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A 20 cm Vertical Step in the Booster-Storage Ring Transfer Line

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A 20cm Vertical Step in the Booster-Storage Ring Transfer Line

Introduction

SESAME injector and storage ring have 1.2m beam height. To accommodate the ALS and SLS wigglers (of ~1.4m beam height) in SESAME ring, it was foreseen to elevate the storage ring beam height by 20cm, as one of the investigated options, keeping the original beam height for the injector. To do so, we need to make vertical step of 20cm height in the booster-storage ring transfer line using 2 equal and opposite vertical bending magnets. As a consequence, a 20cm vertical dispersion is created downstream the first vertical bending magnet and it propagates to the storage ring making mismatch with the storage ring dispersion. To eliminate this dispersion keeping the optical flexibility of the transfer line, three extra quadrupoles are used between the two vertical bending magnets into the existing transfer line [1].

Investigating a new transfer line with a 20cm vertical step, a good optical flexibility and the least additional costs is the aim of this note.

1. Geometry

To elevate the transfer line by 20cm using two vertical bending magnets the following geometry in Fig. 1 is used:

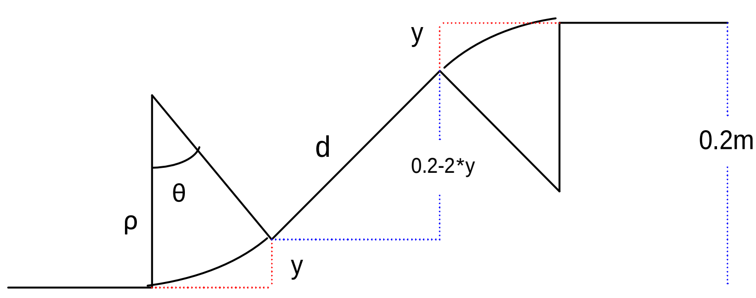

Figure 1

The first dipole elevates the beam to some vertical amplitude ***y*** and so does the 2nd opposite dipole.

$$y = \rho(1 - \cos(\theta)) \quad . \tag{1}$$

The dipole magnetic length is determined by ***y*** and the dipole magnetic field **B**. For some **B** value in the dipole the bending radius,

$$\rho(m) = \frac{E(GeV)}{.299792458 * B} \tag{2}$$

where **E** is the injected beam energy which is 0.8GeV in SESAME case. The bending angle

$$\theta(rad) = \cos^{-1}((\rho - y)/\rho) \quad , \tag{3}$$

hence the dipole magnetic length

$$L(m) = \rho * \theta \quad , \tag{4}$$

and the consequent distance between the dipoles hard edges is

$$d(m) = \frac{.2 - 2 * y}{\sin(\theta)} \tag{5}$$

For each *y* several options of dipole lengths and distance between them are available. They are calculated and presented in Fig. 2. For example, for ***y*** = 4cm and **B** = 0.9T the magnetic length for each bending magnet is L = 0.4876m and the distance between them must be **d** = 0.733m.

