DAΦNE TECHNICAL NOTE

INFN - LNF, Accelerator Division

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MEASUREMENTS ON SIGMA-PHI SQUARE CORRECTOR PROTOTYPE FOR THE DAΦNE MAIN RINGS

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1. Introduction

The first prototype of the Main Rings Square HV (Horizontal/Vertical) Corrector Magnet, built by Sigma-Phi (ΣΦ), Vannes Cedex (France), was delivered to LNF on March 1, 1996, together with other two prototypes, the Rectangular HV Corrector Magnet [1] and the HVSQ (Horizontal/Vertical/SkewQuad) Corrector Magnet [2]. The first and the last one will be installed in the Main Rings in the regions where the vacuum chamber has a circular shape, the second will be used in the achromats, where the chamber has a larger size in the horizontal direction.

These Corrector Magnets were designed by LNF staff and Fig. 1 shows a picture of the first one. Table I gives its main parameters.

Fig. 1 *- Pictorial view of the Square Corrector Magnet*

Table I - Square Corrector Magnet prototype parameters.

Square Corrector H/V	units	CH	CV
Energy	MeV	510	510
Deflection Angle	mrad	3	3
Nominal Field	Gauss	176	176
Magnet Gap	mm	190	190
Magnetic Length (Design)	m	0.29	0.29
Number of turns per pole		364	364
Nominal Current	A	7.48	7.48
Copper Wire Diameter	mm	2.65	2.65

2. Electrical measurements

The resistance of the Square HV Corrector Magnets was measured by means of a micro-ohm-meter (AOIP mod. OM 20) at room temperature.

The measured values were:

Horizontal	0.8666 Ω	@ 23 °C
Vertical	0.8638 Ω	@ 23 °C

The same measurement were accomplished by using the Volt-Ampere method and the following data were measured:

Horizontal	6.44 V @ 7.3 A, corresponding to 88.2 mΩ
Vertical	6.55 V @ 7.3 A, corresponding to 89.7 mΩ

These values were obtained at the same room temperature as in the preceding measurement. The agreement between the results obtained with the two different methods is very good.

The inductance and resistance of the three magnet prototypes were also measured by means of a LCR meter (LCR meter HP 4284 A) at different frequencies. The results are shown in Figure 2. The corresponding dc values can be extrapolated from these data. They are consistent with the measured and design data.

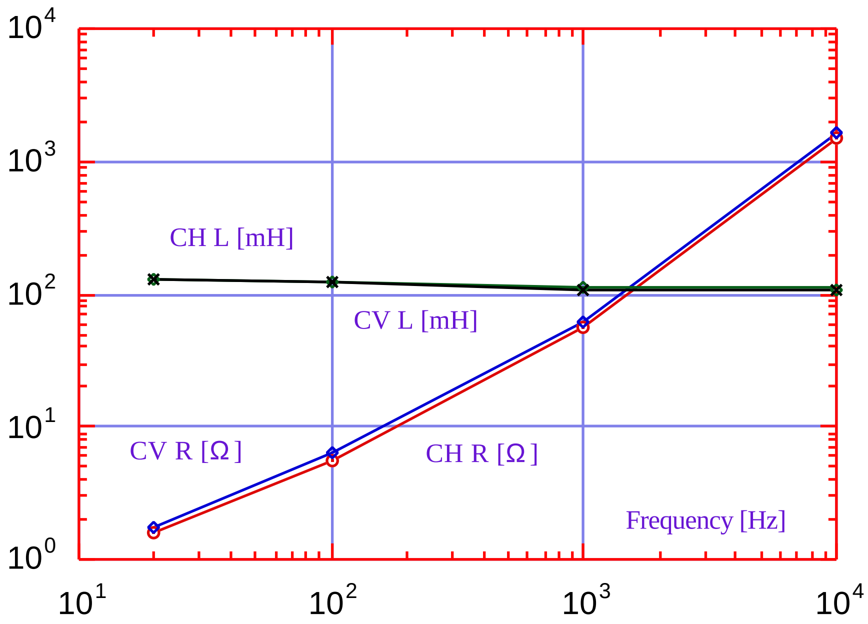

Fig. 2 **-** Resistance and inductance versus frequency for the Square Corrector Magnet

Thermal measurements were also accomplished and the worst figure for the Square HV Corrector Magnet is listed in Table II.

