



Unit 8 - Lecture 17

Building blocks of storage rings

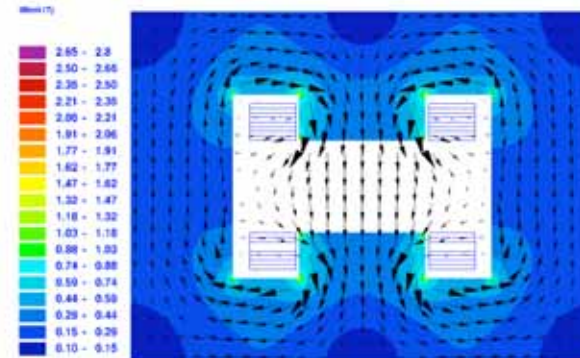
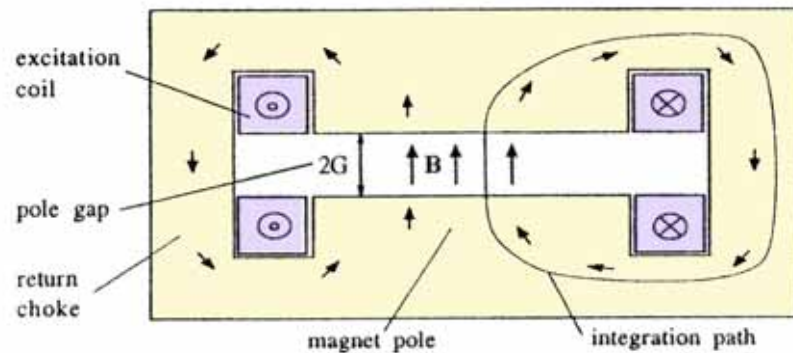
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Dipole magnets to bend the beam



✱ In practical units

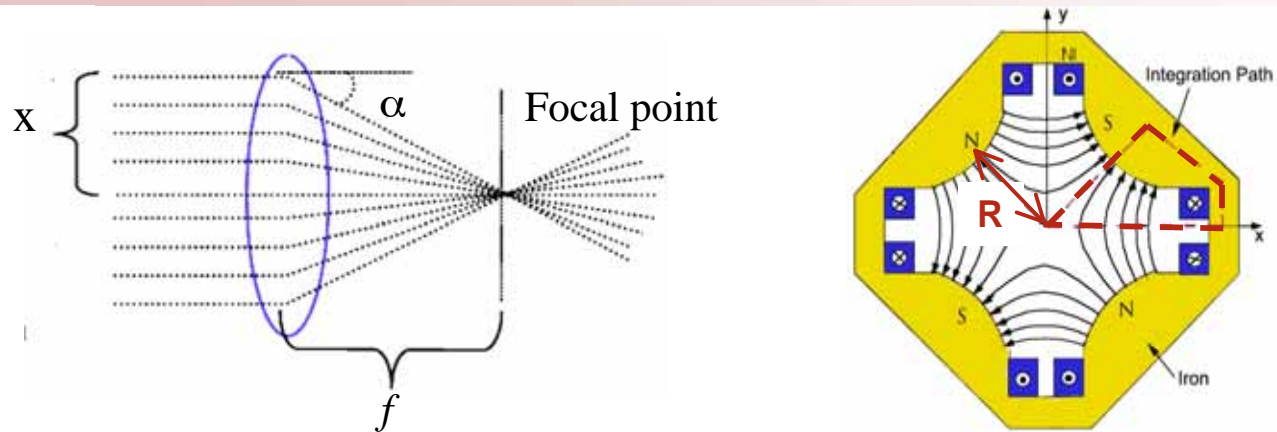
$$\frac{1}{\rho} [m^{-1}] = 0.2998 \frac{B_o [T]}{\beta_{rel} E [GeV]}$$

$$\frac{L_{dipole}}{\rho} = \vartheta_{bend}$$

$$I_{total} (Amp - turns) = \frac{1}{0.4\pi} B_{\perp} (Gauss) G(cm)$$



Quadrupoles to focus the beam



For a Quadrupole with length l & with gradient B'

$$\alpha = -\frac{q}{\beta E} B' x l$$

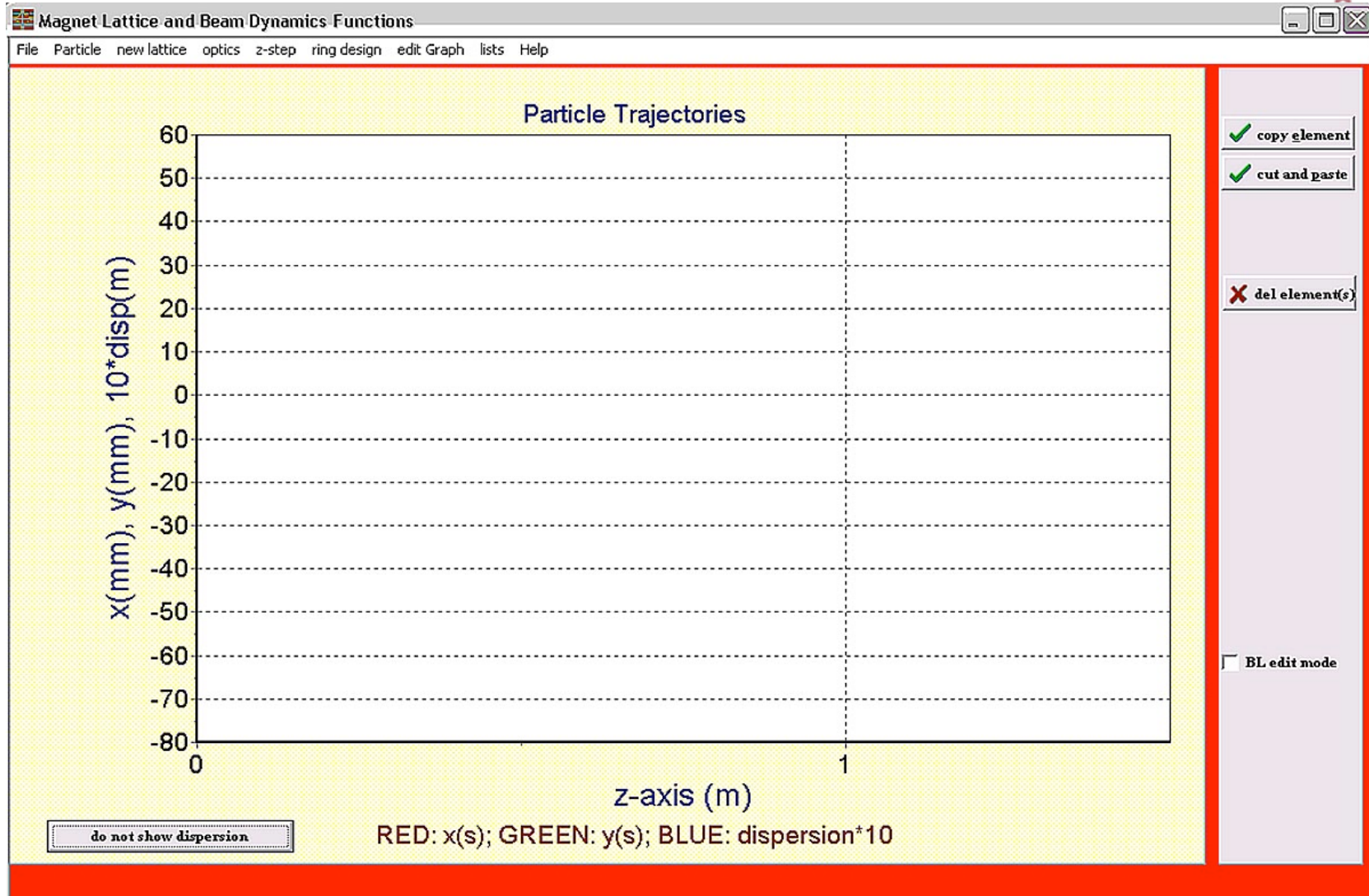
← = → k

$$\text{For } Z = 1 \quad k [m^{-2}] = 0.2998 \frac{B' [T/m]}{\beta E [GeV]}$$

$$B' \left[\frac{T}{m} \right] = 2.51 \frac{NI [A \cdot \text{turns}]}{R [mm^2]}$$



