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ICTP 40th Anniversary

SCHOOL ON SYNCHROTRON RADIATION AND APPLICATIONS
In memory of J.C. Fuggle & L. Fonda

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Beam optics

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Storage Ring Design with Beam Optics Program

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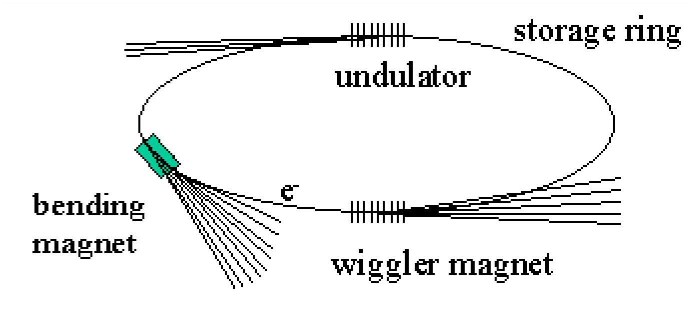
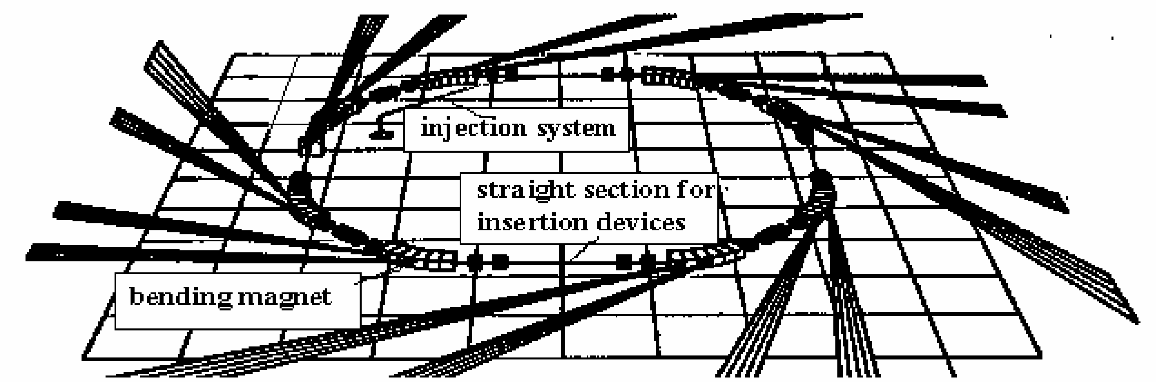
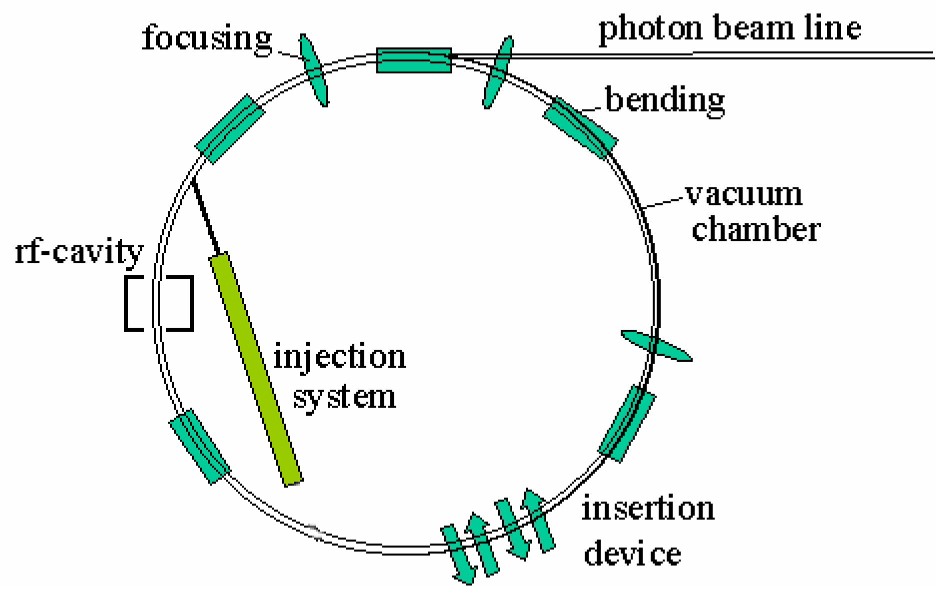
Storage Ring and Synchrotron Radiation

Highly relativistic electrons are stored in a circular path. To keep the electron circulate in the ring, dipole magnets are used to guide the electron to a circular trajectory. Transverse acceleration from the magnetic forces causes the electron to radiate. Insertion devices (undulators, wiggler magnets, and wavelength shifters) are often added to the straight section to generate radiation which specific characteristics.