Table II - Temperature rise of magnet coils.

Time (min)	0	15	30	45	60	75	90
Temperature (°C)	32.7	34.9	39.7	42	42.3	44.2	44.4

3. Magnetic measurements

The horizontal and vertical components of the field at the magnet center have been separately measured as a function of the current in the corresponding coil (in the following we indicate with CH the horizontal corrector coil, which generates the vertical field component, and with CV the other one).

The difference between the two measurement is negligible, and therefore we show the common behaviour in Fig. 3: it is linear over the operating range. Since the magnet was powered by a unipolar power supply, it was not possible to check carefully the behaviour of remanent field when inverting the corrector polarity, which, of course, will be done in the normal operation of the ring with the final bipolar power supplies. However, the remanent fields observed during the cycling operation with the available equipment are of the order of 1 G.

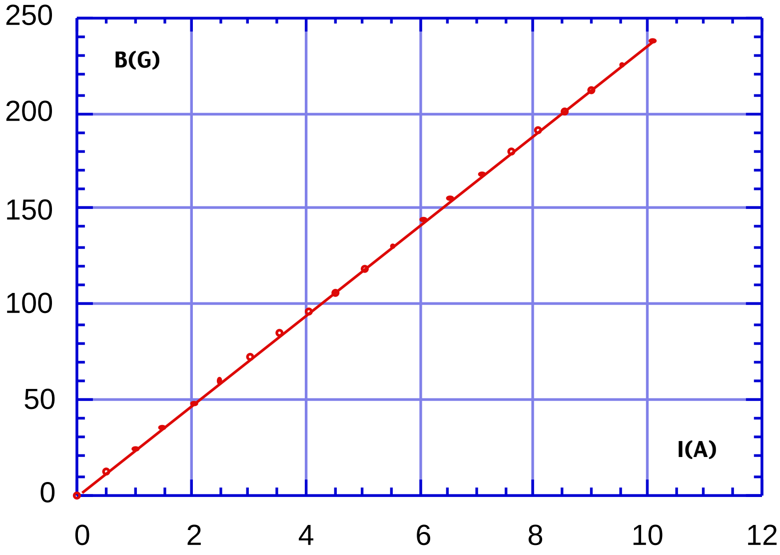

Fig. 3 *- Field components at magnet center versus current.*

We have also measured the dependence of each component on the current in the corresponding coil with the other coil set at the maximum current. Taking into account the remanent field coming from the cycling procedure with both coils excited, the difference with respect to the previous measurement with the other coil switched off is less then 0.5% on the whole operating range.

However, the above mentioned check is not sufficient to demonstrate the independence of the corrections in the two planes. We have therefore measured the vertical component of the field on a vertical plane perpendicular to the magnet axis at its midpoint inside the good field region up to distance of 30 mm from the longitudinal axis in both the horizontal and vertical directions with CH set at the maximum current and CV off. The result is shown on an expanded scale in Fig. 4 as a function of the horizontal position, each curve corresponding to a different vertical position. The field is constant within ≈4% in the good field region (± 30 mm in both directions).

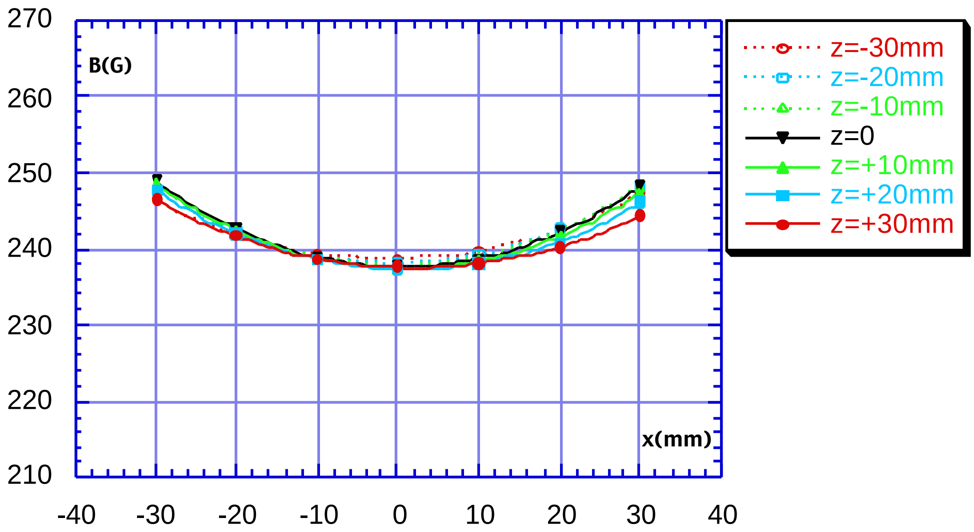

Fig. 4 *- Vertical field component at magnet center with CH @ 10A and CV off (expanded scale)*