BEAM OPTICS screen





Magnet input screens



edit beam line element:

running index	1			next element
drift space	Name			previous element
ID	1			insert element
path length	0.25000	m		delete element
				cancel
				✓ accept data

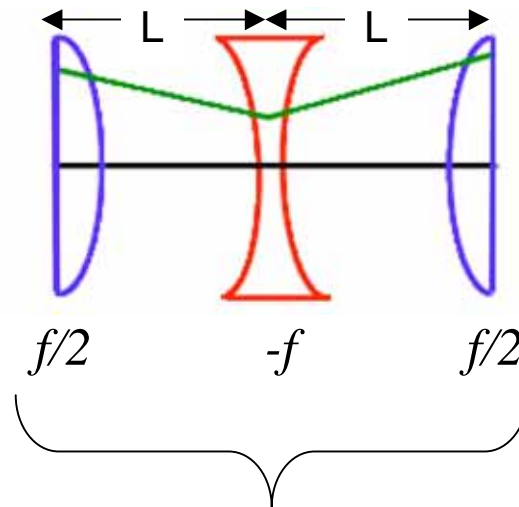
pnMType

edit beam line element:				edit beam line element:			
running index	2			running index	3		
sector magnet	Name			foc. quadrupole	Name		
ID	12			ID	20		
path length	0.25000	m		path length	0.25000	m	
curvature	0.10000	1/m		quadrupole strength	1.00000	1/m^2	
gradient strength	0.00000	1/m^2					
pole face angles: Ain/Aout(rad)	<input type="text" value="0.00000"/>	<input type="text" value="0.00000"/>	<input type="text" value="radian"/>				
full magnet gap	0.00000	cm					
deflection angle	1.43239	degrees					

rect.Magnet
 sector Magnet
 wedge Magnet
 foc.quadrupole
 defoc. quadrupole



FODO transport channel



FODO cell

For stability $\sin \frac{\mu}{2} = \frac{L}{2f} \Rightarrow f > L/2$



FODO transport



✱ The (symmetric) FODO transport matrix is

$$\mathbf{M}_{FODO} = \begin{bmatrix} 1 - 2\frac{L^2}{f^2} & 2L \cdot \left(1 + \frac{L}{f}\right) \\ -\frac{1}{f^*} & 1 - 2\frac{L^2}{f^2} \end{bmatrix} = \begin{bmatrix} \cos\varphi & \beta \sin\varphi \\ \frac{1}{\beta} & \cos\varphi \end{bmatrix}$$

Where

$$\frac{1}{f^*} = 2 \cdot \left(1 - \frac{L}{f}\right) \cdot \left(\frac{L}{f^2}\right) \quad \text{and} \quad \varphi = \text{betatron phase advance}$$

✱ Let $\kappa = f/L$

$$\cos\varphi = 1 - 2\frac{L^2}{f^2} = \frac{\kappa^2 - 2}{\kappa^2} \quad \text{or} \quad \boxed{\sin\frac{\varphi}{2} = \frac{1}{\kappa}}$$



More generally for a lens of finite length



✱ The solution is that of a simple harmonic oscillator

$$\begin{pmatrix} x \\ x' \end{pmatrix}_{out} = \begin{pmatrix} \cos \Theta & \frac{1}{\sqrt{K}} \sin \Theta \\ \sqrt{K} \sin \Theta & \cos \Theta \end{pmatrix} \begin{pmatrix} x \\ x' \end{pmatrix}_{in} \quad \text{where} \quad \Theta = \sqrt{K} l$$

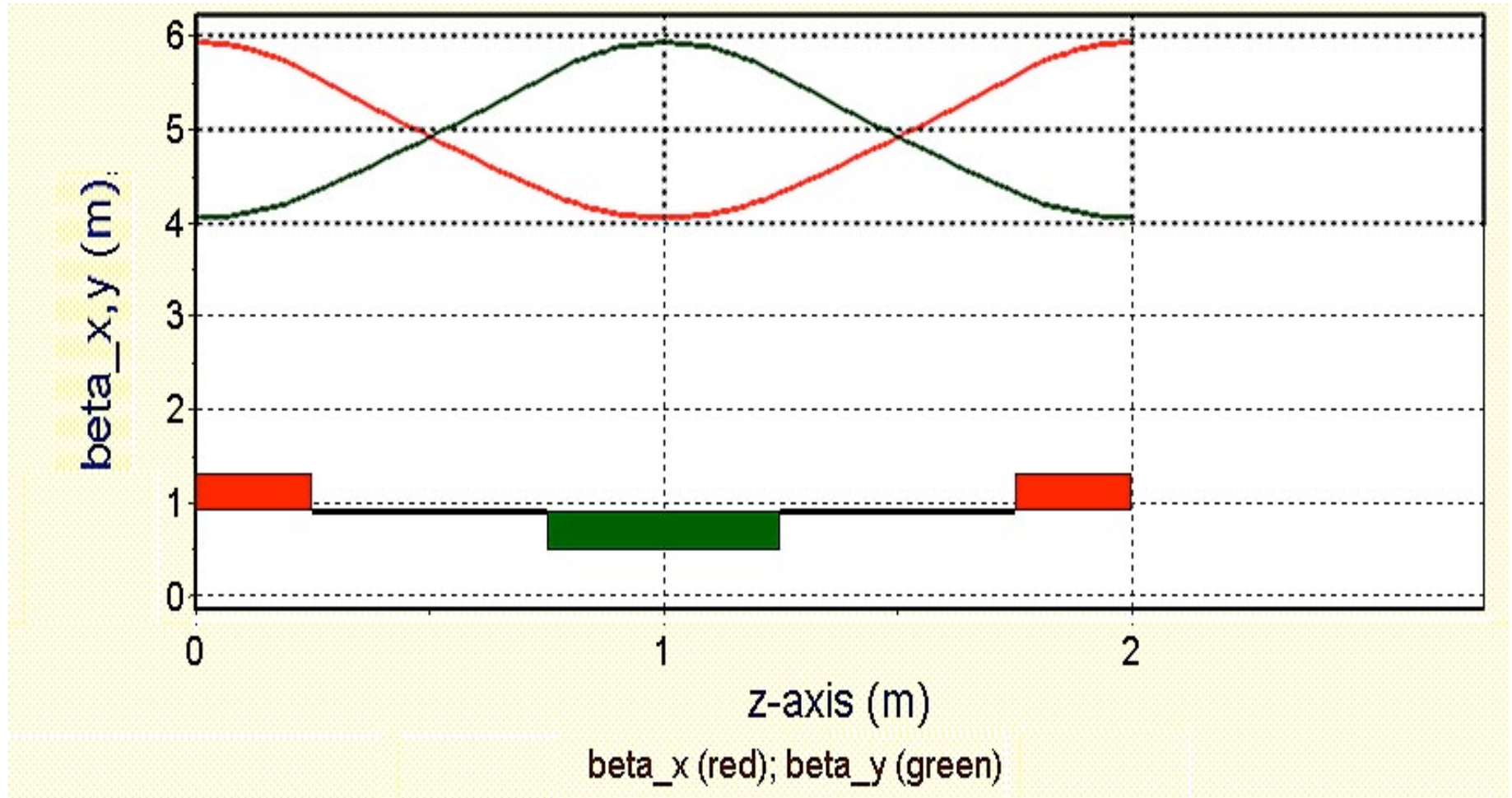
✱ For $K < 0$ the solution is

$$\begin{pmatrix} x \\ x' \end{pmatrix}_{out} = \begin{pmatrix} \cosh \Theta & \frac{1}{\sqrt{|K|}} \sinh \Theta \\ \sqrt{|K|} \sinh \Theta & \cosh \Theta \end{pmatrix} \begin{pmatrix} x \\ x' \end{pmatrix}_{in} \quad \text{with} \quad \Theta = \sqrt{|K|} l$$

