DAΦNE TECHNICAL NOTE

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

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1. Introduction

The first prototype of the Main Rings Rectangular 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 Square HV Corrector Magnet [1] and the HVSQ (Horizontal/Vertical/SkewQuad) Corrector Magnet [2]. The second and the third one will be installed in the Main Rings in the regions where the vacuum chamber has a circular shape, while the first 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 Rectangular prototype. Table I gives its main parameters.

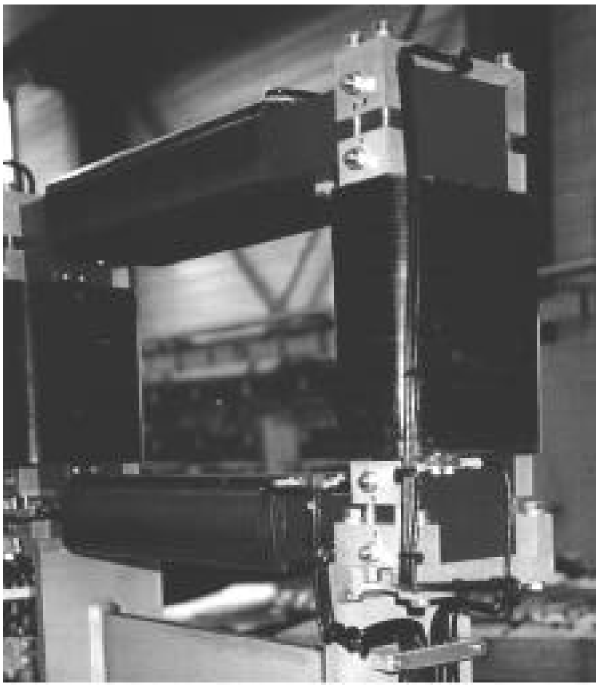

Fig. 1 *- Pictorial view of the Rectangular Corrector Magnet*

Table I - Rectangular HV Corrector Magnet prototype parameters.

Rectangular Corrector H/V	units	CH	CV
Energy	MeV	510	510
Deflection Angle	mrad	3	3
Nominal Field	Gauss	150	80
Magnet Gap	mm	240	540
Magnetic Length (Design)	m	0.34	0.64
Number of turns per pole		303	502
Nominal Current	A	8.78	6.36
Copper Wire Diameter	mm	2.65	2.65

2. Electrical measurements

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

The measured values were:

Horizontal coil 0.9109 Ω @ 23 °C
Vertical coil 1.128 Ω @ 23 °C

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

Horizontal coil 6.94 V @ 7.30 A, corresponding to 0.951 Ω
Vertical coil 7.73 V @ 6.85 A, corresponding to 1.128 Ω

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 Fig. 2. The corresponding dc values can be extrapolated from these data. They are consistent with the measured and design data.

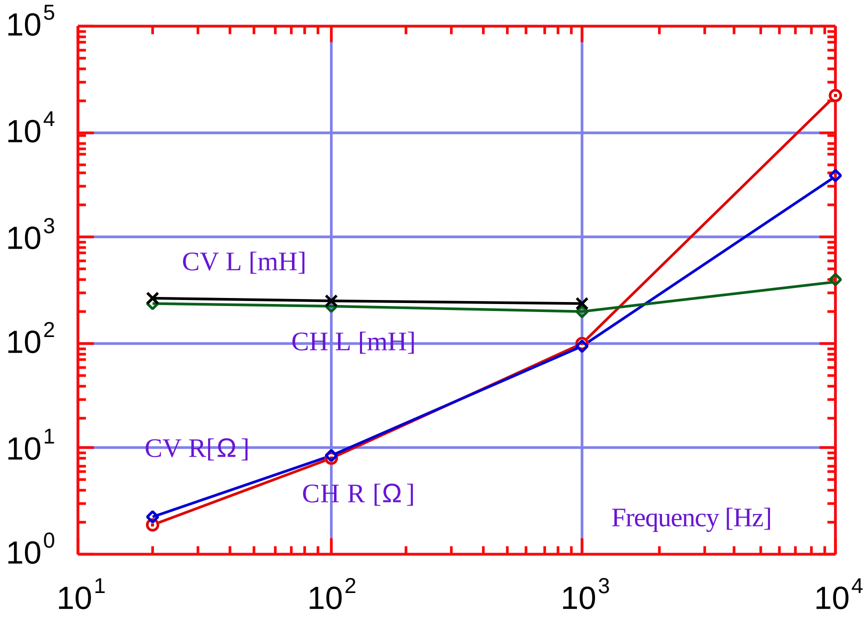

***Fig. 2** - Resistance and inductance versus frequency for the Rectangular Corrector Magnet*

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	30	60	180	195
Temperature (°C)	27	32.5	35.7	38.8	38.7

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). Both field components are linear over the operating range. Since the coils were powered by unipolar power supplies, it was not possible to check carefully the behaviour of remanent fields 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.

