Prospects of Strong Horizontal Focusing Electric Ring: advantages, disadvantages

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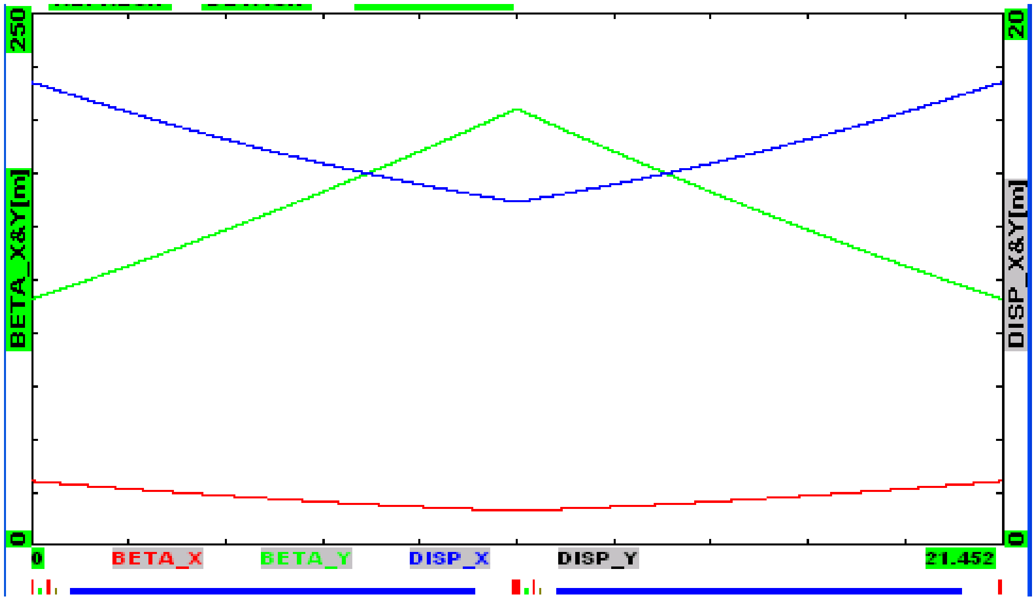
December 9-10, 2013
Storage ring EDM
collaboration meeting