The situation changes significantly when both corrector coils are switched on: Fig. 5 shows the vertical field component, on the same scale as in Fig. 4, when both corrector coils are set at the maximum current. The variation is now ≈20% and depends strongly both on the horizontal and vertical positions. It is clear that this implies that the orbit corrections in the two planes are influenced by each other.

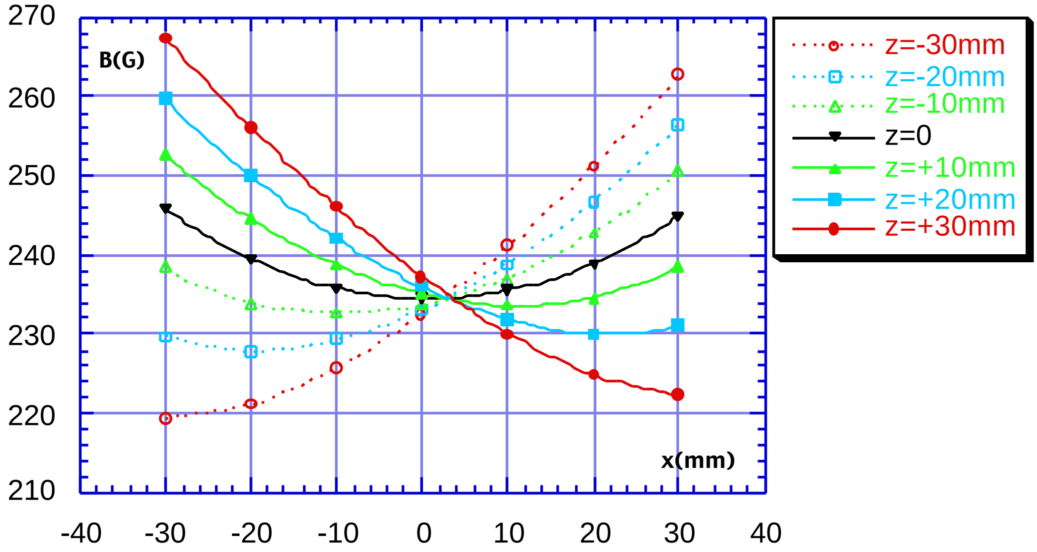

Fig. 5 *- Vertical field component at magnet center with CH and CV @ 10A (expanded scale)*

We have therefore measured the vertical field component when only <u>the other</u> corrector (CV) is set to the maximum current (CH off), and the result is shown in Fig. 6. The behaviour is almost linear in both directions and the center appears to be displaced horizontally by ≈3 mm.