Storage Ring components



Injection system: provides electrons to the storage source

Bending magnets: keep electron beams on a closed path and be synchrotron radiation source

Quadrupole magnets: focus electron beam

RF-cavity: compensate energy loss to synchrotron radiation

Vacuum chamber: eliminating scattering on gas atom, to be able to store electrons for long period of time.

Bending magnet

A bending magnet of B Tesla and length l (m) deflects a charged particle beam with a bending angle φ given by

$$\varphi = \frac{l}{\rho} = \frac{eB}{cp} \quad \text{or in practical unit} \quad \varphi = 0.3\frac{B(\mathrm{T})l(\mathrm{m})}{E(\mathrm{GeV})},$$

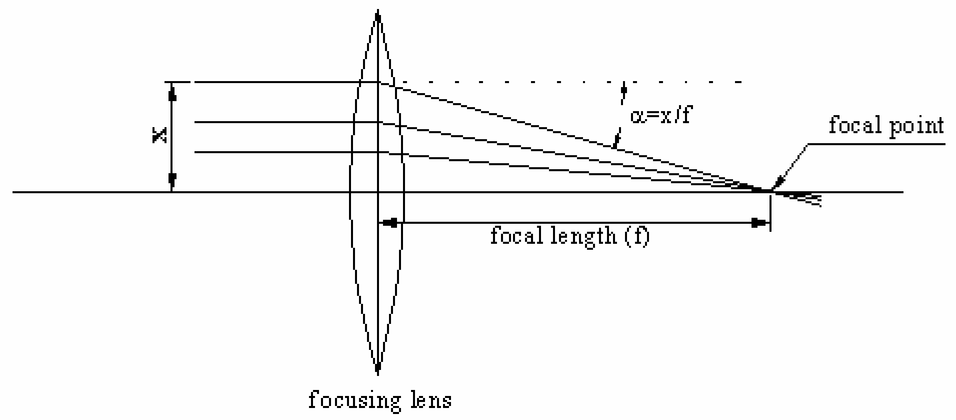
where E is the particle energy.

Example:

For a bending magnet of 1 Tesla, 1 m long and a particle energy of 3 GeV, the deflecting angle is 0.1 rad.

Bending magnets are distributed along the beam path. With appropriate deflection angles, the beam therefore travels in a close orbit(total deflection angle of 360 degree, 2π).

Beam focusing from quadrupole magnets



Quadrupole magnets act in particle beam optics like lenses in light optics.

Deflection angle to the focal point $\alpha = x/f = klx$, where k is the quadrupole strength given by

$$k(m^{-2}) = 0.3\frac{g(T/m)}{cp(GeV)}$$

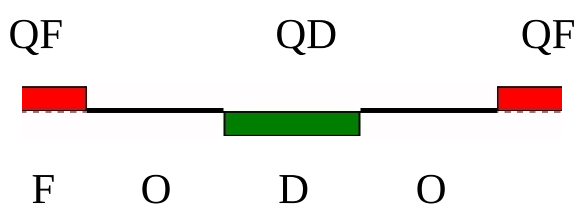
The focal length of the quadrupole is $1/f = kl$ where l is the length of the quadrupole

Magnet Lattice or Lattice

The arrangement of magnets (bending, quadrupole,sextrupole magnets) along the beam path is called magnet lattice or lattice. Most of storage ring consists of a repetitive sequence is called *periodic magnet lattice.*