✱ For the thin lens, let $l \rightarrow 0$ keeping Kl finite and $\rightarrow 1/f$

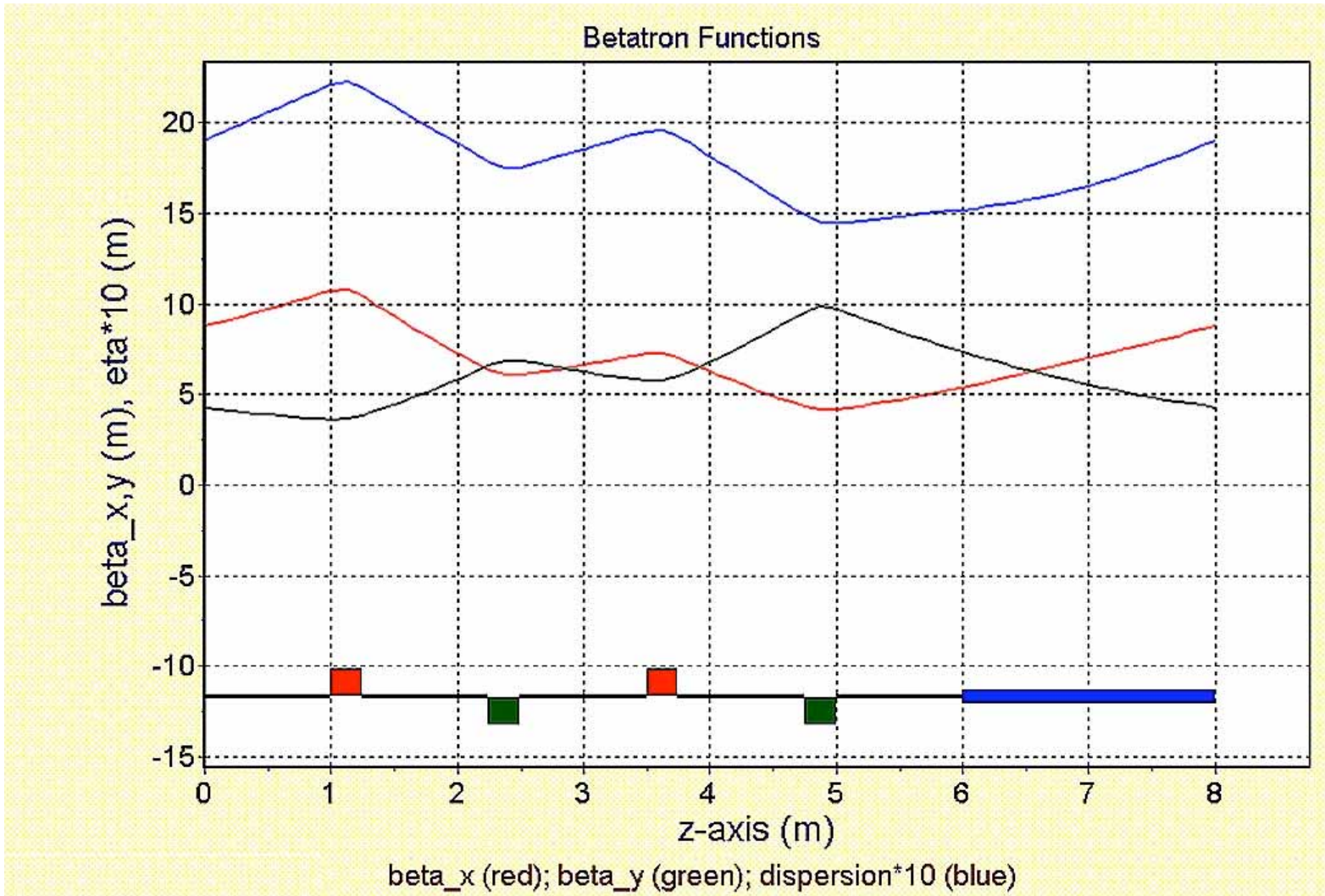


Symmetric FODO cell



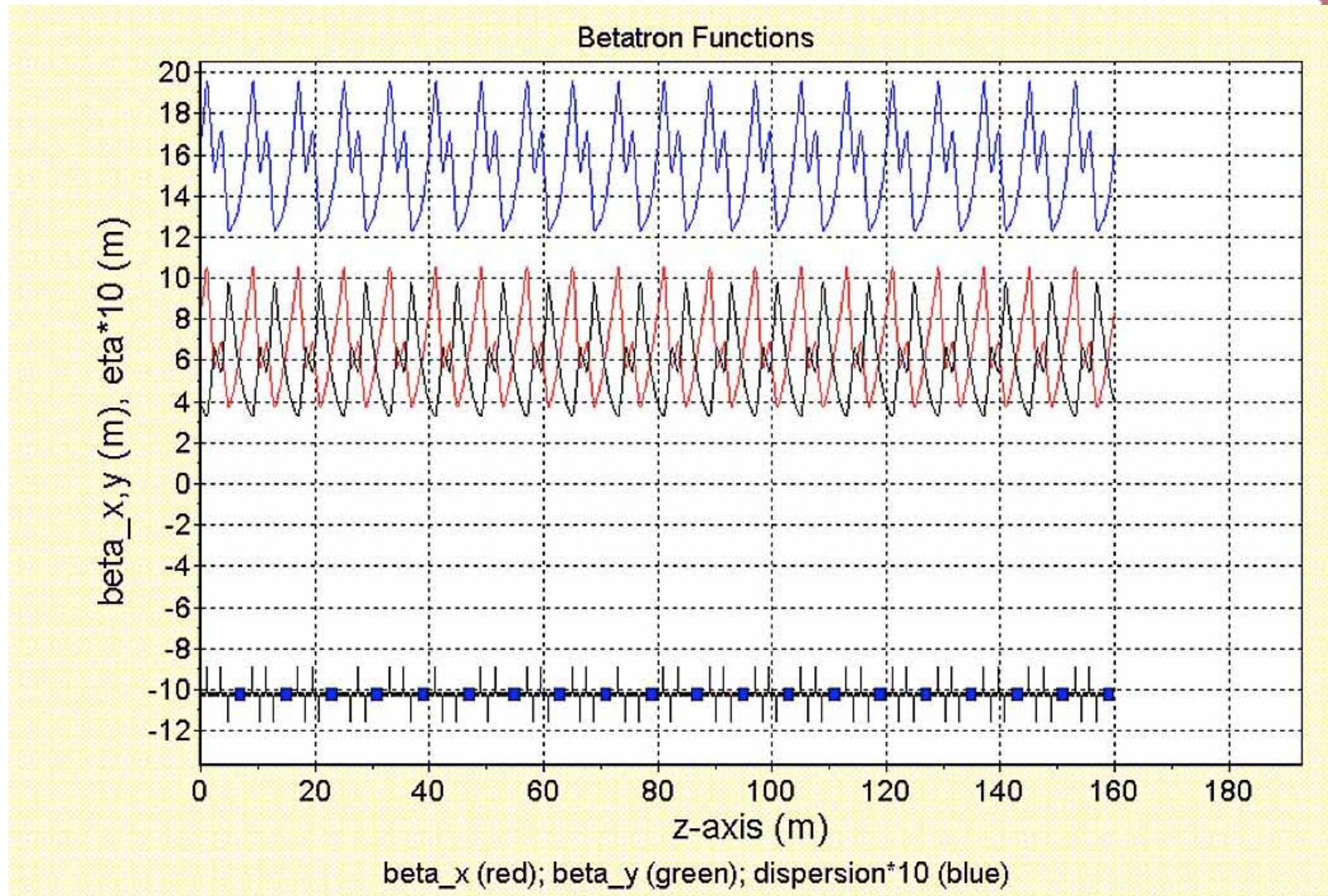


Simple FODO cell





12-fold symmetric 1 GeV FODO ring





RF for 1 GeV FODO ring



rf

File Rf-system energy scan graphs phase space rf-potential

rf voltage, kV <input type="text" value="1000.000"/>	rf frequency = 500.27866 MHz	change beam parameter ?	energy acceptance, % = 0.646
rf power, kW <input type="text" value="200.000"/>	harmonic number = 267.000	momentum cp, GeV <input type="text" value="1.000"/>	over voltage factor = 71.97
energy loss/turn = 13.895 keV		beam current, mA <input type="text" value="100.000"/>	phase = 179.204 deg
addl. energy loss/turn [keV] <input type="text" value="0.0"/>			synchrotron frequency, kHz = 91.250