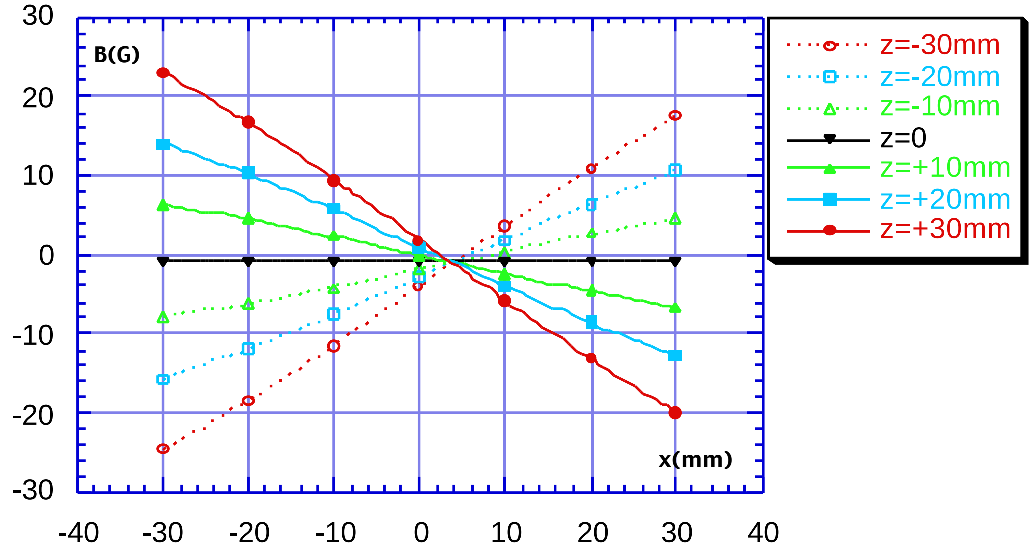

Fig. 6 *- Vertical field component at magnet center with CV @ 10A (CH off)*

We have then compared the field measured with both coils excited with the sum of the fields measured with each coil excited separately, namely the field given in Fig. 5 with the sum of those given in Fig. 4 and Fig. 6. The difference between the corresponding points is 2.25 G for x = z = 0 and within 2.15 G and 2.35 G in all the other points. We have therefore an offset, coming from the different cycling procedures in the three separate measurements, but, apart from this effect, the fields created by the two coils add linearly in the good field region.

For sake of completeness, we show in Figs. 7÷9 the corresponding measurements for the horizontal field component. In this case the above mentioned difference is 0.35 G at the magnet center and within 0.10 G and 0.45 G in the other points. Since we are now considering the correction in the vertical plane, the field is shown on an expanded scale versus the vertical coordinate (z), with the horizontal one (x) as a parameter.

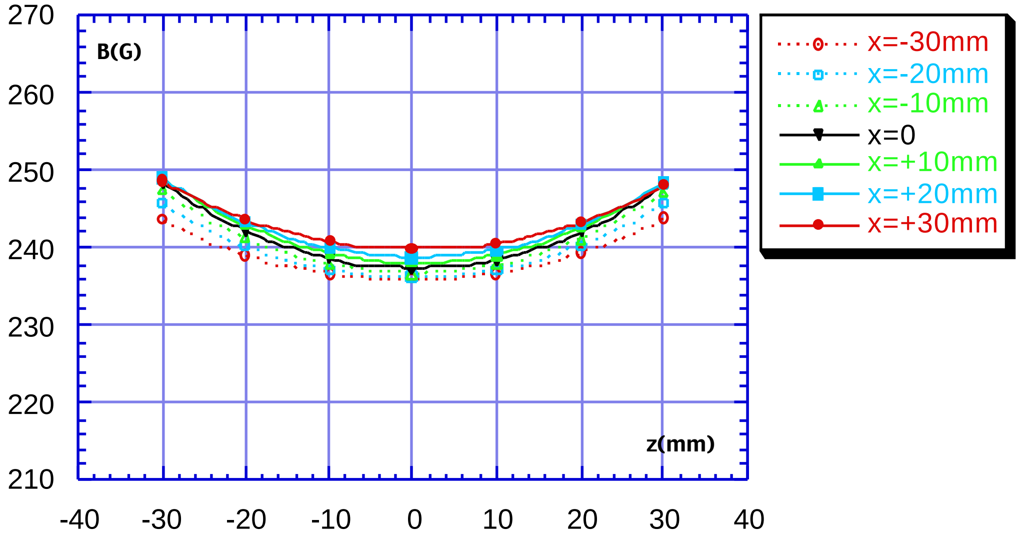

Fig. 7 *- Horizontal field component at magnet center with CV @ 10A (CH off) (expanded scale)*