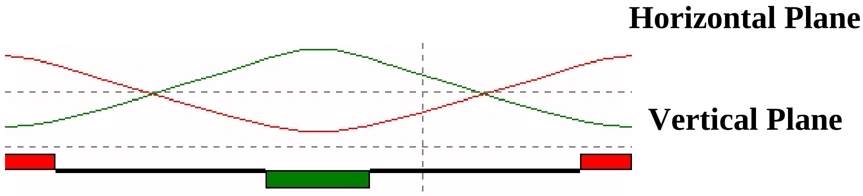
FODO lattice

Equidistant sequence of focusing and defocusing quadrupole

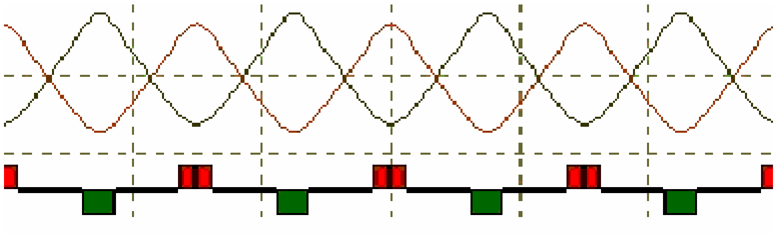


A quadrupole is called focusing if it focus the particle beam in the horizontal plane. The opposite is true for the vertical plane.

A focusing quadrupole in the horizontal plane is defocusing in the vertical plane and vice versa.

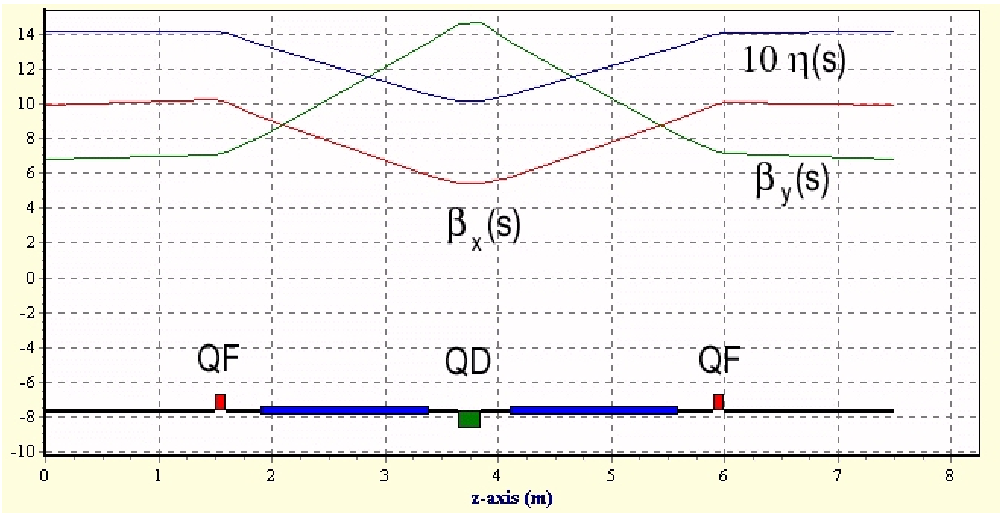


Sequence of FODO cells:



- Periodic cells can be used to construct arbitrary long transport lines.
- To make a ring, insert bending magnets between quadrupoles.

Example of FODO lattice modified to provide magnet free straight sections:



Beam Emittance:

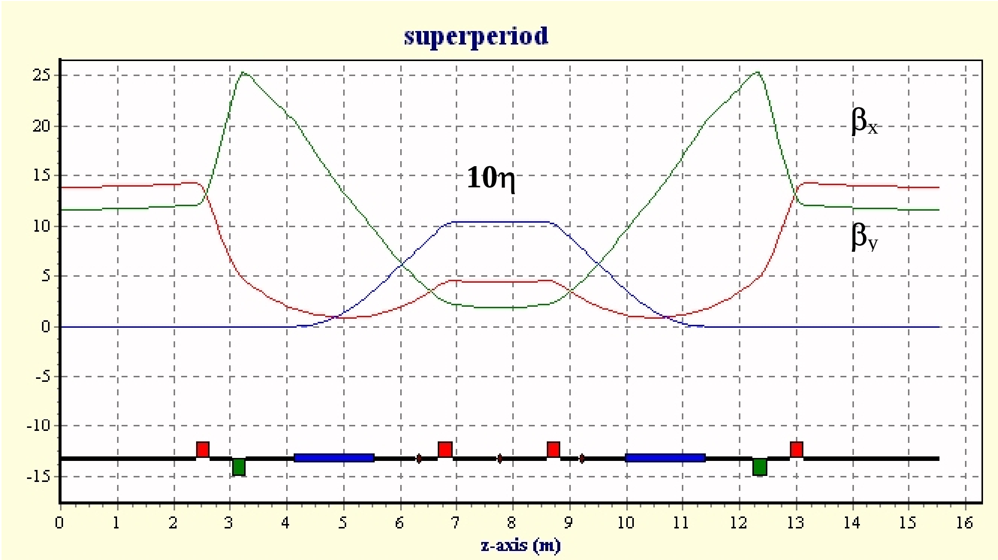
$$\varepsilon_{FODO} \approx 100x\ 10^{-13}\ E^{2}\ \varphi^{3}$$