			rms bunch length, mm = 9.398
			synchrotron tune, nue_s = 0.048700

< cp (GeV) <

RfPower system

rf frequency = 500.27866 MHz rf-wavelength is 0.599 m
of cavity cells/ring: eff. cavity length is 0.300 m

Cavity Impedance

scaled cavity impedance select Impedance

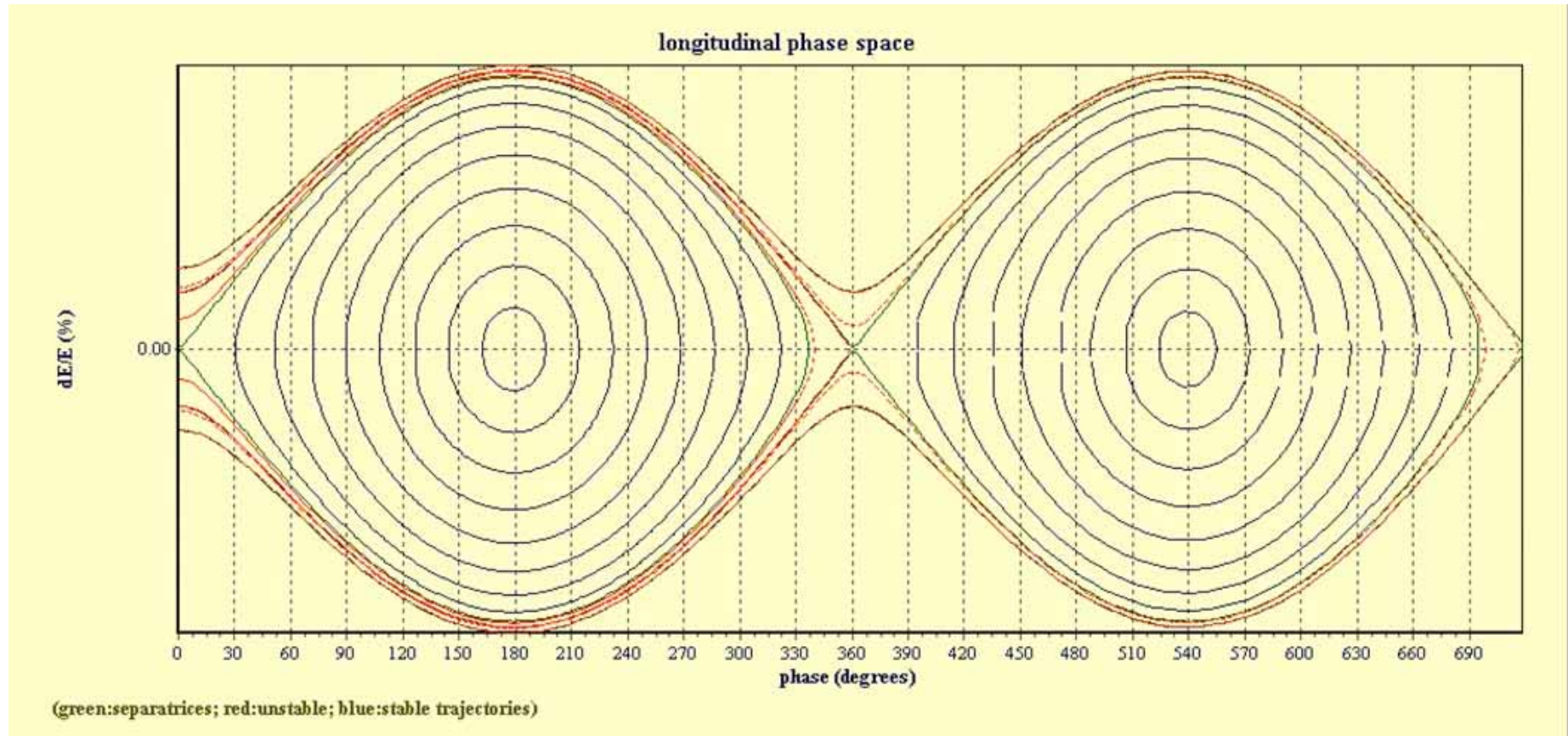
cavity material	pill box shunt impedance
<input checked="" type="radio"/> copper	impedance = 28.630 MOhm/m
<input type="radio"/> aluminum	tot. ring impedance = 8.578 MOhm

Shunt impedance is defined by $R_s = V^2/P$

tot. cavity voltage = 1000.000 kVolt
tot.available rf-power = 200.000 kW
total cavity losses = 116.575 kW
misc.rf-losses = 0.000 kW or % of total power
remaining rf power of 83.425 kW
will sustain a max. total beam current of 6003.794 mA

