H. Marks

Report no. 39

Reporting Repairs to the Wiggler

31 – 05 – 2009

1. Introduction

Deviations in the electron beam trajectory through the planar wiggler of the Israeli Electrostatic Accelerator FEL were found to be primarily caused by small variations in the strength and angle of polarisation of lateral focussing bar magnets which are positioned on both sides of the wiggler, and provide a quadrupole guiding field on axis.

The field of the wiggler on axis was measured using a Labview controlled automated system built in our lab, based on a 2-axis Hall Effect magnetic sensor driven by a stepper motor. Polarisation field components of the individual focussing magnets were measured separately. Then, using an algorithm, the focussing magnets were paired, such that their non-uniformities were utilised to not only cancel out each other's error, but also to cancel out the field errors on axis due to variation in strength and polarisation angle of the wiggler magnets.

The quality of the predicted electron beam transport was evaluated by 3-D simulation with the General Particle Tracer code which allowed the input of all the measured fields.

The enormous improvement in the quality of beam transport is displayed in section 5 of this report. In the past it took considerable time and effort to find the correct parameters to allow the beam to traverse the wiggler. Large deviations in the x and y dimensions from the central axis meant that a proportion of electrons would strike the walls of the waveguide, and the large angle which the electrons left the wiggler in the x dimension made significant energy retrieval impossible. As can be seen from the graphs in section 5, after the improvement we expect the electrons to leave the oscillating field close to the central axis and with sufficiently small angles to proceed along the beam-line. This should increase the power and efficiency of lasing in the device.

Method

The repair of the wiggler is based on measurements of the wiggler field on axis without the "long magnets" (these are the quadrupole magnets placed on either side of the wiggler to provide lateral focusing) and measurements of all magnets available for use as "long magnets".

The method of repair was chosen to be by changing only the paring of the long magnets, keeping all other magnets in place.

GPT was used for determination of the B_{rx} and B_{ry} of the magnets from the measurement data, simulation of the magnetic field along the wiggler axes and simulation of the predicted trajectories. This process will be described in another report.

The new pairing scheme is shown in Fig. 1. The changes are as follows:

1) Instead of 23 pairs of long magnets there are only 17 pairs with spacers (A) chosen to keep the total length 1200mm.
2) The magnets in sites R13 and R17 are half size magnets. They are supported by spacers (B).
3) The following are the dimensions of the spacers:
   A. Regular Teflon spacer 11.11x11.11x21.02 mm
   B. Half width teflon spacer 11.11x5.55x50.8 mm
4) The magnets pairing is according to the list in Table 1 (more details in the next section)

Fig.1. Long magnet configuration of the proposed pairing

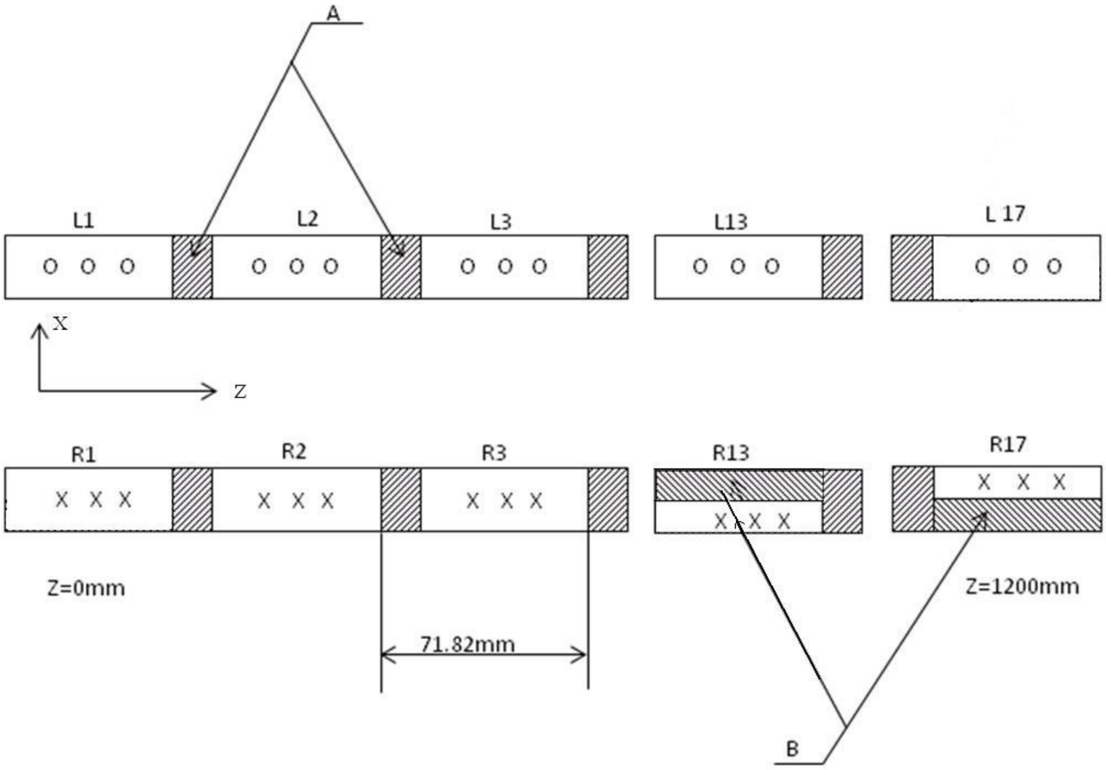


Table 1: The magnets used for the pairing are listed according to the markings that have been placed on them, "C", "U", and "D", and "H", series. The "U" and "D" series are the original focusing magnets. The "D" and "U" represent the original set of magnets in the wiggler. They marked with up or down depending upon which side of the wiggler they were taken out from. The "H" series are the half magnets.

L1	C 21	R1	C 35
L2	D 22	R2	D 16
L3	U 9	R3	U 18
L4	D 3	R4	D 18
L5	C 24	R5	U 15
L6	U13	R6	C 38
L7	C 28	R7	U 20
L8	U 6	R8	U 2
L9	U 21	R9	U 5
L10	D 1	R10	D 17
L11	U 22	R11	C 25
L12	C 36	R12	U 16
L13	C 33	R13	H 12
L14	U 17	R14	U 12
L15	U 11	R15	U 14

L16	C 20	R16	U 3
L17	C 36	R17	H 10

2. Details of the new pairing

Magnets to be placed on the +X side/left side/"UP side"

The magnets are listed from 1 to 17. Where the beginning of the first magnet is placed at -600mm, and the last magnet (at position 17) is placed such that its end is at +600mm.

All the North arrows of these magnets should be pointed UP (+Y direction), in the +Y direction of the wiggler.

The Magnets are listed first by their series, C series, B series, or U or D, and then by the number marked on them. U and D were marked on the original focusing magnets depending upon whether they were removed form the left or right side.

The By and Bx presented in the lists (Table 2 and 3) are the magnitudes of the field produced by the magnet with the magnet aligned as it would be in the wiggler. Measurements of By were made in a jig which had the same spacing between the position of the magnet and probe as the distance between the focusing magnets inside the wiggler and the central axis. By was measured with North pointing in both the –Y and +Y directions and the resultant field calculated as follows:
By = (By1 – By2)/2.

The second column contains the names of the magnets as used in the computer program, and has been included for error checking purposes.

Note: The magnets placed with the North facing up create a negative field at the center of the wiggler.

The Brx and Bry specified in Table 2 were derived by comparing the field strengths of individual magnets measured and simulated in GPT at specific distances from the face of the magnet. The Brx and Bry of the simulated magnets were altered until the strength of the field matched that which was measured at the particular distance.

