (collared coils 121st to 163rd)
  - 9 of Firm1 (1044, 1048, 1051-55, 1057 and 1059)
  - 12 of Firm2 (2024,2033,2035,2037-44 and 2048)
  - 22 of Firm3 (3046-66 and 3068)

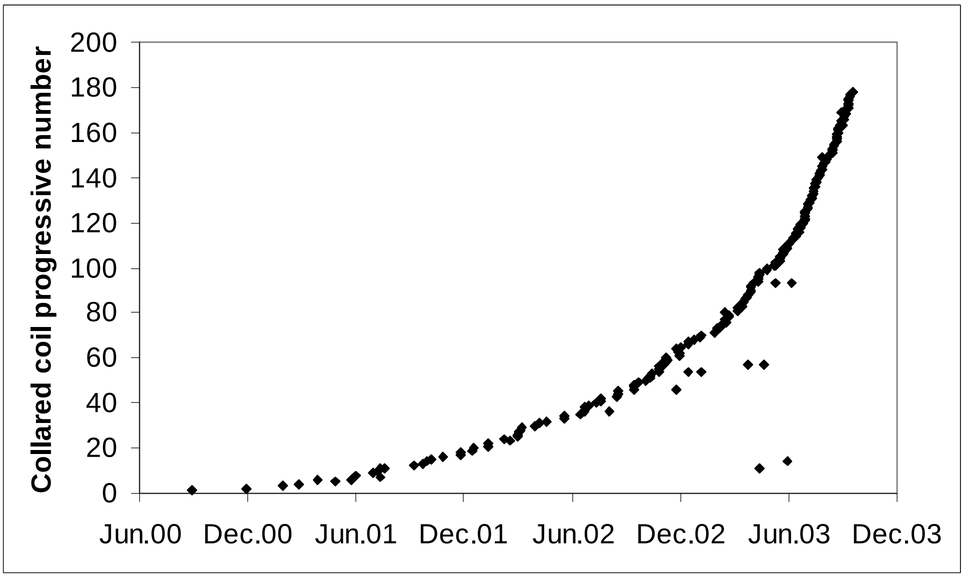

Fig. 1: Collared coil progressive number versus date of magnetic measurement.
Dots out of the main trend are relative to collared coils measured more than one time.

- Cross-section: all magnets with cross-section 2, six magnets with additional mid-plane insulation of 0.125 mm (cross-section 3): 2035, 2040, 2043, 3056, 3059, 3060.
- All shims are nominal, with the exception of nine Firm3 collared coils, featuring 0.05 mm more on the outer layer (outer coil too small) [see Fig. 2]. This has a small impact on field quality. On the other hand, we have one collared coil in Firm1 with 0.1 mm less on both layers (outer and inner layer too large), giving a large effect on allowed multipoles.

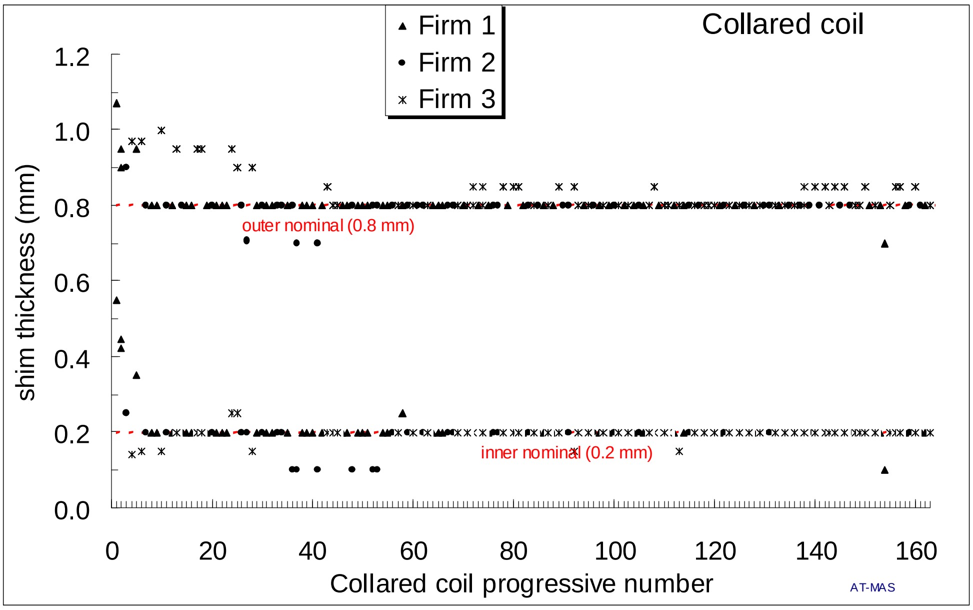

Fig. 2: Thickness of the polar shims used in the collared coils

2. Estimated coil waviness

- Coil waviness estimated from the variation of the multipoles along the axis is below 30 microns. Collared coil 130th (2035) has one aperture with large waviness (45 microns, see Fig. 3), which is related to an assembly defect similar to the case of 105th (2032). More information in Section 10, page 17.

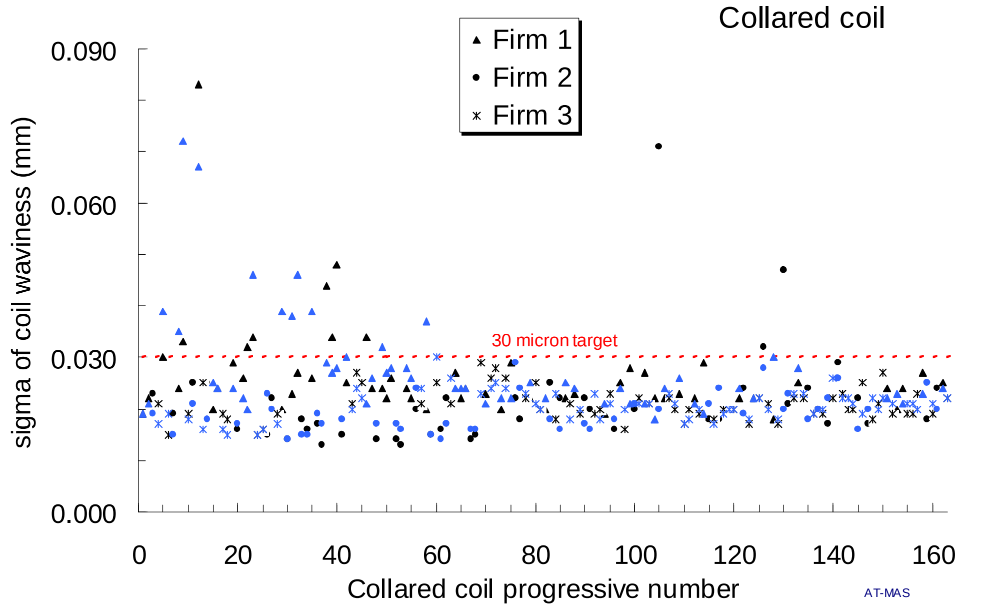

Fig. 3: Estimated coil waviness in the straight part of the measured collared coils (black dots: aperture 1, blue dots: aperture 2).

3. Magnetic length and transfer function

- Magnetic lengths of collared coils 121st to 163rd are well within targets (see Fig. 4). The spread in magnetic length is very low.

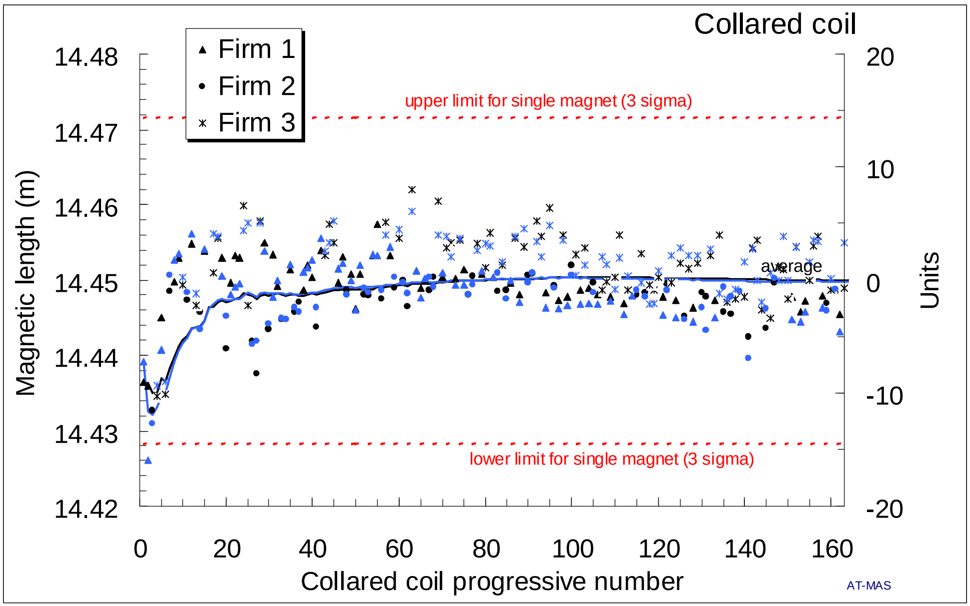

Fig. 4: Magnetic length of the measured collared coils (black dots: aperture 1, blue dots: aperture 2)

- In these two months (collared coil 120th to 163rd in Figs. 5 and 6), Firm3 collared coils have a main field 11 units larger than Firm2 and 10 units larger than Firm1. This previously observed systematic difference between firms (16 between Firm3 and Firm2, and 11 between Firm3 and Firm1) is therefore getting smaller. This is mainly due to an increase of main field in Firm2.
- The sigma is 8 units over all collared coils: this is above the target (5 units in the cold mass, 6 in the collared coils), but we remind that the integrated main field (see next page) is the quantity relevant to beam dynamics.
- No impact of the introduction of cross-section 3 (additional mid-plane insulation) is measured.

