DAΦNE TECHNICAL NOTE

INFN - LNF, Accelerator Division

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MAGNETIC MEASUREMENTS ON THE PERMANENT MAGNET QUADRUPOLES OF THE KLOE INTERACTION REGION

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1. Introduction

The first couple of permanent magnet quadrupoles (QF1), those nearest to the KLOE interaction point (IP), were measured in fall 1994. The results of the measurements are described in [1,2]. The second couple of quadrupoles from the IP is called QD, while the third is called QF2. These magnets were measured in November 1997. In order to check that the field in the QF1 magnets did not change after three years, they were measured again with the rotating coil system.

One quadrupole of each type (all those with serial number 1) was assembled in the common support for a first mechanical test. All quads were measured again with the rotating coil system in February 1998 to check that the magnets did not suffer from any mechanical stress.

Figure 1 shows together one quadrupole of each type.

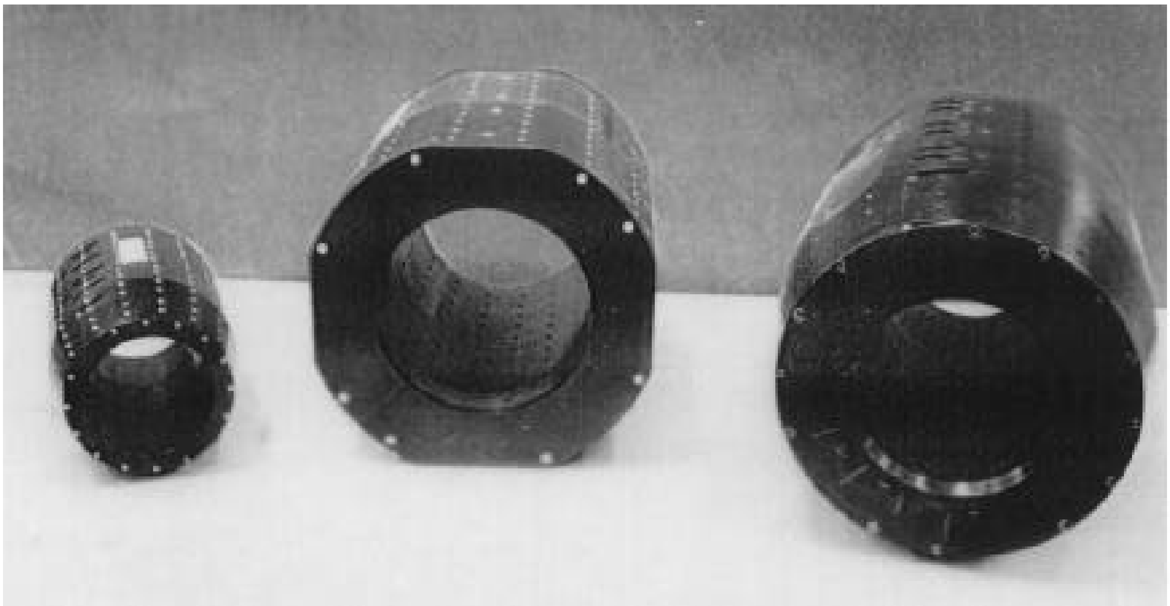


Figure 1 - The three permanent magnet quadrupoles of the KLOE interaction region. Starting from the left: the "small" quad QF1, the "medium" quad QF2, the "large" quad QD.

2. Measurements with the rotating coil

2.1 "Small" quads QF1

The "small" quadrupoles were measured in July 94 for the first time, in November 97 to check that the field did not change and in February 98 after the first mechanical assembly on the common support. We show here the deviation from the ideal quadrupole field at 30 mm from the quadrupole axis of all measurements for sake of comparison.

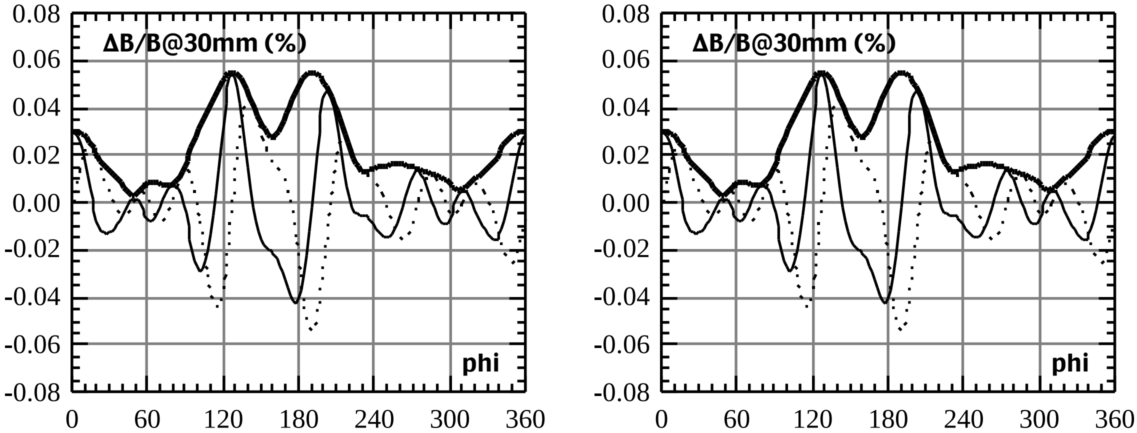


Figure 2 - Measurements 1994: full line = azimuthal component, dotted line = radial component, full bold line = absolute field value; left = QF1 sn.1, right = QF1 sn.2