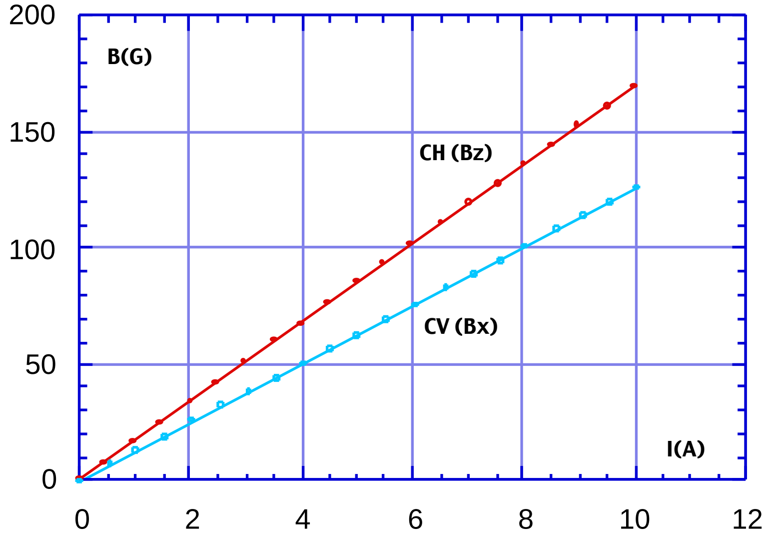

Fig. 3 *- Field components at magnet center versus current.*

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.

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 a distance of 30 mm from the longitudinal axis in both the horizontal and vertical directions with CH set at the nominal working point (8.78A). 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 independent from the horizontal position and increases by ≈3% from the magnet center to the good field region boundary in the vertical direction (± 30 mm).

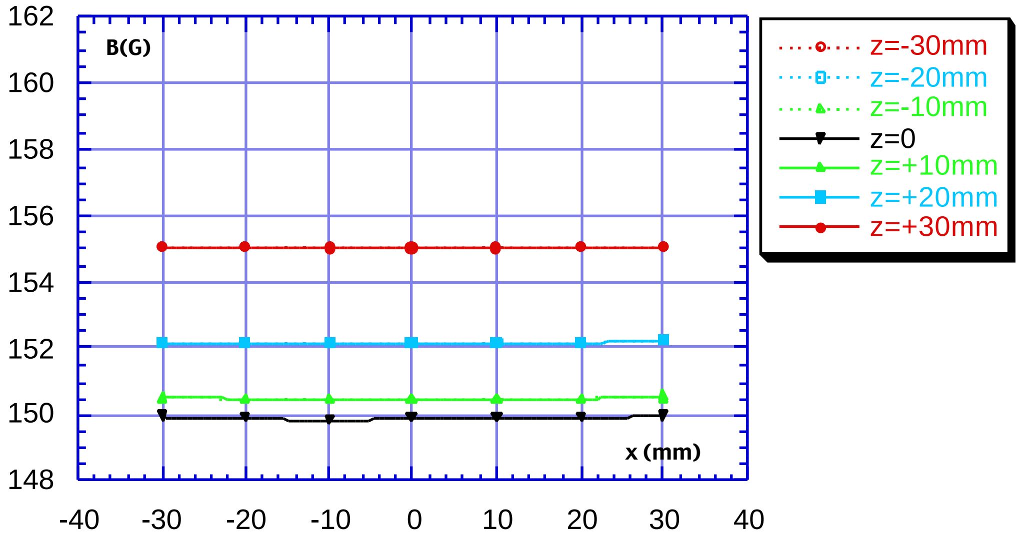

Fig.4 *- Vertical field component at magnet center with CH @ 8.78A, CV off (expanded scale)*

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, with both corrector coils are set at their nominal currents. The overall variation of the field in the good field region (±30 mm in both directions) is now ≈7% and depends both on the horizontal and vertical positions. This implies that the orbit corrections in the two planes are influenced by each other.