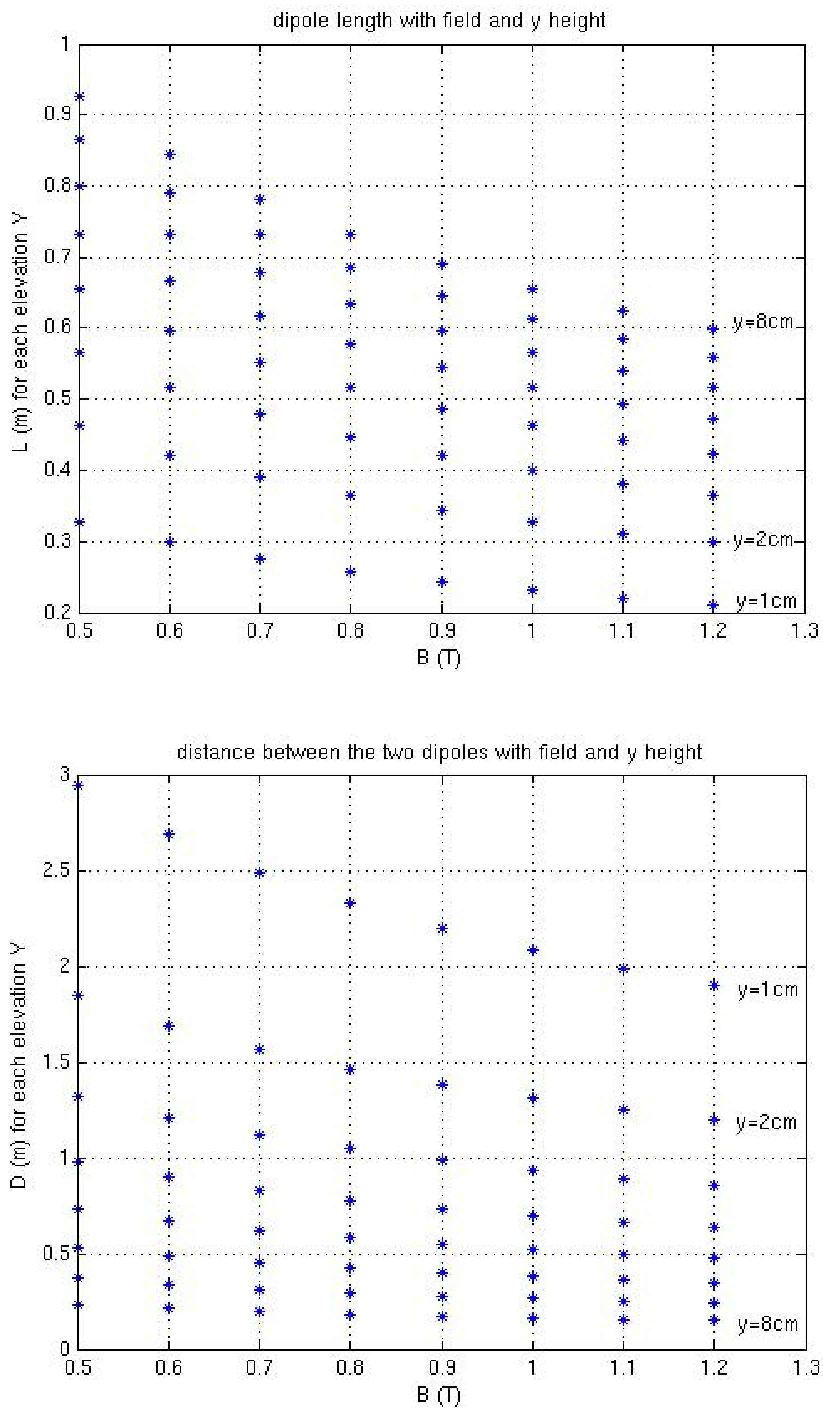

Figure 2: The length of dipole (top) and the edge to edge distance between the two dipoles (bottom) for different **B** and ***y*** values.

The choice of **y**, **B** and the position of this cell - in the transfer line - will be a compromise between the available space in our transfer line, the optical and economical issues.

2. The vertical dispersion problem

The 20cm vertical step creates vertical dispersion of -20cm propagates downstream of the vertical bending cell and continues to the storage ring, see Fig. 3. This will complicate the injection process and could decrease injection efficiency. So this dispersion has to be cancelled before the end of the injection septum.

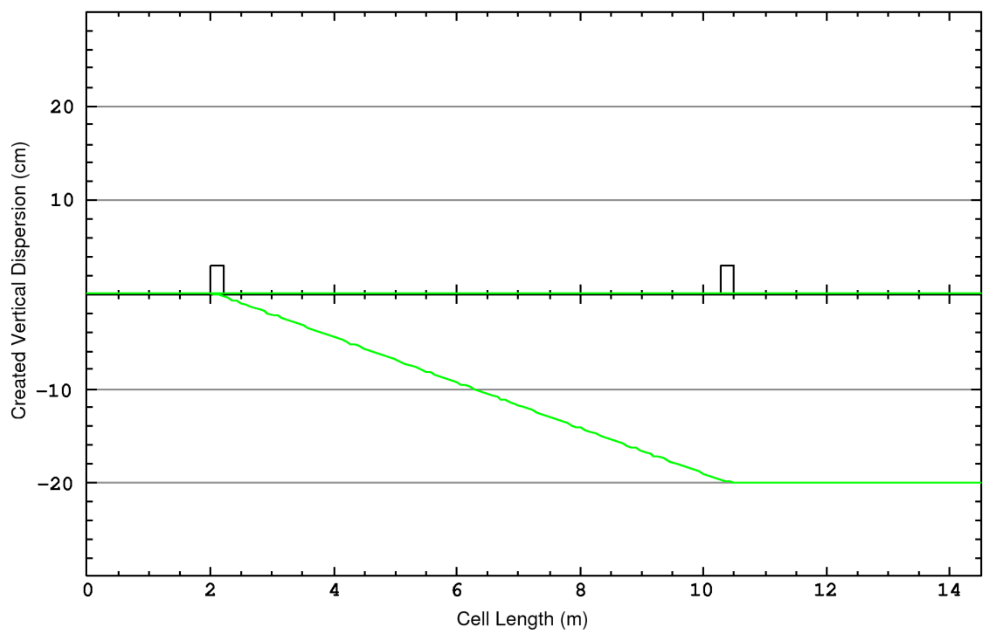

Figure 3: The vertical dispersion created by the two vertical bending magnets in the transfer line.

As a trial, three extra quadrupoles were added to the last section of the transfer line in order to make the created vertical dispersion η_z and its derivative η_z' zero at the end of injection septum. In addition to that, these quadrupoles must realise the full and flexible optical matching with the storage ring. It was not possible to get both η_z and η_z' equal to zero using this method, for $\eta_z = 0$, η_z' was about 0.03.

The way to make both η_z and η_z' equal to zero was to use two equal vertically focusing quadrupoles between the vertical bending magnets [2]. The role of these quadrupoles is to focus

η_z created by the first bending and advancing its phase by 2π at the beginning of the second bending. Then η_z and η_z' are made zero by the second bending, see Fig. 4.

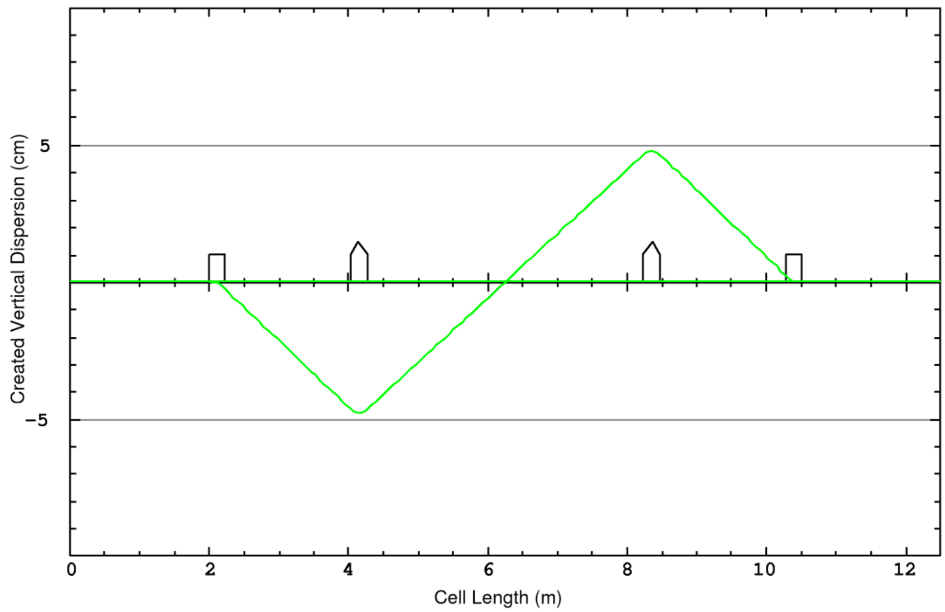

Figure 4: Eliminating the vertical dispersion by two vertically focusing quadrupoles in addition to the two vertical bending magnets.