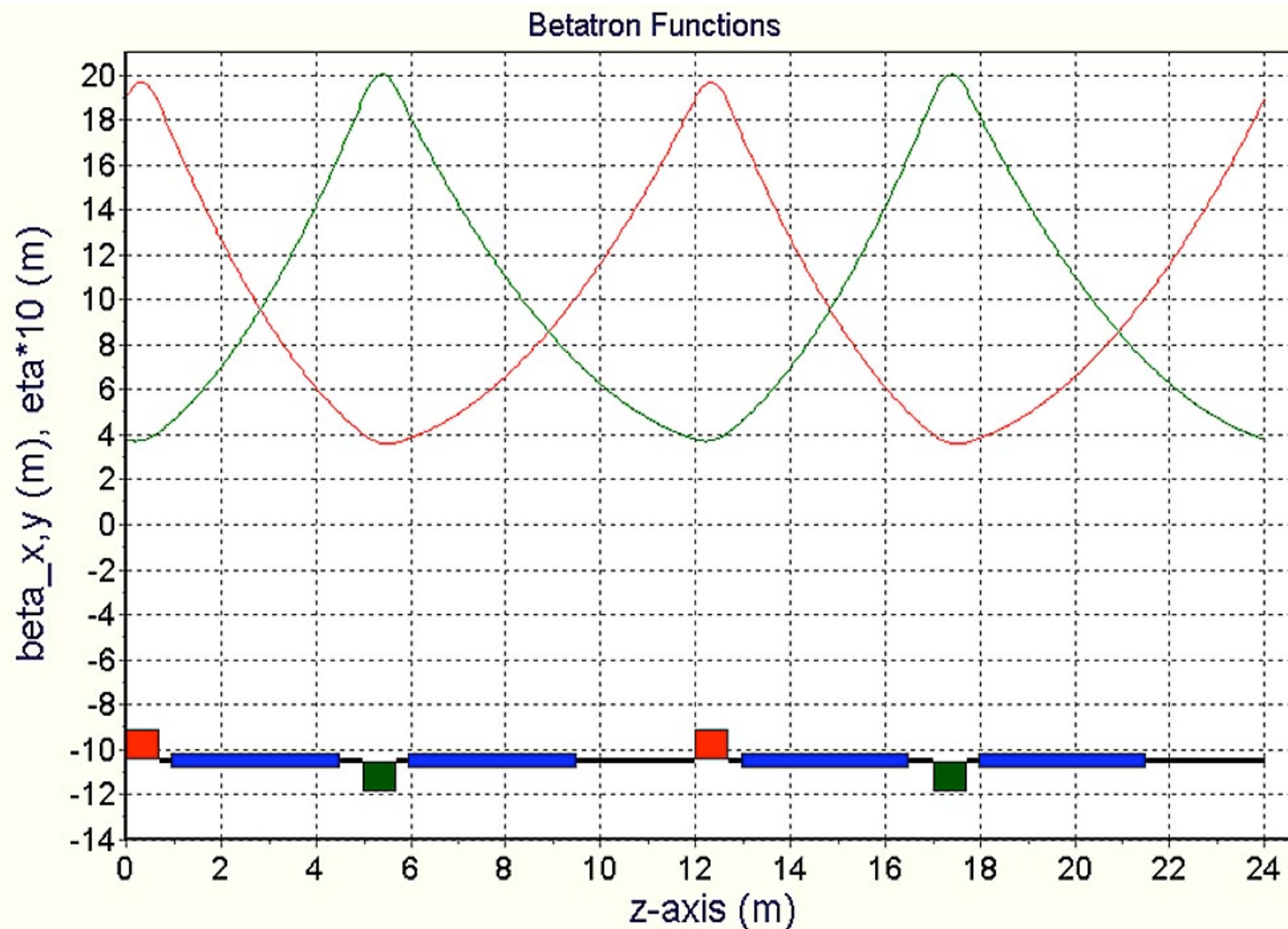


Longitudinal phase space





The bend magnet can be in the drift: 1/12th of 10 GeV DESY ring



show dispersion

beta_x (red); beta_y (green); dispersion*10 (blue)



DESY ring parameters



Storage Ring Parameters

```

particle..... =          electron
particle momentum, cp..... =    10.000 GeV
gamma ..... = 19569.34144
beam current..... =    100.000 mA
ring circumference,C..... =    288.24000 m
energy loss/turn ..... =    32.618 MeV
tot. radiation power ..... =     3.262 MW
horiz.damping time ..... =    309.458 usec
vert.damping time ..... =    294.764 usec
synchrotron damping time ..... =    143.964 usec

```

```

betatron tunes,Q_x..... =    6.08396
           Q_y ..... =    5.92782
natural chromaticity,xi_xo ..... =   -7.03662
           xi_yo ..... =   -7.17701
corrected chromaticity,xi_x ..... =    0.00000
           xi_y ..... =    0.00000

```

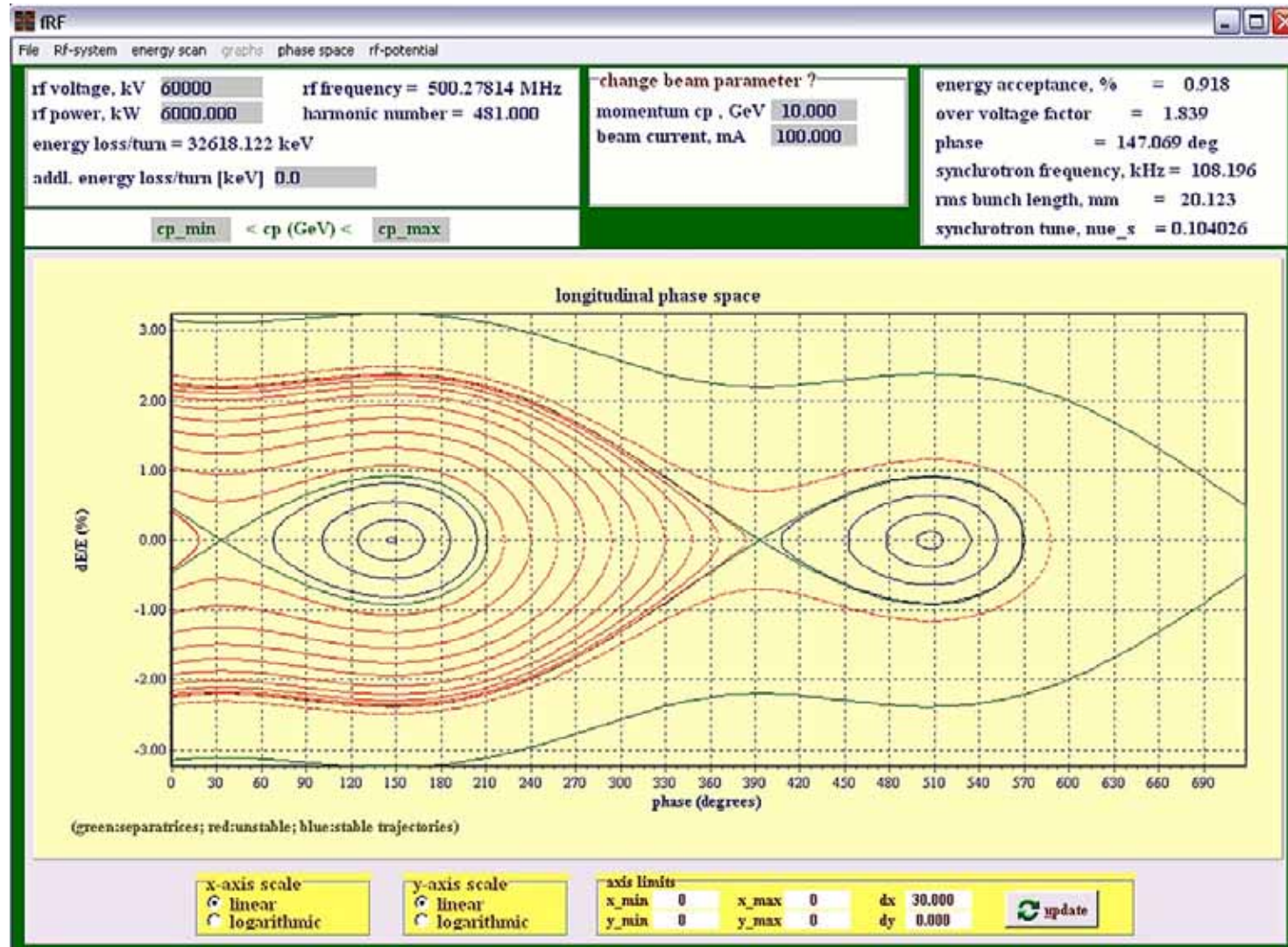
ring geometry
of superperiods (full ring: 12 cells)
ring circumference = 288.240 m
revolution frequency = 1.04008 MHz
rf frequency, MHz
harmonic number is 481.000
now total defl.angle is 360.000 deg
perfect ring with integer harmonic number!

study full ring?

study superperiod?