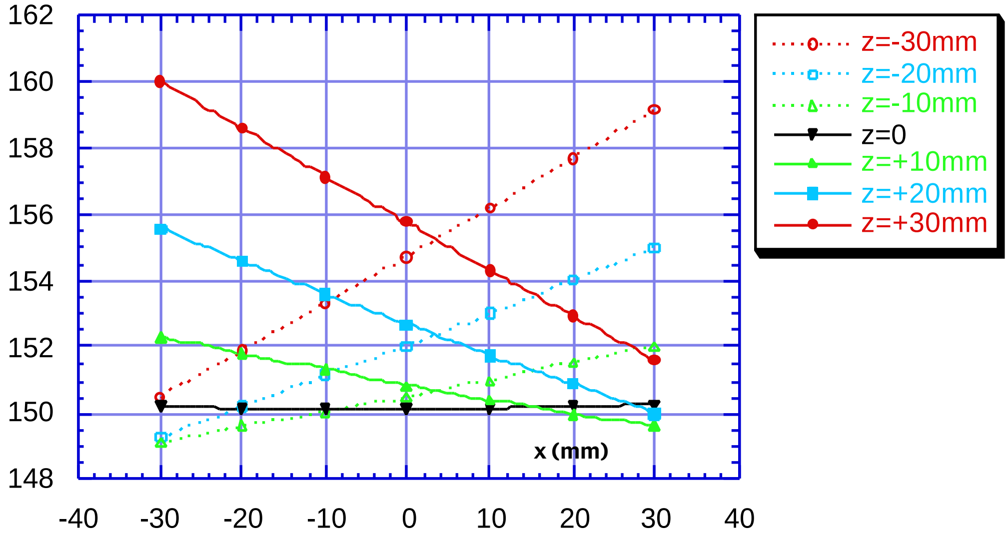

Fig. 5 *- Vertical field component at magnet center with CH @ 8.78 A and CV @ 6.36A (expanded scale)*

We have therefore measured the vertical field component when only <u>the other</u> corrector (CV) is set to its nominal current (CV@6.36 A, 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.

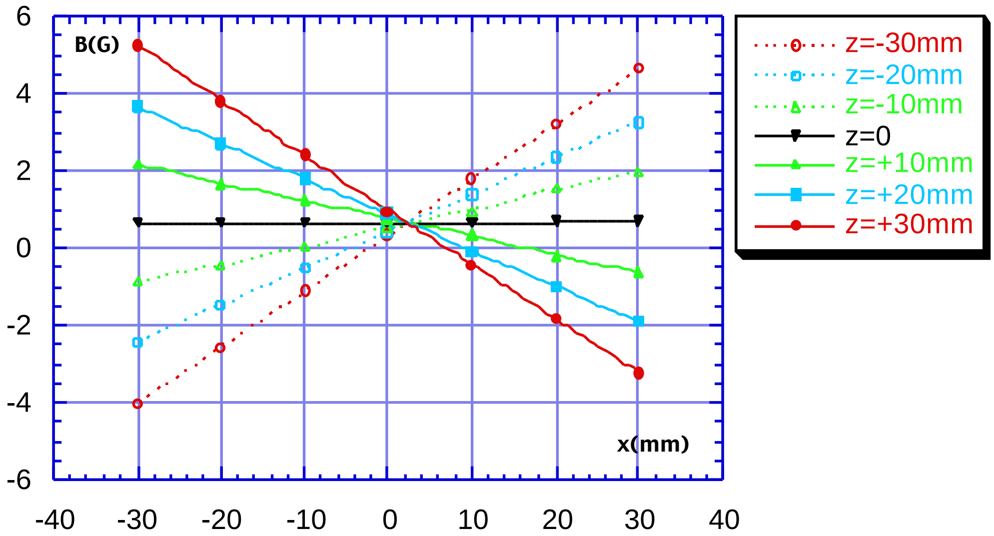

Fig. 6 *- Vertical field component at magnet center with CV @ 6.36A, CH off*

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 Figs. 4 and 6. The difference between the corresponding points is 0.40 G for x = z = 0 and within 0.30 G and 0.60 G in all the other points. We have therefore a small 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.