In such an achromatic translation the quadrupole's strength depends on the total distance between the vertical bendings and to some limit on the quadrupole positions from the bendings. If length of the achromatic cell is such that it can be inserted between two bendings in the transfer line the quadrupoles of magnetic length 0.25m will be very strong ($k > 13m^{-2}$), consequently they must be new since no such strong quadrupoles are existing from the old transfer line of BESSY I.

The existing 0.25m-magnetic-length quadrupoles for transfer line have maximum strength of $\pm 4.5m^{-2}$ at 800MeV beam energy. In order to use these magnets in the above achromatic cell, the distance between the two vertical bendings was chosen to be d = 8.0574m. According to the above geometry (see Figs. 1 and 2): $\boldsymbol{y}$ = 2.6mm and the parameters of the vertical bending magnets were $\mathbf{B}$ = 0.3T, ρ = 8.895m, θ = 0.0242rad and $\mathbf{L}$ = 0.2151m.

The structure of this achromatic cell is given in Table 1.

Table 1

Element	Length (m)	ρ(m)	θ(rad)	k-value (m^{-2})
Rect. Dipole	0.2151	8.895	0.0242	
Distance	1.8			
Quadrupole	0.25			-4.03312
Distance	3.9574			
Quadrupole	0.25			-4.03312
Distance	1.8			
Rect. Dipole	0.2151	-8.895	-0.0242	

3. Transfer line with two vertical bending magnets

To accommodate the above achromatic cell in the transfer line a third focusing quadrupole is put in the middle of the cell to compensate the strong optical defocusing of the two main quadrupoles. The 3rd quadrupole parameters are $L = 0.25m$ and $k = 2.5m^{-2}$. This quadrupole doesn't affect the vertical dispersion. Fig. 5 shows the transfer line structure including the modified achromatic cell.

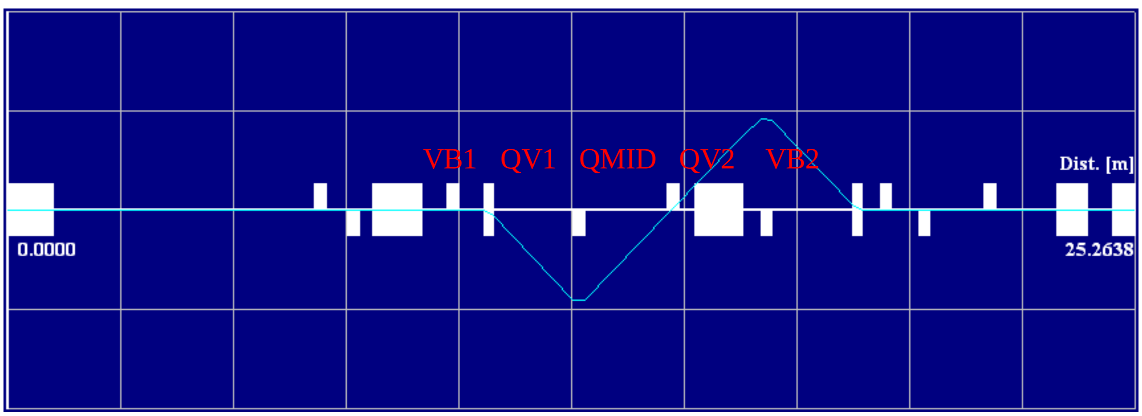

Figure 5: The overall transfer line structure including the modified achromatic cell (given by WinAgile code). VB1, 2: vertical bending 1, 2, QMID: focusing quadrupole, QV1, 2: defocusing quadrupoles.

The second main horizontally bending magnet is now in the modified achromatic cell between the middle quadrupole and one of the last main quadrupole of the cell. So it slightly modified the dispersion function due to its edge focusing. To close again the achromatic cell the main quadrupoles in the cell become with slightly different strengths $-4.0732m^{-2}$ and $-3.7763m^{-2}$ (i.e. by maximum of ~ 6.4% difference). These quadrupoles can be fed by one power supply but shunting the second one. Fig. 6 displays the vertical elevation in the transfer line.

Figure 6: Transfer line layout (Auto Cad drawing) showing septums (brown), quadrupoles (red), horizontal bendings (green) and vertical bendings (blue). The final elevation is 20cm from zero level. (plotted by A. Amro).

4. Transfer line optical matching

The task of the modified achromatic cell is to elevate the beam by 20cm and to eliminate any created vertical dispersion. The conditions $\eta_z = 0$ and $\eta_z' = 0$ are easily achieved by fitting the two main quadrupoles.

The optics of the storage ring is fully matched using another six quadrupoles distributed outside the achromatic cell, three from each side. Any change in the strengths of these matching quadrupoles, due to different matching conditions, will not affect the vertical dispersion distribution.

The transfer line lattice had high flexibility to match different optical conditions, this is shown by Fig. 7, 8 and 9 while Table 2 shows that the maximum quadrupole strength is still within the range of our existing quadrupoles.