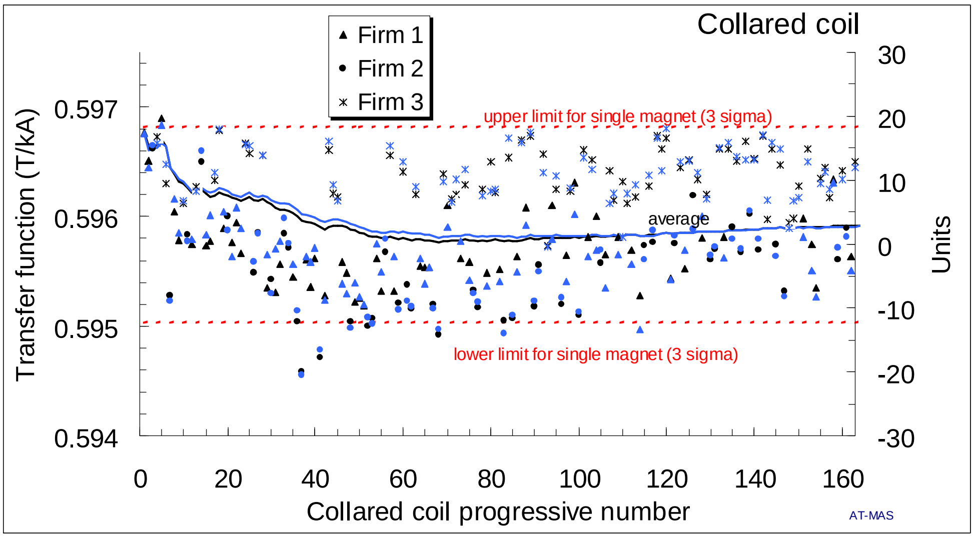

Fig. 5: Main field in the straight part of the collared coils (black dots: aperture 1, blue dots: aperture 2) and average over all collared coils (solid lines).

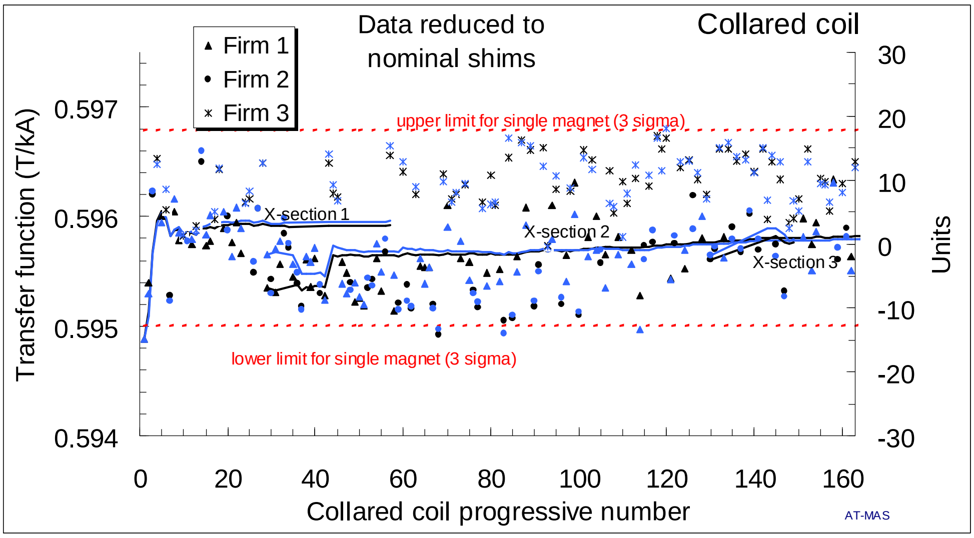

Fig. 6: Main field in the straight part of the collared coils (black dots: aperture 1, blue dots: aperture 2) and best estimate of systematic (solid lines). Data are reduced to nominal shims and separated according to different cross-sections.

- The spread of the integrated transfer function in all collared coils is 10 units (one sigma), i.e. at the limit of the target (9.6 in the collared coil, 8 units in the cold mass). Spread within the same firm is 5 to 6 units. Systematic differences between firms over all collared coils are of 14 units between Firm3 and Firm1, and of 17 units between Firm2 and Firm3. These values are reduced to 13 and 14 units respectively for the collared coils measured during July and August.
- 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 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).
- Data of cold masses at 300 K and of cryodipoles at 1.9 K only partially confirm this systematic difference. The calibration of measuring systems (both main field and magnetic length) has been carried out in all manufacturers, and result of the analysis will be ready at the end of September. On the basis of these results, it will be decided if the correction with ferromagnetic laminations will be implemented.

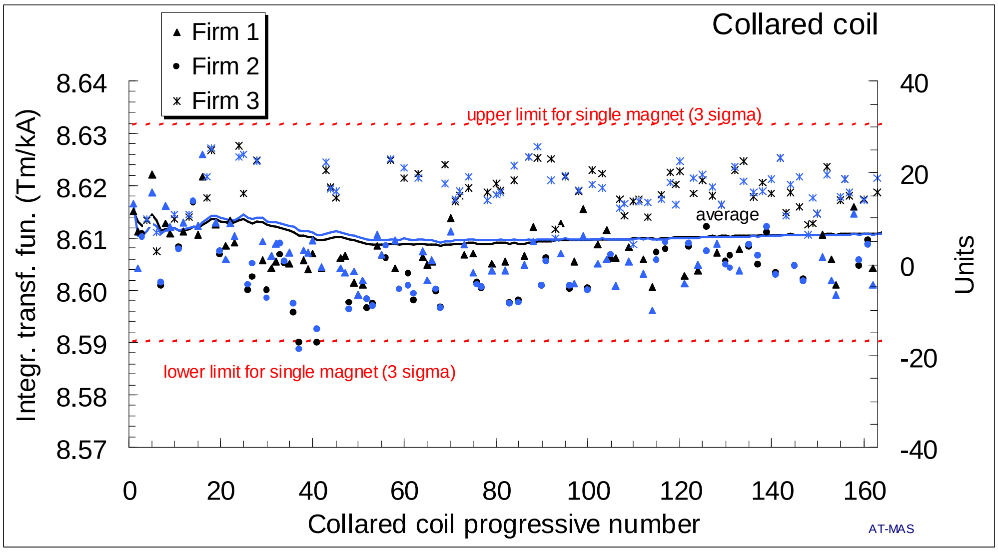

Fig. 7: Integrated transfer function (black dots: aperture 1, blue dots: aperture 2) and average over all collared coils (solid lines)

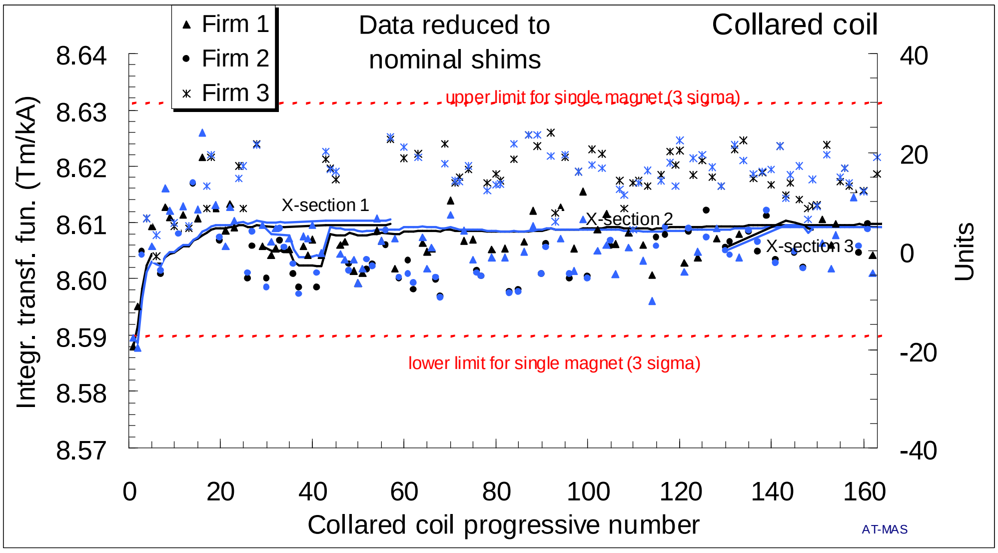

Fig. 8: Integrated transfer function (black dots: aperture 1, blue dots: aperture 2) and best estimate of systematic (solid lines). Data are reduced to nominal shims and separated according to different cross-sections.