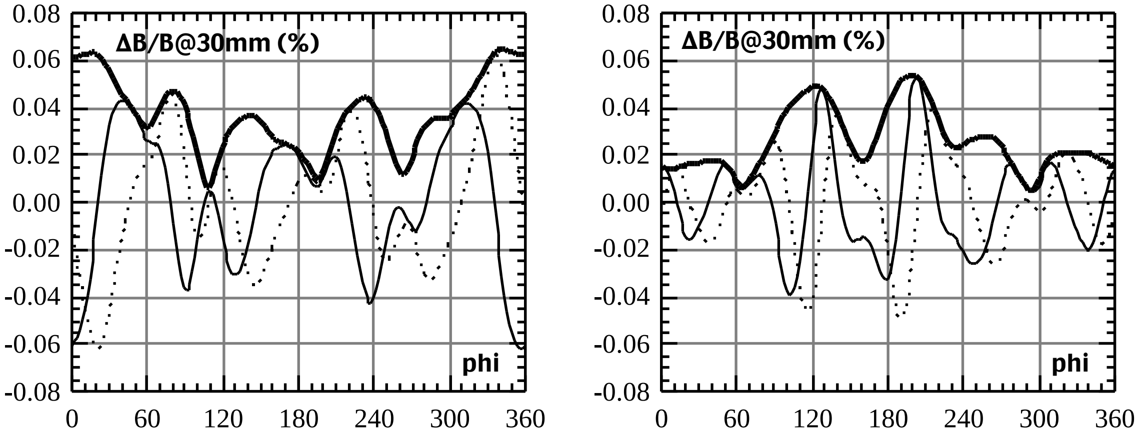


Figure 3 - Measurements 1997: full line = azimuthal component, dotted line = radial component, full bold line = absolute field value; left = QF1 sn.1, right = QF1 sn.2

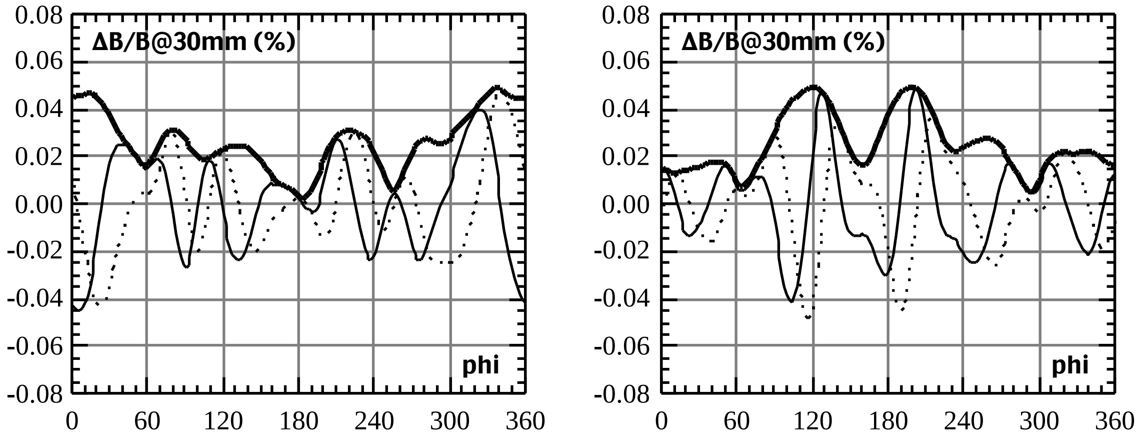


Figure 4 - Measurements 1998: full line = azimuthal component, dotted line = radial component, full bold line = absolute field value; left = QF1 sn.1, right = QF1 sn.2

Table 1 shows the integrated gradient, the average of the absolute value of the field deviation and the contributions of the most important harmonics on the boundary of the good field region (a circle of 30 mm diameter) for the three measurements on the QF1 quads. All values are scaled by the proper power of the different harmonics to this diameter from the original values measured at the coil radius of 49 mm.

Table 1 - Integrated gradient, average deviation from ideal quadrupole and main harmonics for the measurements on the "small" quadrupoles QF1.