Table 2

Magnet name	GPT name	$B_y(0)$ [Gauss]	$B_x(0)$[Gauss]	Bry	Brx
C 21	ByC21	134.38	1.85	8105	73
Down 22	ByO49	145.4	-1.95	8769	-77
Up 9	ByO40	155.1	-11.85	9354	-472
Down 3	ByO65	150.1	-5.85	9052	-233
C 24	ByO10	133.4	0.715	8045	28
Up13	ByO36	150.4	8.15	9070	324 5
C 28	ByO11	134.8	1.55	8130	61
Up 6	ByO42	156.4	15.75	9432	627
Up 21	ByO28	151.5	6.6	9137	263
Down 1	ByO66	136.5	5.2	8232	207
Up 22	ByO27	144.8	18.5	8733	737
C 36	ByO14	132.4	4.77	7985	190
C 33	ByO16	132.1	-5.15	7967	-205
U 17	ByO32	147.5	-6.15	8896	-245
U 11	ByO38	151.1	0.75	9113	29
C 36	ByO09	132.6	-0.8	7997	-31
C 31	ByO02	133.7	-4.4	8063	-175

It was thought that it might be helpful to shorten the last full long magnet at position L17, an experiment was performed to test whether cutting a magnet would result in a deterioration of the field. The magnet which was "cut" using a grinder was found to be undamaged. However, ultimately there was no use for the cut magnets.

Magnets to be placed on the -X side/right side/"Down side"

On the right side for the first time we introduce the use of half magnets along the length of the wiggler. The half magnets are represented by H and have been placed at points 13 and 17. The number written after the "H" corresponds to the number written on the magnet.

Table 3

Magnet name	GPT name	$B_y(0)$	$B_x(0)$	B_{ry}	B_{rx}
C35	C35	131.7	8.25	8029	329
D 16	ByO55	156.2	0.65	9420	25
U 18	ByO31	155.1	-26.9	9354	-1072
D 18	ByO53	150.1	1.95	9052	77
U 15	ByO34	150.4	-9.6	9070	-382
C 38	ByO18	133	9.1	8021	362

U 20	ByO29	154.3	2.15	9306	85
U 2	ByO46	145.8	-27.5	8793	-1096
U 5	ByO43	153.7	-18.4	9270	-733.61
D 17	ByO54	149.8	1.1	9034	43
C 25	ByO07	133.3	6.25	8039	249
U 16	ByO33	157	-19.4	9469.	-773
H 12	BH12	140.7	4.64	8488	185.38
U 12	ByO37	155.1	5.85	9354	233
U 14	ByO35	156.9	-9.55	9463	-380
U 3	ByO45	152	5.1	9167	203
H 10	BH10	140.9	18.05	8502	719.83

Note: The magnets placed with the North facing down create a positive field at the center of the wiggler.

The Background Field Bx and By of the Wiggler

The background field of the wiggler was averaged over the 17 sections into which the wiggler has been divided for this pairing: The long magnets were chosen such that the sum of their fields on axis (weighed in one side direction of the spacing) would cancel out this field. The units of the numbers given below are in Gauss.

Background Field of the Wiggler in the 17 Sections:

Table 4

B_y (G)	B_x (G)
71.3	3.7
-11.7	1.9
-0.3	-14.7
-5.8	-6.6
-16.5	0.3
7.4	0.1
-19.5	2.9
12.4	10.1
2.4	10.7
-14.0	7.3
11.2	14.7
-25.4	23.0
31.0	10.8
-8.0	11.0
-6.3	10.8
-19.4	4.6
61.6	2.6

Ambiguity in the Bx Orientation of the Pairing

All the magnets are marked with an arrow to indicate North. However, only the B and C magnets are marked with an arrow showing the direction of Bx.

With the magnet in the same orientations they were in for the By measurements but the probe rotated 90 degrees, Bx was measured, that is, the Bx field was measured in the +X and –X directions. And the resultant worked out using the equation Bx = (Bx1+Bx2)/2.

Preparatory Work for Magnet Insertion into the Wiggler

On the 21/01/2009 the following steps were taken towards inserting the magnets into the Wiggler:

The probe was placed into the jig which was bolted down to the table and aligned initially so that it would give a positive Bx reading when the North face of one of the long magnets was facing towards +X. That is, when the arrow (North South arrows have been marked on all the magnets) was pointing in the +X direction, a positive reading was recorded on the probe.

The magnets designated for the pairing of the left and right sides of each of the seventeen sections were placed in pairs into the left and right side of the jig in order to measure the combined Bx field. This was then noted down and checked against the computed background Bx field it is supposed cancel.

A rectangular steel block of similar dimensions to the Wiggler was used to mount the magnets after they had been paired. The block was wrapped in paper. On the paper the Wiggler coordinates axis were noted. After measurement and verification of the Bx field of each pair the pair was transferred to the block in the orientation in which it needed to be inserted into the Wiggler. All the magnets on the left hand have a North By field pointing in the +Y directions. This is the side in which the UP magnets previously resided. The reverse is true of the magnets on the right hand side. Their North arrow points in the –Y direction.

All the magnets inserted on the left hand side have their North face pointing upwards. The direction of Bx of the magnets was less clear. To avoid any confusion each and every magnet has been marked with a single red dot. Any marks larger than a dot where used to cross out an earlier attempt at a notation (this I believe applies to pairs 2-4) and should be ignored. But this should be fairly clear.

The magnets should not be shifted or lifted from their positions until the time of the pairing to avoid confusion. The magnets are laid out exactly as they should be in the Wiggler.

The half magnets should be placed closer to the Wiggler axis.

After a complete pairing on the steel 'Dummy-Wiggler' and verification of the combined Bx fields the probe was re-oriented. This time the probe was 90 degrees from its previous position such that a magnet placed in the left side of the jig with the North arrow in the +Y direction a maximal negative reading was received.

After this aforementioned alignment the combined By field of each pair of magnets was measured to verify its nullification of the background By Wiggler perturbation.

The results of both the combined Bx and By measurements are presented in two separate tables below.

Measurement of the magnetic field cancelation new pairing

All results are given in units of Gauss.

Table 5 B_y field cancelation

	By Field - Long Mags on Axis	Background	Delta
1			
2	7.7	-11.7	-4
3	-5.2	-0.3	-5.5
4	0.8	-5.8	-5
5	16.4	-16.5	-0.1
6	-20.9	17.4	-3.5
7	17.5	-19.5	-2
8	-10.1	12.4	2.3
9	-1.3	2.4	1.1
10	9.7	-14	-4.3
11	-17.9	11.2	-6.7
12	25.1	-25.4	-0.3
13	-33.8	31	-2.8
14	-3.7	-8	-11.7
15	0.3	-6.3	-6
16	14.3	-19.4	-5.1
17			

The combined fields of By for the first and last pair were not measured outside the wiggler, as whilst magnets had been chosen for these positions, it was not on the basis of cancelling out a specific perturbation this was because filtering the first and last regions of the wiggler was problematic, unlike for positions 2-16.

