DAΦNE TECHNICAL NOTE

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MAGNETIC MEASUREMENTS ON THE PERMANENT MAGNET QUADRUPOLES OF THE FI.NU.DA. INTERACTION REGION

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1. Introduction

The permanent magnet quadrupoles for the FI.NU.DA. interaction region have been built by ASTER Enterprises, and have been measured with the same procedures adopted for those now installed on KLOE [1,2,3]. The magnets are arranged in two doublets: the first two quadrupoles starting from the crossing point are called Q1 (short), the second ones Q2 (long). The following table summarizes the Specifications relevant to the magnetic measurements set by LNF.

Table 1 - Specifications for the FI.NU.DA permanent magnet quadrupoles

	Units	**Q1**	**Q2**
Magnetic length	mm	157.5±1	300±1
Nominal gradient	T/m	9.433	-10.802
Integrated gradient	T	1.486±0.5%	-3.241±0.5%
Good field region radius	mm	30	30
Integrated field quality		$5x10^{-4}$	$5x10^{-4}$
Maximum allowable mismatch of integrated gradient between the two quadrupoles		10^{-3}	10^{-3}

2. Measurements with the rotating coil

2.1 "Short" quads Q1

The measurements have been performed in January 2000 at LNF, no corresponding ones at ASTER are available. The integrated gradients of the two magnets have been found to be 1.478T (sn#1) and 1.477T (sn#2), ≈ 0.6% smaller than the specified value. Table 2 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). 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.

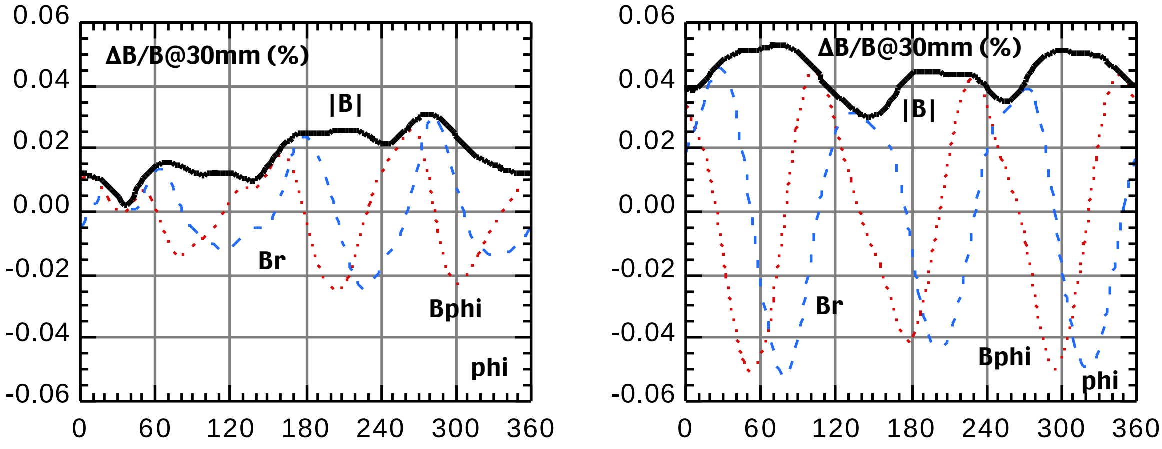

Figure 1 - Relative deviation from ideal quadrupole field @ 30 mm from magnet axis: full line = azimuthal component, dotted line = radial component, full bold line = absolute field value; left = QF1 sn#1, right = QF1 sn#2

Table 2 - Integrated gradient, average deviation from ideal quadrupole and main harmonics for the measurements on the "short" quadrupoles Q1.

Serial Number	**1**	**2**
Integrated gradient (T)	1.4783	1.4774
<ΔB/B> @ 30 mm (%)	0.017	0.043
6-pole @ 30 mm (%)	0.015	0.042
8-pole @ 30 mm (%)	0.009	0.005
10-pole @ 30 mm (%)	0.003	0.003
12-pole @ 30 mm (%)	0.002	0.007
14-pole @ 30 mm (%)	0.003	0.001
16-pole @ 30 mm (%)	0.002	0.000
18-pole @ 30 mm (%)	0.001	0.001
20-pole @ 30 mm (%)	0.002	0.001

For both quadrupoles the field quality is within specification, and, in particular for sn#2, the main contribution comes from the sextupole term which, as explained in the references, is the multipole affected by the largest measurement error.