Serial Number	**1**			**2**		
Measurement	LNF 94	LNF 97	LNF 98	LNF 94	LNF 97	LNF 98
Integrated gradient (T)	1.2047	1.2026	1.2033	1.2048	1.2031	1.2030
$\langle \Delta B/B \rangle$ @ 30 mm (%)	0.023	0.037	0.026	0.024	0.025	0.025
6-pole @ 30 mm (%)	0.011	0.031	0.016	0.008	0.005	0.005
8-pole @ 30 mm (%)	0.014	0.016	0.014	0.011	0.013	0.012
10-pole @ 30 mm (%)	0.012	0.012	0.011	0.018	0.018	0.018
12-pole @ 30 mm (%)	0.007	0.006	0.007	0.010	0.009	0.010
14-pole @ 30 mm (%)	0.007	0.008	0.007	0.002	0.002	0.002
16-pole @ 30 mm (%)	0.008	0.008	0.008	0.005	0.006	0.006
18-pole @ 30 mm (%)	0.002	0.002	0.002	0.010	0.011	0.010
20-pole @ 30 mm (%)	0.006	0.007	0.007	0.006	0.002	0.006

It can be noticed that there is a substantial agreement, within the sensitivity of the rotating coil system, between the successive measurements on the same quadrupole. Only the result of Serial #1 in 97 is slightly different from the others, but the difference comes mainly from the sextupole contribution, for which the uncertainty of the measuring system is maximum. This difference seems therefore accidental: it should not be explained with a deformation due to the assembly procedure on the common support, also because the results of the measurements performed in 98 after this operation are in substantial agreement with those obtained 3 years before. As already mentioned in [1], the results are also in agreement with those performed at the builder's site (ASTER Enterprises).

We remind that in a permanent magnet quadrupole the four-fold symmetry is not as strong as in the case of normal electromagnets, and this is the reason why the 12-pole and 20-pole harmonics are not larger than the others.

2.2 "Large" quads QD

The specified good field region for the "large" quadrupoles QD is 37 mm, because the distance between the beam trajectory and the quadrupole axis (≈1 cm) at the second quadrupole in the interaction region is much larger than in the first one. All our results are therefore normalized to this radius.

Figures 5 and 6 show the results of the measurements performed in November 1997 and February 1998 respectively, while Table 2 gives the relevant parameters as in the previous case.

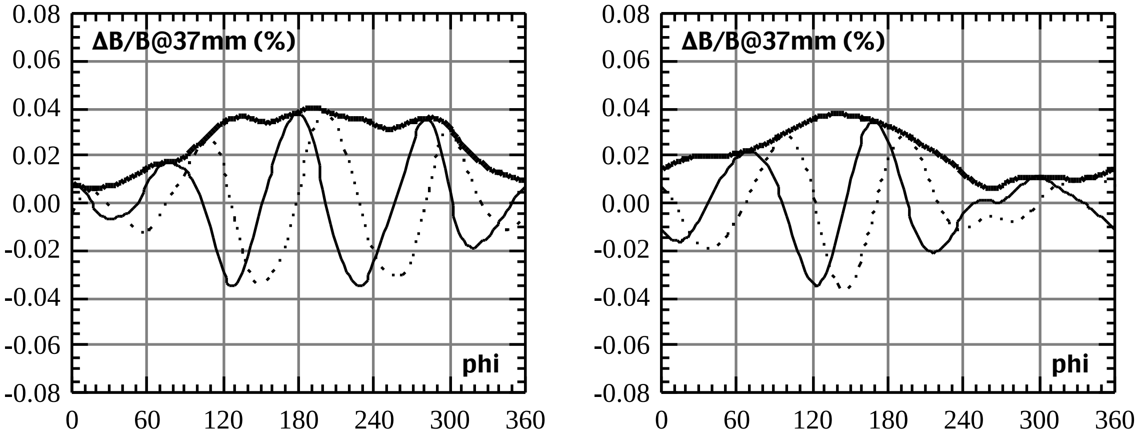


Figure 5 - Measurements 1997: full line = azimuthal component, dotted line = radial component, full bold line = absolute field value; left = QD sn.1, right = QD sn.2

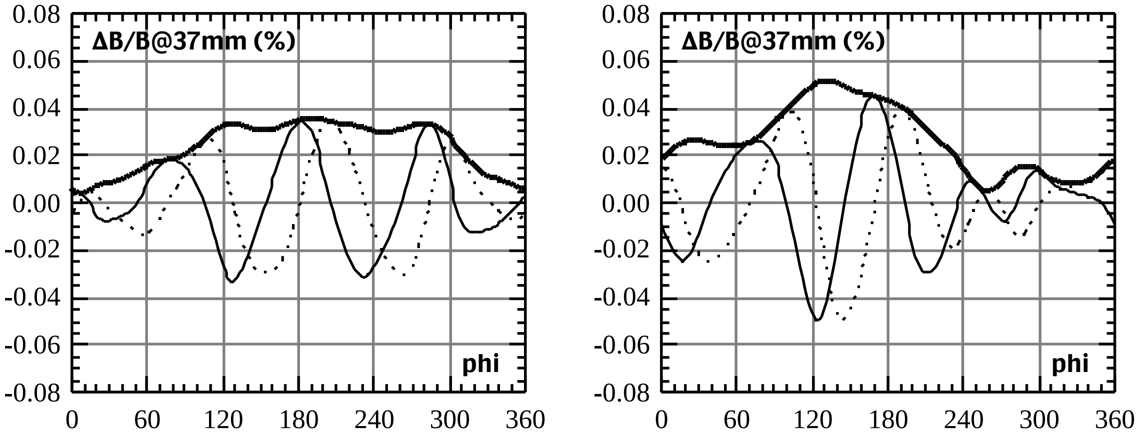


Figure 6 - Measurements 1998: full line = azimuthal component, dotted line = radial component, full bold line = absolute field value; left = QD sn.1, right = QD sn.2

Table 2 - Integrated gradient, average deviation from ideal quadrupole and main harmonics for the measurements on the "large" quadrupoles QD.