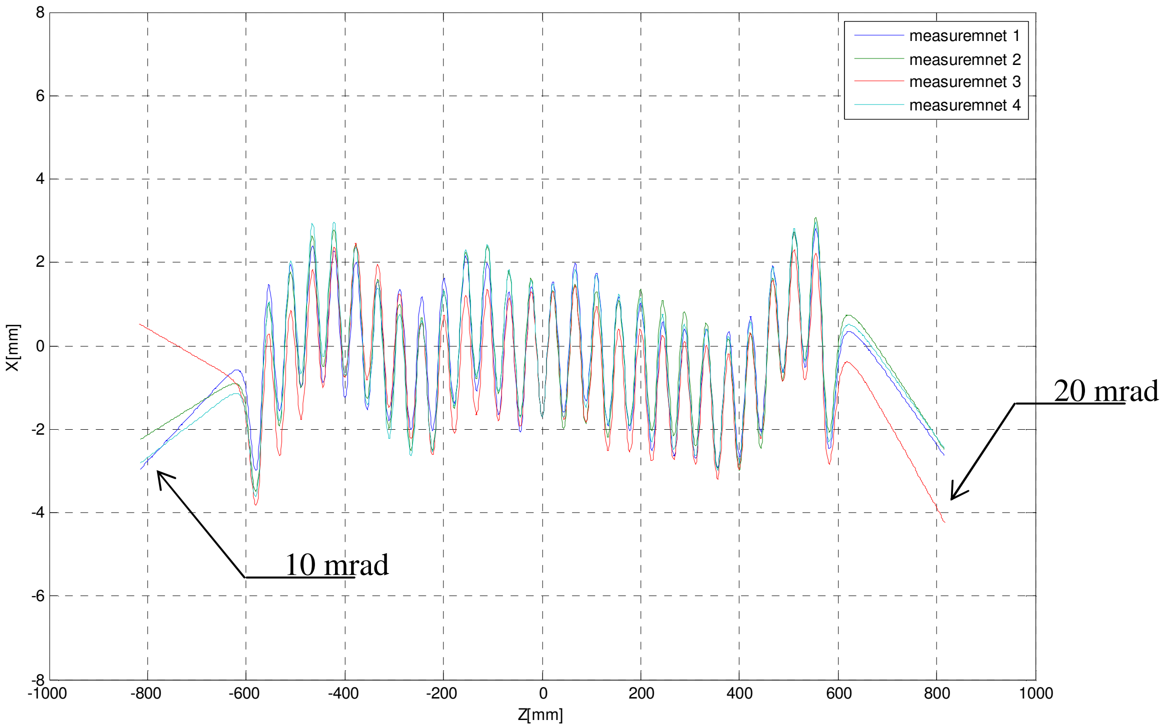
Table 6 B_y field cancelation

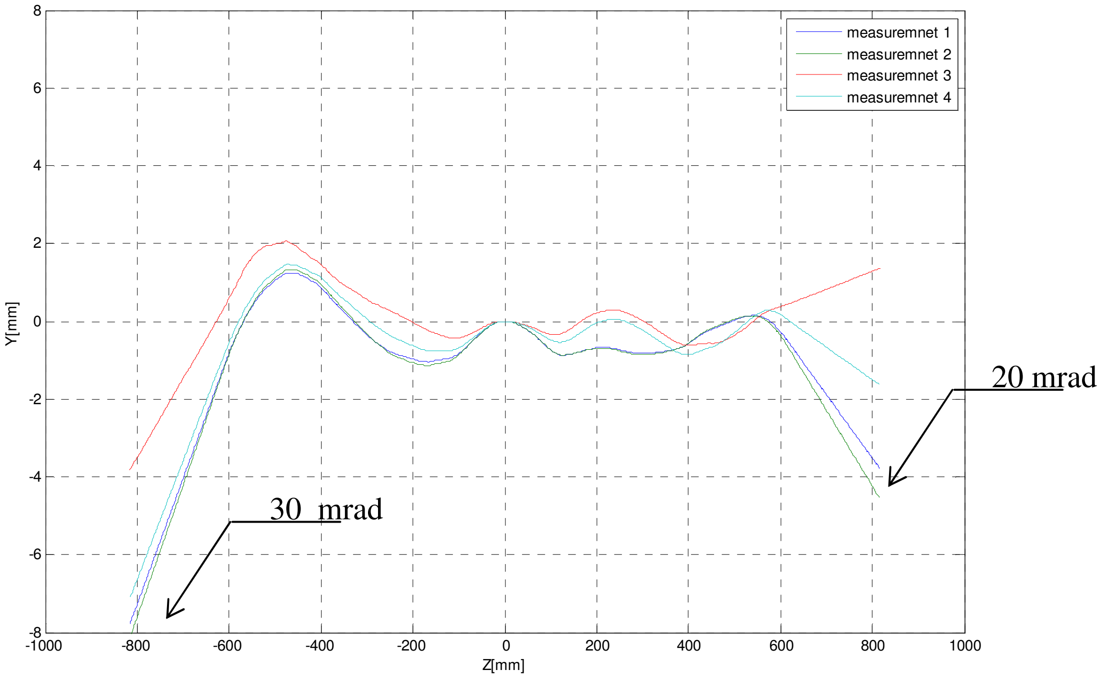
	Bx Field - Long Mags on Axis	Background	Delta
1	-2.8	3.7	0.9
2	-3.9	2	-1.9
3	13.1	-14.7	-1.6
4	-5	-6.6	-11.6
5	-4.5	0.3	-4.2
6	3.53	0.1	3.63
7	-0.5	2.9	2.4
8	-13	10.1	-2.9
9	-9.7	10.7	1
10	1.5	7.3	8.8

11	-17.7	14.7	-3
12	-21.7	23	1.3
13	-9	10.8	1.8
14	-15.8	11	-4.8
15	-8.3	10.8	2.5
16	-3.9	4.6	0.7
17	-0.8	2.6	1.8

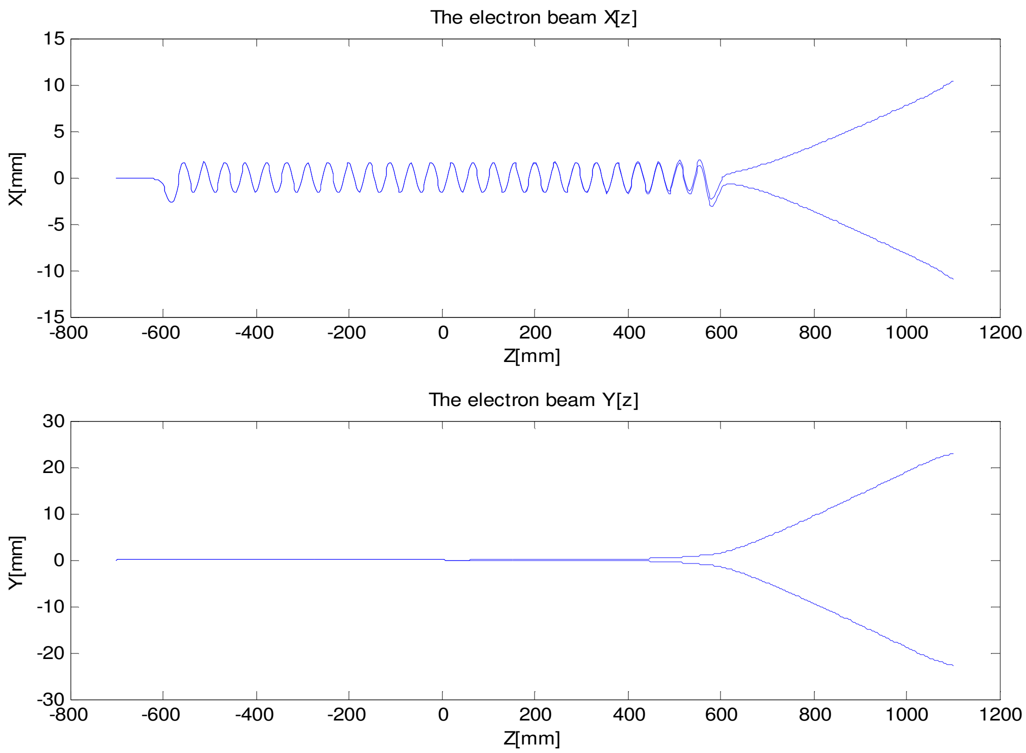
3. The single trajectory with the configuration of Fig. 1 according to different measurements

Simulation of transport (from z=0) for the wiggler according to measurements of the wiggler in the four possible orientations (as slight variations in field were measured depending upon the orientation of the block within the wiggler due to limitations in precision with which the block was be produced). In each simulation shown trajectory, corresponds to X(0), which provide the best transport

