# Unit 8 - Lecture 17
# Building blocks of storage rings

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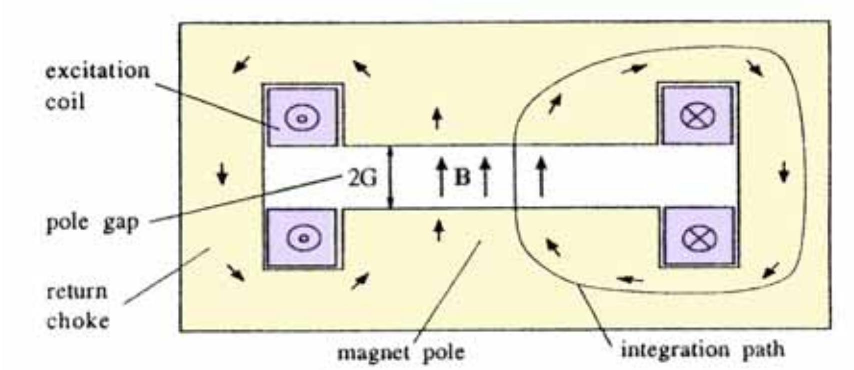
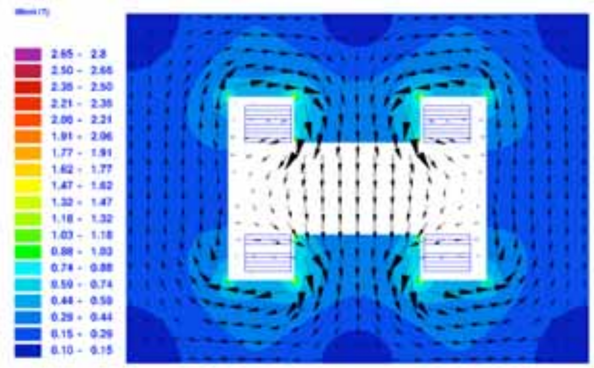
# Dipole magnets to bend the beam



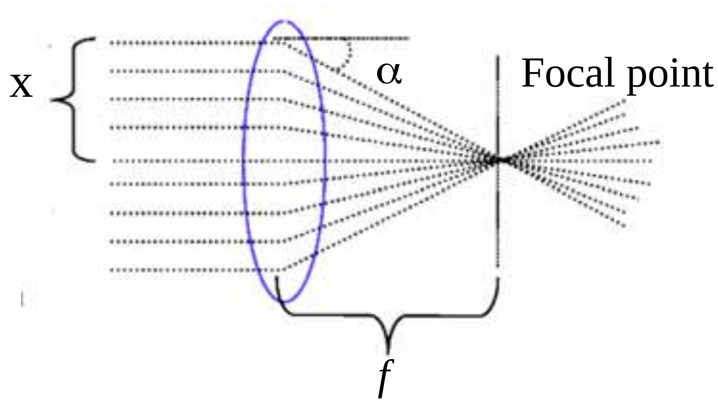
- In practical units

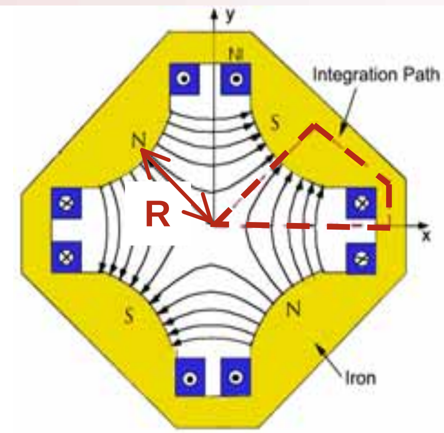
$$\frac{1}{\rho}\left[m^{-1}\right] = 0.2998 \; \frac{B_o\left[T\right]}{\beta_{\rm rel} E\left[GeV\right]}$$

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

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

# Quadrupoles to focus the beam




For a Quadrupole with length *l* & with gradient B'