Due to the different gap sizes in the two transverse directions, we show in Figs. 7÷9 the corresponding measurements for the horizontal field component. 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. In this case, apart from a general offset of ≈1 G , due to the different cycling procedure in the two measurements, the horizontal component does not change significantly when CH is switched on.

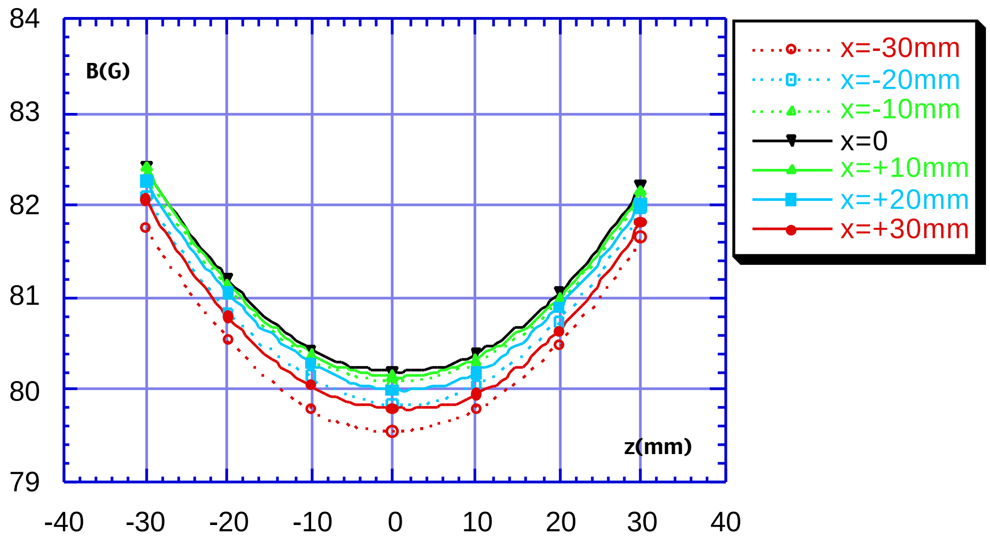

Fig. 7 *- Horizontal field component at magnet center with CV @ 6.36 A, CH off (expanded scale)*

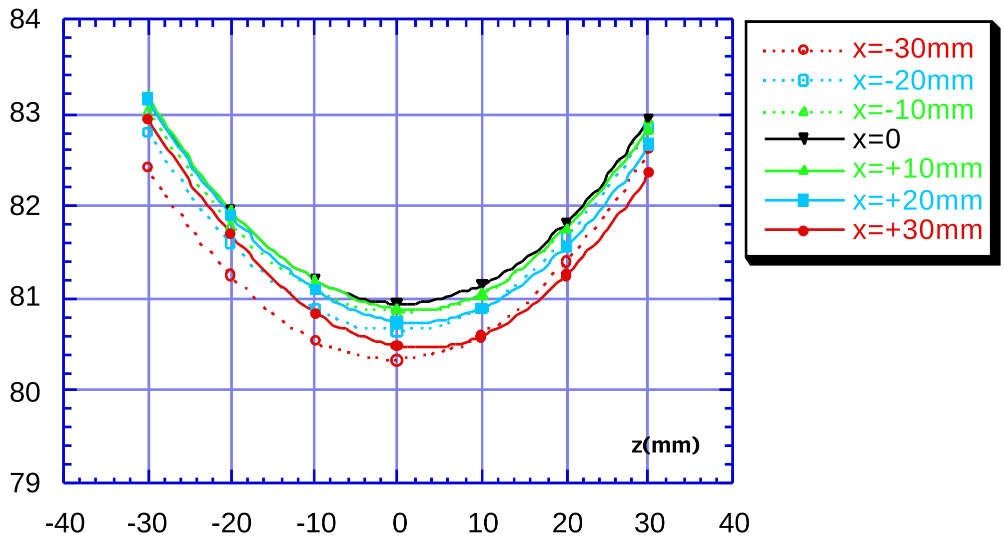

Fig. 8 *- Horizontal field component at magnet center with CV @ 6.36 A and CH @ 8.78 A (expanded scale)*

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. Both field components on the central axis (x = z = 0) are shown in Fig. 9, at the maximum excitation current. The full width at half maximum is 320 mm for the vertical component and 396 mm for the horizontal one. As in the case of the Square HV Corrector [1] 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.