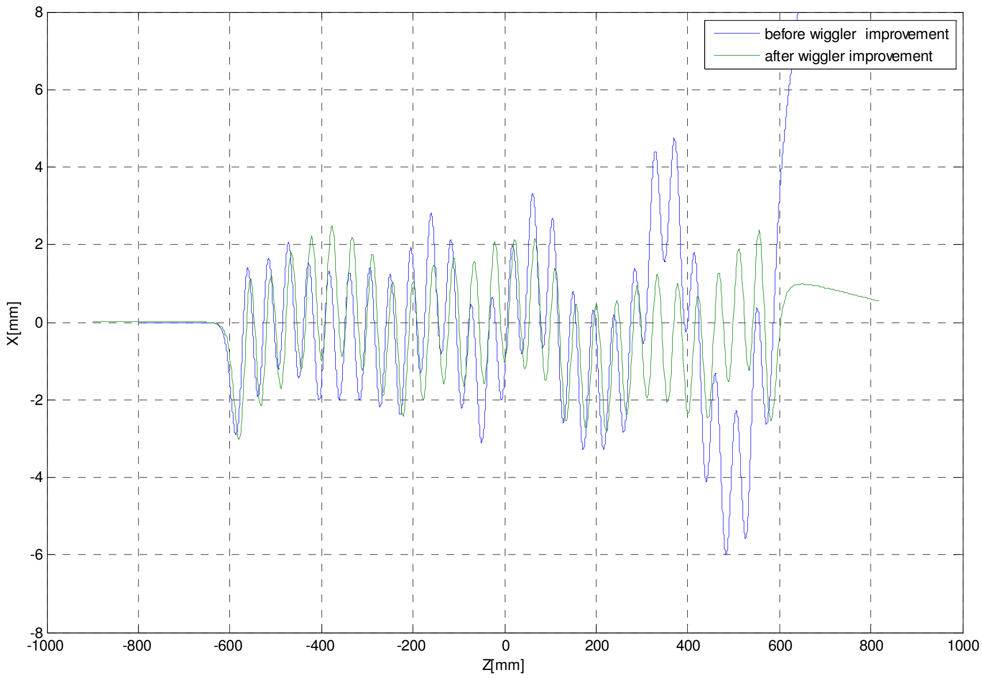


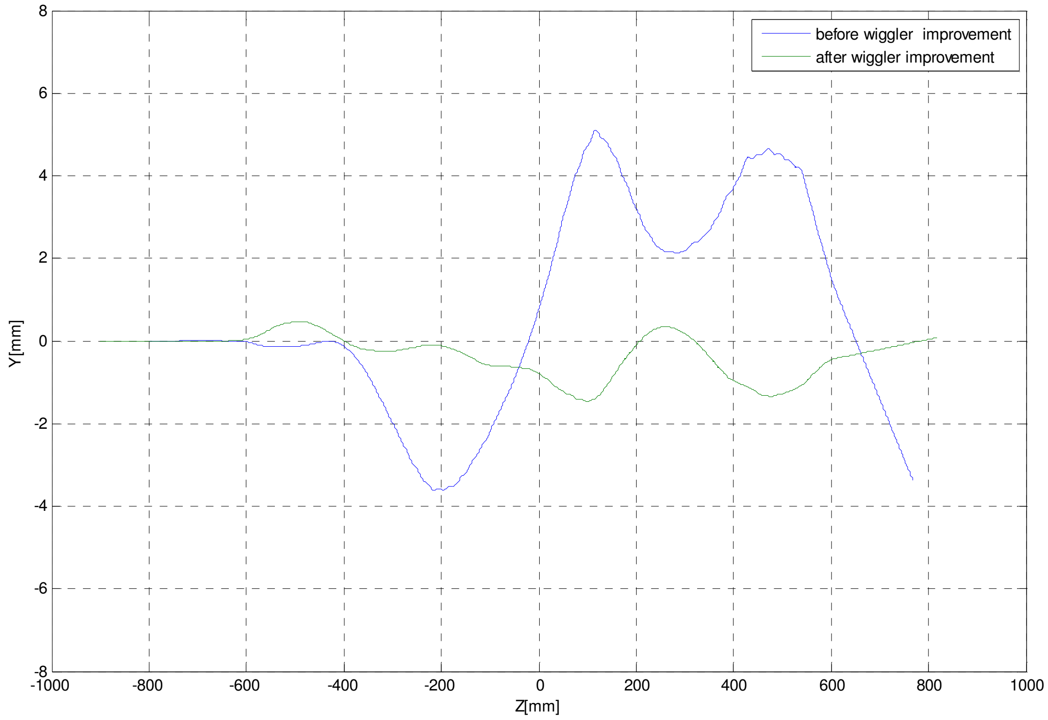


placed at Z= 594 mm. At Q5 position Z=1100 mm ΔX=±11mm (deflection about ±24mrad) , ΔY=±23mm (deflection about ±48mrad)