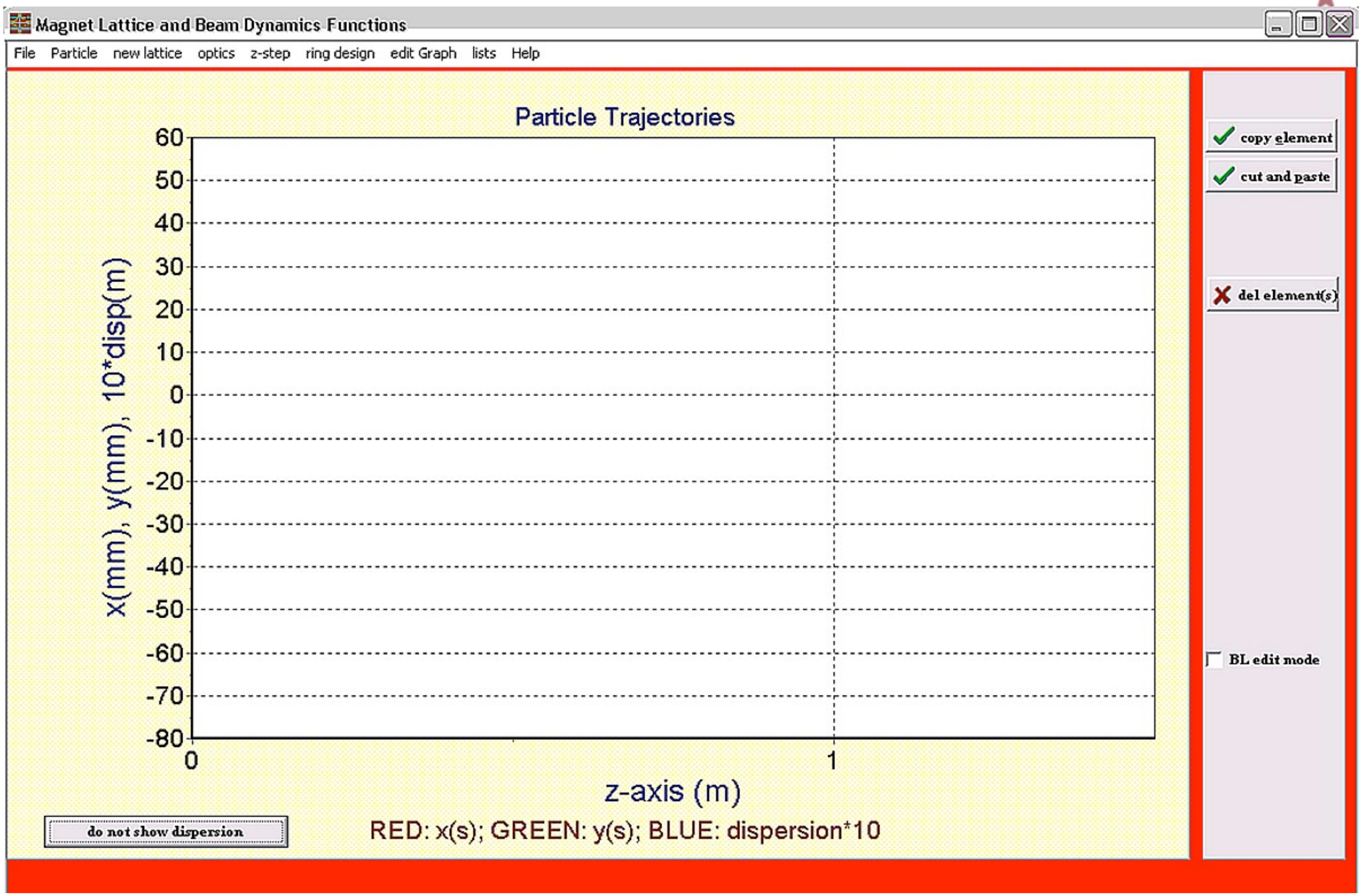
$$\alpha = -\frac{q}{\beta E} B' x l$$

$\frac{q}{\beta E} B' = k$

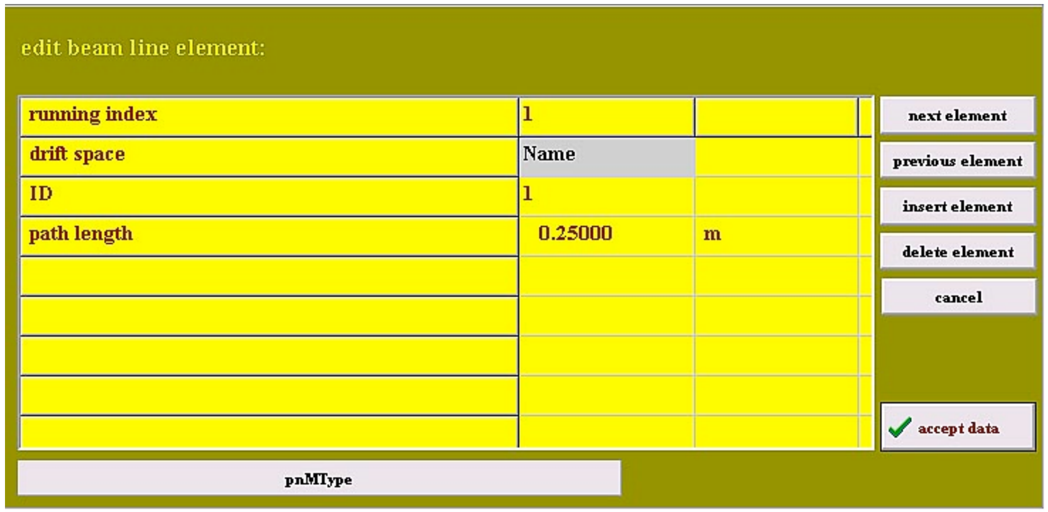
For Z = 1 $\quad k\left[m^{-2}\right] = 0.2998 \frac{B'[T/m]}{\beta E[GeV]}$

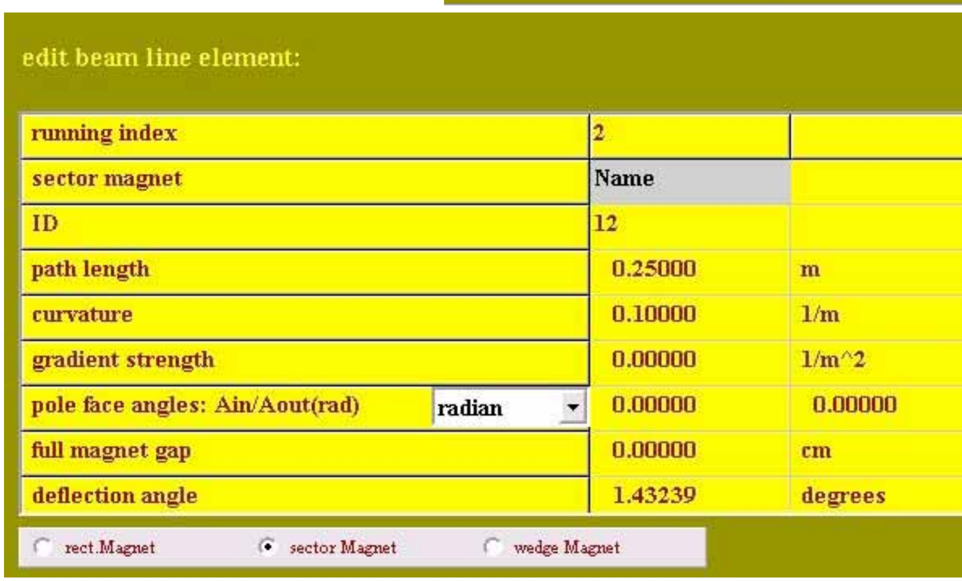
$$B'\left[\frac{\mathrm{T}}{\mathrm{m}}\right] = 2.51 \frac{NI\ [\mathrm{A\text{-}turns}]}{\mathrm{R}\ [\mathrm{mm}^2]}$$

# BEAM OPTICS screen

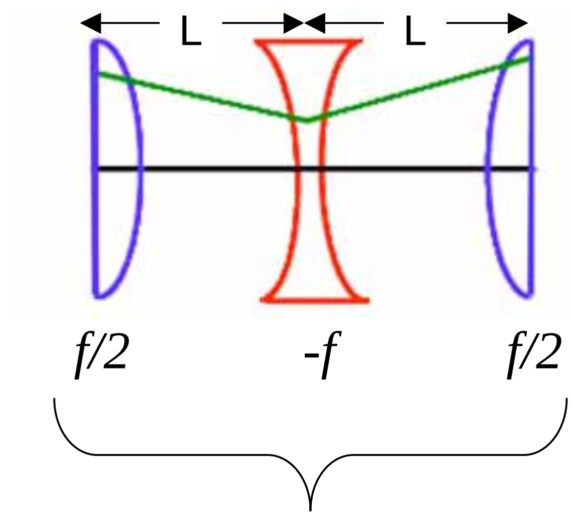


# Magnet input screens




# FODO transport channel




FODO cell

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

# 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

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

- 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

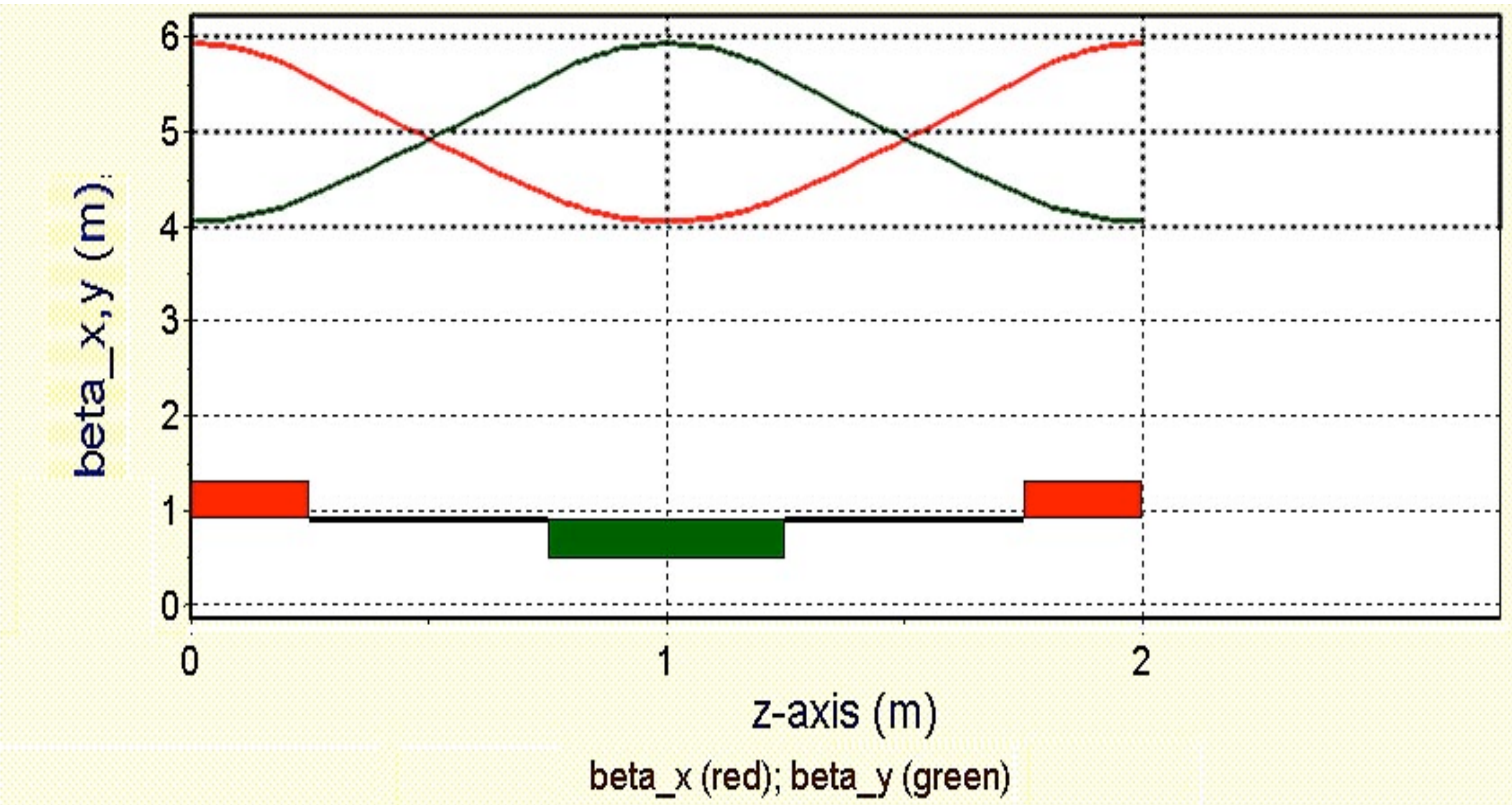
$$\begin{pmatrix} x \\ x' \end{pmatrix}_{out} = \begin{pmatrix} \cos\Theta & \frac{1}{\sqrt{K}}\sin\Theta \\ \sqrt{K}\sin\Theta & \cos\Theta \end{pmatrix} \begin{pmatrix} x \\ x' \end{pmatrix}_{out} \quad \text{where} \quad \Theta = \sqrt{K}\, l$$