Serial Number	**1**			**2**		
Measurement	LNF 94	LNF 97	ASTER	LNF 94	LNF 97	ASTER
Integrated gradient (T)	3.3771	3.3774	3.3810	3.3778	3.3767	3.3813
<ΔB/B> @ 37 mm (%)	0.025	0.023	-	0.027	0.026	-
6-pole @ 37 mm (%)	0.017	0.018	0.009	0.022	0.020	0.008
8-pole @ 37 mm (%)	0.021	0.018	0.020	0.019	0.020	0.011
10-pole @ 37 mm (%)	0.001	0.002	0.001	0.010	0.010	0.011
12-pole @ 37 mm (%)	0.002	0.002	0.002	0.005	0.005	0.004
14-pole @ 37 mm (%)	0.001	0.001	0.003	0.004	0.004	0.003

Also in the case of the "large" quadrupoles" the agreement between the measurements at LNF is within the accuracy of the system, demonstrating, in the case of Serial #1, that there was no effect on the field from the assembly procedure on the support. However, the results obtained at ASTER are different by 0.1% in the integrated gradient and slightly better in the harmonic content. The specified limit of $5x10^{-4}$ for ΔB/B is always fulfilled.

2.3 "Medium" quads QF2

The specified good field region for the "medium" quads QF2 is 55 mm, due to the fact that the distance between the beam trajectory and the straight section axis in these quads is of the order of 2 cm. Since the rotating coil radius is 49 mm, this is the first case where the data are extrapolated at a radius larger than the coil one. The high harmonics are therefore more sensitive to the noise in the measurement and they tend to be enhanced. The effect on the results can be observed in Figures 7 and 8, which refer to successive measurements taken in 1997: there is clearly an enhancement of high frequency oscillations and the shape of |ΔB/B| on the boundary of the good field region is not the same in the different measurements. The plots should therefore be interpreted as an upper limit on the deviation from the ideal quadrupole field. Figure 9 shows the results of the measurement performed in February 98.

The comparison between the measurements at LNF and ASTER is given in Table 3, where the explanation for the above mentioned effects shows up rather clearly: the results obtained at ASTER exhibit only negligible contributions to the overall field deviation from harmonics higher than the 14-pole, while this is not the case for the measurements at LNF, where we find large contributions from harmonics larger than the 30-pole (we remind that our estimate of ΔB/B takes into account up to the 36-pole harmonic). There is also a larger discrepancy (≈0.9%) in the integrated gradient between the results of ASTER and LNF.

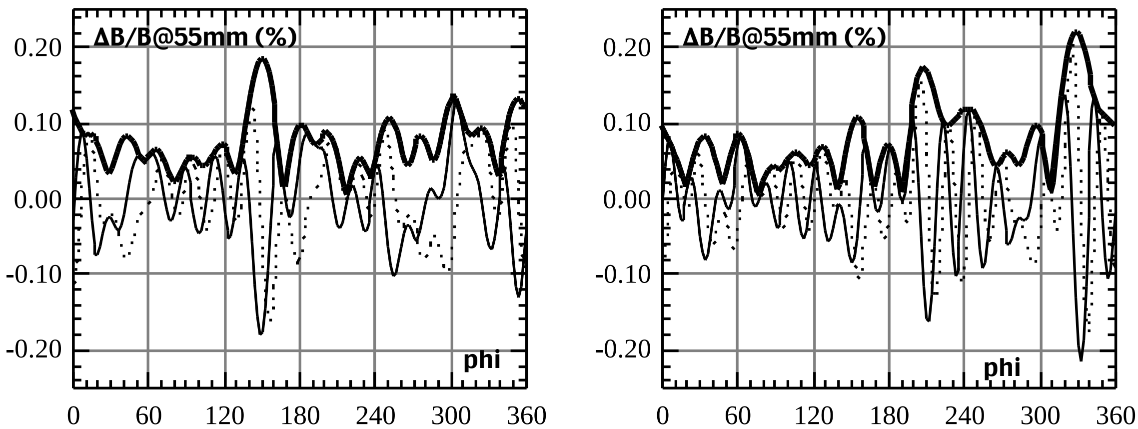


Figure 7 - Measurements 1997 #1: full line = azimuthal component, dotted line = radial component, full bold line = absolute field value; left = QF2 sn.1, right = QF2 sn.2