4. Electron trajectory improvement (before and after repairing)

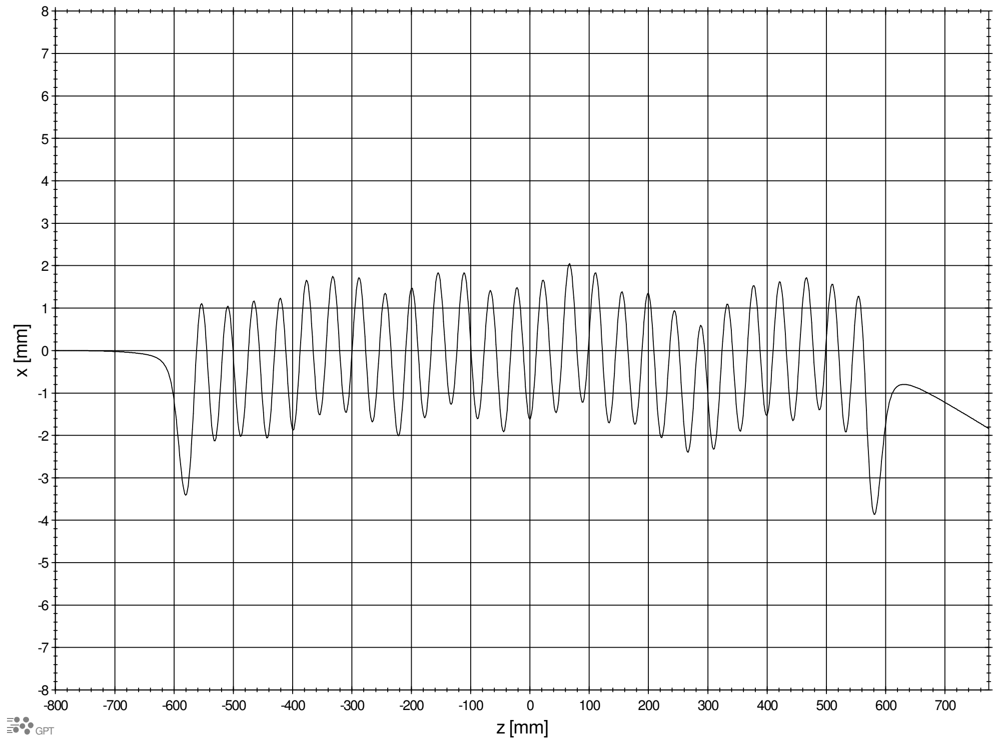


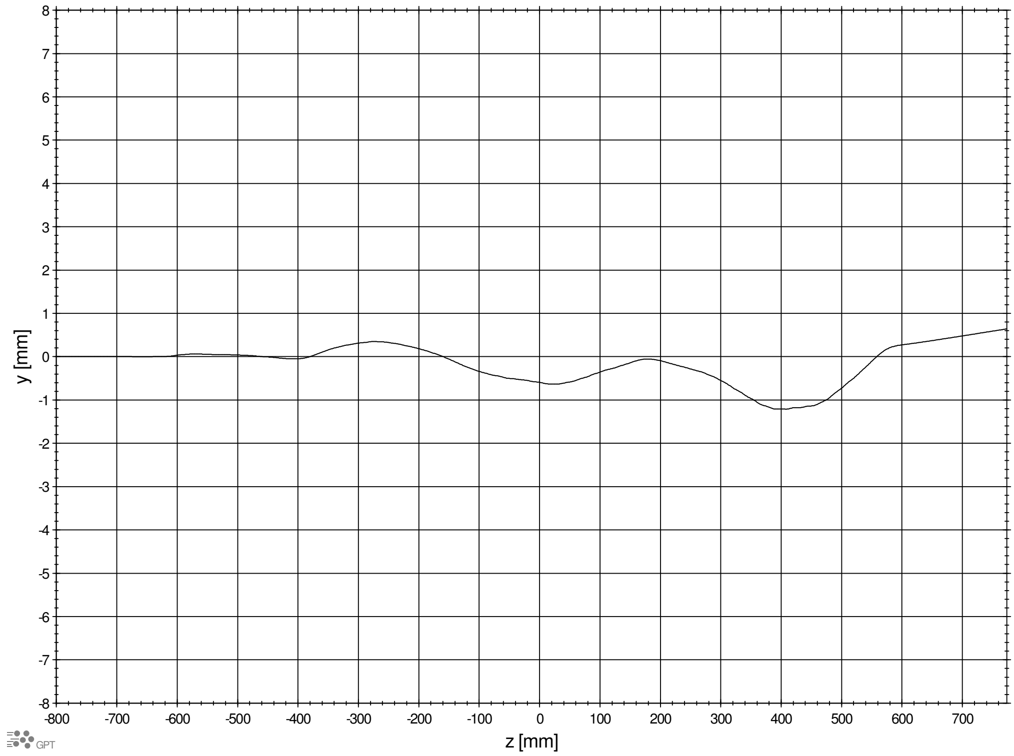


5. <u>The trajectory improvement expected</u>

As we indicated before, in the first stage, magnet will be kept uncut. This data need for first stage comparison to the measurements after executing first stage change.