- For K < 0 the solution is

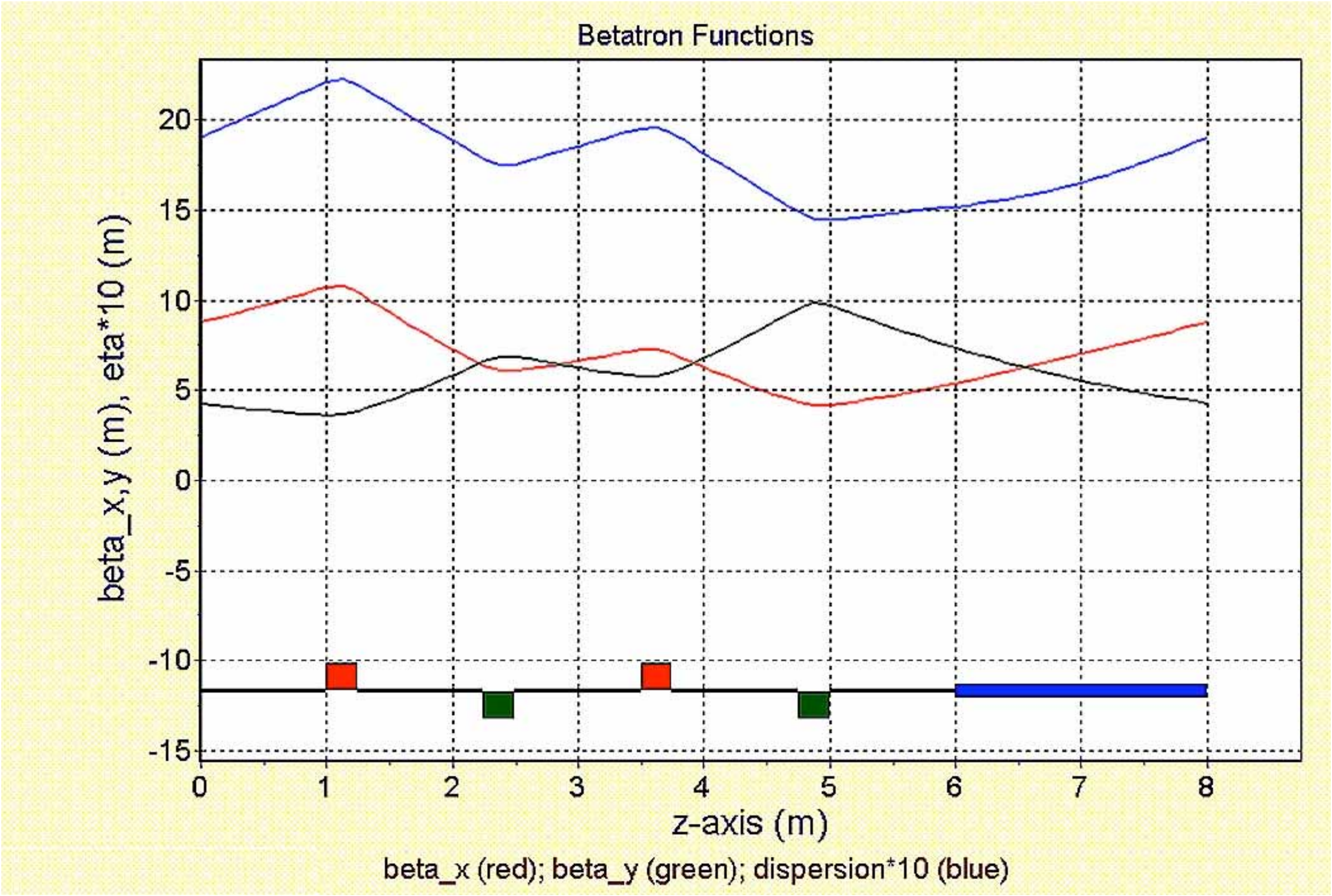
$$\begin{pmatrix} x \\ x' \end{pmatrix}_{out} = \begin{pmatrix} \cosh\Theta & \frac{1}{\sqrt{|K|}}\sinh\Theta \\ \sqrt{|K|}\sinh\Theta & \cosh\Theta \end{pmatrix} \begin{pmatrix} x \\ x' \end{pmatrix}_{out} \quad \text{with} \quad \Theta = \sqrt{|K|}\, l$$