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.

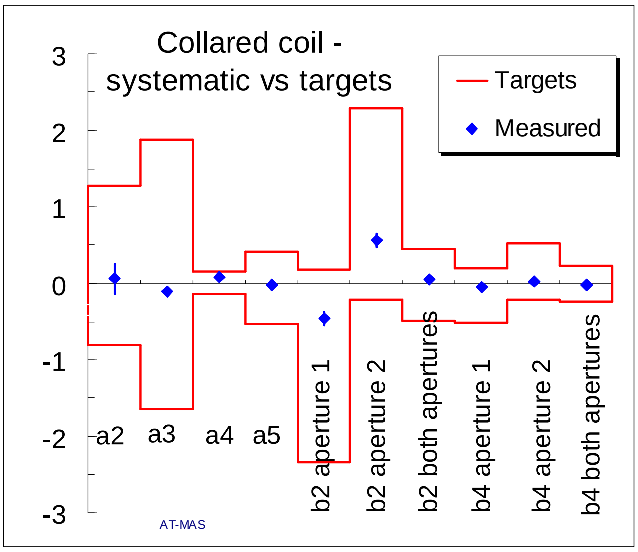

Fig. 9: Best estimate for systematic skew multipoles and even normal multipoles (markers) versus beam dynamics limits (red line). An error of two sigma (95% confidence limit) is associated to the best estimates of systematics.

- 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 the manufactured collared coils: b_3 and b_5 are larger than the upper specifications of 1.6 and 0.51 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, 122 have cross-section 2, 6 have cross-section 3). With the cross-section 3, b_3 is within target, 1.5 units far from the upper limit (i.e., 1.8 at high field), and b_5 at the lower part of the target window (i.e., 0.5 at injection). b_7 is 0.22 units larger than the targets (i.e. 0.28 at injection). The estimate for b_5 is biased from the absence of data from Firm1, the systematic being defined as the average of the averages of Firm2 and Firm3. A non-biased estimate for b_5 gives values in the centre of the acceptance range (see Appendix B).

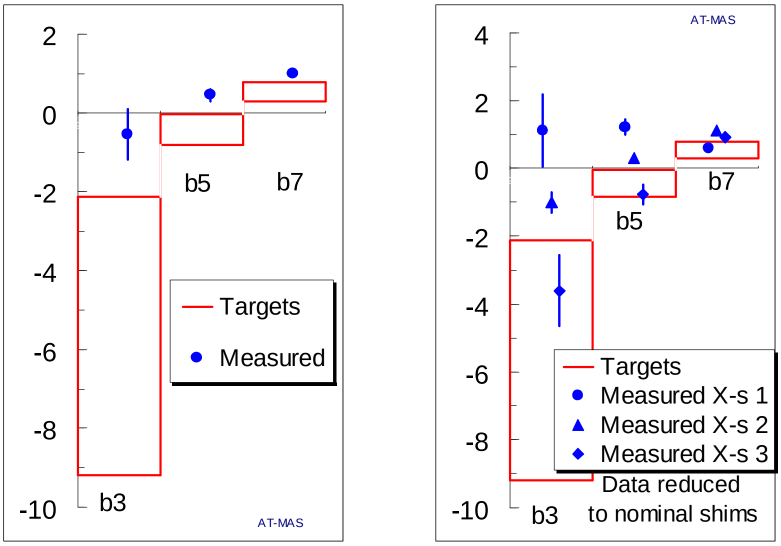

Fig. 10: Best estimate for systematic odd normal multipoles (markers) versus beam dynamics limits (red line). An error of two sigma (95% confidence limit) is associated to the best estimates of systematics. Raw data (left) and data reduced to nominal shims and separated according to different cross-sections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

5. Summary of systematic differences between firms

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

- Main field: Firm3 is higher than Firm2 of around 15 units, Firm1 being in between (see Fig. 5). This difference (around 3 times the natural spread within the same manufacturer) is getting smaller during the last phase of the production.

In other cases, we observe a small systematic difference between firms (from one to two times the natural sigma within the same manufacturer).

- Normal decapole b_5: Firm1 has a systematic b_5 of 0.8 units larger than Firm2, Firm3 being in between. This difference is two times the natural sigma within the same manufacturer.
- Skew sextupole a_3: Firm3 has a systematic a_3 of 0.3 units, against –0.5 in Firm2, Firm1 being in between. This difference is two times the natural sigma within the same manufacturer.
- Normal 14th pole: b_7 at Firm1 is 0.25 units higher than Firm2, Firm3 being in between. This difference is between one and two times the natural sigma within the same manufacturer.
- Skew octupole a_4: Firm2 has a systematic a_4 of 0.3 units, against 0.0 in Firm2 and Firm1. This difference is equal to the natural sigma within the same manufacturer.

No systematic differences between firms are visible 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.
- 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.
- Collared coils from Firm2 manufactured in the last months have a systematic a_4 of about 0.3 units (see Fig. 13); this could be worrying since beam dynamics targets are very narrow. Indeed, the systematic is within target.

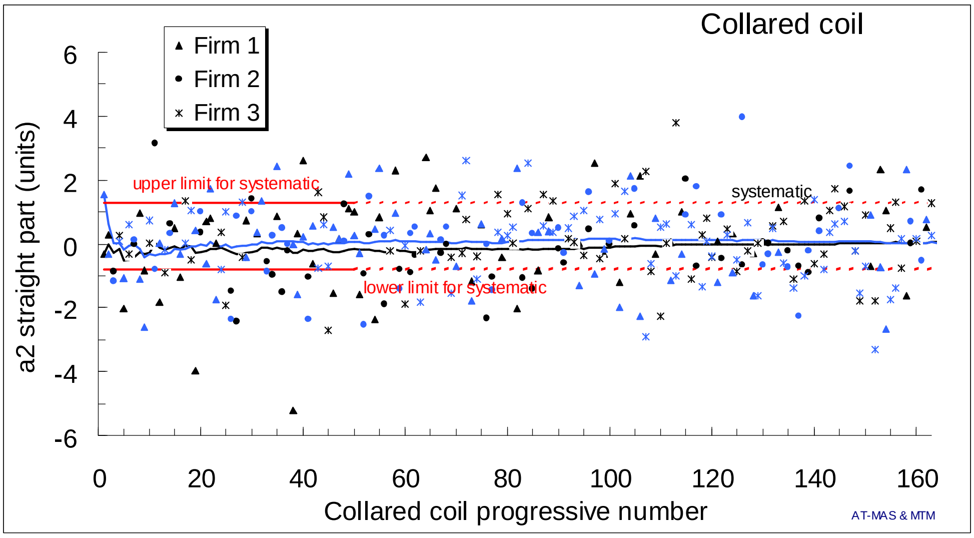

Fig. 11: Average a_2 in the straight part of the collared coils (black dots: aperture 1, blue dots: aperture 2), best estimate for systematic in each aperture (solid lines), and beam dynamics limits for the systematic (red lines) based on correlations with 49 cryodipoles.