2.2 "Long" quads Q2

Measurements performed at ASTER are also available for comparison for the long Q2 quadrupoles. However, the magnets were delivered without any identification, so that it was not possible to establish a correspondence between the two measurements (ASTER calls the quadrupoles sn#1 and sn#2) and the magnets. At LNF the magnets were identified with a punched plate with codes sn#3 and sn#4. Fig. 2 shows the deviation from the ideal quadrupole field at 30 mm from the magnet axis while Table 3 presents the results of the measurements with the rotating coil compared to those performed at ASTER, taking for the correspondence the results which look more similar to each other.

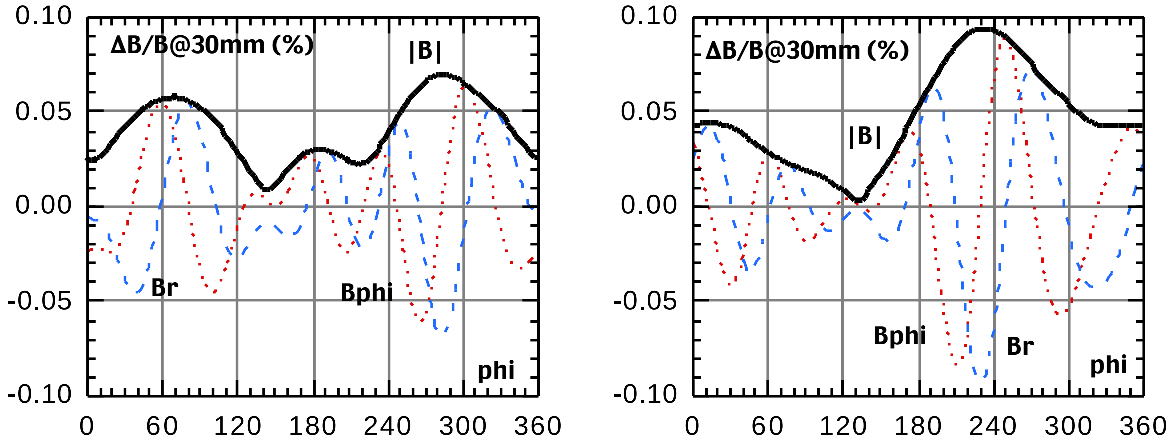

Figure 2 - Relative deviation from ideal quadrupole field @ 30 mm from magnet axis: full line = azimuthal component, dotted line = radial component, full bold line = absolute field value; left = QF2 sn#3, right = QF2 sn#4

Table 3 - Integrated gradient, average deviation from ideal quadrupole and main harmonics for the measurements on the ""long" quadrupoles Q2.

Serial Number	**3**		**4**	
Measurement	LNF	ASTER (#1)	LNF	ASTER (#2)
Integrated gradient (T)	3.2520	3.229	3.244	3.227
<ΔB/B> @ 37 mm (%)	0.040	-	0.046	-
6-pole @ 37 mm (%)	0.026	0.018	0.020	0.013
8-pole @ 37 mm (%)	0.023	0.016	0.041	0.019
10-pole @ 37 mm (%)	0.011	0.007	0.018	0.011
12-pole @ 37 mm (%)	0.005	0.016	0.019	0.011
14-pole @ 37 mm (%)	0.002	0.004	0.001	0.000
16-pole @ 37 mm (%)	0.001	0.001	0.003	0.001
18-pole @ 37 mm (%)	0.000	0.000	0.001	0.000
20-pole @ 37 mm (%)	0.000	0.000	0.001	0.000

Both the integrated gradients measured at LNF and at ASTER are within specification, although the results are different by 0.7% for sn#3 and 0.5% for sn#4. The requirement on the field quality is fulfilled if the average deviation on the circle of 3 cm radius is taken into account, while, as shown in Fig. 2, the limiting value of .05% is exceeded in both magnets on a rather large fraction of the circle. The results on the contributions to the individual harmonics are quite different between the measurements performed at ASTER and LNF.