On axis electron trajectory in optimized wiggler

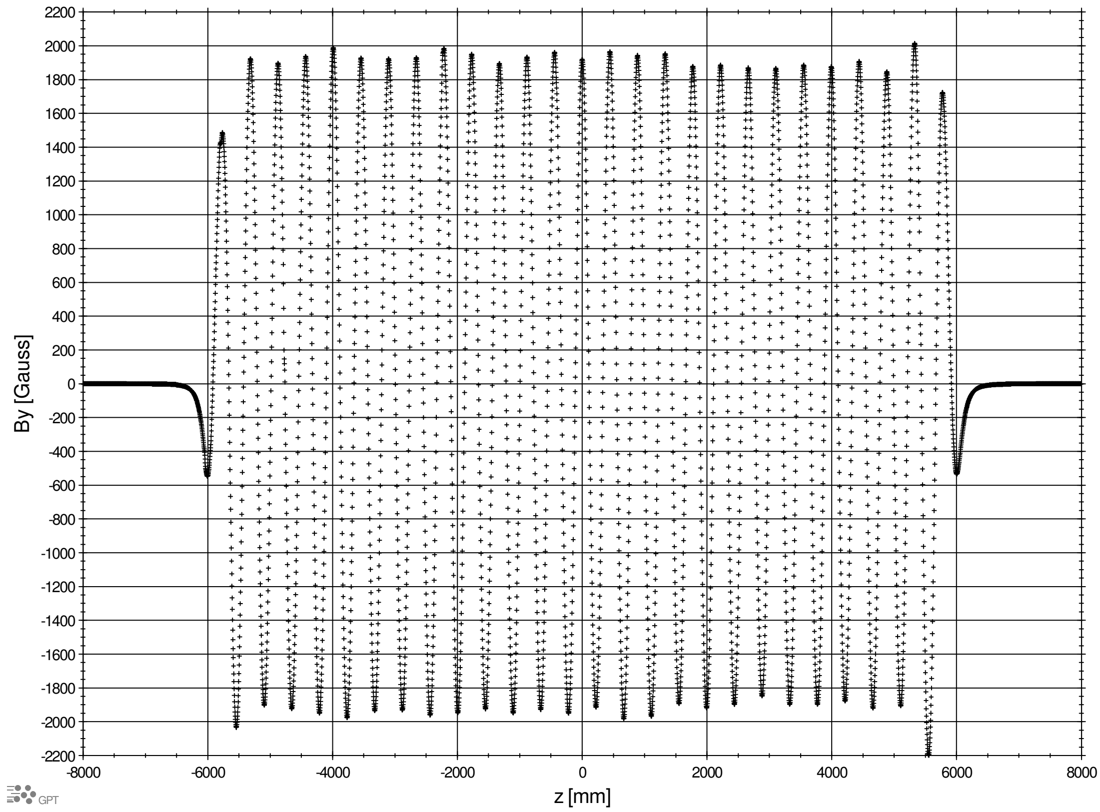


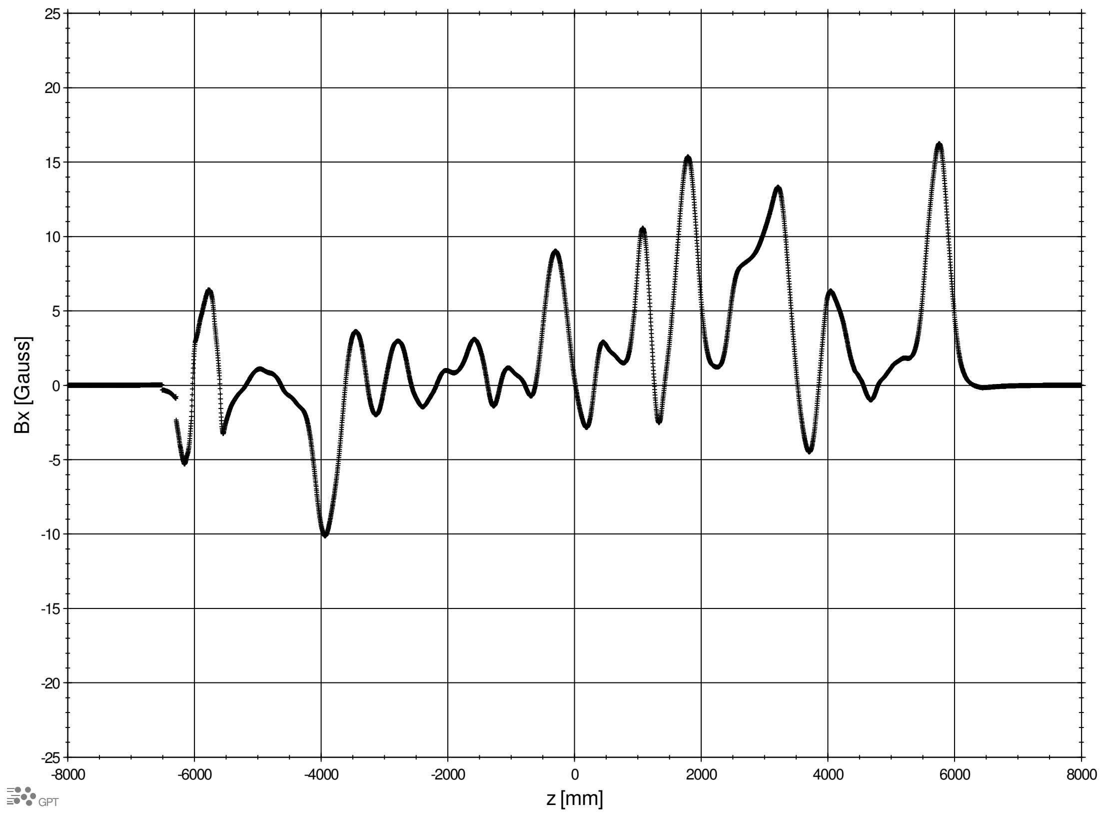


6. The magnetic fields expected after assembly according to Fig. 1 (but with full C31)

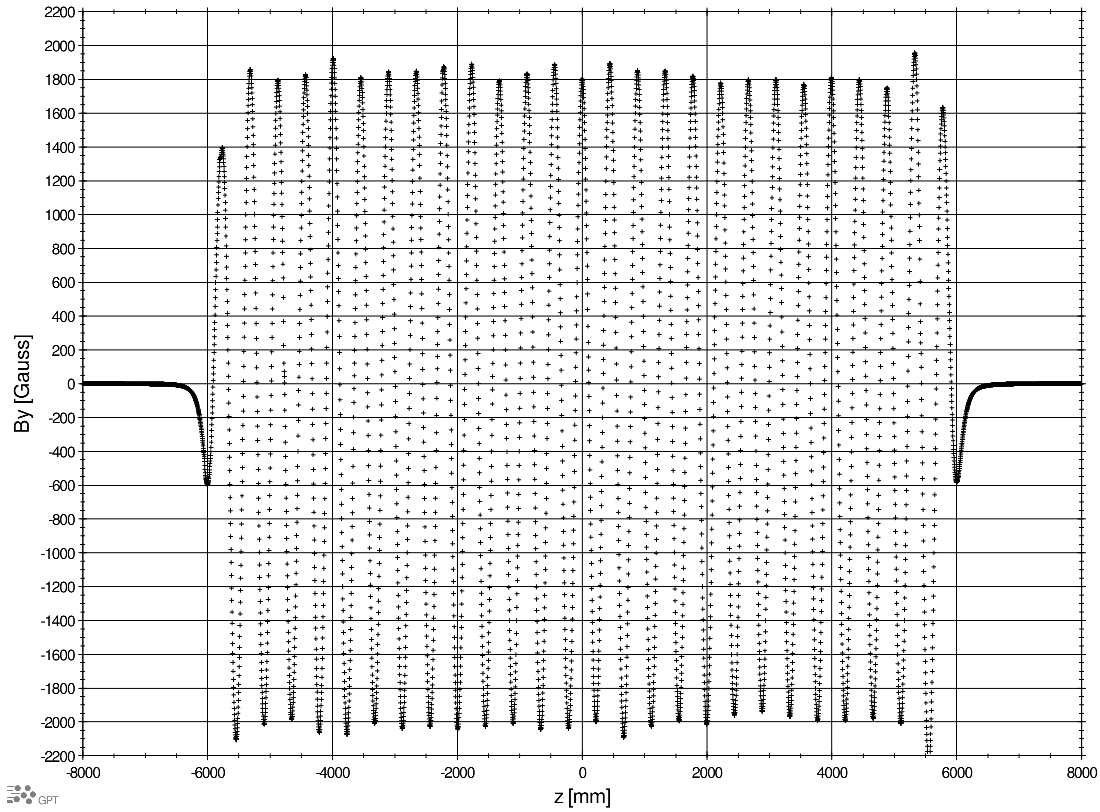
Expected B_x B_y magnetic field in the new configuration wiggler field on 5 axes of measurement

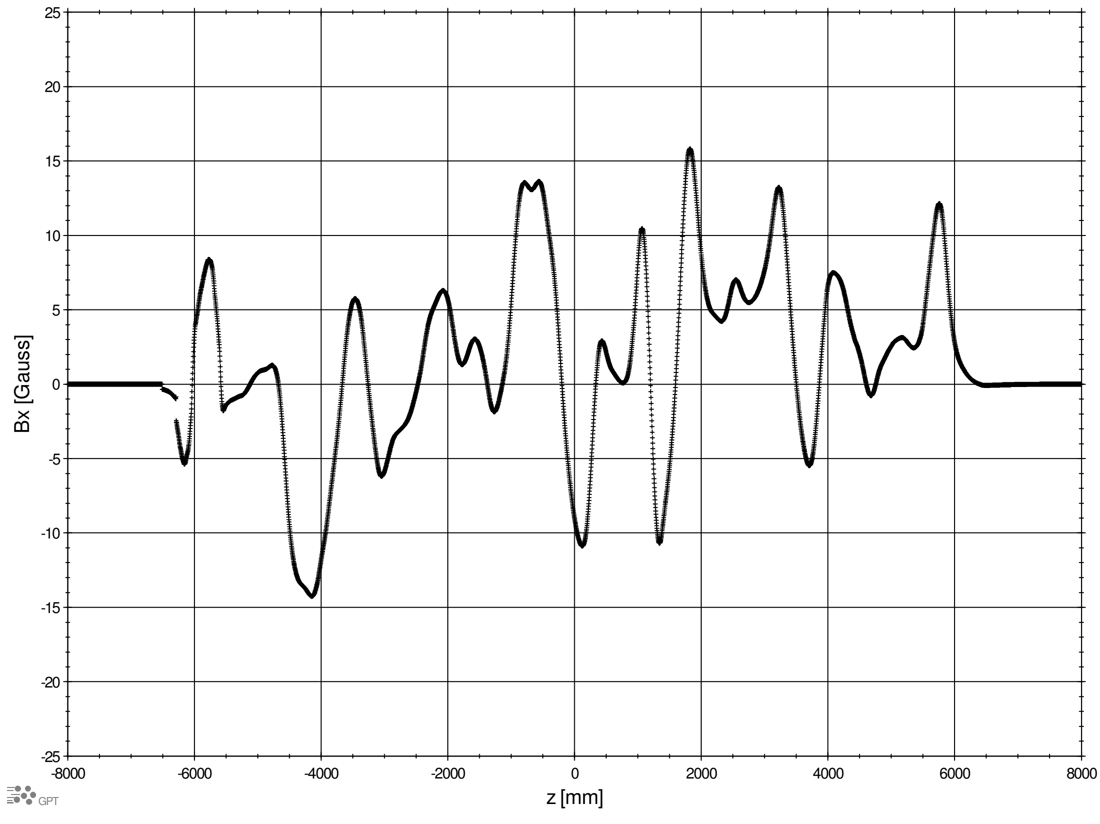
1) x=0[mm], y=0[mm]