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

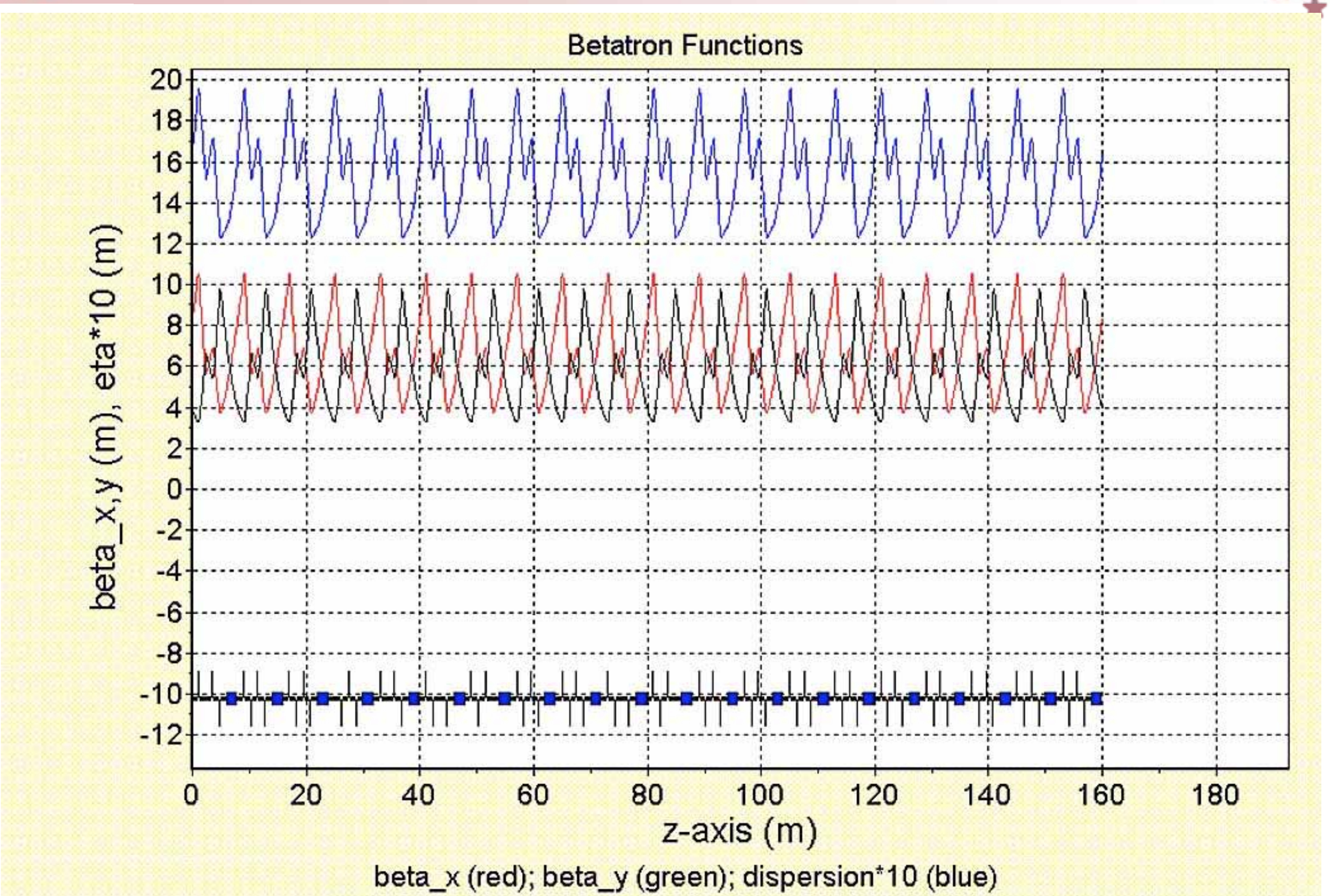
# Symmetric FODO cell



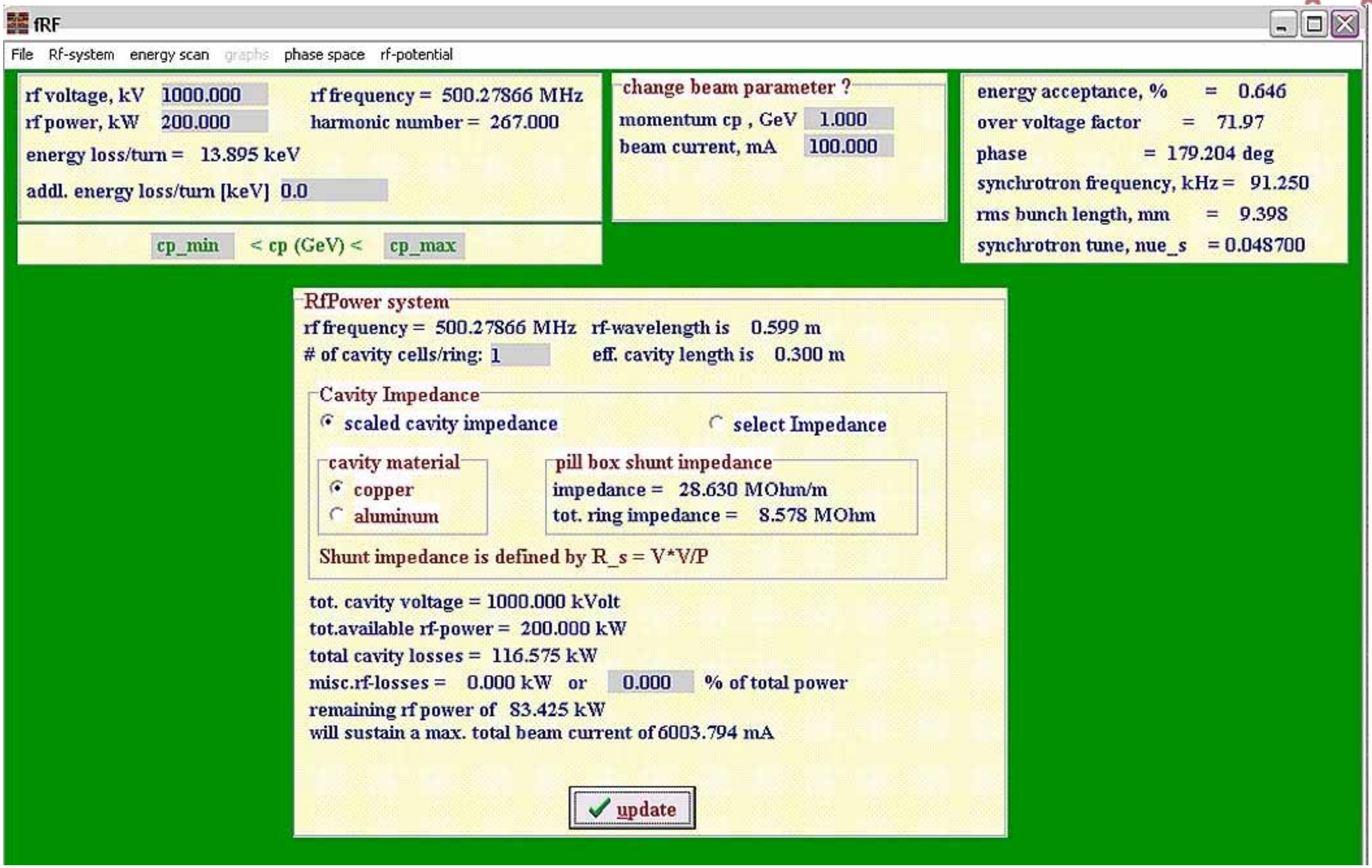
# Simple FODO cell



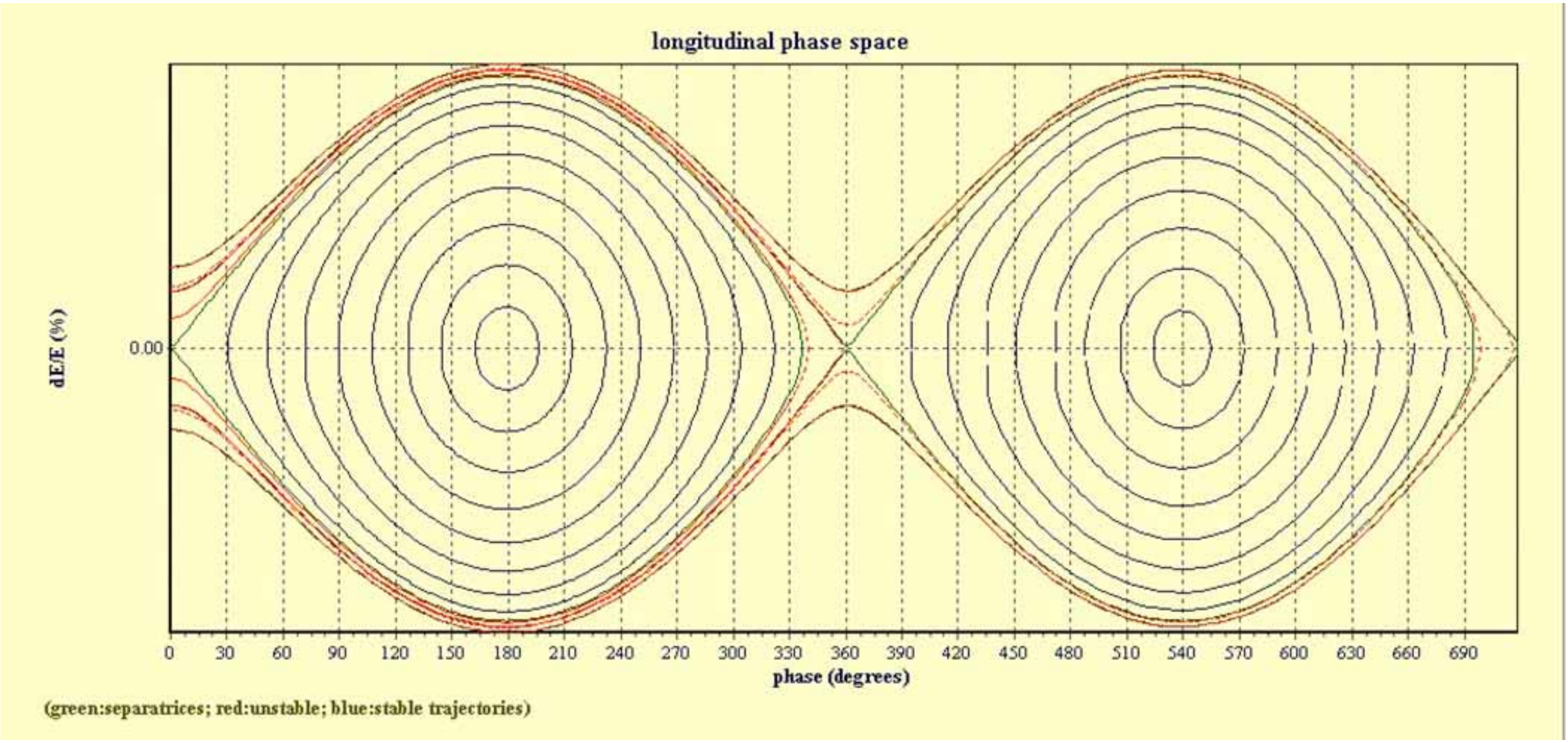
# 12-fold symmetric 1 GeV FODO ring



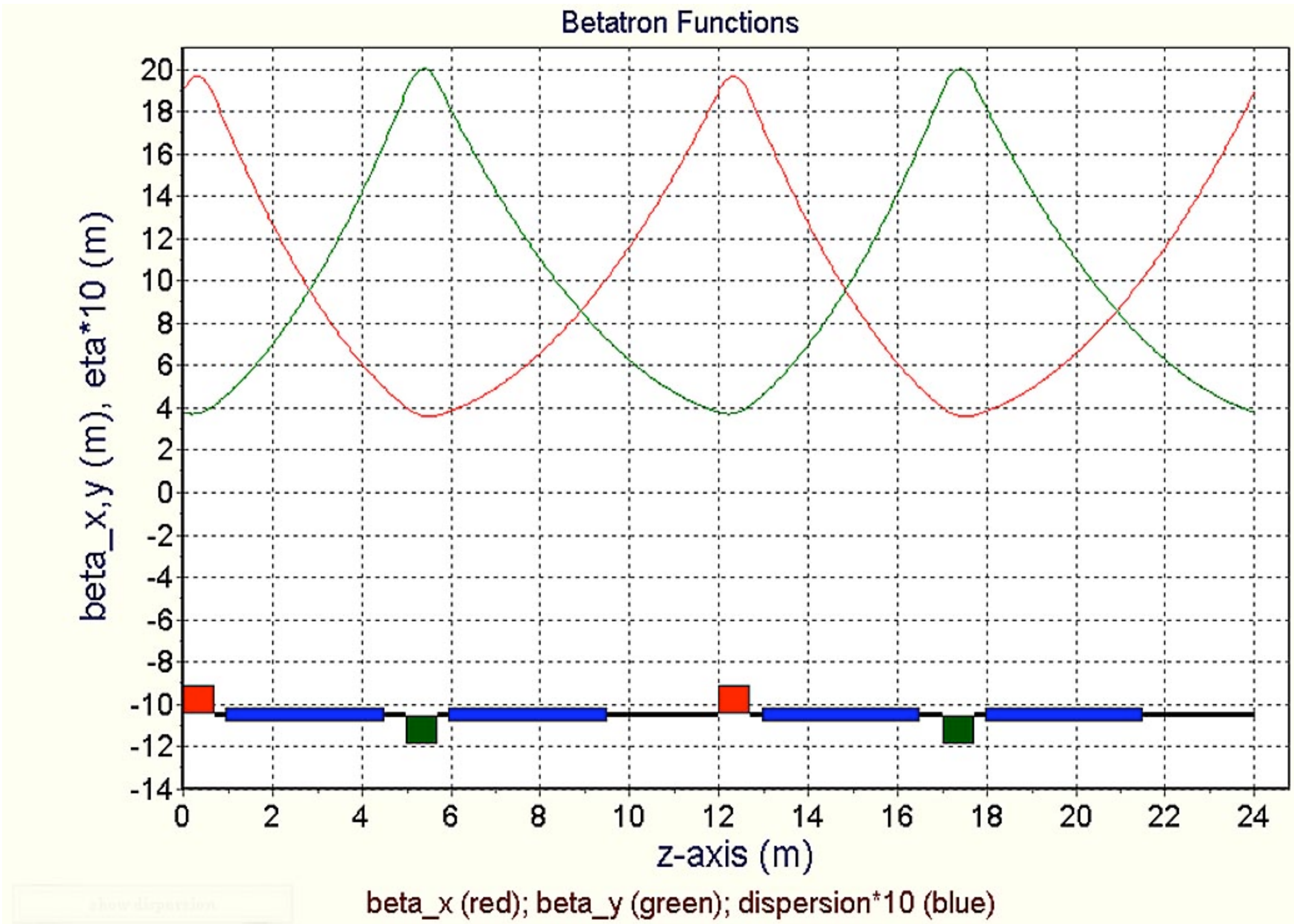
# RF for 1 GeV FODO ring



# Longitudinal phase space



# The bend magnet can be in the drift: $1/12^{th}$ of 10 GeV DESY ring



# DESY ring parameters

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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

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   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