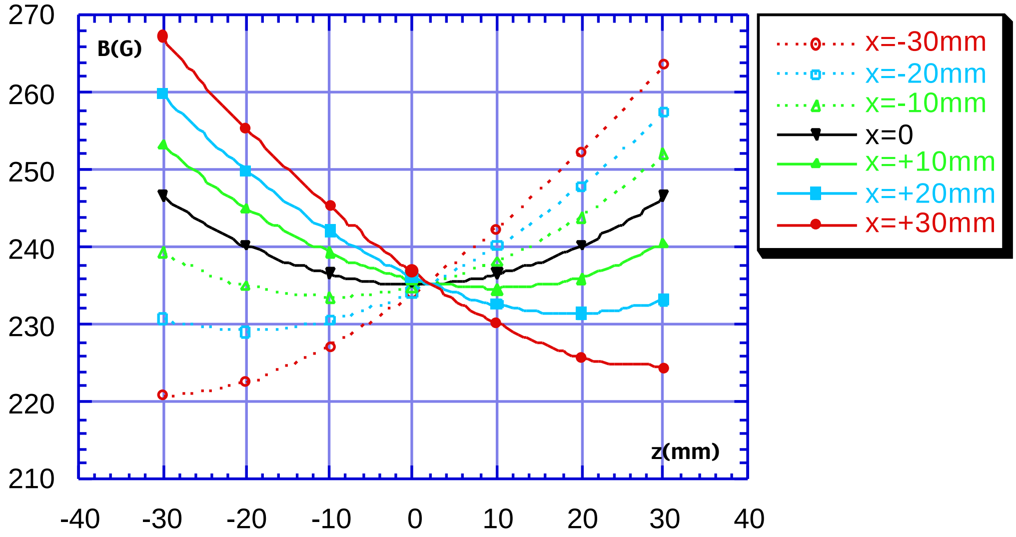

Fig. 8 *- Horizontal field component at magnet center with CV and CH @ 10A (expanded scale)*

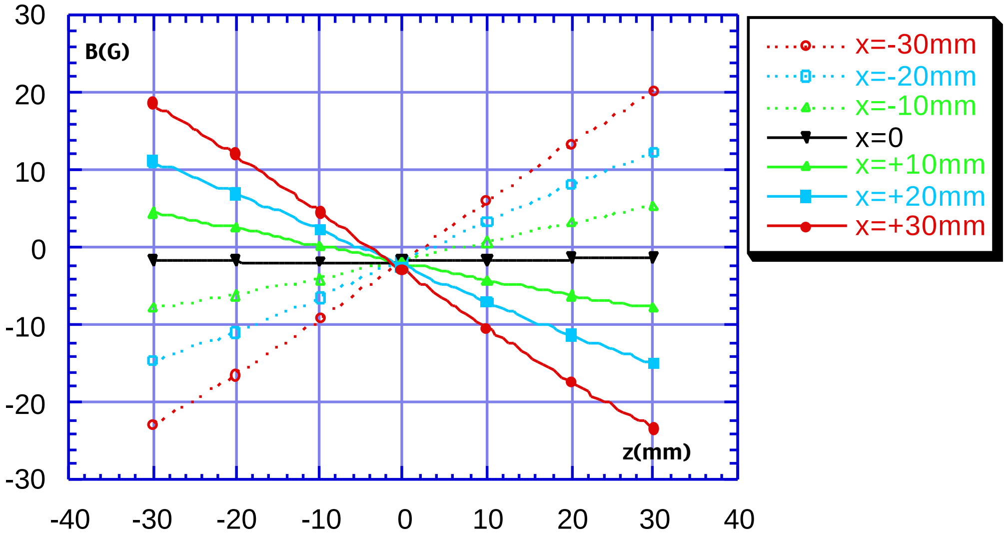

Fig. 9 *- Horizontal field component at magnet center with CH @ 10A (CV off)*

The behaviour of the field has been measured in steps of 20 mm along straight lines parallel to the magnet axis at different horizontal and vertical distances from it in steps of 10 mm inside the good field region. The field on the central axis is shown in Fig. 10 for the vertical component, the horizontal one being the same within a fraction of G. The full width at half maximum is 245 mm, but there are long tails, not negligible even at half a meter from the magnet center. This should be kept in mind for those correctors located into the ring near other magnetic elements, since the calibration could change significantly due to the absorption of the field lines by the yokes of the neighbouring magnets.