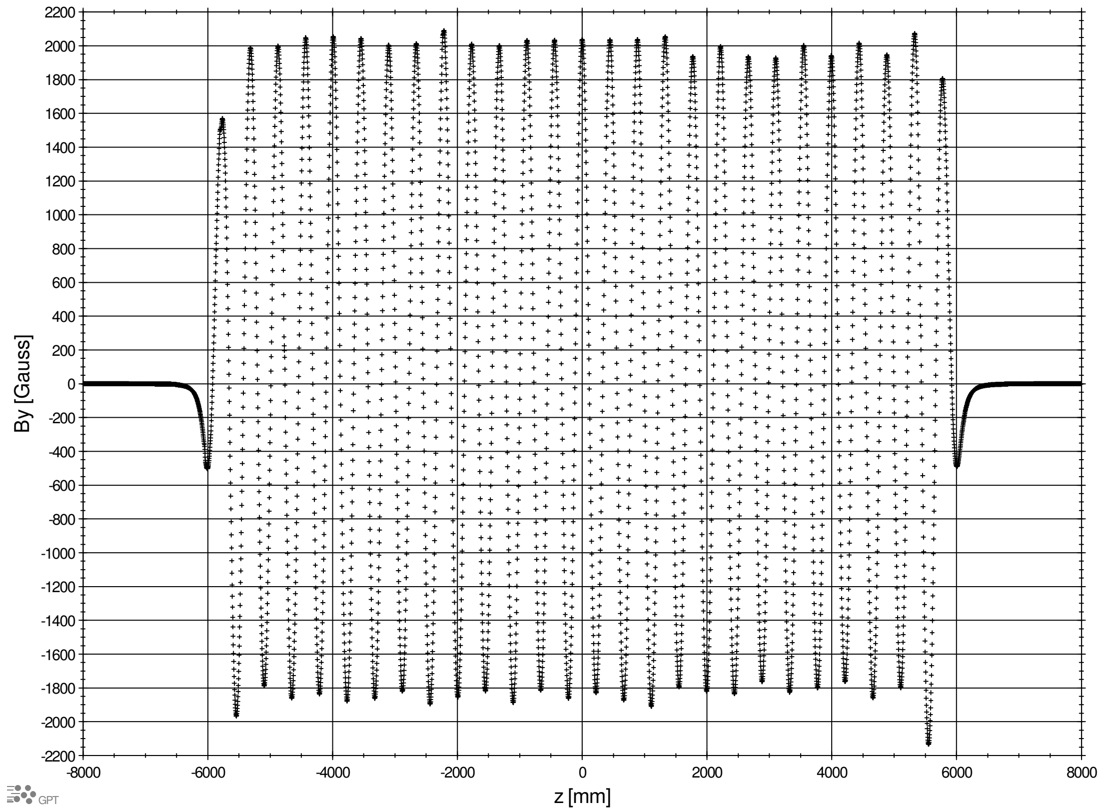


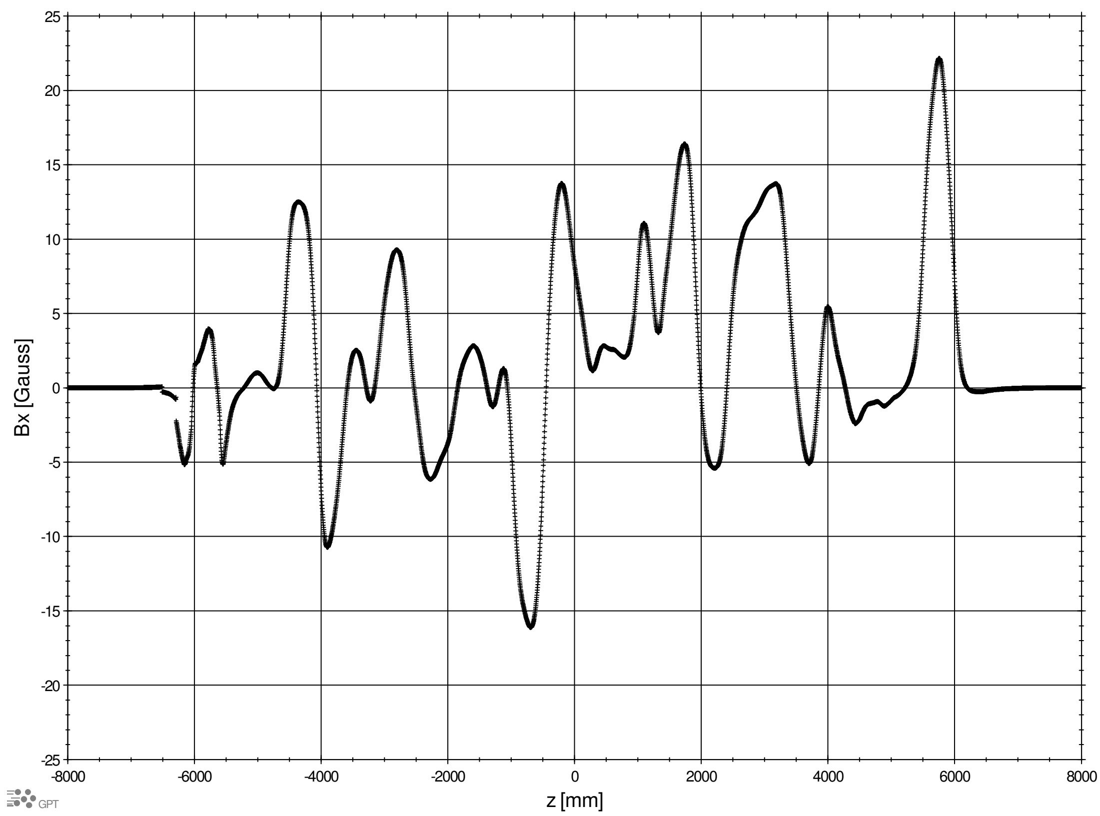
2) x=4[mm], y=0[mm]