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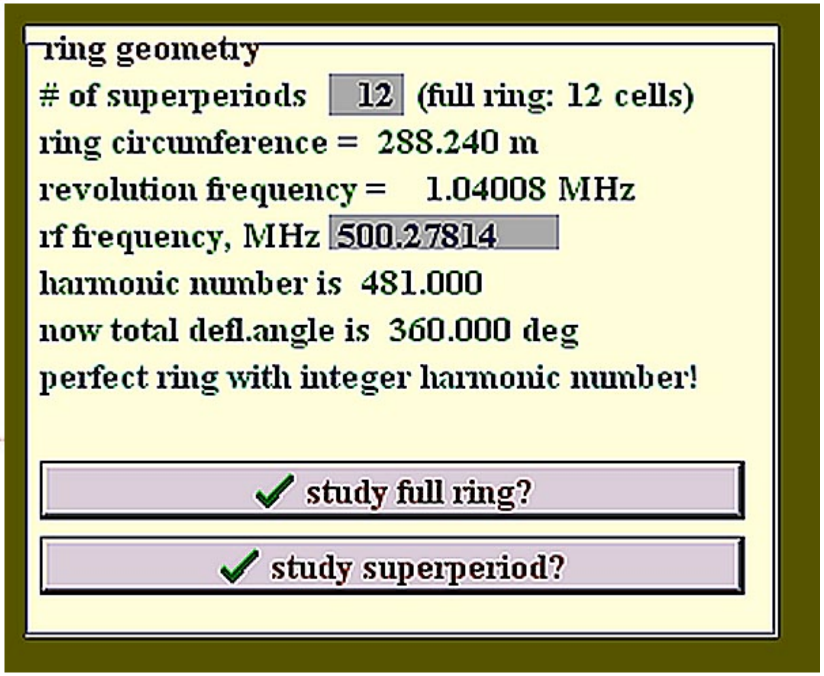
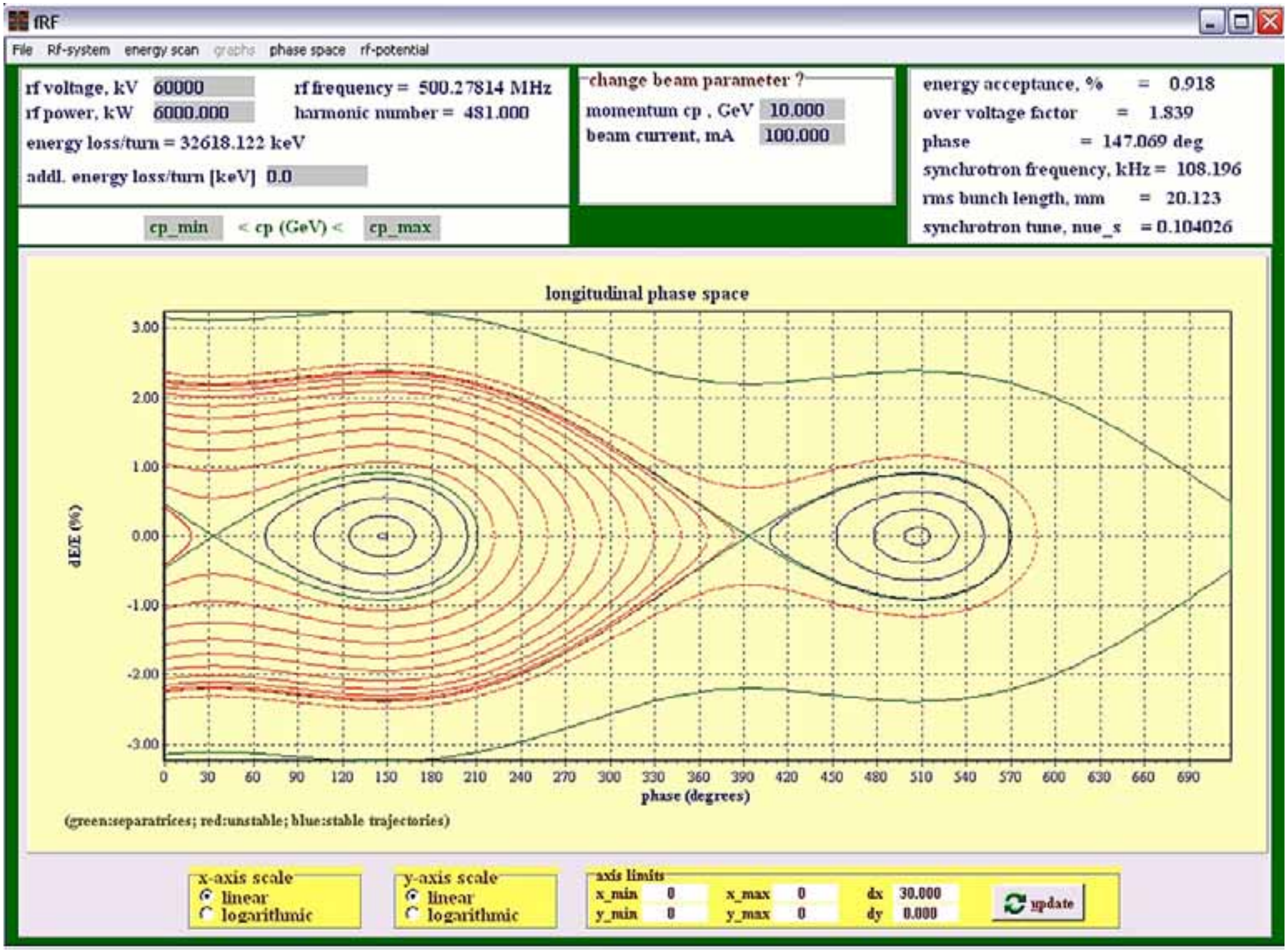
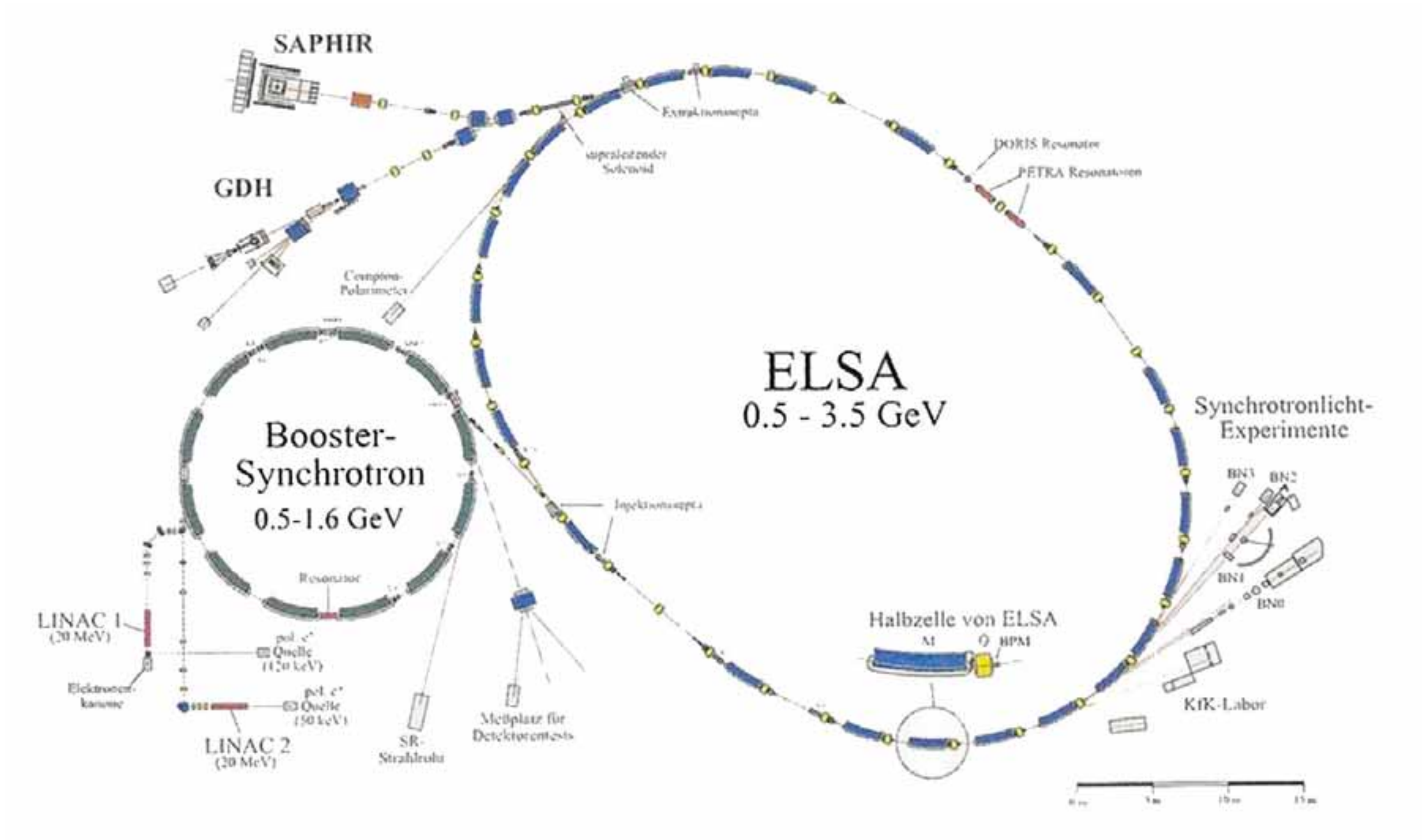