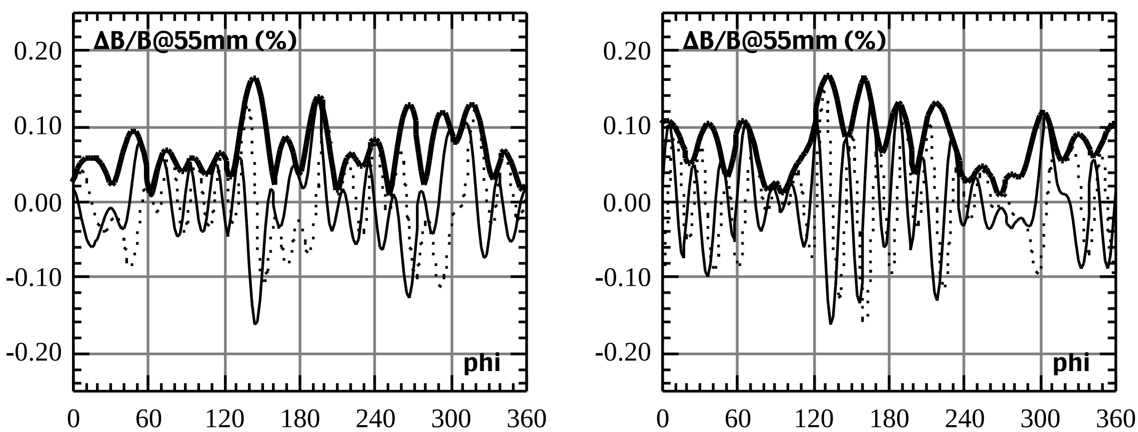
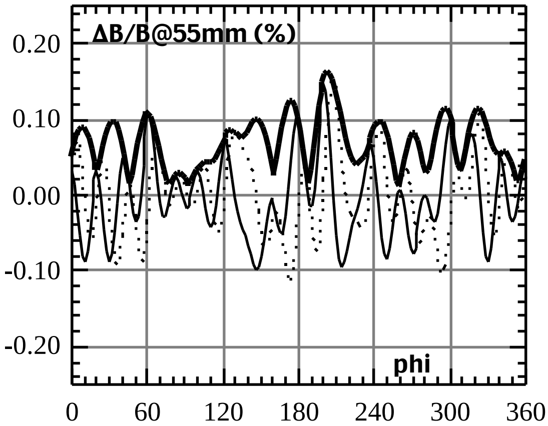


Figure 8 - Measurements 1997 #2: full line = azimuthal component, dotted line = radial component, full bold line = absolute field value; left = QF2 sn.1, right = QF2 sn.2



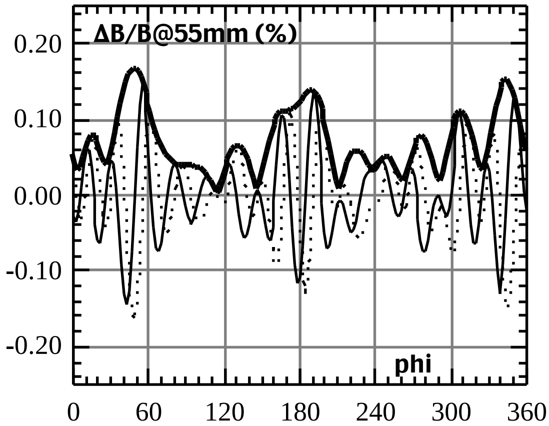


Figure 9 - Measurements 1998; full line = azimuthal component, dotted line = radial component, full bold line = absolute field value; left = QF2 sn.1, right = QF2 sn.2

Table 3- Integrated gradient, average deviation from ideal quadrupole and main harmonics for the measurements on the "medium" quadrupoles QF2.

Serial Number	**1**			**2**		
Measurement	LNF 97-2	LNF 98	ASTER	LNF 97-2	LNF 98	ASTER
Integrated gradient (T)	1.3136	1.3132	1.3040	1.3150	1.3158	1.3030
<ΔB/B> @ 55 mm (%)	0.068	0.069	-	0.078	0.070	-
6-pole @ 55 mm (%)	0.040	0.033	0.007	0.016	0.003	0.007
8-pole @ 55 mm (%)	0.015	0.011	0.003	0.004	0.006	0.013
10-pole @ 55 mm (%)	0.008	0.011	0.009	0.013	0.005	0.011
12-pole @ 55 mm (%)	0.032	0.032	0.028	0.030	0.029	0.023
14-pole @ 55 mm (%)	0.009	0.007	0.006	0.007	0.015	0.006
16-pole @ 55 mm (%)	0.001	0.003	0.001	0.003	0.000	0.001
18-pole @ 55 mm (%)	0.005	0.009	0.003	0.010	0.010	0.002
20-pole @ 55 mm (%)	0.016	0.024	0.002	0.014	0.022	0.003
22-pole @ 55 mm (%)	0.006	0.008	0.000	0.006	0.014	0.000
24-pole @ 55 mm (%)	0.013	0.008	0.002	0.007	0.012	0.001
26-pole @ 55 mm (%)	0.010	0.022	0.003	0.018	0.029	0.001
28-pole @ 55 mm (%)	0.013	0.011	0.002	0.010	0.013	0.002
30-pole @ 55 mm (%)	0.004	0.009	0.001	0.017	0.007	0.002
32-pole @ 55 mm (%)	0.014	0.012	0.002	0.036	0.043	0.001
34-pole @ 55 mm (%)	0.023	0.011	0.001	0.027	0.023	0.001
36-pole @ 55 mm (%)	0.035	0.041	0.002	0.055	0.033	0.002

In order to get an idea of the behaviour of ΔB/B under the assumption that the higher harmonics are due only to noise in the measuring system, we show in Figure 10, using the same scale of the other figures, the results obtained in 1998 truncated to the 14-pole. In this case the required maximum deviation of $5x10^{-4}$ at the boundary of the good field region is fulfilled for quadrupole sn.2, while sn.1 exceeds it due to a strong sextupole contribution which does not appear in ASTER results.