3. Longitudinal scans

The vertical component of the field has been measured on the horizontal symmetry plane of the magnets up to the good field limit defined in the Specification (±30 mm). This kind of measurement has been performed to find out the magnetic length and the longitudinal dependence of the higher harmonics.

3.1 "Short" quads Q1

The results of the longitudinal scans on the "short" quadrupoles Q1 are shown in Figs. 3 and 4 for sn#1 and sn#2 respectively.

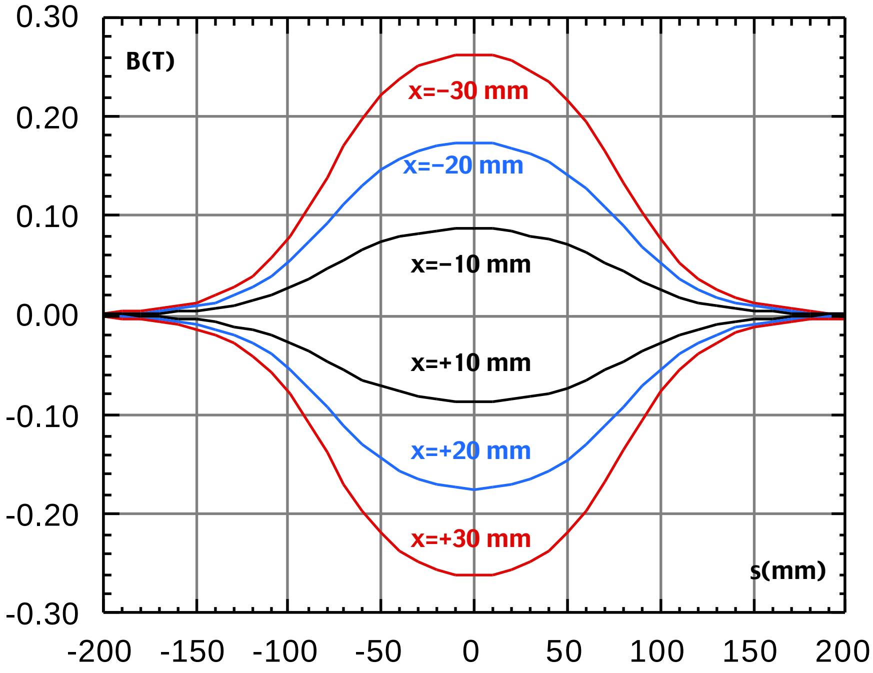

Figure 3 - Longitudinal field behaviour along straight lines parallel to the quadrupole axis. Quadrupole Q1 sn#1

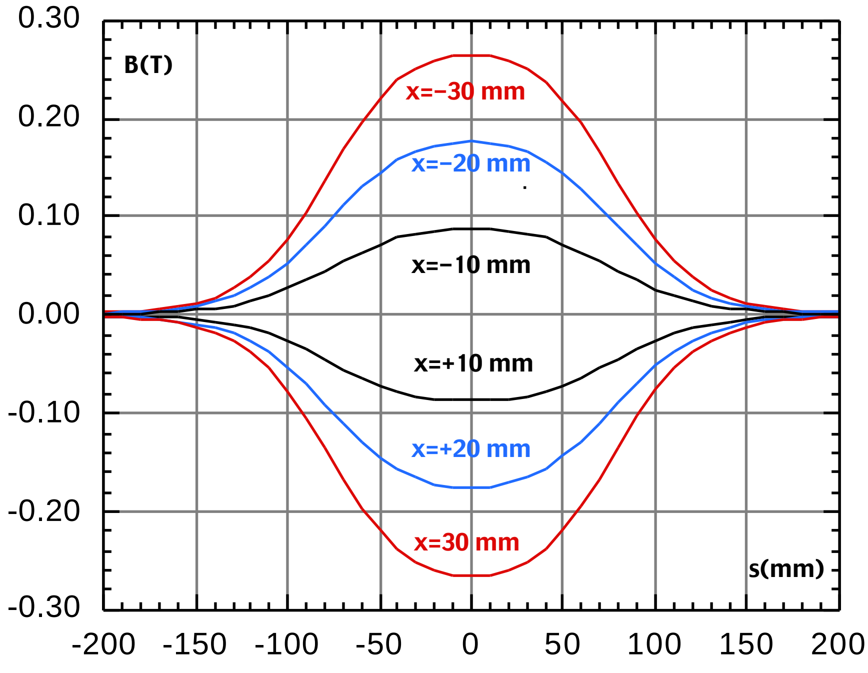

Figure 4 - Longitudinal field behaviour along straight lines parallel to the quadrupole axis. Quadrupole Q1 sn#2