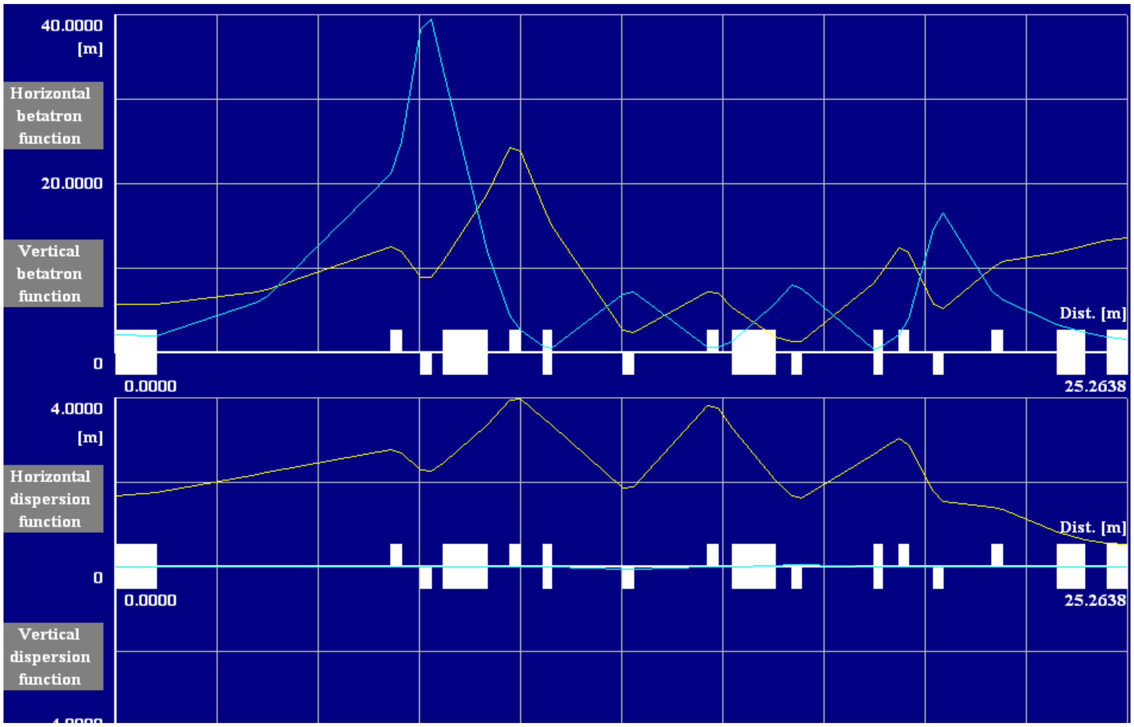

Figure 7: Full optical matching to the ring parameters: β_x = 13.61m, α_x = 0, η_x = 0.53m, η'_x = 0, β_z = 1.65m, α_z = 0, $\eta_z = \eta'_z = 0$.

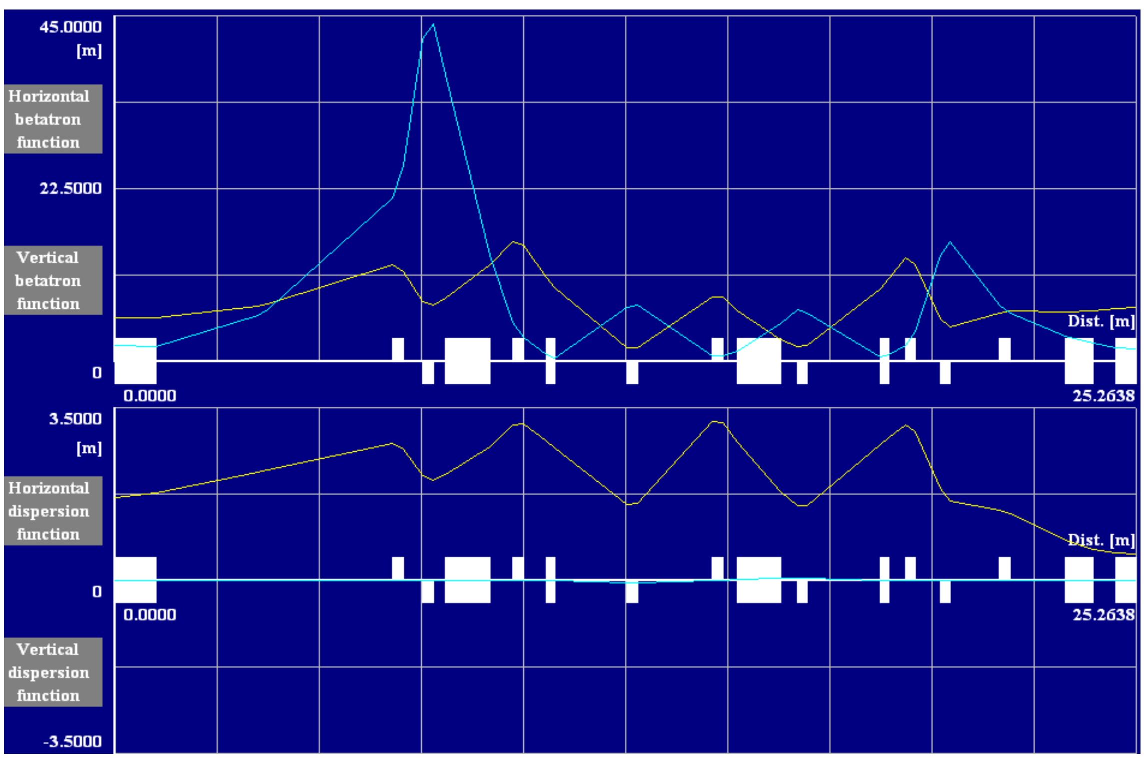

Figure 8: Full matching to the ring parameters but with β_x = 7m.