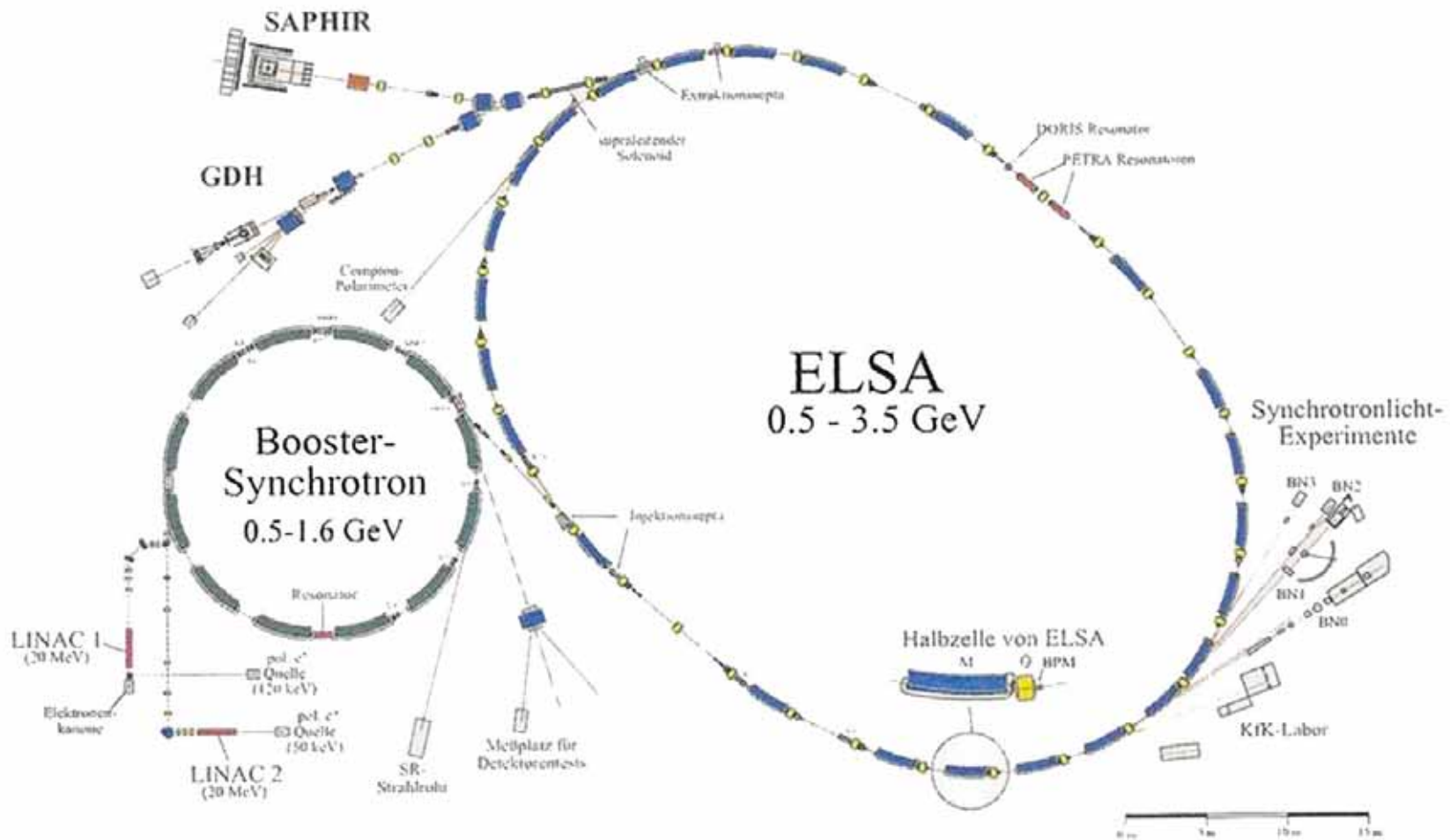


DESY ring RF



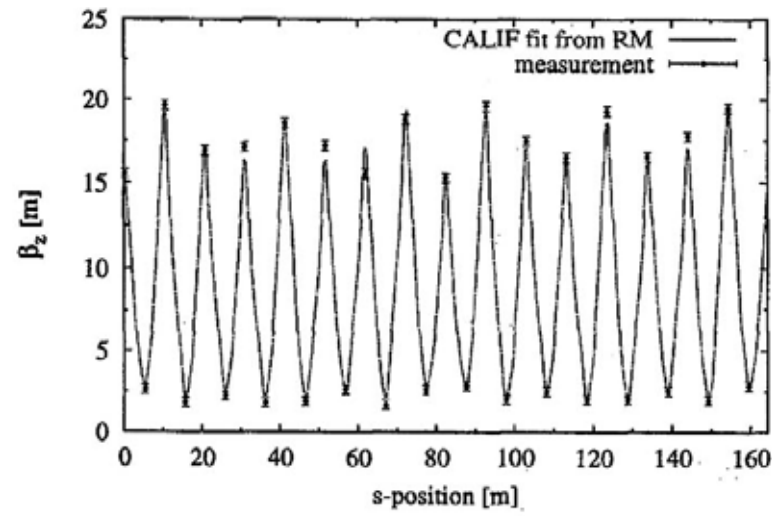
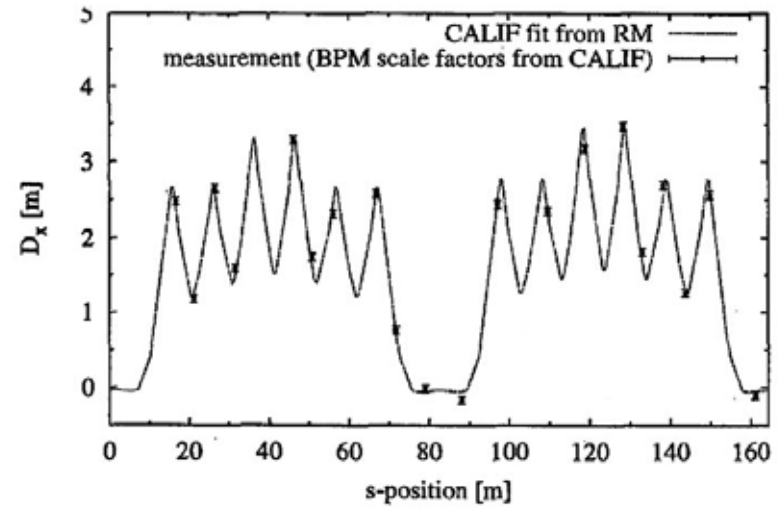
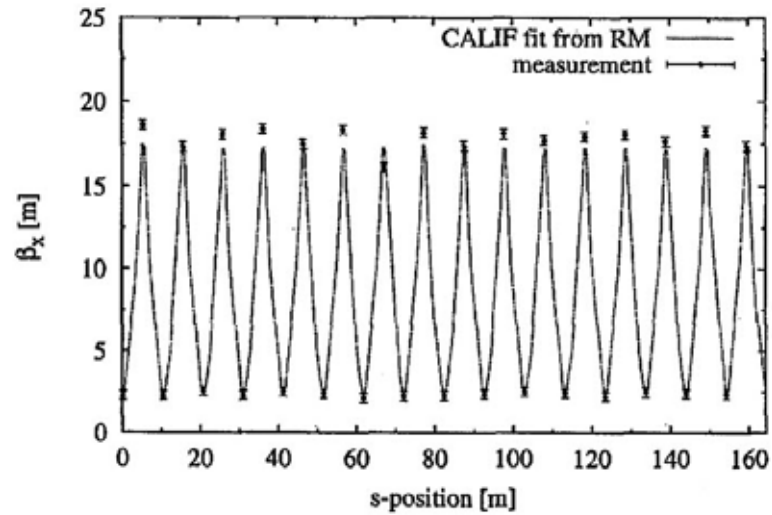