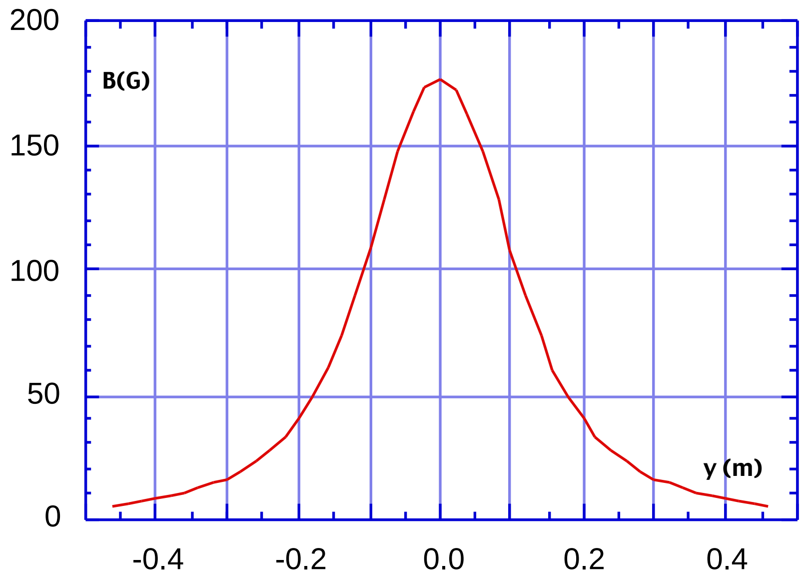

Fig. 10 *- Vertical field component along the magnet axis with CH @ 7.48A*

The value of the field integral taken along lines parallel to the magnet axis at different horizontal and vertical positions are given in Fig. 11 and Fig. 12 for the vertical and horizontal component respectively (the scale is expanded).

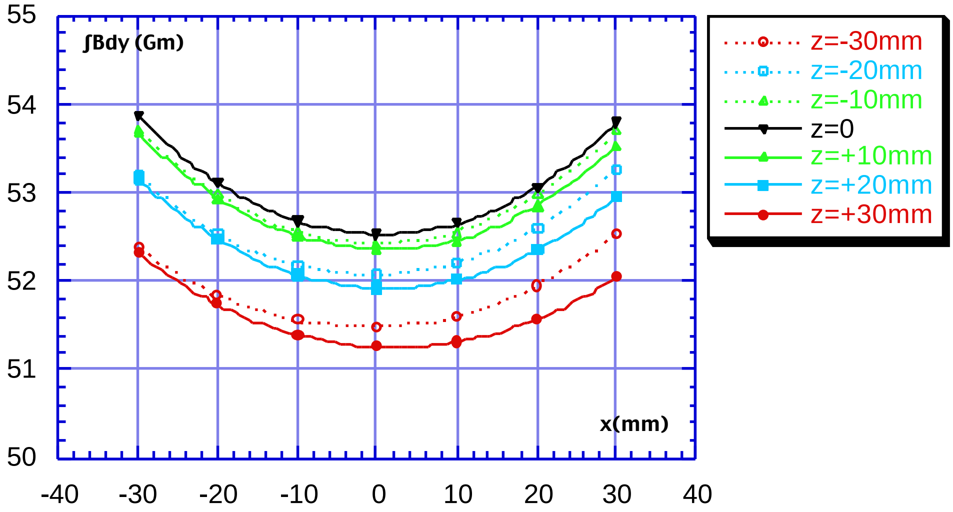

Fig. 11 *- Integrated vertical component with CH @ 7.48A, CV off (expanded scale)*

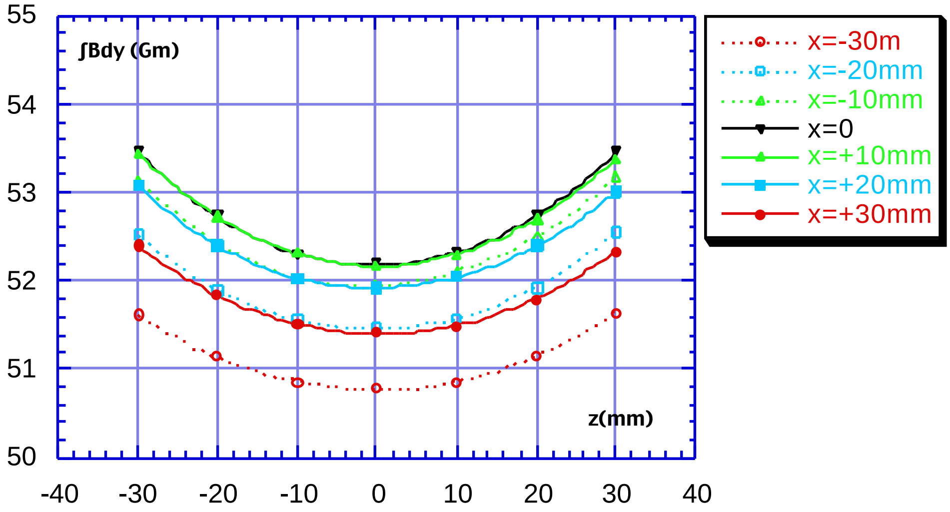

Fig. 12 *- Integrated horizontal component with CV @ 7.48A, CH off (expanded scale)*

From the comparison of the last two figures we point out that there is a difference of ≈0.7% in the calibration between the horizontal and vertical components. The calibration changes by ≈±2.5% within the good field region with respect to its value taken at the magnet center. There are also left-right and up-down asymmetries of the order of 1% with respect to the mechanical center.