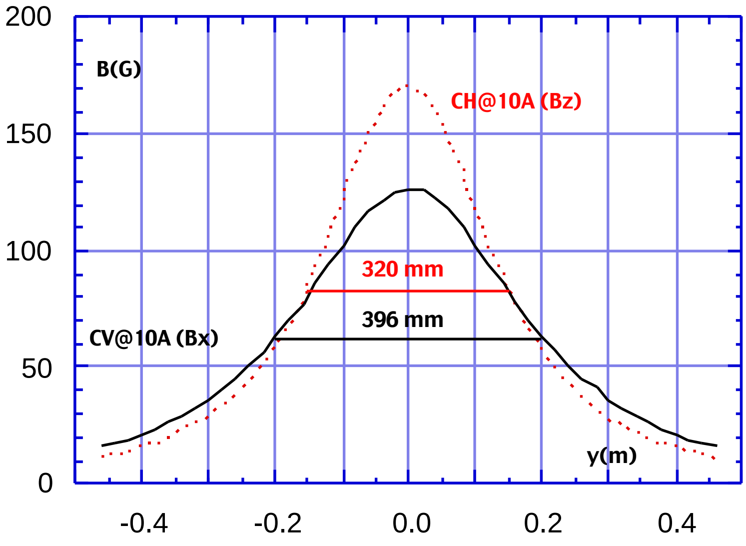

Fig. 9 *- Horizontal and vertical field component along the magnet axis. CH = CV @ 10A*

The value of the field integral taken along lines parallel to the magnet axis at different horizontal and vertical positions are given in Figs. 10 and 11 for the vertical and horizontal component respectively (the scale is expanded).

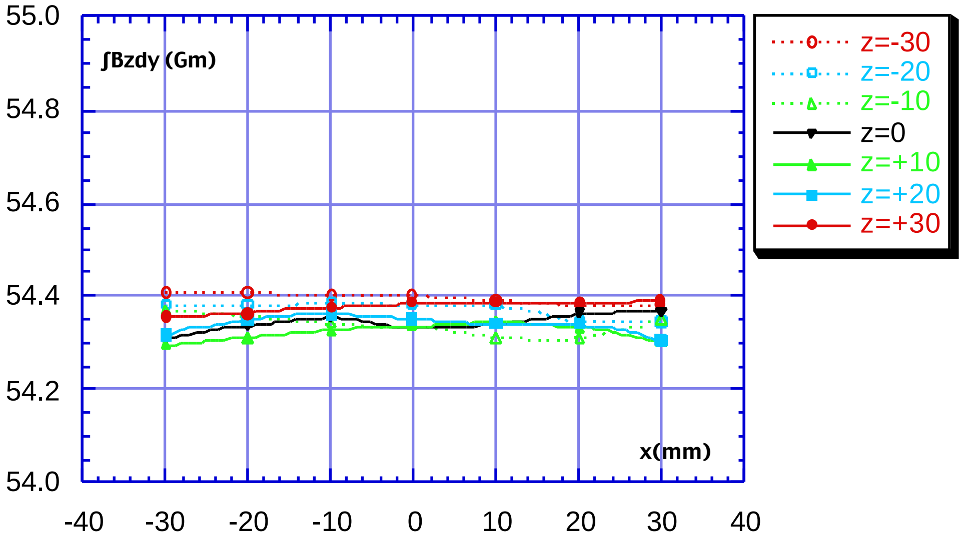

Fig. 10 *- Integrated vertical component with CH @ 8.78A, CV off (expanded scale)*