The field has been recorded along the quadrupole axis and 6 straight lines parallel to it at distances of ±10 mm, ±20 mm and ±30 mm. The range in the longitudinal direction was ±0.48 m from the mechanical center, although the field is significantly different from zero only between ±0.2 m from the center. The plots 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 7 points measured at each longitudinal position have been fitted with a third order polynomial in order to show the longitudinal dependence of the gradient and of the octupole term (the sextupole term is rather small and exhibits strong fluctuations between adjacent longitudinal positions). The result are shown in Fig. 5 and Fig. 6 for sn#1 and sn#2 respectively. The integrated gradients, calculated by summing up all the values of the first order term of the fit, are larger than the values obtained with the rotating coil by ≈0.17%.

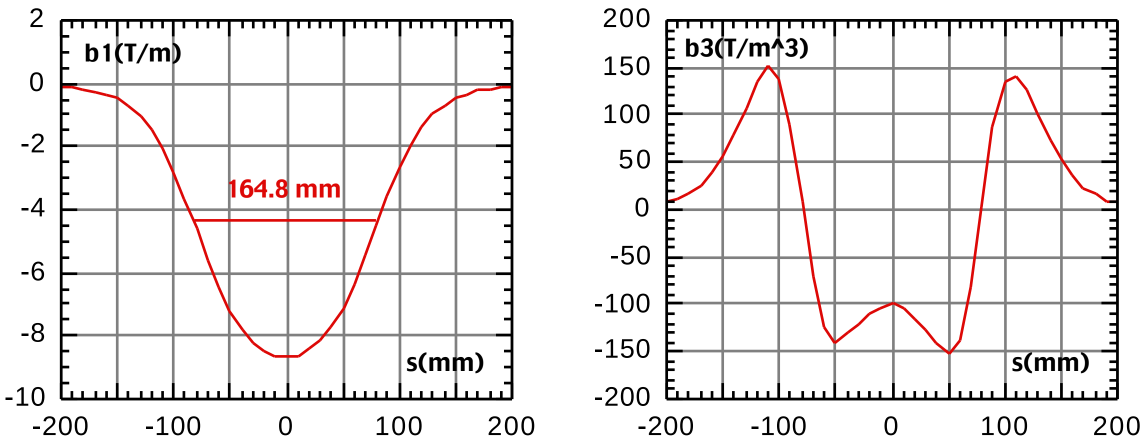

Figure 5 - Fitted gradient and third order term of the transverse expansion of the field measured on the horizontal symmetry plane for Q1 sn#1

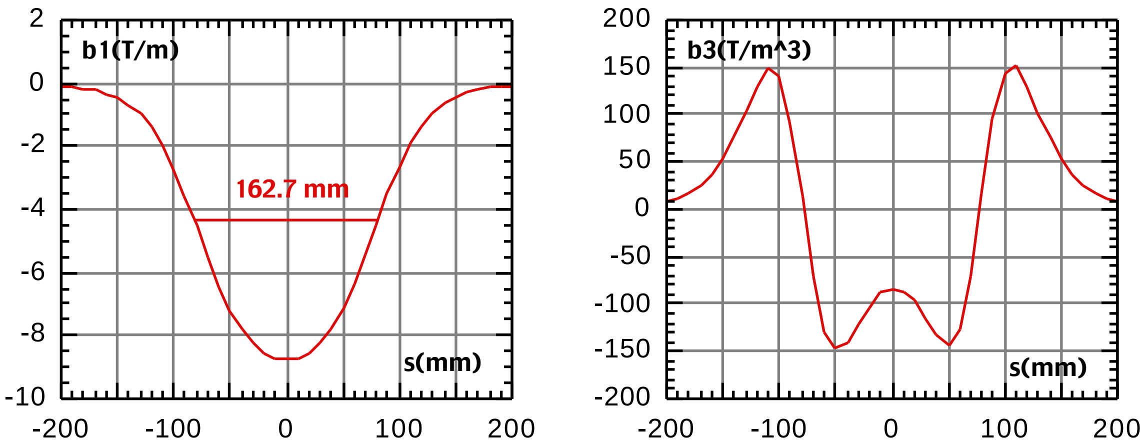

Figure 6 - Fitted gradient and third order term of the transverse expansion of the field measured on the horizontal symmetry plane for Q1 sn#2