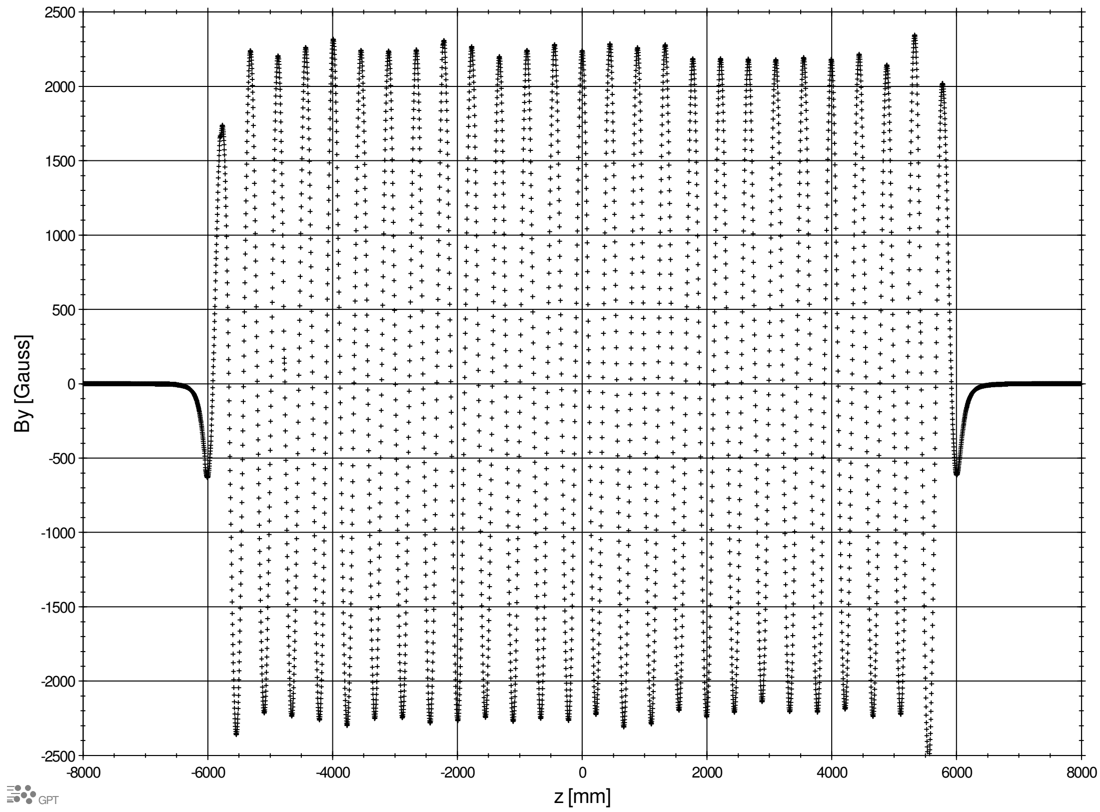


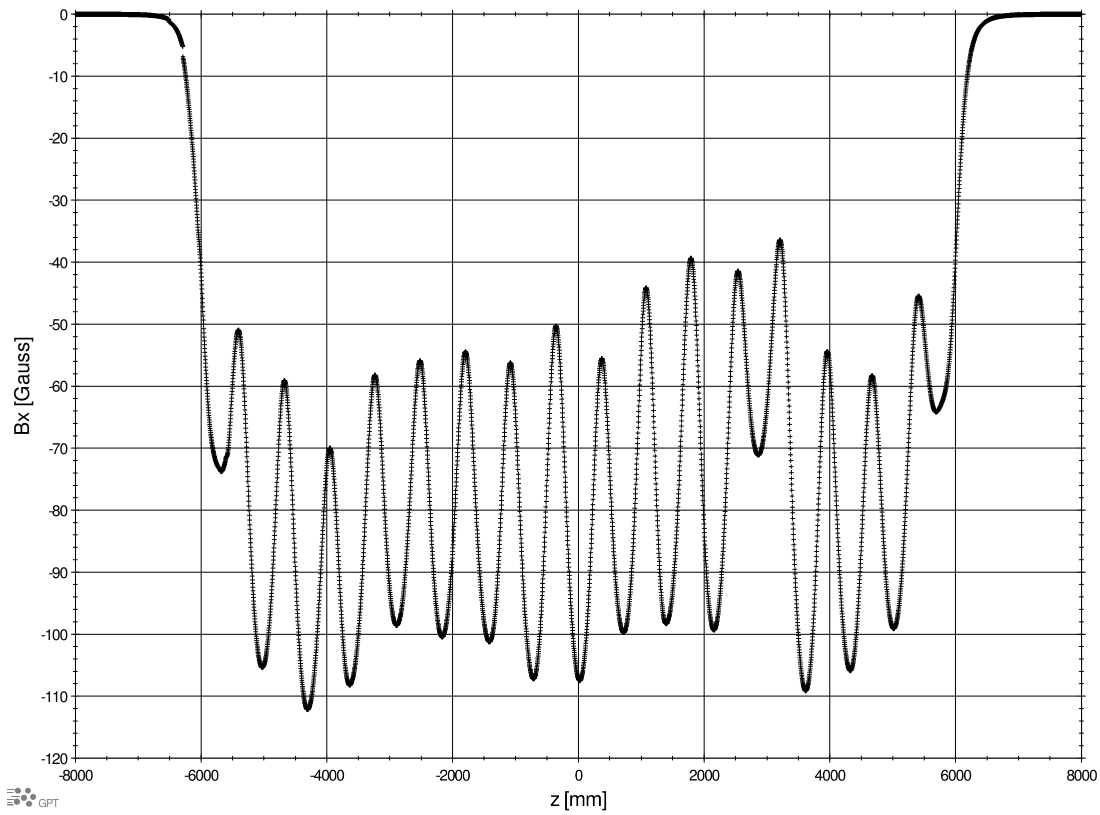
3) x=-4[mm], y=0[mm]



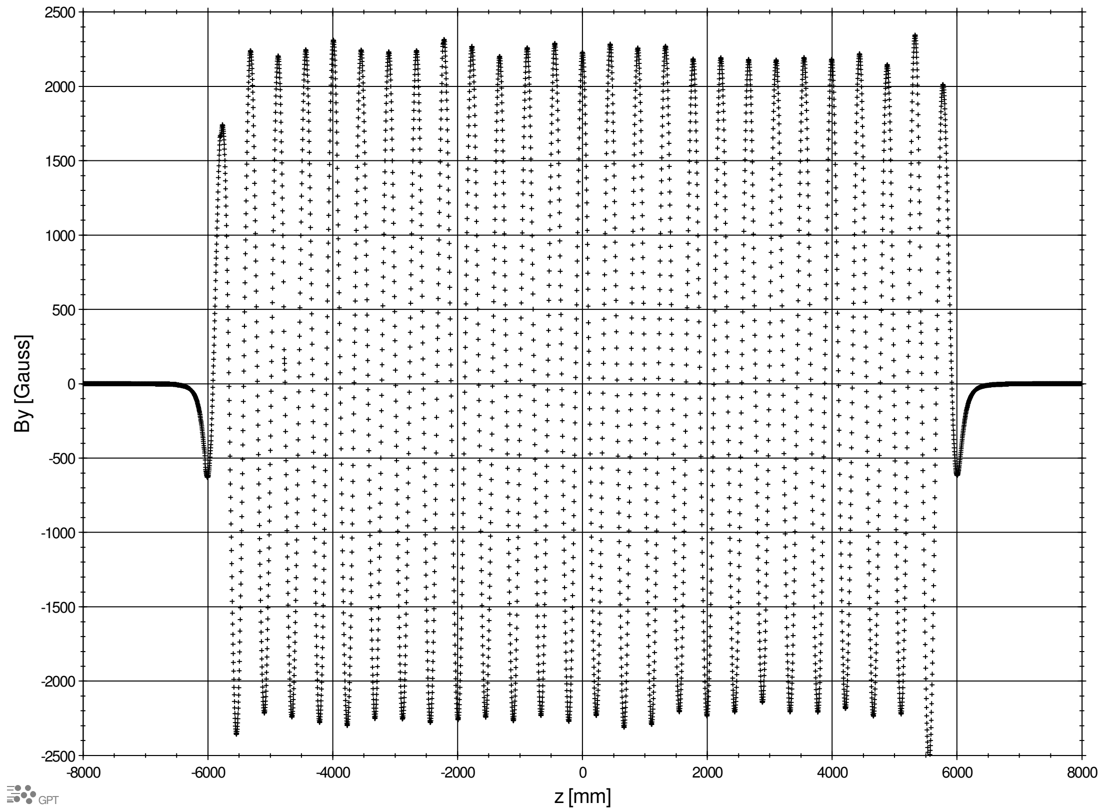


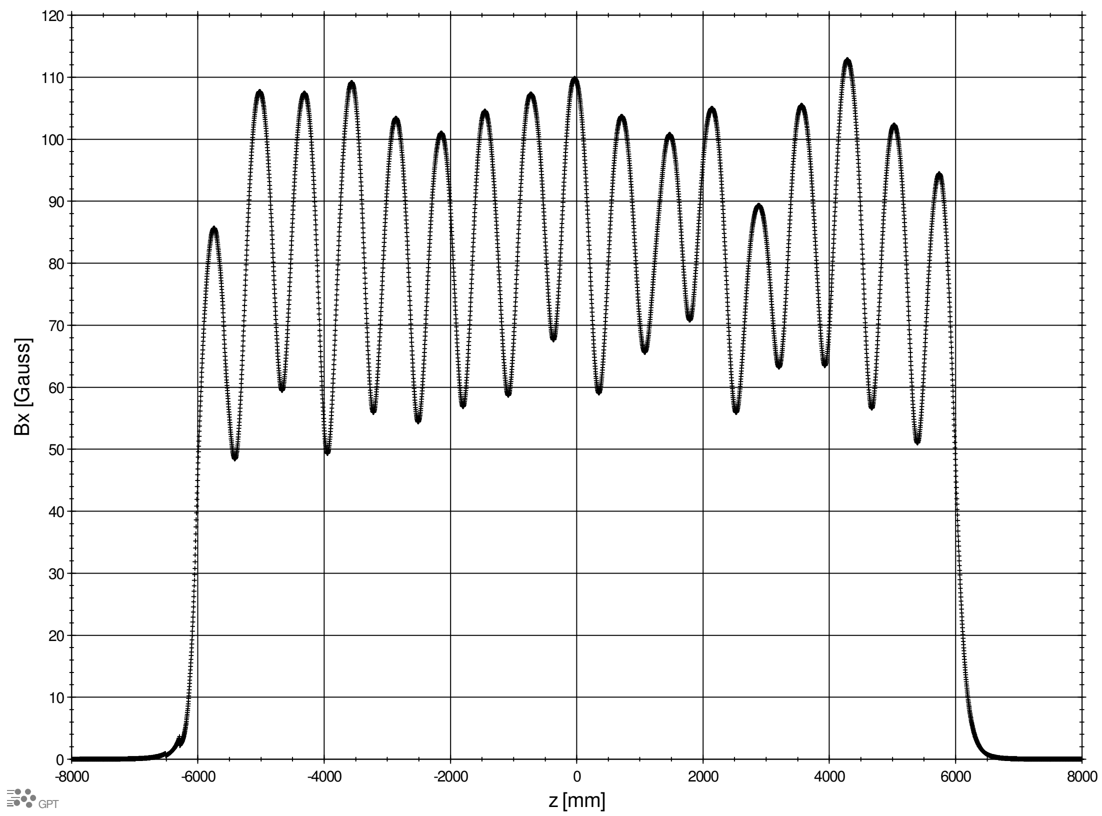
4) x=0[mm], y=4[mm]





5) x=0[mm], y=4[mm]


By [Gauss]
z [mm]
GPT


Bx [Gauss]
z [mm]
GPT