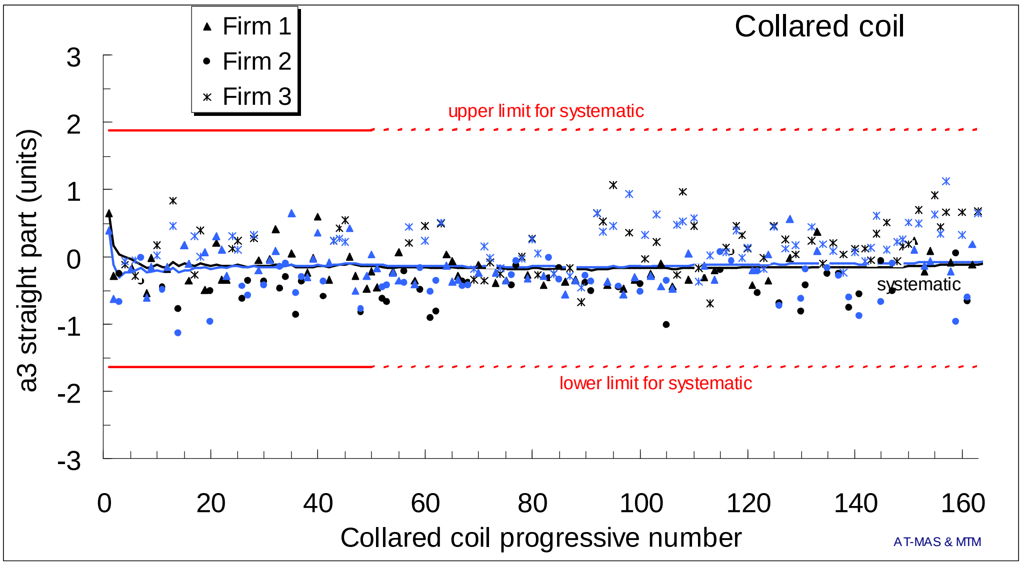

Fig. 12: Average a_3 in the straight part of the collared coils (black dots: aperture 1, blue dots: aperture 2), best estimate for systematic in each aperture (solid lines), and beam dynamics limits for the systematic (red lines) based on correlations with 49 cryodipoles.

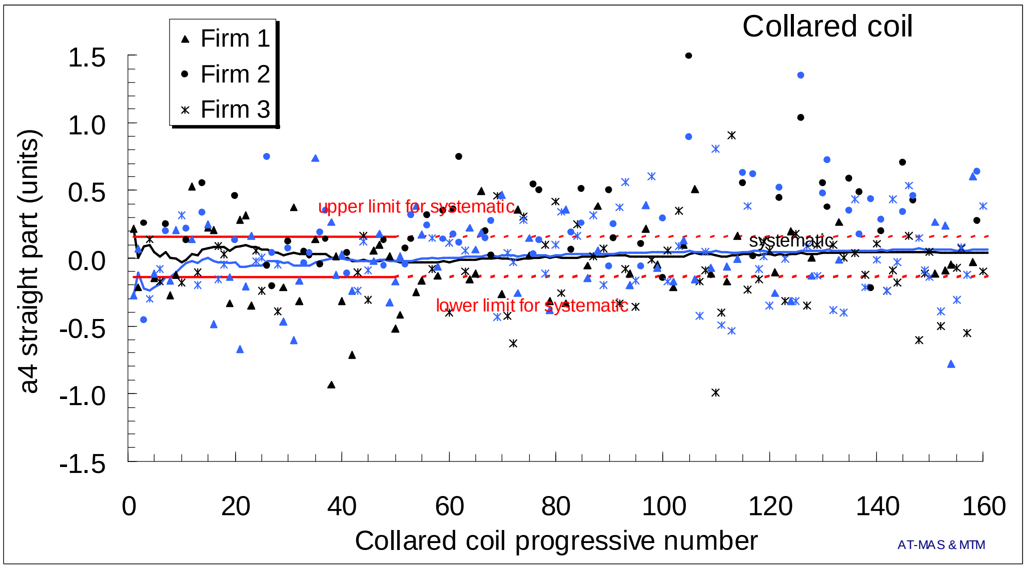

Fig. 13: Average a_4 in the straight part of the collared coils (black dots: aperture 1, blue dots: aperture 2), best estimate for systematic in each aperture (solid lines), and beam dynamics limits for the systematic (red lines) based on correlations with 49 cryodipoles.

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).

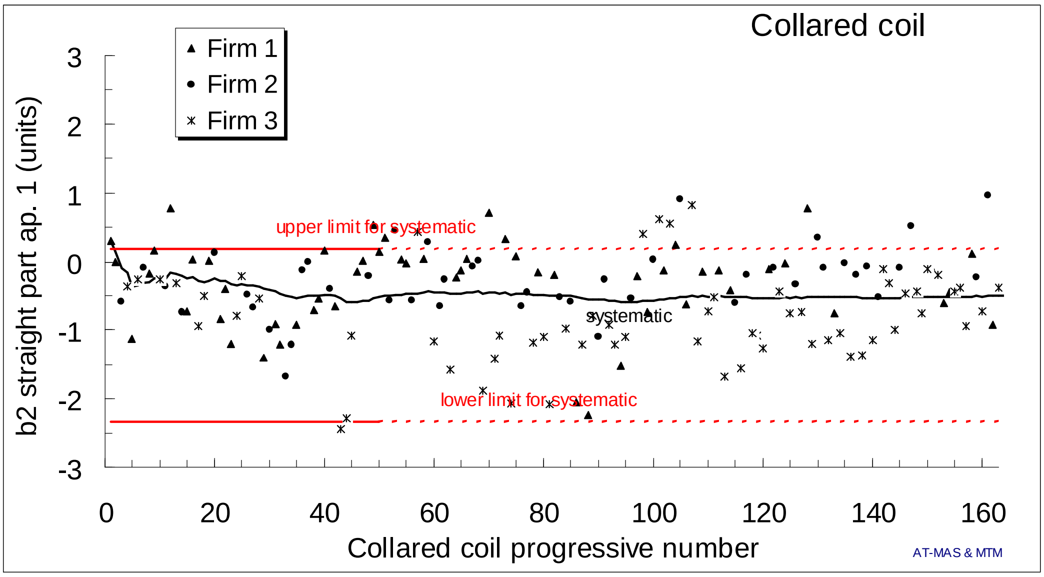

Fig. 14: Average b_2 in the straight part of the aperture 1 collared coils (black dots), best estimate for systematic per aperture (black line), and beam dynamics limits for the systematic (red lines) based on correlations with 49 cryodipoles.

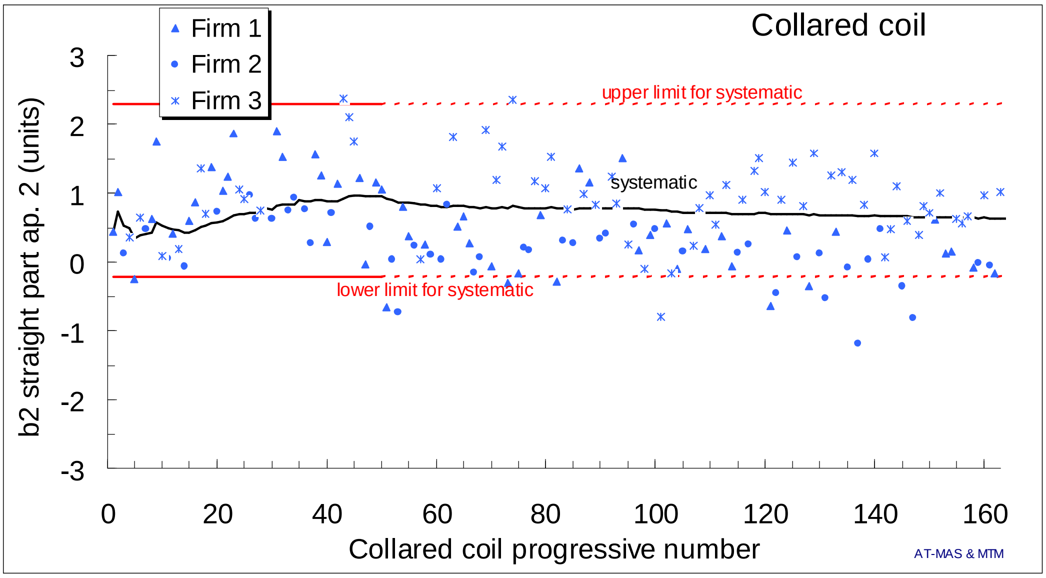

Fig. 15: Average b_2 in the straight part of the aperture 2 collared coils (blue dots), best estimate for systematic per aperture (blue line) and beam dynamics limits for the systematic (red lines) based on correlations with 49 cryodipoles.