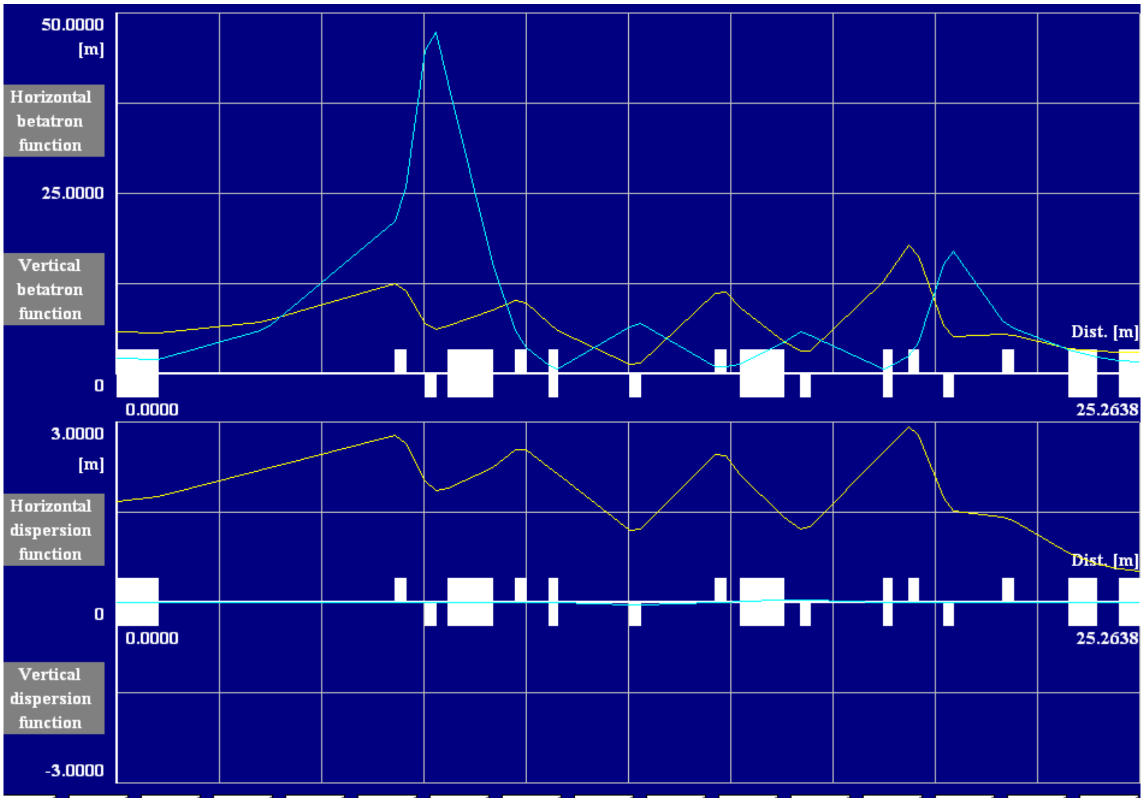

Figure 9: Full matching to the ring parameters but with β_x = 3m.

Table 2

ELEMENT	MATCH 1	MATCH 2	MATCH 3
Q1	1.442	1.826	2.102
Q2	-2.575	-2.762	-2.871
Q3	1.859	1.736	1.624
QV1	-4.073	-4.073	-4.073
QMID	2.5	2.5	2.5
QV2	-3.776	-3.776	-3.776
Q4	3.117	3.219	3.266
Q5	-4.04	-3.961	-3.994
Q6	0.8059	0.673	0.876

QV1 and QV2 are the main quadrupoles in the achromatic cell and QMID is extra one used for optical compensation.

5. Injected beam size issue

Concerning the injected beam size, we see that it is always governed by the horizontal dimension. On the condition that the booster horizontal exmittance is 155nm.rad and the energy spread is $1x10^{-3}$, the maximum 3rms σ_x = 1.33cm in the quadrupole for full matching case (Fig. 7). The available transfer line pipe has inner radius of 2.2cm. In the vertical bending magnets, the maximum 3rms σ_x = 1.15cm for full matching case, hence a half-gap of 1.6cm for this magnet is expected to be enough. It is worth to mention that the optimum β_x for the injection is most probably less than 7m, consequently the above beam size calculations will be conservative.

6. A second solution

A second solution is to use the quadrpoles from BESSY I storage ring for focusing in the achromatic cell. These quadrupoles have magnetic length 0.44m and maximum gradient 13.37T/m (maximum $k = 5m^{-2}$ at 800MeV electron energy). Hence the distance between the two vertical bending magnets could be shortened giving the opportunity to the horizontal bending magnet to be taken out of the achromatic cell after some distance modifications.

In this solution the distance **d** = 4.9122m and $\boldsymbol{y}$ = 5.63mm, consequently the vertical bending magnet parameters with **B** = 0.35T are $\boldsymbol{\rho}$ = 7.624322m, $\boldsymbol{\theta}$ = 0.0384322rad and **L** = 0.293019m. This solution offers much easier alignment process for the achromatic cell elements.

The achromatic cell structure is displayed in Table 3 while the total transfer line structure is given in Table 4.

Table 3

Element	Length (m)	ρ(m)	θ(rad)	k-value (m^{-2})
Rect. Dipole	0.293	7.6243	0.03843	
Distance	0.95			
Quadrupole	0.44			-3.948811
Distance	0.8461			
Quadrupole	0.44			2.45
Distance	0.8461			
Quadrupole	0.44			-3.948811
Distance	0.95			
Rect. Dipole	0.293	-7.6243	-0.03843	

Table 4

Element	**θ (^{O})**	**ρ (m)**	**L (m)**	**K (m^{-2})**	**Availability**
Extra. septum	10	5.874	1.0252		Available from BEESY-I TL
D			2.847		Available from BEESY-I TL
Q1 (QF)			0.25	1.138226	Available from BEESY-I TL
D			2.85		Available from BEESY-I TL
Q2 (QD)			0.25	-2.11147	Available from BEESY-I TL
D			0.35		Available from BEESY-I TL
BEND1	23.5	2.66852	1.0945		Available from BEESY-I TL
D			0.25		Available from BEESY-I TL
Q3 (QD)			0.25	2.209804	Available from BEESY-I TL
D			0.4		Available from BEESY-I TL
VBEND1	2.202	7.624322	0.29302		To be manufactured
D			0.95		Available from BEESY-I TL
QV1 (QD)			0.44	-3.948811	Available from BEESY-I Ring
D			0.8461		Available from BEESY-I TL
QMID (QF)			0.44	2.45	Available from BEESY-I Ring
D			0.8461		Available from BEESY-I TL
QV2 (QD)			0.44	-3.948811	Available from BEESY-I Ring
D			0.95		Available from BEESY-I TL
VBEND1	-2.202	-7.624322	0.29302		To be manufactured
D			0.4		Available from BEESY-I TL
Q4 (QF)			0.25	2.826401	Available from BEESY-I TL
D			0.25		Available from BEESY-I TL
BEND2	23.5	2.66852	1.0945		Available from BEESY-I TL
D			0.3		Available from BEESY-I TL
Q5 (QD)			0.25	-2.085532	Available from BEESY-I TL
D			3.682		Available from BEESY-I TL
Q6 (QF)			0.25	1.36506	Available from BEESY-I TL
D			1.591		Available from BEESY-I TL
Thick septum	15	2.66852	0.6986		Available from BEESY-I TL
D			1.015		Available from BEESY-I TL
Inject. septum	9	3.18311	0.5		A new one is needed