Example of synchrotron complex: ELSA





ELSA optical functions



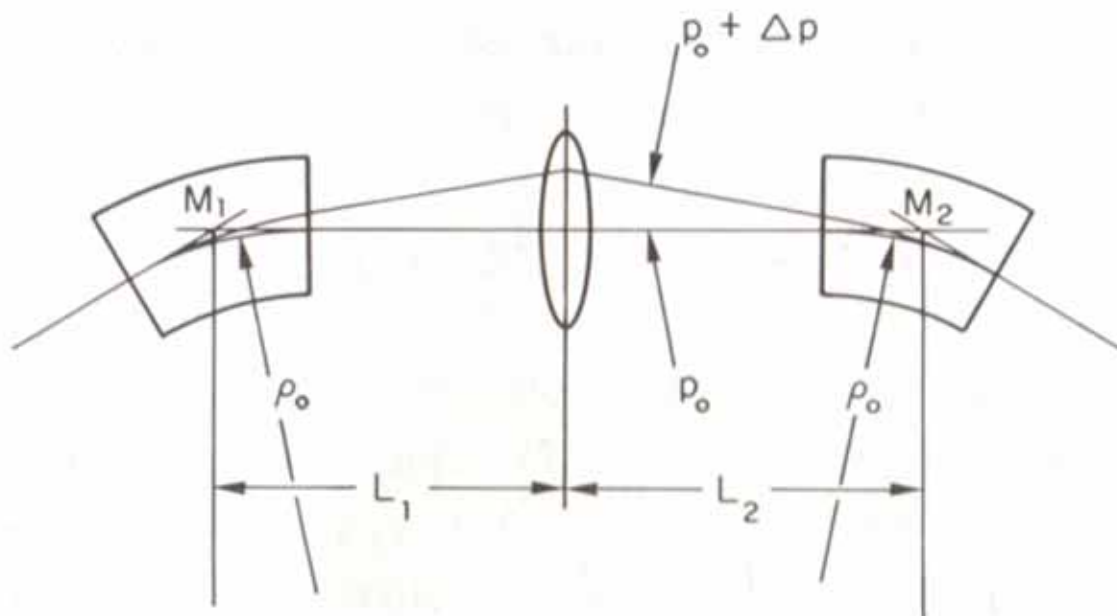


Figure 5.5 A simple achromatic system consisting of two bending magnets separated by a horizontally focusing quadrupole.



Why use achromats?



- ✱ We may want to deliver the beam to a region with no residual dispersion (energy dependent orbit displacement)
 - Interaction regions in colliders
 - Insertion devices in storage rings

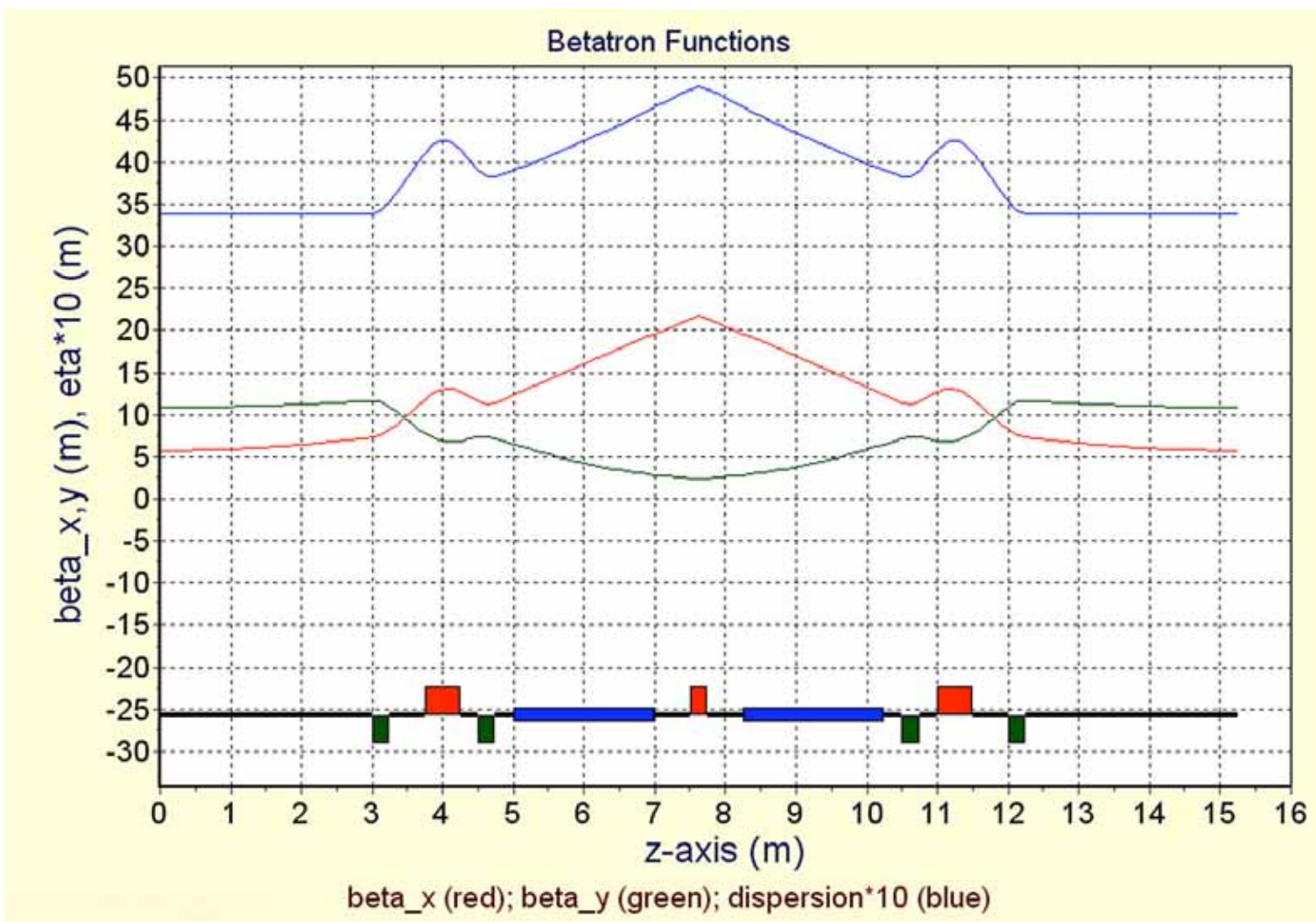
- ✱ For circulating electron beams we may want a very low emittance
 - Synchrotron light sources

- ✱ We would like many long straight sections

- ✱ Hence the low-emittance Chasman-Green lattice (1975)
 - Basis is Double Bend Achromat (Panofsky, 1965)