Taking for the calibration the average between the two components, we get for the angular kick α to the beam:

$$\alpha \text{ (mrad)} = 0.21 \text{ I (A)} / \text{E (GeV)}$$

By fitting the curves in Fig. 11 and Fig. 12 with a polynomial, we find also an integrated sextupole term. Averaging between the two correctors:

$$S \text{ (T/m)} = \int (\partial^2 B_{z,x}/\partial x,z^2) \, dy = 3.6\text{x}10^{-2} \text{ I (A)}$$

Due to the close proximity of the two rings and the peculiar design of the corrector magnet, stray field on the outer side of the coils can reach non negligible values. For this reason, we have measured the vertical field component on the horizontal symmetry plane along a straight line perpendicular to the magnet axis at its center. The result is shown in Fig. 13, where the origin of the horizontal coordinate is at the magnet center, like in all the previous plots, and both coils are excited at the maximum current. The difference between the fields measured on the right and left sides of the magnet is negligible.

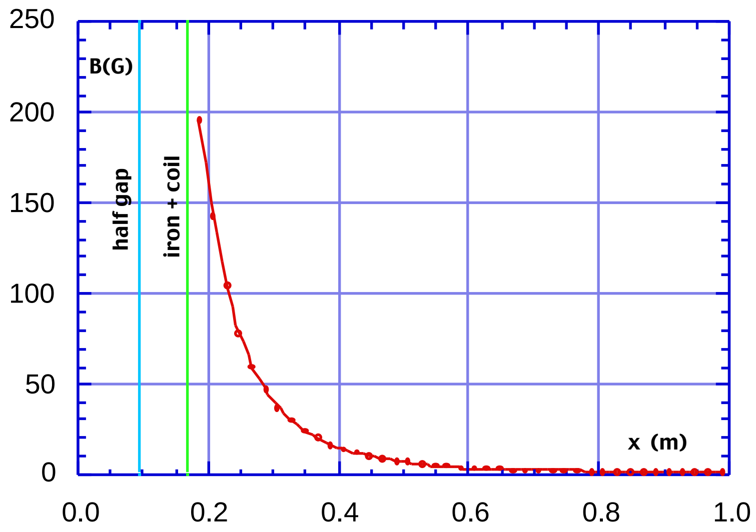

***Fig. 13** - Vertical component of the stray field on the horizontal symmetry plane with CH and CV @ 10 A*

4. Conclusions

The Square HV Corrector Magnet prototype has been fully characterised at LNF. The measurement confirmed the reliability of its magnetic design. The main drawback of this kind of large, combined functions magnet, namely the interplay between the corrections in the two planes, is kept within reasonable values, and should not represent a problem for the routine operation of orbit correction. The linearity of the field within the good field region ensures a comfortable control of the overall orbit correction procedure even at the beginning of commissioning, when large initial orbit errors are foreseen.

The interference of the field tails with the yoke of other magnetic components in the ring should be carefully checked during commissioning by calibrating each corrector with the beam and the closed orbit detection system.

As a consequence of all the above described measurements, the prototype has been accepted and series production authorised.

References

[1] B. Bolli, F. Iungo, N. Ganlin, F. Losciale, M. Paris, M. Preger, C. Sanelli, F. Sardone, F. Sgamma, M. Troiani - "Measurements on SIGMA-PHI Rectangular Corrector Prototype for the DAΦNE Main Rings" - DAΦNE Technical Note MM-15.

[2] B. Bolli, F. Iungo, N. Ganlin, F. Losciale, M. Paris, M. Preger, C. Sanelli, F. Sardone, F. Sgamma, M. Troiani - "Measurements on SIGMA-PHI CHV+SkewQuad Corrector Prototype for the DAΦNE Main Rings" - DAΦNE Technical Note MM-16.