# DESY ring RF

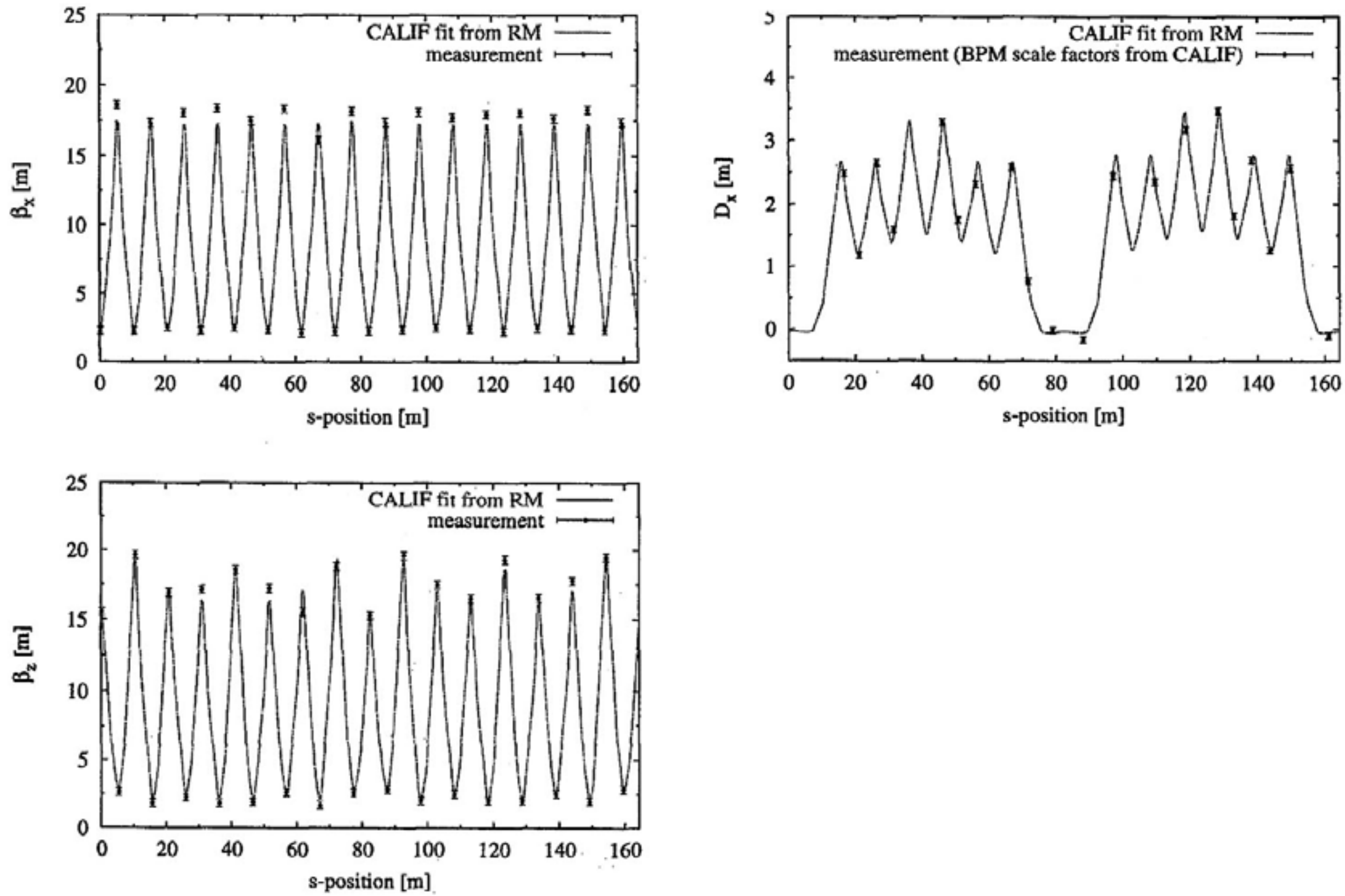


fRF
File Rf-system energy scan graphs phase space rf-potential
rf voltage, kV 60000
rf power, kW 6000.000
rf frequency = 500.27814 MHz
harmonic number = 481.000
energy loss/turn = 32618.122 keV
addl. energy loss/turn [keV] 0.0
change beam parameter ?
momentum cp , GeV 10.000
beam current, mA 100.000
energy acceptance, % = 0.918
over voltage factor = 1.839
phase = 147.069 deg
synchrotron frequency, kHz = 108.196
rms bunch length, mm = 20.123
synchrotron tune, nue_s = 0.104026
cp_min < cp (GeV) < cp_max
longitudinal phase space
dE/E (%)
phase (degrees)
(green:separatrices; red:unstable; blue:stable trajectories)
x-axis scale
linear
logarithmic
y-axis scale
linear
logarithmic
axis limits
x_min 0
x_max 0
y_min 0
y_max 0
dx 30.000
dy 0.000
update

# Example of synchrotron complex: ELSA



# ELSA optical functions



# Achromatic Transport Cells

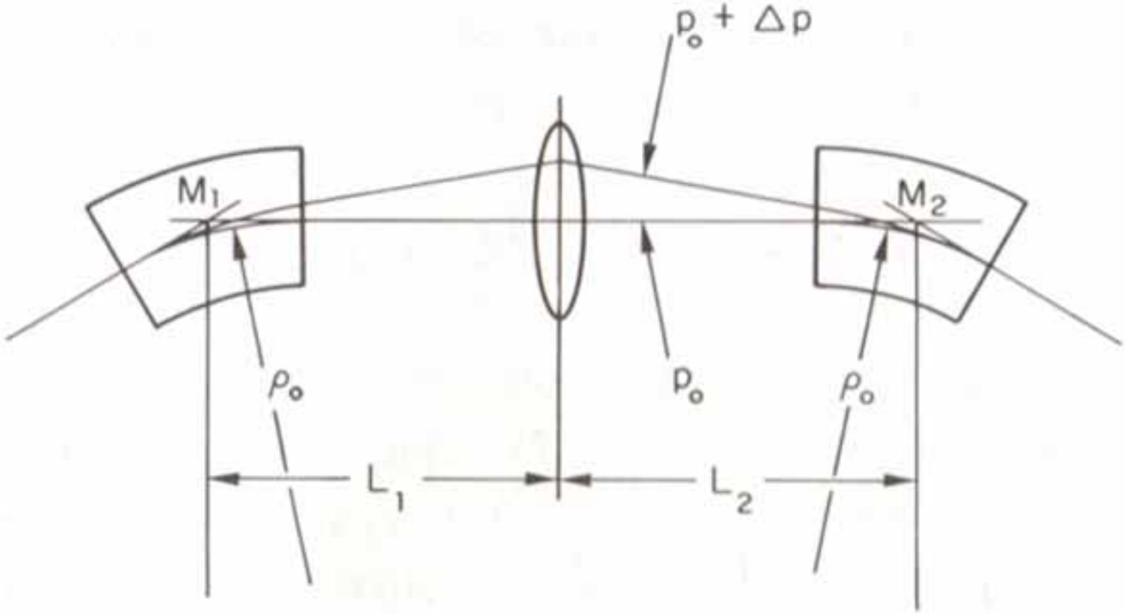



**Figure 5.5** A simple achromatic system consisting of two bending magnets separated by a horizontally focusing quadrupole.

# Why use achromats?

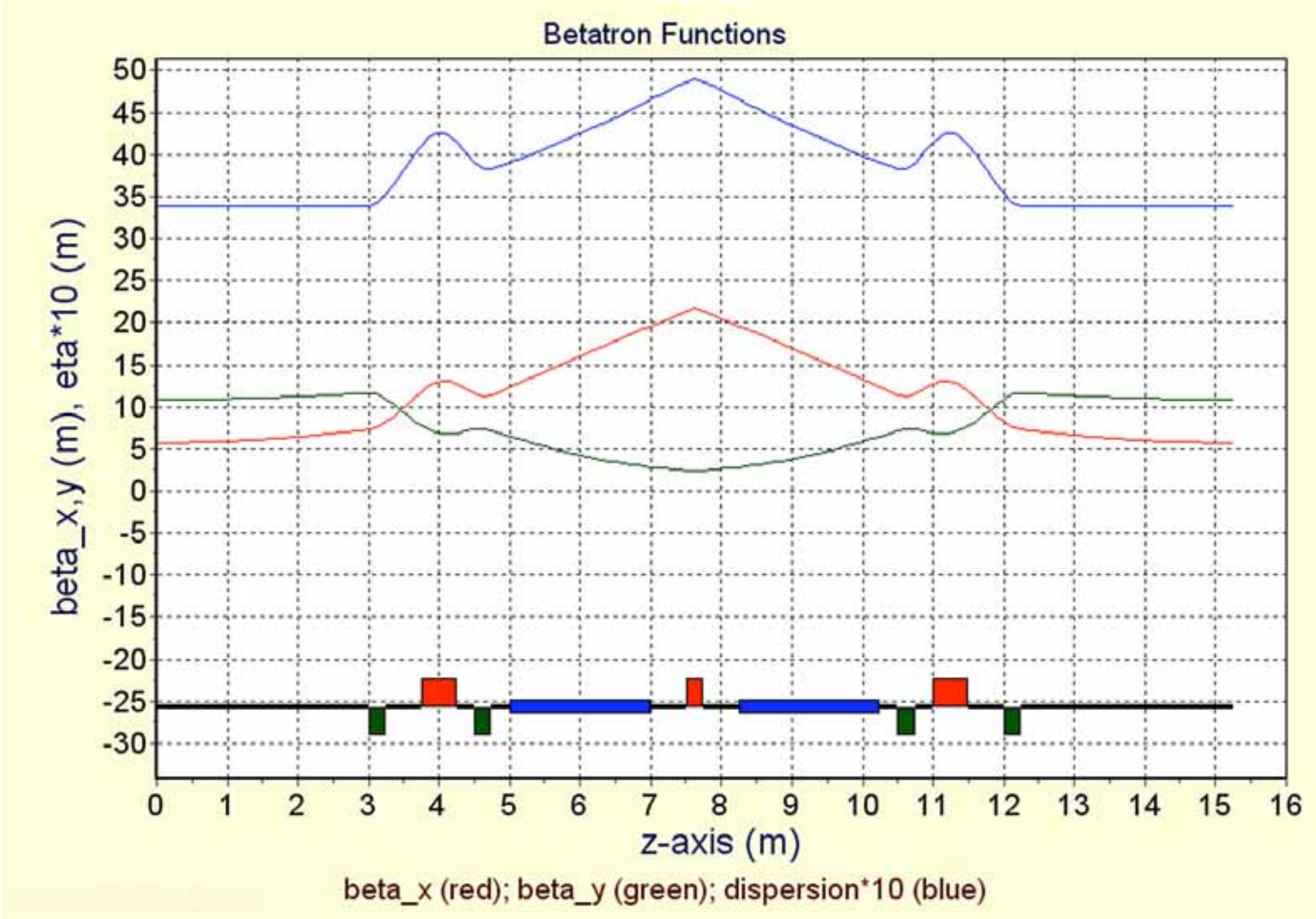
- We may want to deliver the beam to a region with no residual dispersion (energy dependent orbit displacement)
  - Interaction regions in colliders
  - Insertion devices in storage rings