E: beam energy(GEV)

φ: deflection angle per bending magnet(degree)

Double Bend Achromat (DBA) lattice

DBA lattice provides dispersion free straight section.



DBA lattice of LNLS, Campinas, Brazil

Beam Emittance :

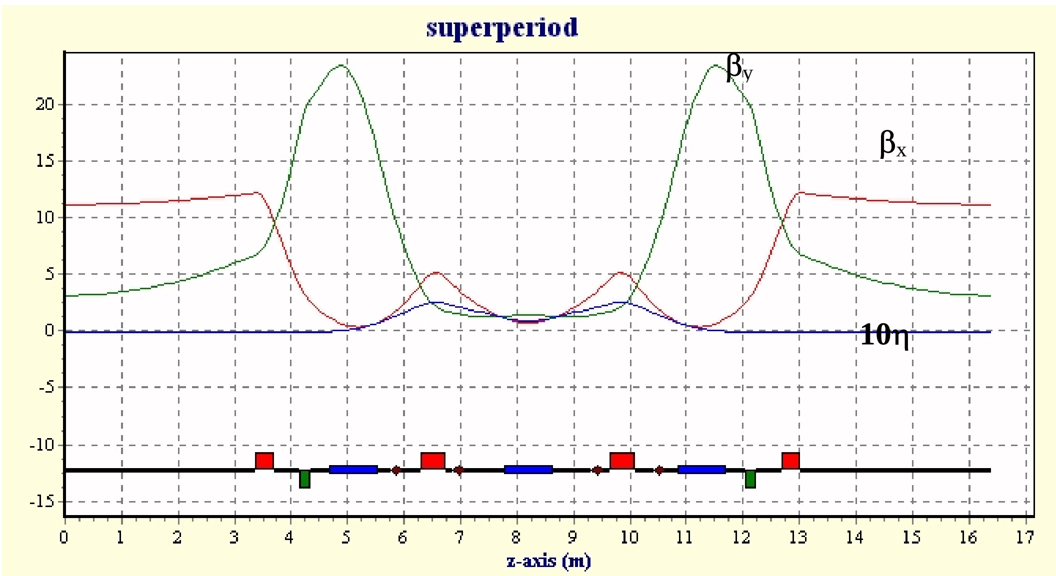
$$\varepsilon_{DBA} \approx 5x\ 10^{-13}\ E^{2}\ \varphi^{3}$$

E: beam energy(GEV)

φ: deflection angle per bending magnet(degree)

Triple Bend Achromat (TBA) lattice

TBA lattice can be used to reduce the ring circumference. Used usually for smaller, low energy rings.