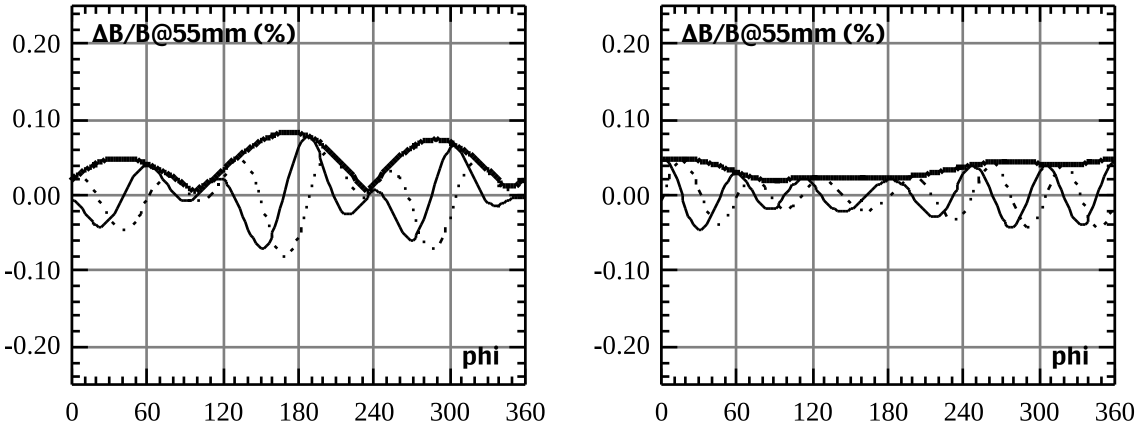


Figure 10 - Measurements 1998 truncated to the 14-pole; full line = azimuthal component, dotted line = radial component, full bold line = absolute field value; left = QF2 sn.1, right = QF2 sn.2

3. Longitudinal scans

The vertical component of the field has been measured on the horizontal symmetry plane of the magnets. Due to the fact that only one supporting frame has been built for the magnetic measurements with the Hall probe of the three different kinds of quadrupoles, the available range in the horizontal plane is limited to ±30 mm, smaller than the good field region specified for QD and QF2. However, this kind of measurement is useful mainly to find out the magnetic length and the longitudinal dependence of the higher harmonics, and the above quoted range is sufficient for this purpose.

3.1 "Small" quads QF1

Longitudinal scans on the "small" quadrupoles QF1 where not performed during the measurements in 97 and 98. The results of the measurements in 1994 are described in [1].

3.2 "Large" quads QD

The measurement has been performed on quadrupole sn.2. The field has been recorded along the quadrupole axis and 6 straight lines parallel to it at a distance of ±10 mm, ±20 mm and ±30 mm from it. The range in the longitudinal direction was between -0.45 m from the quadrupole magnetic center to +0.40 m. However, the field is significantly different from zero only between ±0.3 m from the center. The positive side of the longitudinal coordinate corresponds to that side of the magnet where the outer diameter decreases in order to leave a larger free solid angle to the detector. Figure 11 shows the result of the these longitudinal scans: the plots displayed in this figure are obtained by subtracting from the field values measured along the straight lines at the quoted distances those measured on the quadrupole axis in order to subtract any distortion coming from the alignment on the measurement bench or from the finite size of the probe. The magnetic length, defined as the average of the full widths at half maximum of the curves in the figure, is 33.3 cm.

The 7 points measured at each longitudinal position have been fitted with a third order polynomial in order to find the longitudinal dependence of the octupole term. The result is shown in Figure 12. The integrated gradient, calculated by summing up all the values of the first order term of the fit, is 3.3852 T, 0.23% larger than the value obtained with the rotating coil at LNF, 0.11% larger than that measured at ASTER. The backward/forward asymmetry is a consequence of thee particular shape of the magnet (see Figure 1).