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

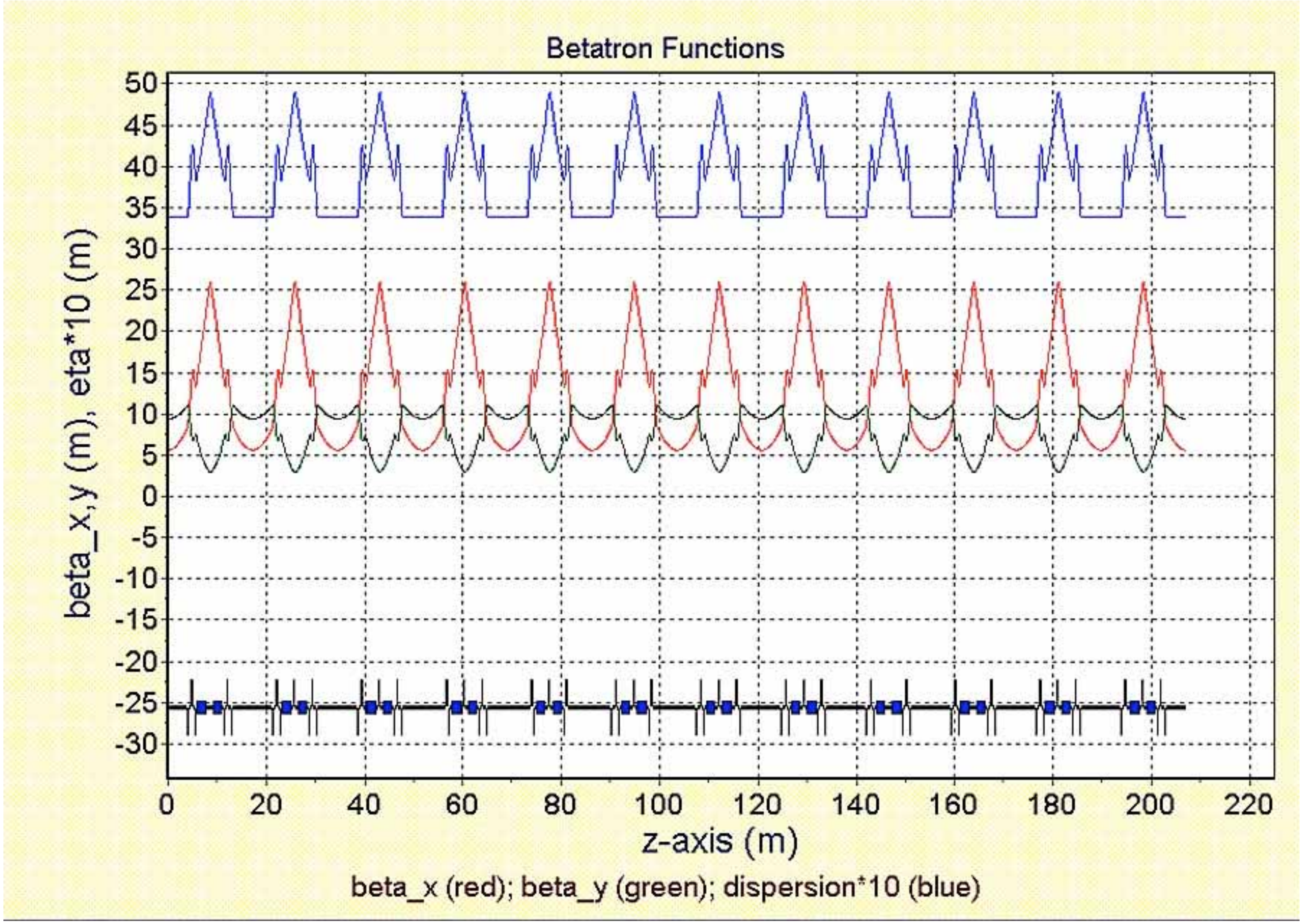
- We would like many long straight sections

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

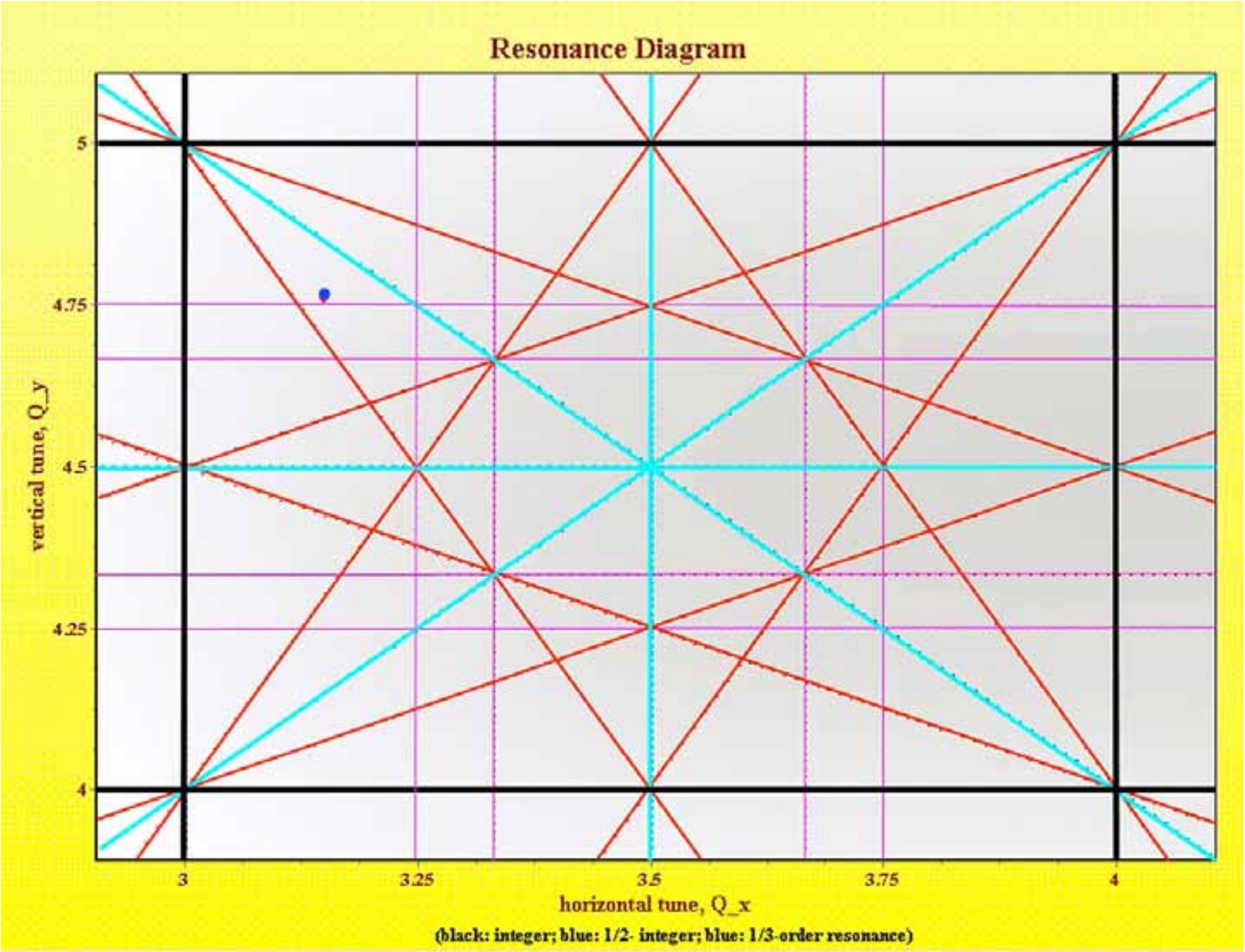
# Storage ring building blocks: Double Bend Achromat



# 12 of the cells make a 2 GeV electron ring



# With a tane in a dangerous position



# The longitudinal phase space is