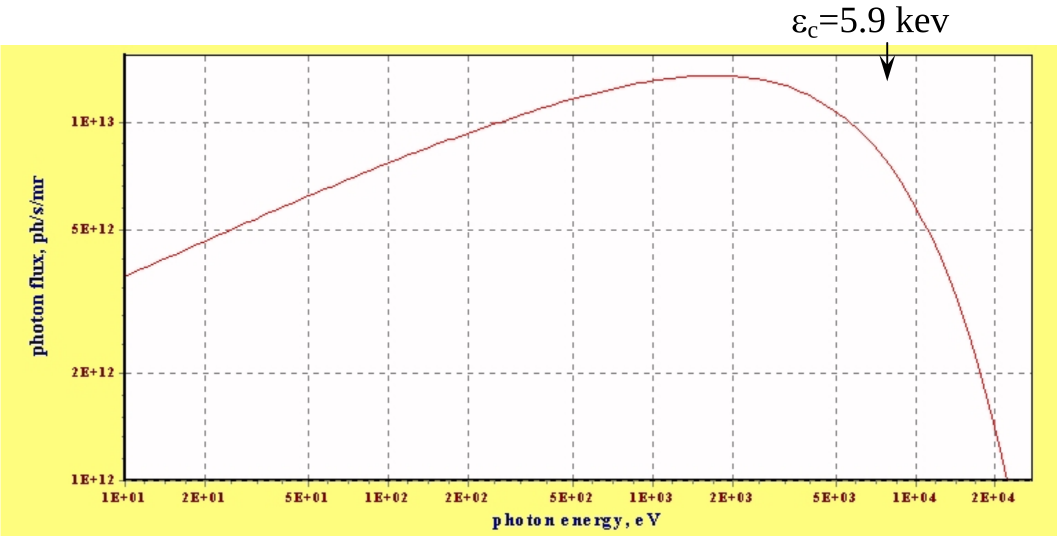
TBA lattice of ALS, California, USA

Beam Energy and Critical Photon energy

The synchrotron radiation spectrum from bending magnets is determined by the particle energy and the magnetic field strength. The useful spectrum extends from low photon energy up to a few times of the critical energy.

Critical photon energy of synchrotron radiation from bending magnet,

$$\varepsilon_c\,(\text{keV}) = 0.665E^2(\text{GeV}^2)B(\text{T}).$$

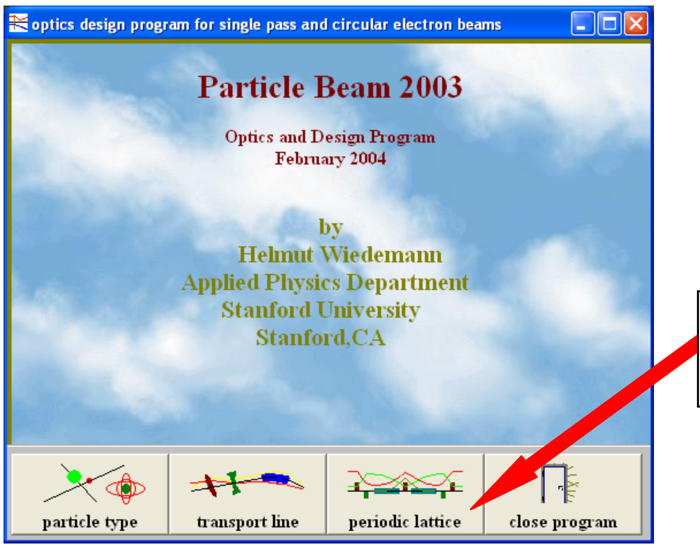


Synchrotron radiation from a 1 Tesla bending magnet and a 3 GeV beam.

The desired maximum photon energy and the bending field strength determine the required particle energy.