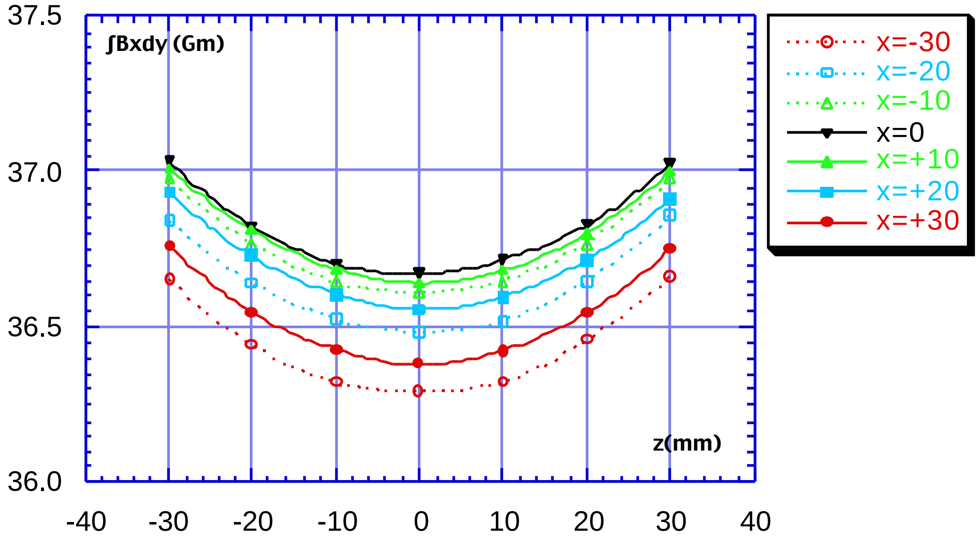

***Fig. 11** - Integrated horizontal component with CV @ 6.36 A, CH off (expanded scale)*

Due to the large gap in the horizontal direction, the horizontal correction is almost constant in the good field region: its overall variation, mainly depending on the vertical position, is of the order of 0.2%. The vertical correction exhibits a behaviour similar to the Square HV Corrector [1]; however, due to the larger value of the vertical gap, the variation of the calibration factor within the good field region is smaller, ±1.0%. All left-right or up-down asymmetries are less than 0.3%.

The calibration factors, taken at the magnet center, give for the angular kick α to the beam:

$$\alpha_x \text{ (mrad)} = 0.186 \text{ I (A) / E (GeV)}$$

$$\alpha_z \text{ (mrad)} = 0.173 \text{ I (A) / E (GeV)}$$

By fitting the curves in Fig. 11 with a polynomial, we find also a small integrated sextupole term for the vertical corrector, while the effect is negligible for the horizontal one:

$$S \text{ (T/m)} = \int (\partial^2 B_x / \partial x^2) \, dy = 1.2 \text{x} 10^{-2} \text{ I (A)}$$

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. 12, 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.

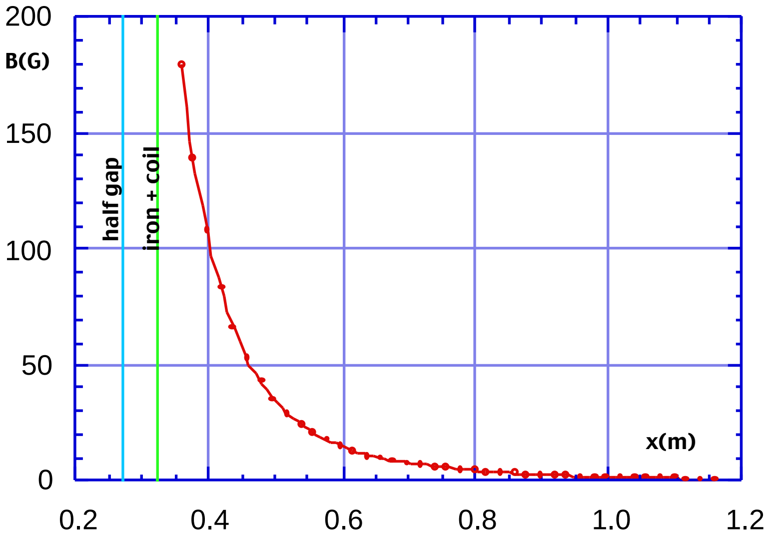

***Fig. 13** - Vertical component of the stray fieldon the horizontal symmetry plane with CH and CV @ 10 A*

4. Conclusions

The Rectangular HV Corrector Magnet prototype has been fully characterised at LNF. The measurements confirmed the reliability of its magnetic design. The interplay between the corrections in the two planes is negligible for the vertical correction, while the horizontal one depends on the current in the vertical corrector to a much smaller extent than in the case of the Square HV Corrector [1]. The linearity of the field within the good field region ensures, in any case, 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. Given the distance between the achromats of the two rings, stray fields on the horizontal plane do not interfere with other magnetic components.

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 Square Corrector Prototype for the DAΦNE Main Rings" - DAΦNE Technical Note MM-14.

[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.