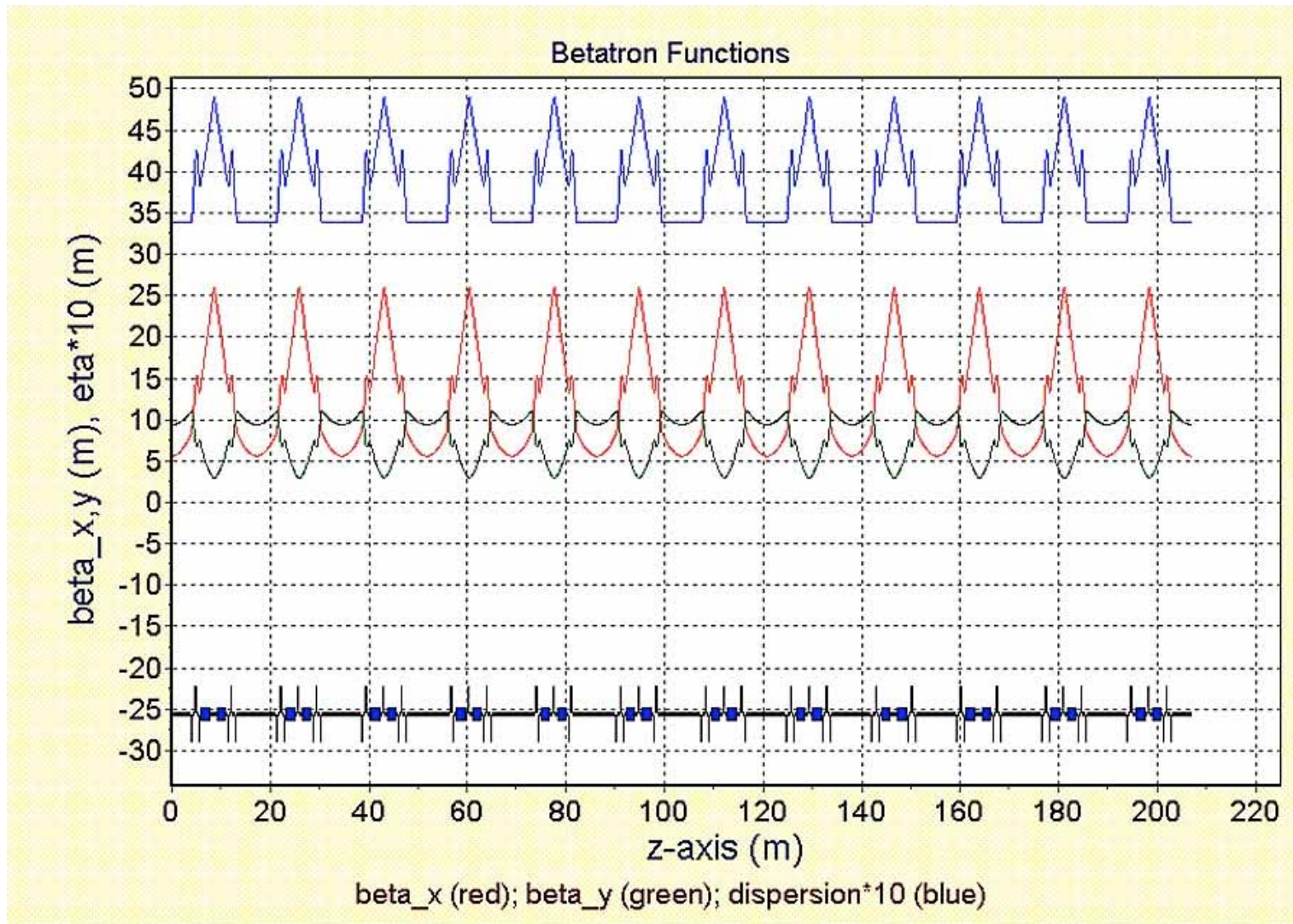


Storage ring building blocks: Double Bend Achromat



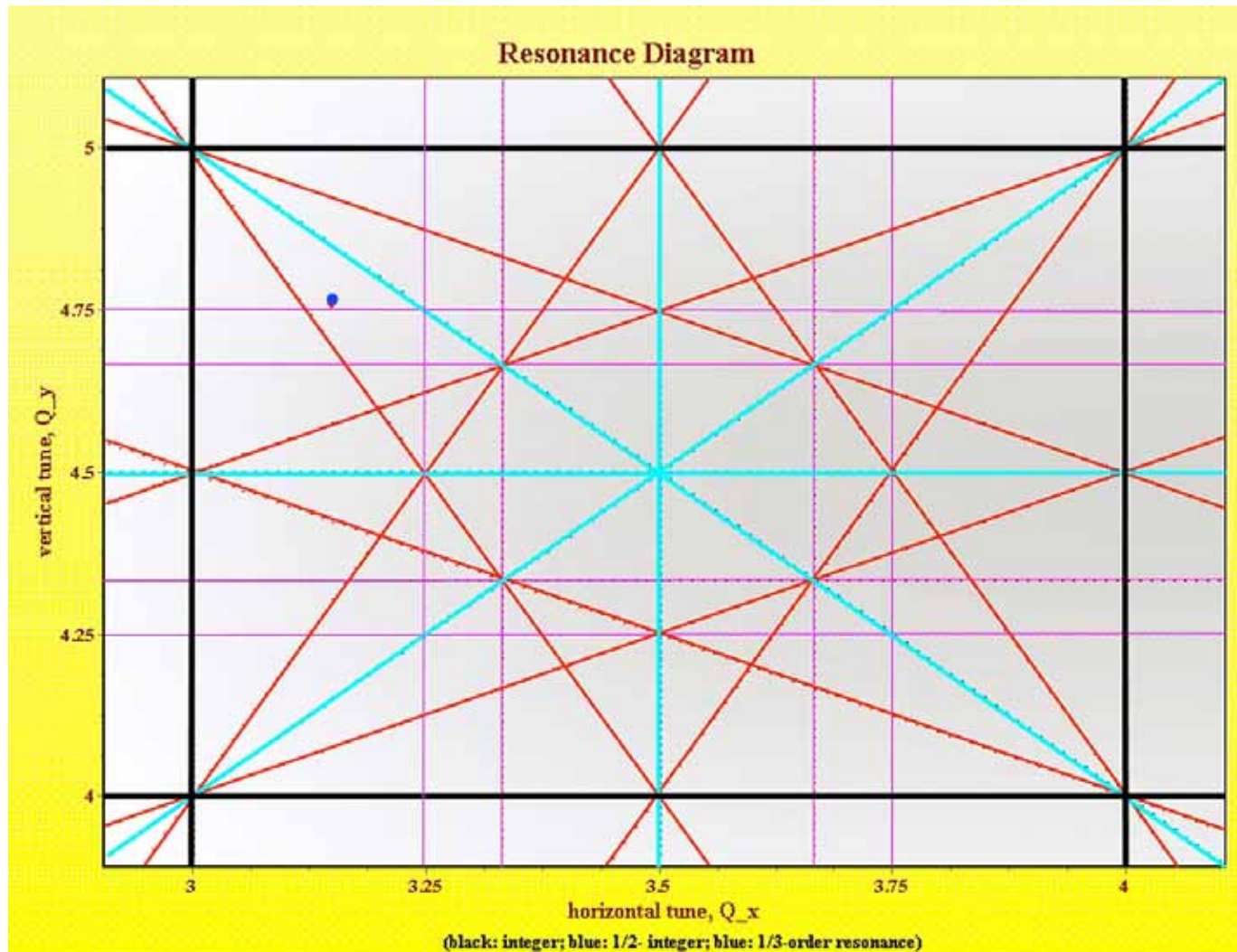


12 of the cells make a 2 GeV electron ring





With a tune in a dangerous position





The longitudinal phase space is