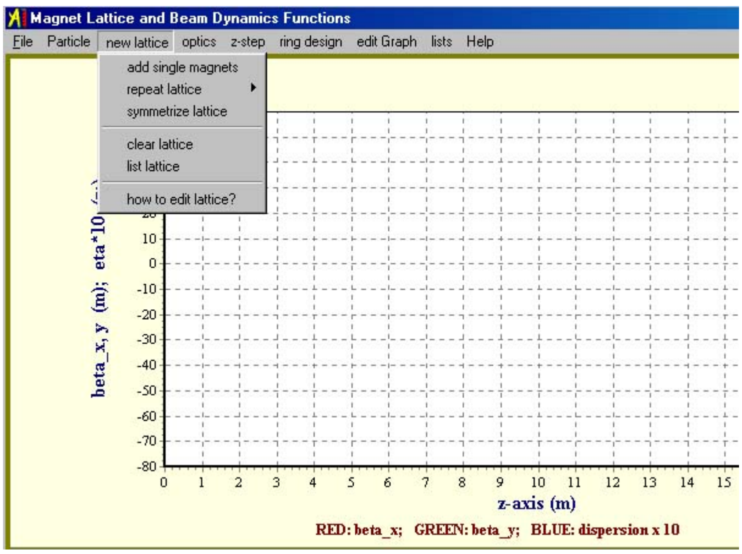
Storage Ring Design using Particle Beam

Optics and Design Program

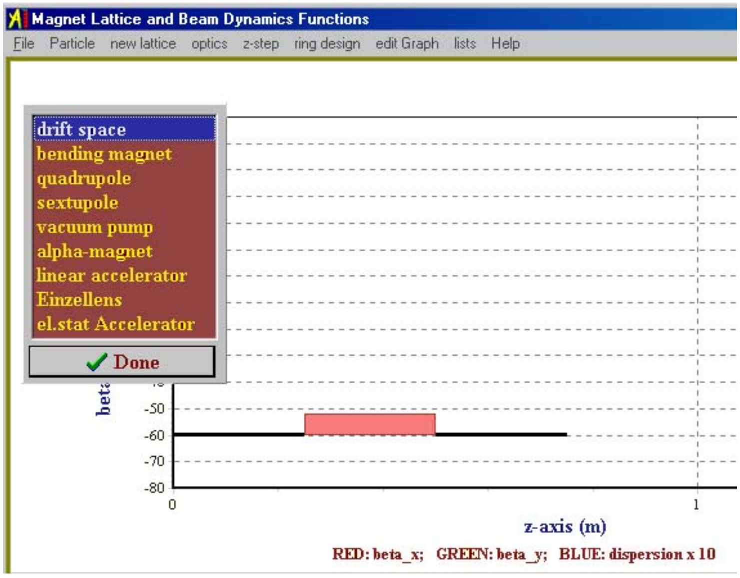


for periodic lattice design

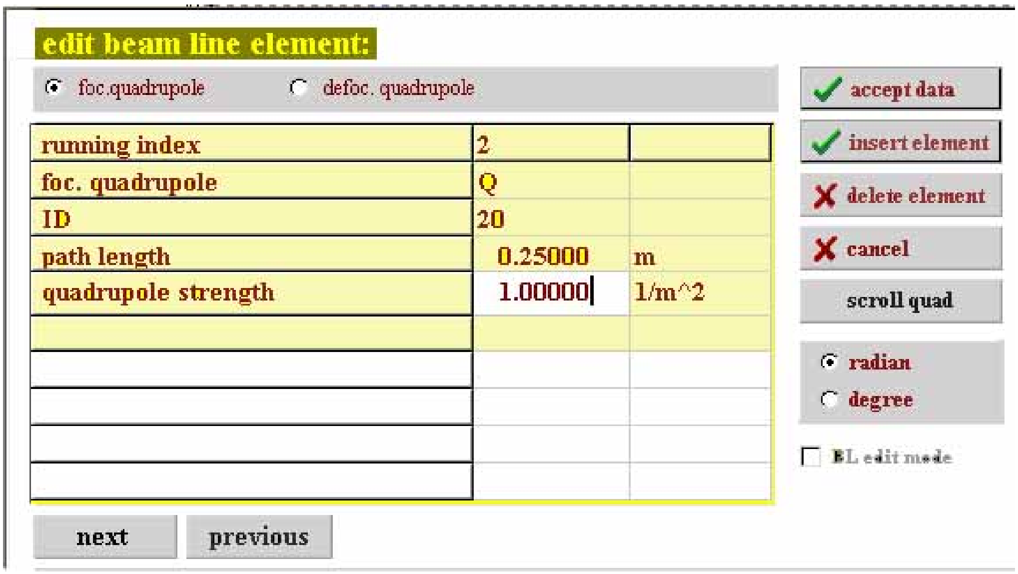
- Start by creating a new lattice.



- Add elements to compose a lattice. Once completed, click done.



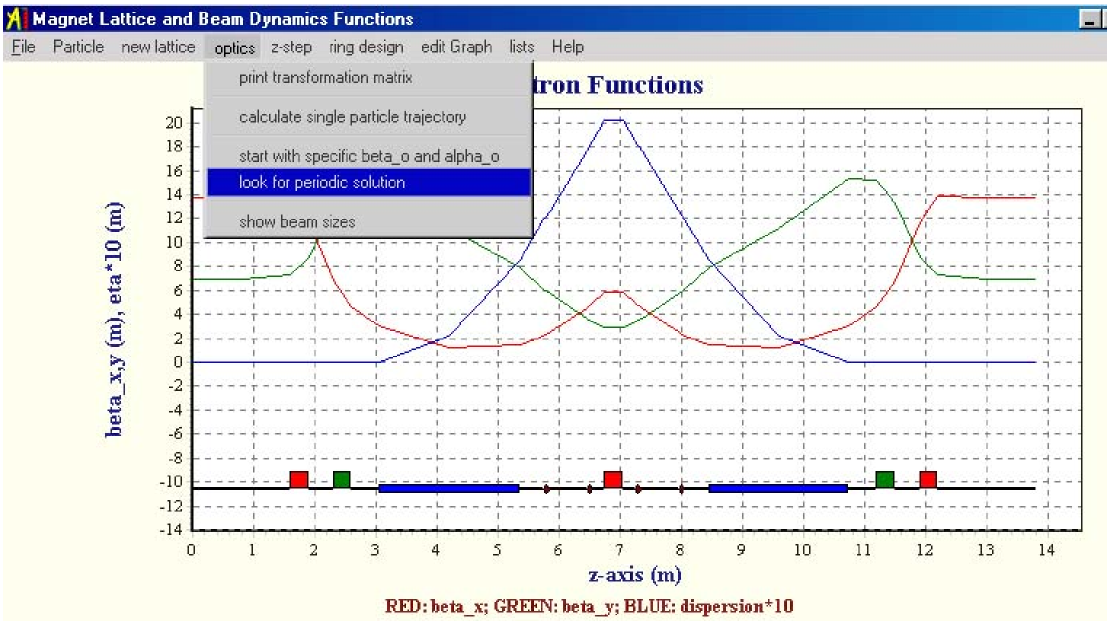
- Edit properties of each element e.g. length, quadrupole strength, curvature of dipole magnets, etc.