The two defocusing quadrupoles now have the same strength value. The given quadrupole strengths are those for full optical matching case. Fig. 10 shows the transfer line structure with the vertical elevation.

Figure 10: Transfer line drawing showing extraction and injection septums (brown), quadrupoles (red), horizontal bendings (green) and vertical bendings (blue). The final elevation is 20cm from zero level. (plotted by A. Amro).

The three quadrupoles between the two vertical bending magnets will be aligned with longitudinal slope angle dy/ds = 2.202^{o}. The flexibility of the transfer line lattice is shown through Figs. 11, 12 and 13 while the quadrupole strengths for the other matching cases (Figs. 12 and 13) are given in Table 5.

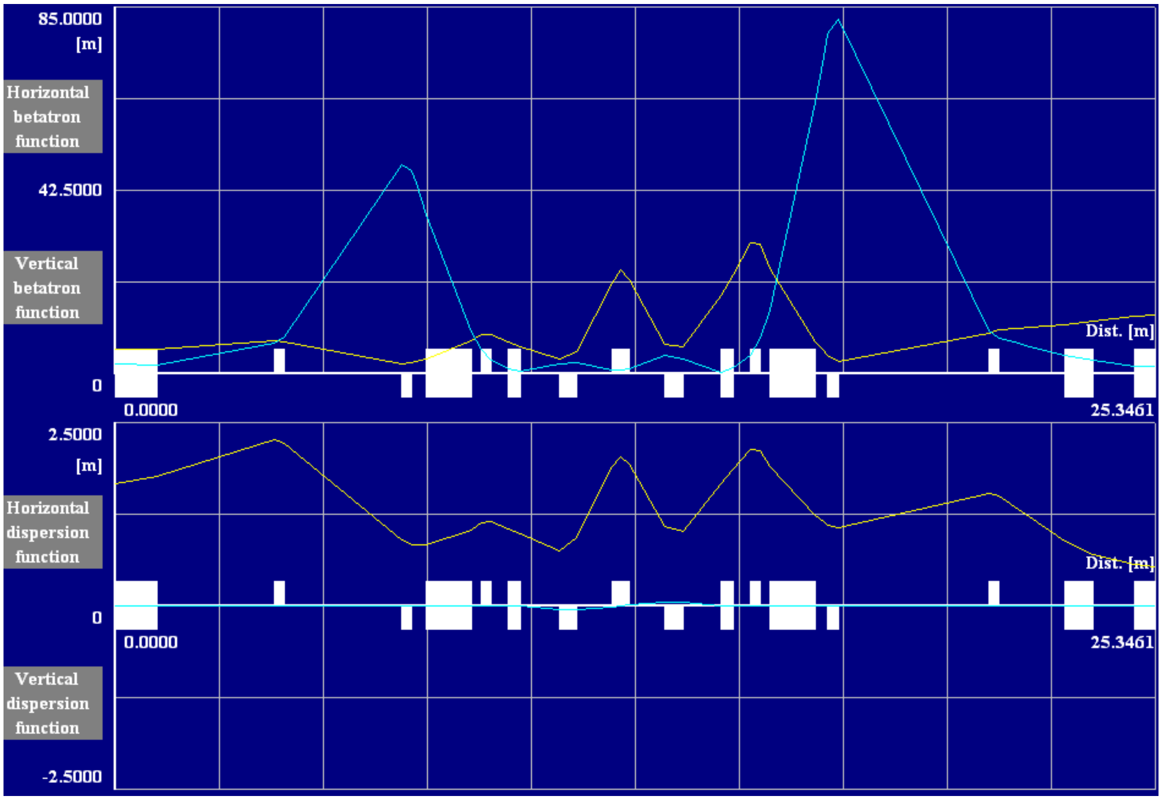

Figure 11: Full optical matching to the ring parameters: β_x = 13.61m, α_x = 0, η_x = 0.53m, η'_x = 0, β_z = 1.65m, α_z = 0, $\eta_z = \eta'_z$ = 0.