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

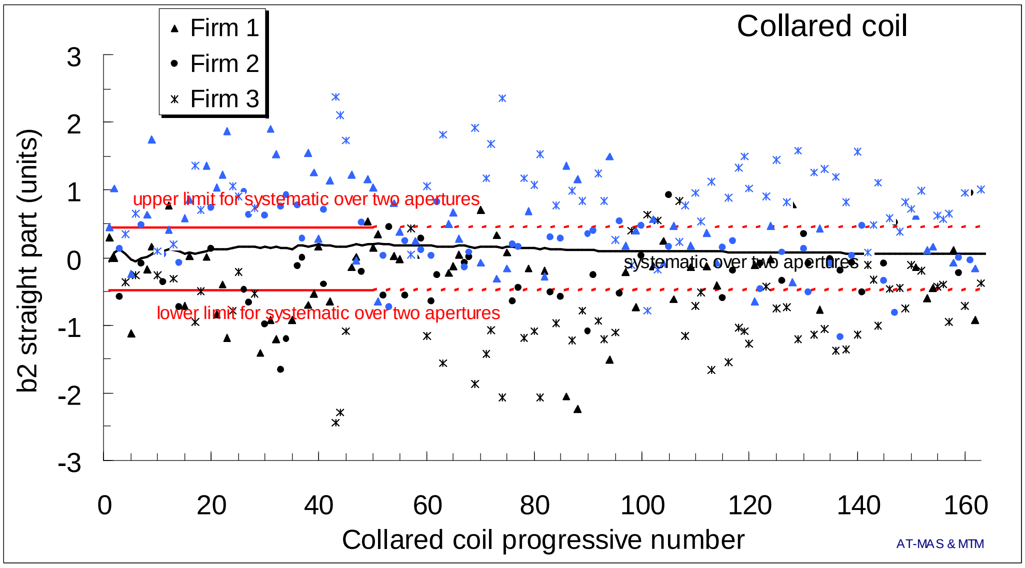

Fig. 16: Average b_2 in the straight part of collared coils ((black dots: aperture 1, blue dots: aperture 2), best estimate for systematic per beam (soild line) and beam dynamics limits for the systematic (red lines) based on correlations with 49 cryodipoles.

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).

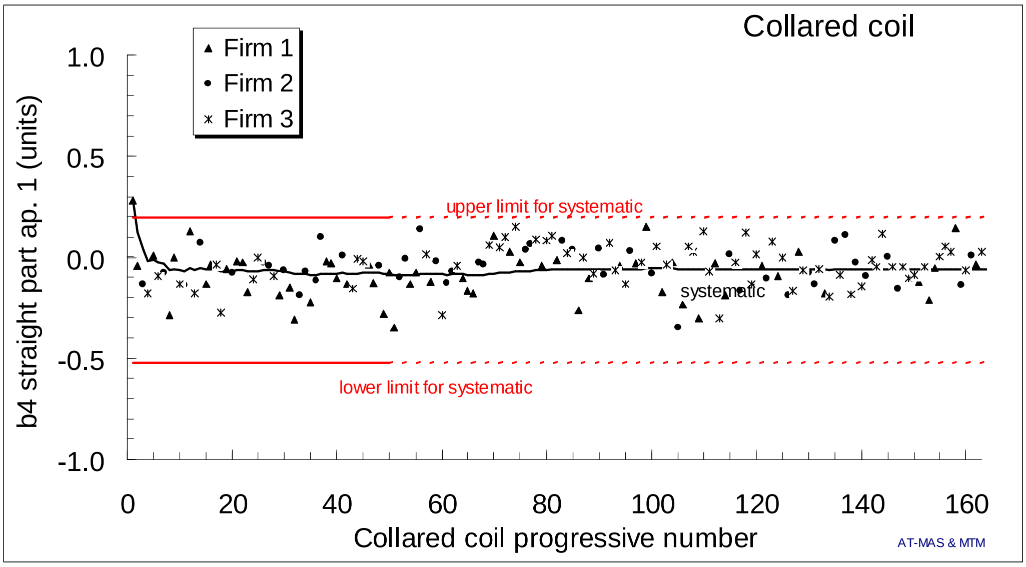

Fig. 17: Average b_4 in the straight part of the aperture 1 collared coils (black dots), best estimate for systematic per aperture (black line), and beam dynamics limits for the systematic (red lines) based on correlations with 49 cryodipoles.

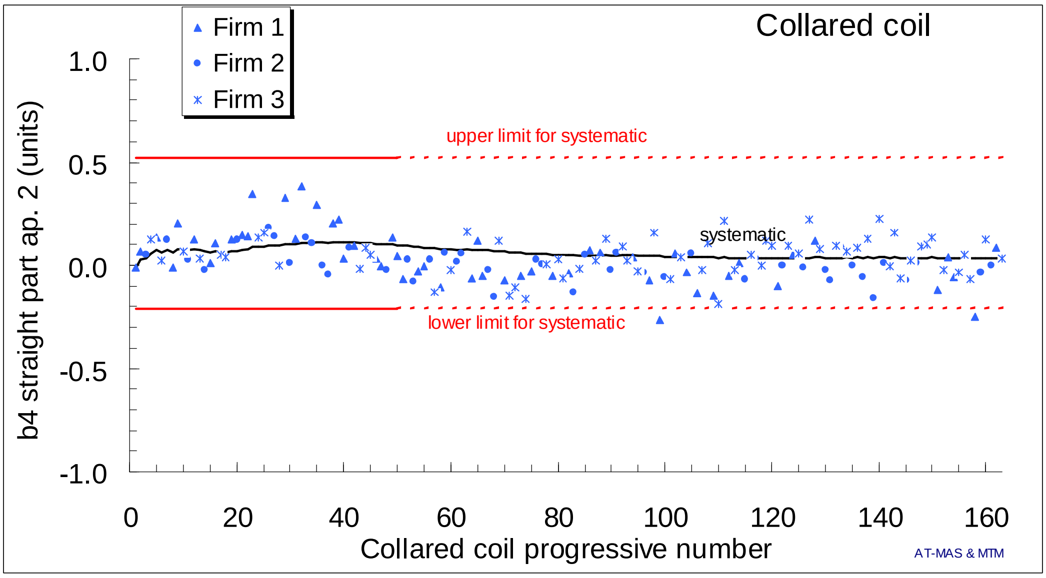

Fig. 18: Average b_4 in the straight part of the aperture 2 collared coils (blue dots), best estimate for systematic per aperture (black line) and beam dynamics limits for the systematic (red lines) based on correlations with 49 cryodipoles.

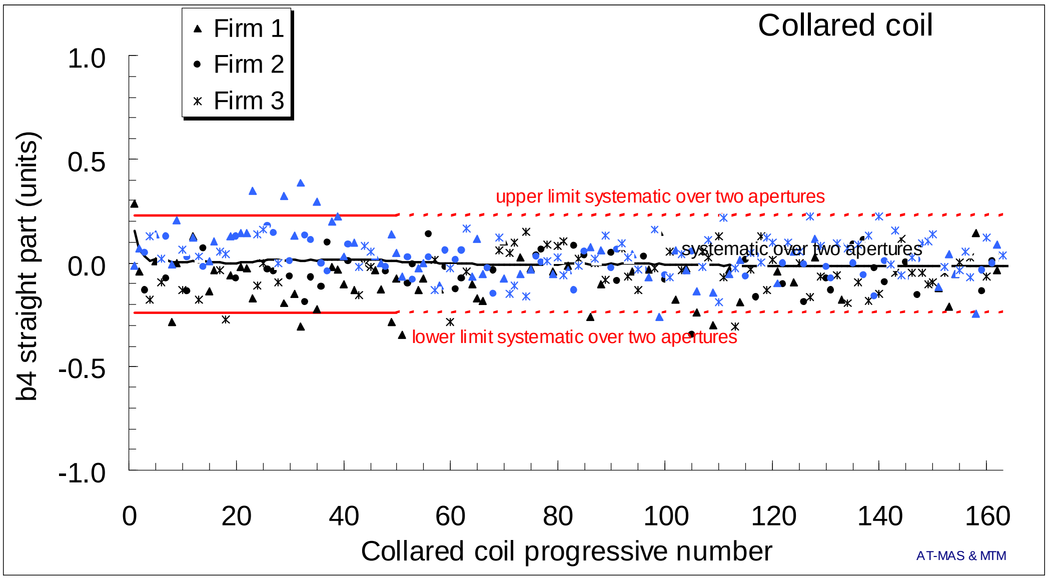

Fig. 19: Average b_4 in the straight part of collared coils (black dots: aperture 1, blue dots: aperture 2), best estimate for systematic per beam (black line) and beam dynamics limits for the systematic (red lines) based on correlations with 49 cryodipoles.

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).
- Average b_3 in cross-section 2 reduced to nominal shims (see Fig. 21) had a rather small positive trend from the first value of –1.6 units to –0.90 units (average of 122 collared coils). This is mainly due to a positive trend in Firm3, which started from –1.5 units (collared coil 44th), arrived up to +2.0 units (collared coil 118th). Indeed, recent collared coils from Firm3 feature a normal sextupole back to –1.5 units (collared coil 150th to 163rd).
- Systematic differences between firms are negligible.
- Cryodipoles with the cross-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.
- Cryodipoles with the cross-section 3 should feature 2.0 units of b_3 at high field; correction of the bias due to the lack of Firm1 data (see Appendix B, page 17-18) gives a value of 1.2 units. This is safely within the targets, and leaves a small geometric contribution to have partial correction of persistent current at injection, giving an optimal starting value for the full-speed production.