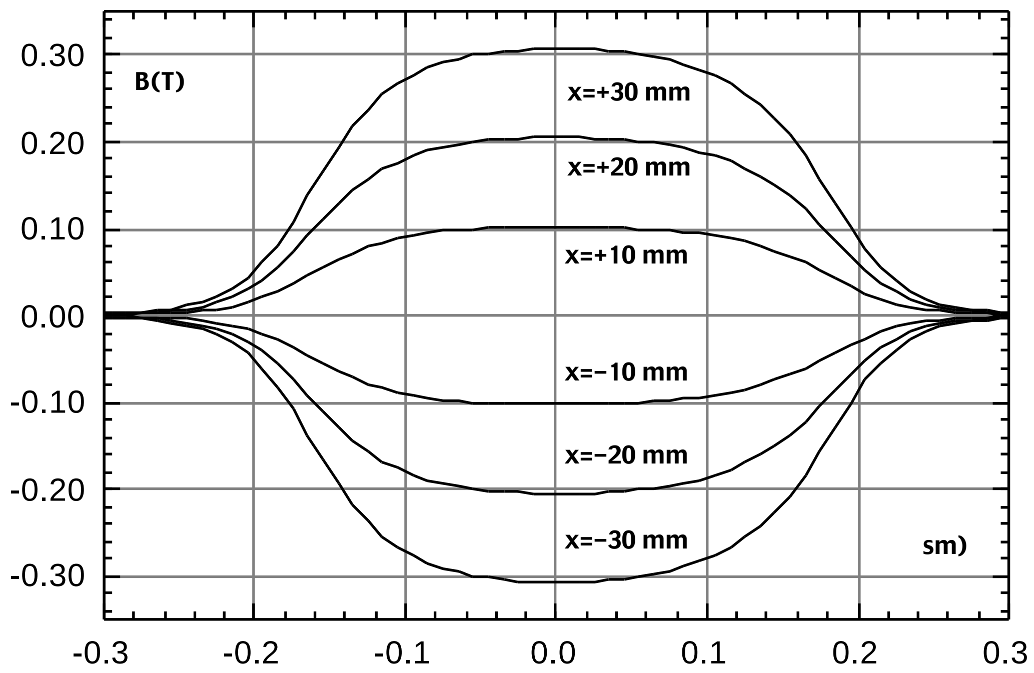


Figure 11 - Longitudinal field behaviour along straight lines parallel to the quadrupole axis. Quadrupole QD sn.2

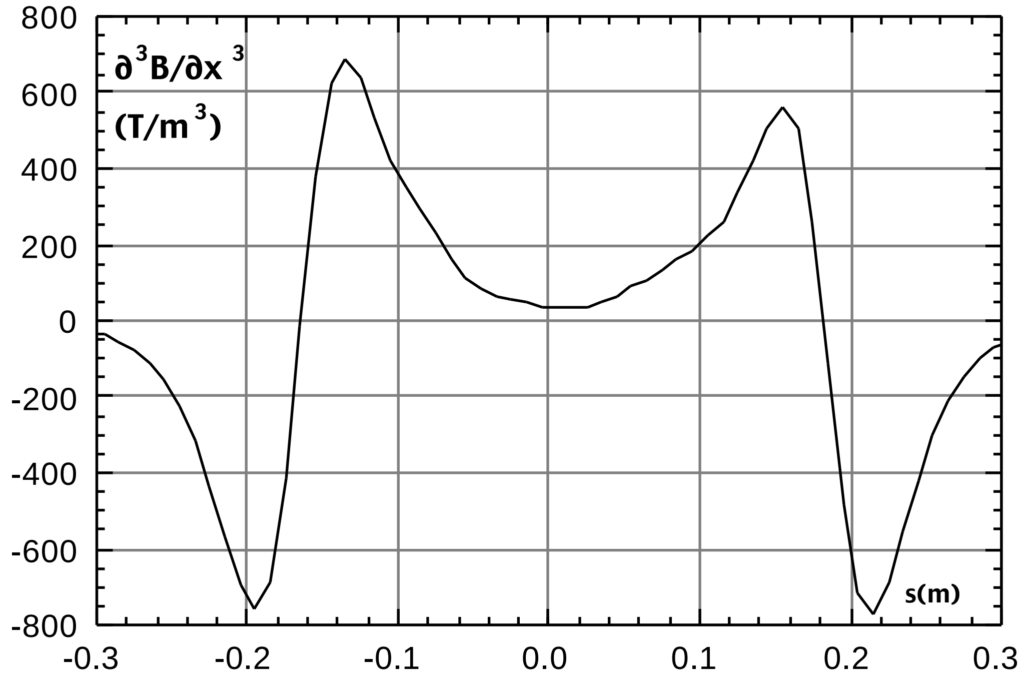


Figure 12 - Longitudinal behaviour of the third order derivative of the field as a function of the horizontal coordinate. Quadrupole QD sn.2

3.3 "Medium" quads QF2

The same measurements have been performed on QF2 quadrupole sn.2. For this magnet there is no backward/forward asymmetry, since its design is symmetric in the longitudinal direction. The magnetic length, defined in the same way as for QD, is 26.8 cm. The integrated gradient obtained from the measurements with the Hall probe is 1.3181 T, 0.2% larger than the result obtained with the rotating coil at LNF and 1.1% larger than that obtained at ASTER.