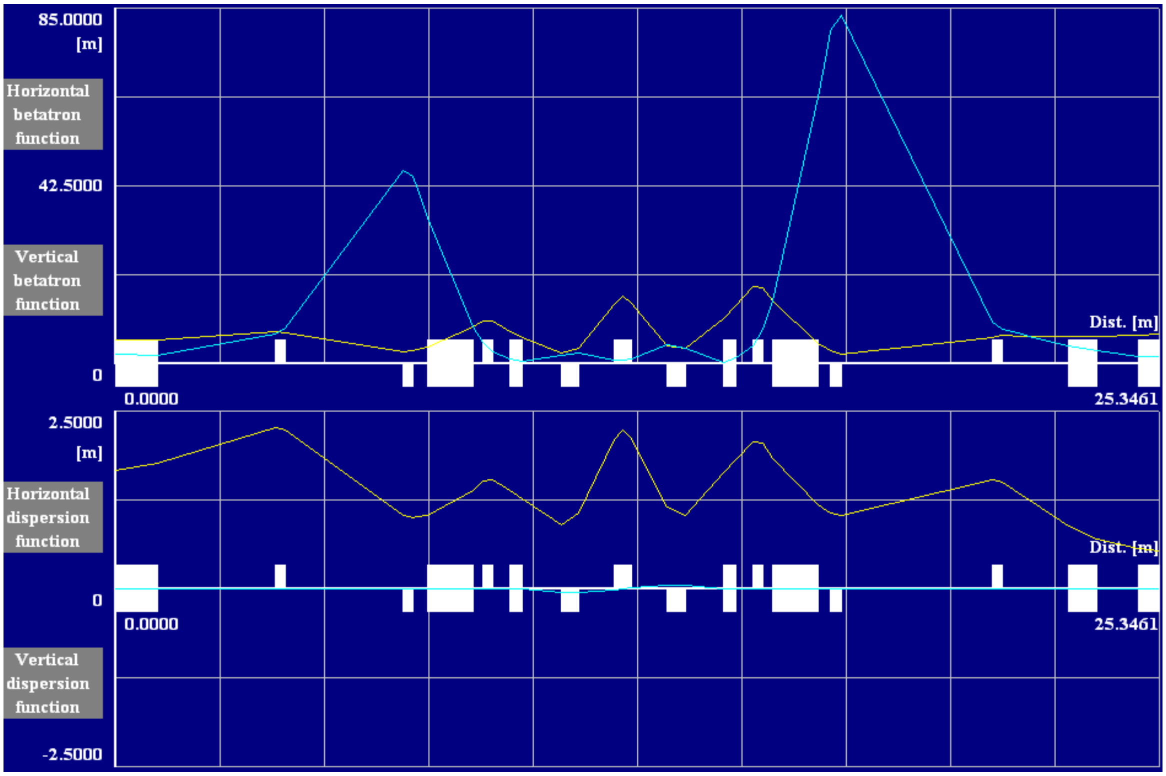

Figure 12: Full matching to the ring parameters but with β_x = 7m.

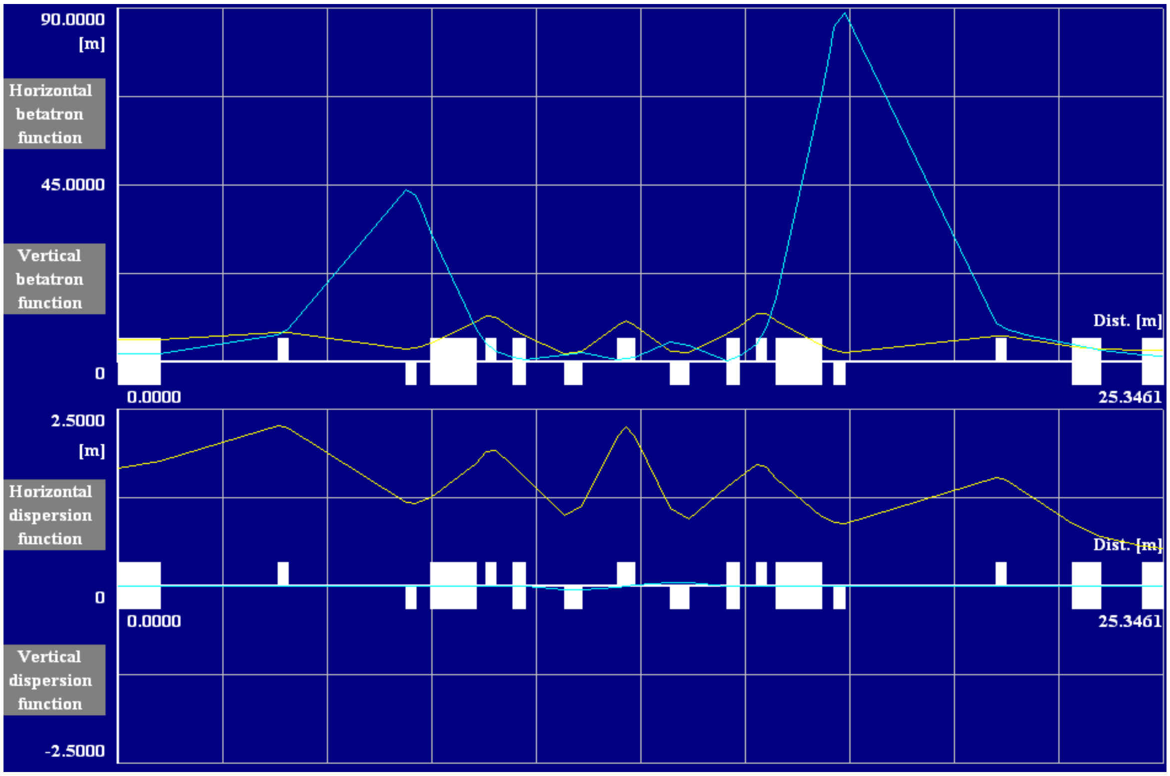

Figure 13: Full matching to the ring parameters but with β_x = 3m.

Table 5

Element	Match 2	Match 3
Q1	1.051064	.962574
Q2	-2.111651	-2.104548
Q3	2.366061	2.507438
QV1	-3.948811	-3.948811
QMID	2.45	2.45
QV2	-3.948811	-3.948811
Q4	2.768903	2.701952
Q5	-2.088014	-2.096671
Q6	1.386061	1.489691

In all matching cases, we see that the maximum quadrupole strength, outside the achromatic cell, is $2.8264 m^{-2}$ which is about 63% of the maximum possible strength ($4.5 m^{-2}$).

7. Beam Size and vertical dipole gap

In the above matching cases the maximum horizontal 3rms beam size is ~ 9.1mm (Match 1) while the maximum vertical one is ~ 3.6mm (Match 3). Taking into account the beam size value in the vertical dipoles in addition to conservative safety margin, the full gap of the vertical dipole was foreseen to be 32mm.