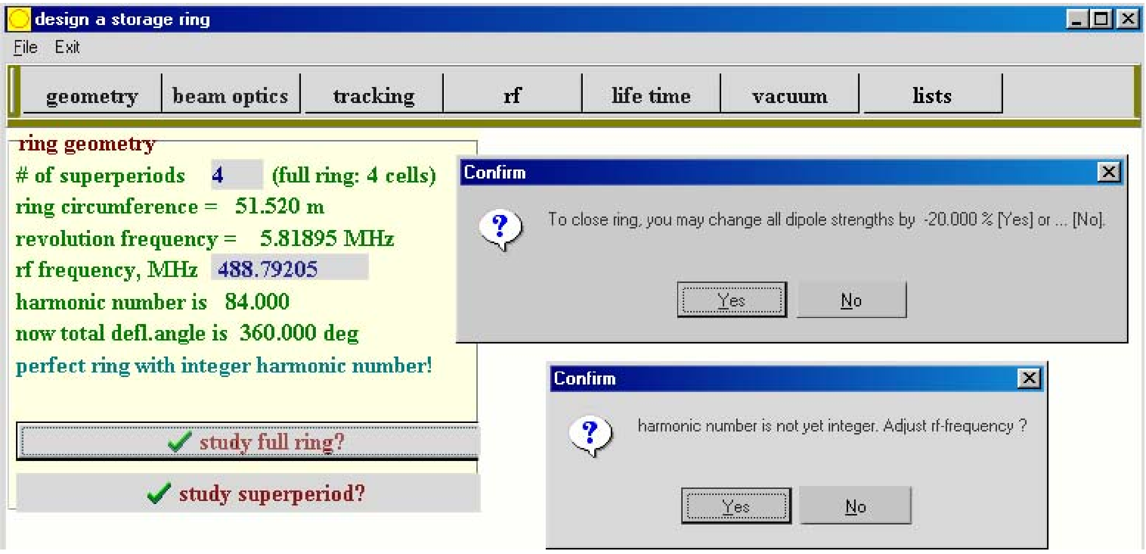
- Select the <u>Beam Line Edit Mode (BL edit mode),</u> for editing several elements at once.

- A special feature for the quadrupole magnet editing is **<u>scroll quad</u>**, in which the quadrupole strength can be adjusted using a scroll bar. This scroll quad will become handy for optimizing the lattice and the quadrupole doublet design exercise.

- To obtain a periodic solution for the lattice, select **look for periodic solution** under the **optics** menu.
- If exist, the periodic solution of β_x (red), β_y (green) and dispersion(η) function (blue) will be displayed.



- Select **ring design** to compose a ring from the periodic lattice.



- To get a completed circular path, it is required a total bending angle of 360 degree. The RF frequency should be an integer multiple of the revolution frequency for the beam to gain energy from the RF-cavity. (this integer multiple is called harmonic number)

- Selecting **beam parameters** under the **beam optics** menu will show the ring parameters. **Resonance diagram** can also be viewed under this menu.
- Parameter lists can be chosen under the **lists** menu.
- More features in the ring design are tracking, rf-cavity, vacuum system and beam lifetime.