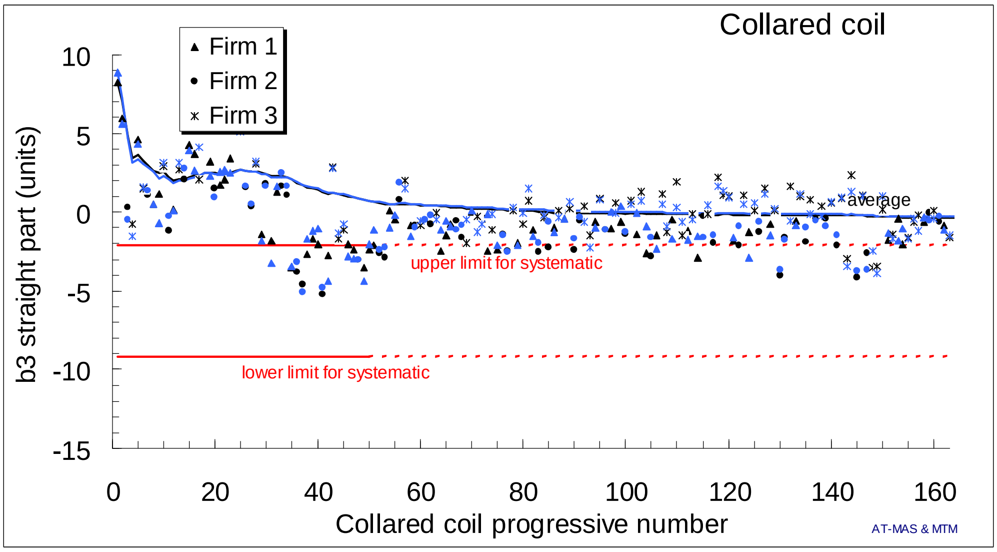

Fig. 20: Average b_3 in the straight part of the collared coils (black dots: aperture 1, blue dots: aperture 2), best estimate for systematic (solid lines), and beam dynamics limits for the systematic (red lines) based on correlations with 49 cryodipoles.

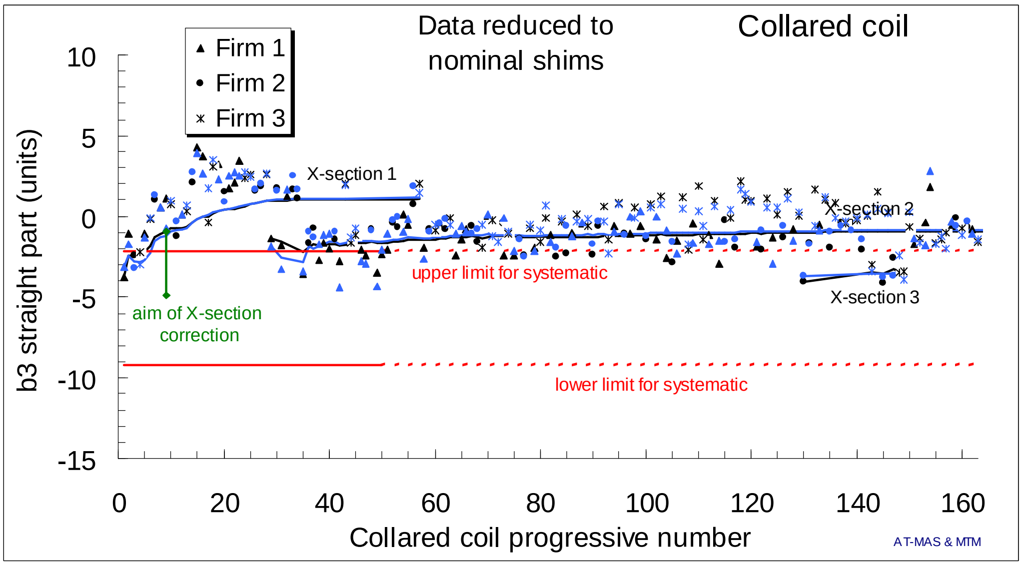

Fig. 21: Average b_3 in the straight part of the collared coils (black dots: aperture 1, blue dots: ap. 2), best estimate for systematic (solid lines), and beam dynamics limits for the systematic (red lines) based on correlations with 49 cryodipoles. Data reduced at nominal shims and separated according to cross-section type.

8.2 Normal decapole

- Data not reduced to nominal shims and not separated according to different cross-section show a negative trend due to introduction of cross-section 2 (see Fig. 22, from 35th to 120th) and then due to the introduction of cross-section 3 (same Figure, between 140th and 150th).
- Indeed, when data are separated according to cross-sections and reduced to nominal shims one finds that average b_5 in cross-section 2 is stable between 0.3 and 0.4 units (see Fig. 23).
- In Firm3 b_5 has started with values around 0.15 units (from collared coil 44th to 108th), then it went down to –0.2 units (from 107th to 163rd). This trend could be partially related to what observed in b_3.
- Systematic differences between firms are up to two times the sigma within the manufacturer: we observe 0.8 units difference between Firm1 and Firm3.
- Cryodipoles with the cross-section 2 should feature 1.4 units of b_5 at injection, i.e. 0.3 units more than the target of 1.1 units.
- Cryodipoles with the cross-section 3 should feature 0.5 units of b_5 at injection; correction of the bias due to the lack of Firm1 data gives values of around 0.8 units at injection. This would place b_5 at the centre of the target range, giving an optimal starting value for the full-speed production.

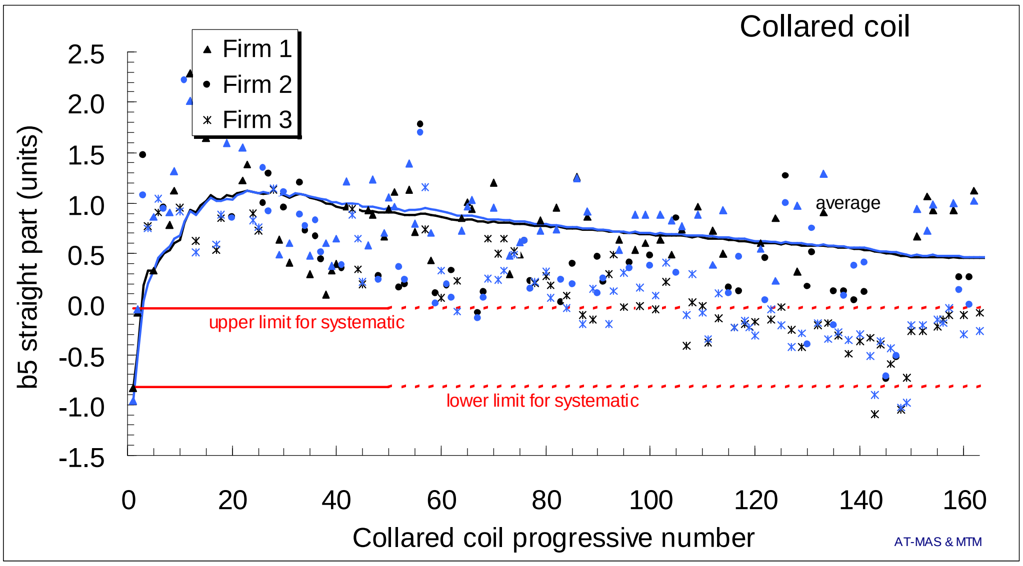

Fig. 22: Average b_5 in the straight part of the collared coils (black dots: aperture 1, blue dots: aperture 2), best estimate for systematic (solid lines), and beam dynamics limits for the systematic (red lines) based on correlations with 49 cryodipoles.

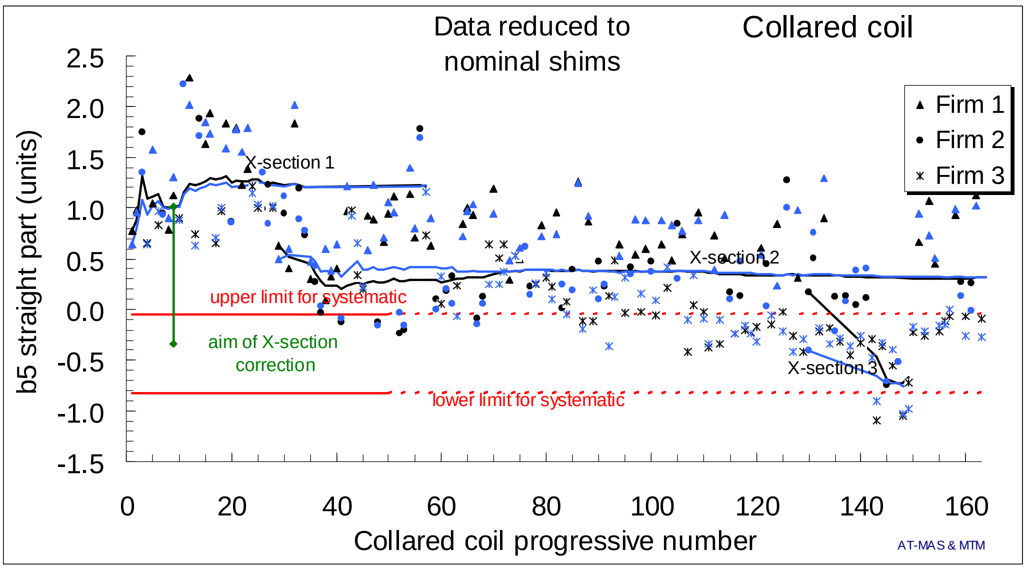

Fig. 23: Average b_5 in the straight part of the collared coil (black dots: aperture 1, blue dots: aperture 2), best estimate for systematic (solid lines), and beam dynamics limits for the systematic (red lines) based on correlations with 49 cryodipoles. Data are reduced to nominal shims and separated according to different cross-sections.