8. Diagnostic elements

Proposed positions for the existing five Foil Monitors (FOMs), 1 Fast Current Transformer (FCT) and six Correctors in addition to 1 new FCT are shown in Fig. 14.

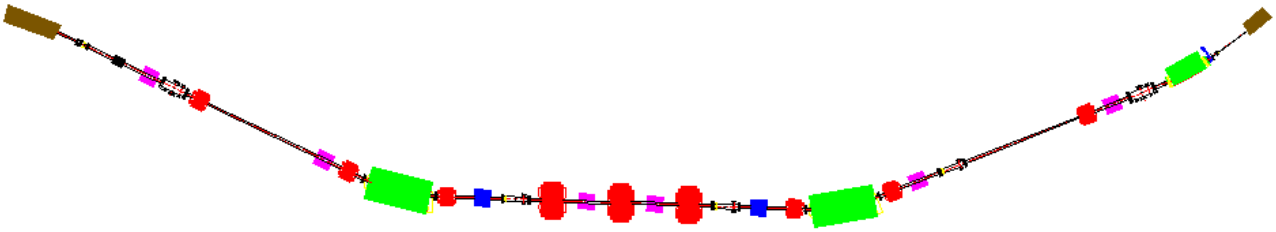

Figure 14: Top view of the transfer line showing : extraction and injection septums (brown), horizontal bending magnets and thick septum (green) , vertical bending magnets (blue), correctors (pink), quadrupoles (red), FCTs (black) and FOMs (colour free). (plotted by A. Amro)

9. Shielding wall modification

The shielding wall part that is crossed by the transfer line has been modified in order not to cross any magnet or diagnostic element. This is shown in Fig. 15.

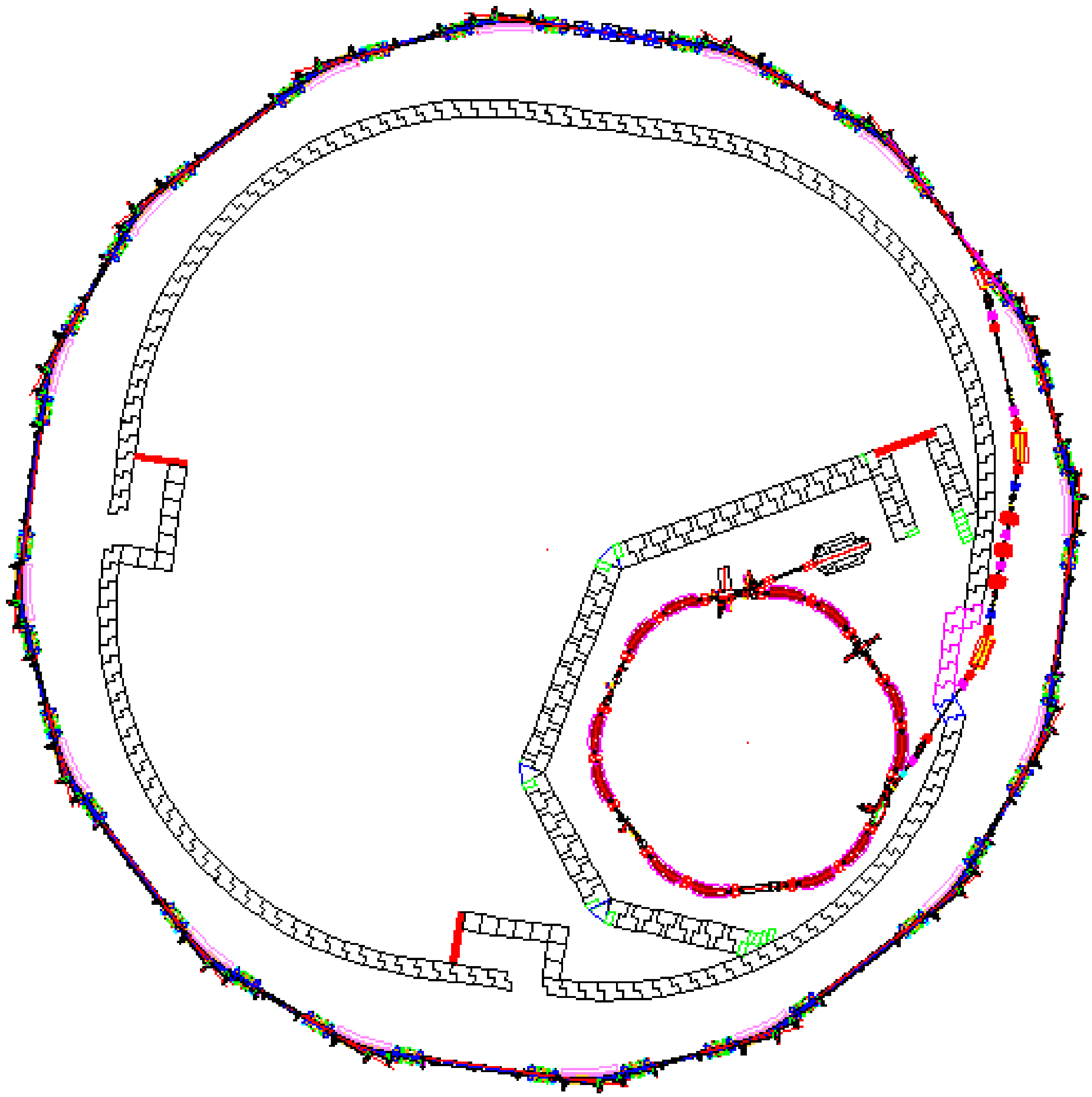

Figure 15: A general lay out showing the microtron, booster, transfer line, internal shielding wall and the storage ring. (plotted by A. Amro)

References

[1] M. Attal & A. Amro, Technical Note, " The Transfer Line TL2".

[2] H. Wiedemann, Particle Accelerator Physics, page 172-173.