The magnetic length can is usually defined as the full width at half maximum of the gradient or as the integrated gradient divided by the maximum gradient inside the magnet. Table 4 compares the values obtained with the two different methods, which are found to be different by ≈ 4%, both largely outside the specified value of 157.5±1 mm

Table 4 - Magnetic length of the short quadrupoles Q1

	sn#1	**sn#2**
FWHM (mm)	164.8	162.7
∫Gds/Gmax (mm)	170.7	168.8

3.2 "Long" quads Q2

The same measurements have been performed on the long quads Q2 and Figs. 7 and 8 show the vertical field component measured along straight lines parallel to the magnet axis on the horizontal symmetry plane at distances of ±10,±20 and ±30 mm from it. Also in this case the field measured on the axis has been subtracted to compensate misalignment errors. A non negligible forward/backward asymmetry can be observed in both magnets.

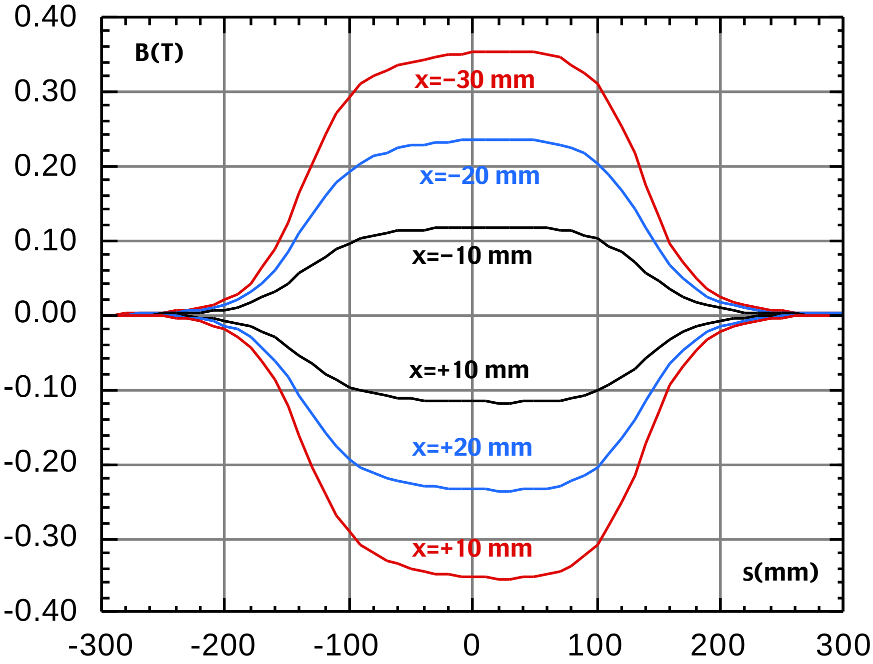

Figure 7 - Longitudinal field behaviour along straight lines parallel to the quadrupole axis. Quadrupole Q2 sn#3