8.3 Normal 14-th pole

- Data not reduced to nominal shims and not separated according to different cross-section show values between 1.0 and 1.4 units over the last 100 collared coils (see Fig. 24).
- Average b_7 in cross-section 2 is stable between 1.0 and 1.4 units (see Fig. 25).
- Collared coil 2024 (126^{th} on Figs. 30 and 31) has a very low b_7. This collared coil underwent re-collaring, which usually provokes a reduction of b_7 up to 0.2 units.
- In Firm3 b_7 has shown a positive trend in cross-section 2: it went from 1.0 unit to nearly 1.3 units. This could be related to trends observed in b_3 and b_5.
- Systematic differences between firms are between one and two times the sigma within the manufacturer: we observe 0.3 units difference between Firm1 and Firm2.
- Cryodipoles with the cross-section 2 should feature 0.36 units of b_7 at injection, i.e. 0.26 units more than the target of 0.1 units.
- Cryodipoles with the cross-section 3 should feature 0.23 units of b_7 at injection. This would place b_7 above the target, but within the previous target of 0.30 units (see Fig. 31).

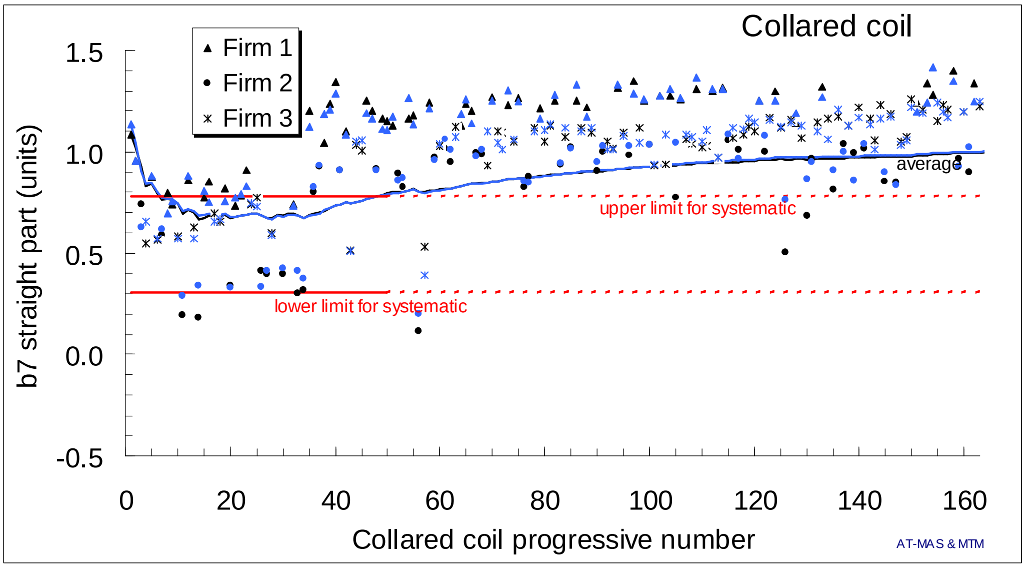

Fig. 24: Average b_7 in the straight part of the collared coils (black dots: aperture 1, blue dots: aperture 2), best estimate for systematic (solid lines), and beam dynamics limits for the systematic (red lines) based on correlations with 49 cryodipoles.

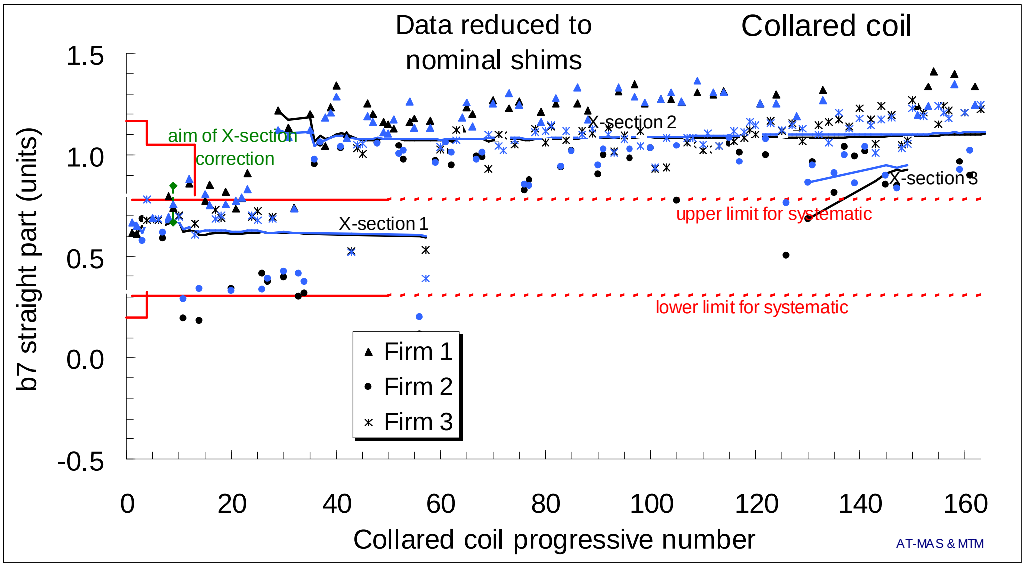

Fig. 25: Average b_7 in the straight part of the collared coils (black dots: aperture 1, blue dots: aperture 2), best estimate for systematic (solid lines), and beam dynamics limits for the systematic (red lines) based on correlations with 49 cryodipoles. Data are reduced to nominal shims and separated 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 targets 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 cross-section 1: this is due to the initial upward trend between collared coil 1st and 20th (see Section 8.1, Fig. 21). This is the only out of tolerance in the cross-section 1.
- For cross-section 2, all the multipoles are within specifications, global integrated main field BdL being slightly above the specification.