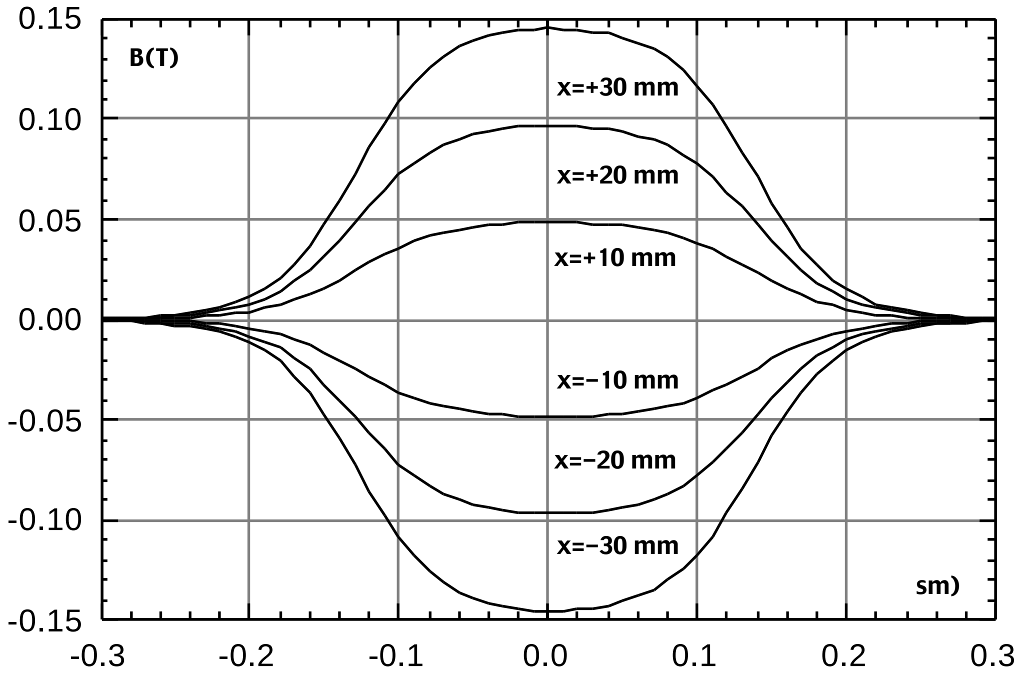


Figure 13 - Longitudinal field behaviour along straight lines parallel to the quadrupole axis. Quadrupole QF2 sn.2

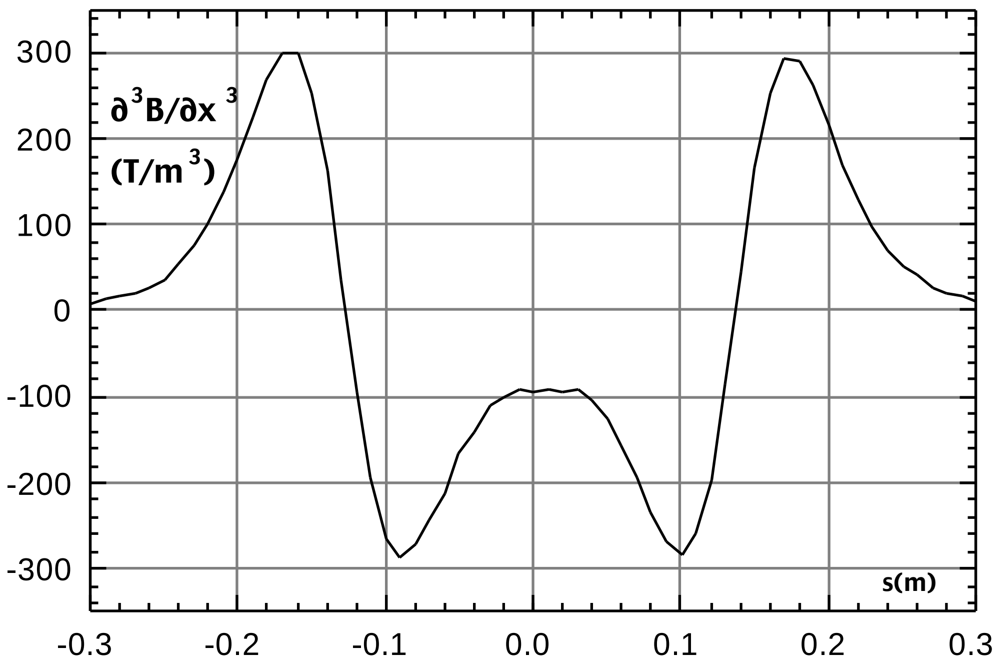


Figure 14 - Longitudinal behaviour of the third order derivative of the field as a function of the horizontal coordinate. Quadrupole QF2 sn.2

4. Conclusions

The measurements performed on the permanent magnet quadrupoles of the KLOE interaction region have demonstrated that the specifications on the field quality have been substantially met. In the case of QF2 the extrapolation of the result to a normalization radius of 55 mm has put in evidence that the highest harmonics are dominated by noise when the analysis is pushed beyond the physical radius of the coil. For this quadrupole there is also a non negligible disagreement between the integrated gradients measured at LNF and ASTER with the rotating coil system.

References

[1] B. Bolli, F. Iungo, M. Preger, C. Sanelli, M. Modena, F. Sardone, F. Sgamma, M. Troiani "Magnetic measurements on the first permanent magnet quadrupoles (Q1) of the KLOE interaction region" - DAΦNE Technical Note MM-3 (8/11/1994).

[2] B. Bolli, F. Iungo, C. Sanelli, F. Sardone, "Misura quadrupolo ASTER #2 con sistema Danfysik. Ricerca dell'asse magnetico" - DAΦNE Technical Note MM-5 (19/12/1994).