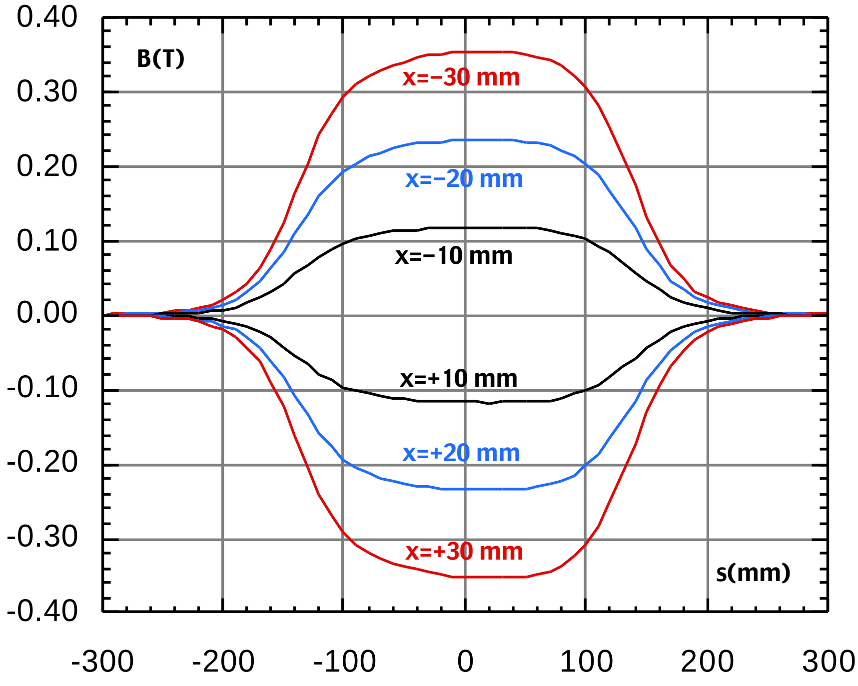

Figure 8 - Longitudinal field behaviour along straight lines parallel to the quadrupole axis. Quadrupole Q2 sn#4

Figures 9 and 10 show the first and third order terms of the transverse fits of the seven field measurements at each longitudinal position, while Table 4 summarizes the results of the magnetic lengths of the two long quadrupoles, which are ≈8% shorter than the specified value.

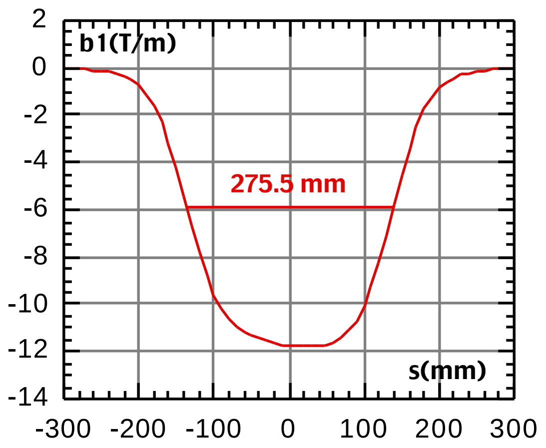

Figure 9 - Fitted gradient and third order term of the transverse expansion of the field measured on the horizontal symmetry plane for Q2 sn#3

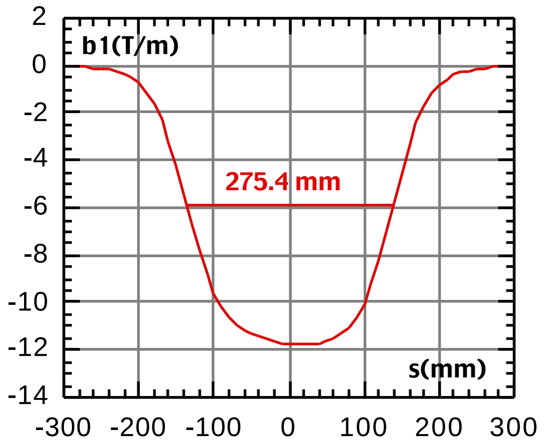

Figure 10 - Fitted gradient and third order term of the transverse expansion of the field measured on the horizontal symmetry plane for Q2 sn#4

Table 4 - Magnetic length of the long quadrupoles Q2

	sn#3	**sn#4**
FWHM (mm)	275.5	275.4
∫Gds/Gmax (mm)	276.4	276.1

4. Conclusions

The results of the measurements performed on the permanent magnet quadrupoles of the FI.NU.DA. interaction region are slightly worse than those obtained for the KLOE ones [3]. The short quadrupoles are in a better agreement with the Specifications than the long ones, although the magnetic length, in the best case, is longer by 5 mm (against an allowed deviation of 1 mm). The long quadrupoles are clearly asymmetric in the longitudinal direction, the magnetic length is ≈25 mm shorter than desired, and the requirement on the field quality is only partially fulfilled.

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).

[3] B. Bolli, S. Ceravolo, F. Iungo, F. Losciale, M. Paris, M. Preger, C. Sanelli, F. Sardone, F. Sgamma, M. Troiani "Magnetic measurements on the permanent magnet quadrupoles of the KLOE interaction region" - DAΦNE Technical Note MM-31 (23/6/1998).