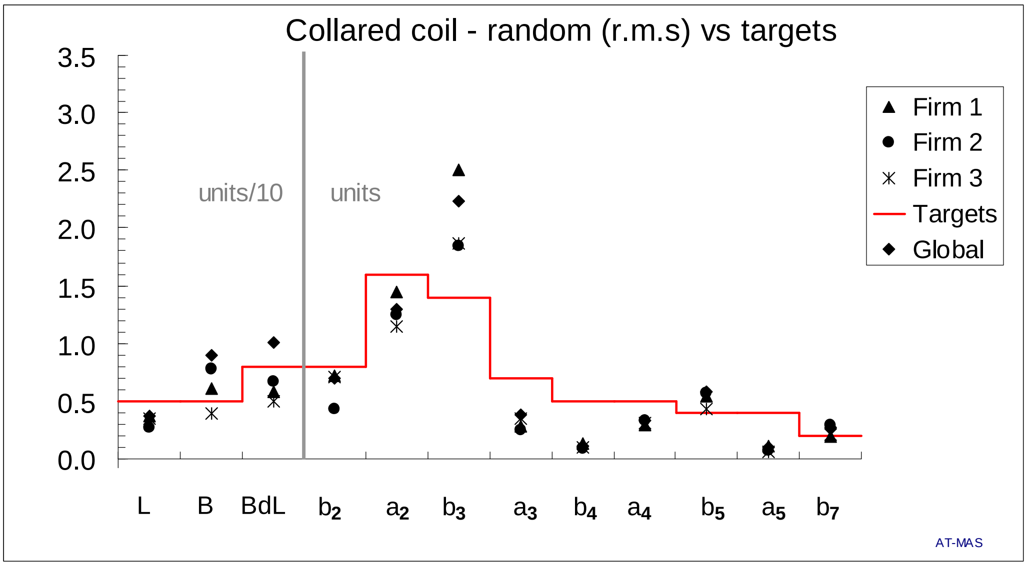

Fig. 26: Random component in the measured collared coils

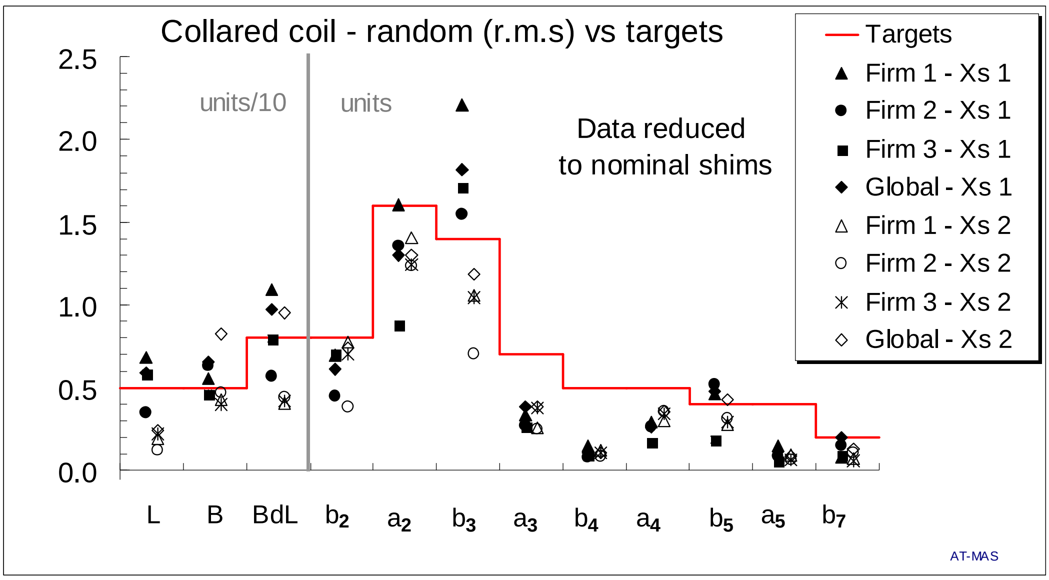

Fig. 27: Random component in the measured collared coils. Data reduced to nominal shims and split according to different cross-sections.

10. Holding point results

Table I: results of the holding point for the measured collared coils (OK are not reported)

	Magnet name	Collared coil measure	Result	Comments
125th	3047	04/07/03	OK-W	Warning due to a red alarm on b4 in the end NCS Ap. 1
126th	2024	07/07/03	OK-W	Coil has been recollared. Warning due to yellow alarm on coil waviness
130th	2035	14/07/03	HOLD	First magnet with additional midplane insulation – large variations on high order multipoles in position 19 Ap. 1 – similar pattern to 2032 (inner shift of block 6)

- 2024 has been re-collared, but not measured after the first collaring. This is giving higher coil waviness, and a much lower b_7 (see Section 8.3). Updated summary of the impact of re-collaring on field quality can be found in the report of May-June 2003, or on the web site http://lhc-div-mms.web.cern.ch/lhc-div-mms/MMSPAGES/MA/2013.html.
- 2035 had a spike in all multipoles, in one position, aperture 1, with a pattern very similar to 2032; simulations show that this could be due to inner radial movement of block6 (the block of inner layer close to the pole) of 0.5 to 0.8 mm, in one quadrant only. The collared coil has been held, waiting for results on 2032. This is the first collared coil with midplane shim: there is no indication any relation between this change and the observed field quality anomalies, since they were observed already in 2032 (no additional insulation). The other five collared coils with additional insulation show no field anomalies.

11. Acknowledgements

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Appendix A

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

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

1st	1001	21st	1010	41st	2014	61st	2015	81st	3022	101st	3034	121st	1044	141st	2039	161st	2048
2nd	1002	22nd	1011	42nd	1021	62nd	2020	82nd	1036	102nd	1040	122nd	2037	142nd	3055	162nd	1054
3rd	2001	23rd	1012	43rd	3011	63rd	3015	83rd	2026	103rd	3036	123rd	3046	143rd	3056	163rd	3068
4th	3001	24th	3007	44th	3012	64th	1020	84th	3023	104th	1046	124th	1052	144th	3057		
5th	1003	25th	3008	45th	3013	65th	1030	85th	2027	105th	2032	125th	3047	145th	2040		
6th	3002	26th	2008	46th	1026	66th	1031	86th	1037	106th	1042	126th	2024	146th	3058		
7th	2003	27th	2007	47th	1022	67th	2021	87th	3024	107th	3037	127th	3048	147th	2043		
8th	1004	28th	3009	48th	2016	68th	2022	88th	1038	108th	3026	128th	1057	148th	3059		
9th	1005	29th	1013	49th	1023	69th	3016	89th	3025	109th	1047	129th	3049	149th	3060		
10th	3003	30th	2006	50th	1024	70th	1032	90th	2028	110th	3041	130th	2035	150th	3061		
11th	2002	31st	1014	51st	1025	71st	3018	91st	2029	111th	3038	131st	2033	151st	1059		
12th	1006	32nd	1015	52nd	2017	72nd	3017	92nd	3027	112th	1049	132nd	3050	152nd	3062		
13th	3004	33rd	2010	53rd	2018	73rd	1033	93rd	3028	113th	3039	133rd	1055	153rd	1053		
14th	2005	34th	2009	54th	1027	74th	3019	94th	1045	114th	1050	134th	3051	154th	1051		
15th	1007	35th	1016	55th	1028	75th	1034	95th	3029	115th	2036	135th	2042	155th	3063		
16th	1008	36th	2013	56th	2011	76th	2023	96th	2030	116th	3042	136th	3052	156th	3064		
17th	3005	37th	2012	57th	3010	77th	2025	97th	1039	117th	2034	137th	2038	157th	3065		
18th	3006	38th	1017	58th	1029	78th	3021	98th	3030	118th	3044	138th	3053	158th	1048		
19th	1009	39th	1018	59th	2019	79th	1035	99th	1041	119th	3043	139th	2041	159th	2044		
20th	2004	40th	1019	60th	3014	80th	3020	100th	2031	120th	3045	140th	3054	160th	3066		

Appendix B

On September 24 we have 10 collared coils with additional mid-plane insulation: 3 from Firm1, 4 from Firm2 and 3 from Firm3. Results on allowed multipoles and main field are given in Table III. In the first three rows we give the expected effect of this change according to a 'rigid' electromagnetic model[1], to a model which includes coil and collar deformations[2], and to the results of the experiment on a short model. In the following rows we give the difference between measured multipoles of collared coils with cross-section 3 and with cross-section 2, separated according to different manufacturers. The different effect on b5 and b7 in Firm3 can be due to the trend quoted in Section 8, which is not taken into account since the comparison is done with all magnets with cross-section 2. The effect on average even skews is within one sigma, i.e. there is no measurable effect on skew multipoles from the additional mid-plane insulation as expected.

		c1	b3	b5	b7
Model	Rigid	-3.1	-3.2	-0.81	-0.20
	Defor	-3.1	-4.0	-0.60	-0.23
Measure	Short	-7.9	-3.5	-0.52	-0.18
	Firm1 (3)	-5.1	-3.6	-0.72	-0.18
	Firm2 (4)	0.1	-2.5	-0.66	-0.15
	Firm3 (3)	-6.1	-3.0	-0.93	-0.09
	System	-3.7	-3.0	-0.77	-0.14

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

[1] 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.

[2] In this model the collar and coil deformations (both azimuthal and radial) are evaluated through a finite element code.

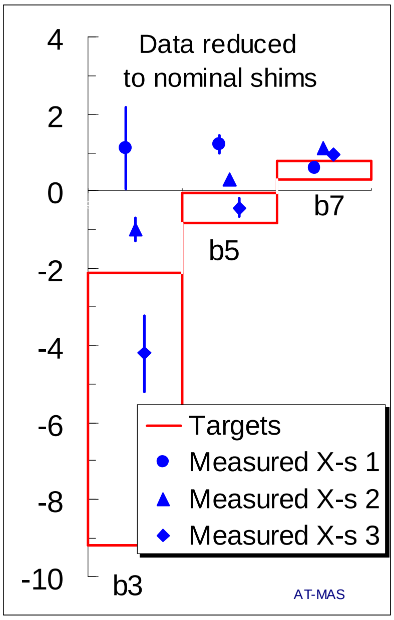

Fig. 28: Best estimate for systematic odd normal multipoles (markers) versus beam dynamics limits (red line). An error of two sigma (95% confidence limit) is associated to the best estimates of systematics. Data reduced to nominal shims and separated according to different cross-sections (right).

Results of this set of collared coils with additional mid-plane insulation are given in Fig. 28. Normal sextupole is at around –4 units in the collared coil, corresponding to 1.2 units at high field. Normal decapole is at –0.4 units in the collared coil, corresponding to 0.8 units at injection (maximum target of 1.1 units) and at –0.5 at high field (minimum target of –0.8 units). Normal 14th pole is at 0.96 units in the collared coil, corresponding to 0.25 at injection (maximum target of 0.1 units).