All electric storage ring

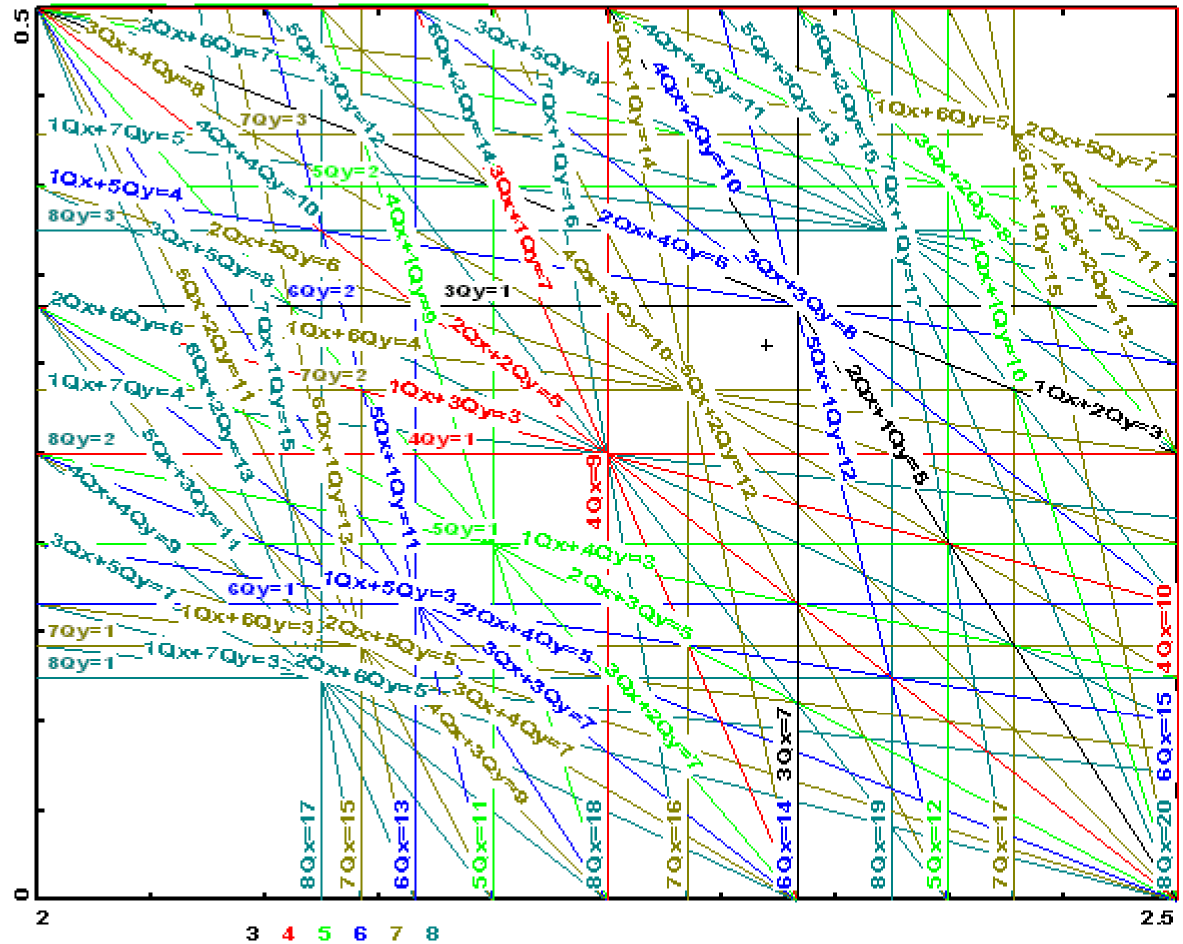
- Ring structure
  - 14 periods. Each includes:
    - 2 electric bends with R_0=40 m and L=8.97 m
      - Gap between plates 3 cm, V= ±157 kV,
      - m = 0 (no vert. focusing)
    - 2 electric quads, one F and one D
      - L=15 cm, G_F = 17.2 kV/cm, G_D = -13.8 kV/cm
      - Each quad can be independently adjusted
  - One of two 80 cm gaps between quads and bends are filled with
    - H or V corrector, skew-quad corrector, F or D sextupole, and BPM
    - Other can be used by experiment, + RF cavity



- Circumference – 300 m
- Kinetic energy - 232.79 MeV

Transverse Focusing

- Large flexibility in choice of beam optics
- For chosen optics its parameters are:
  - β_{xmax}=29.1 m, β_{ymax}=204 m, D_{xmax}=17.35 m, Q_x=2.32, Q_y=0.31
  - Considerable space in the tune diagram
    - Distance to 4-th order resonances is ~0.06. It is sufficient to accommodate the space charge tune shifts



- Weak vertical focusing was chosen for control of radial magnetic field
  - It results in high sensitivity to focusing errors

Longitudinal Motion Parameters and Ring Acceptances

- Longitudinal motion parameters
  - Revolution frequency: 597.3 kHz
  - Momentum compaction: $\alpha = 0.51$
  - Slip-factor: $\eta = \alpha - 1/\gamma^2 = -0.132$
  - Transition energy – 376 MeV
- Acceptances and rms emittances
  - The gap between plates, $2a=3$ cm, determines
    - Maximum momentum deviation:
      $\Delta p/p|_{\max} = \pm 8.6\cdot 10^{-4}$ (versus $3.3\cdot 10^{-4}$)
    - Horizontal acceptance (normalized):
      5.8 mm mrad (versus 5 mm mrad)
  - IBS determines (see below)
    - equilibrium rms momentum spread: $\sigma_p = 2.9\cdot 10^{-4}$
    - equilibrium rms norm. horizontal emittance: 0.31 mm mrad
    - equilibrium rms norm. vertical emittance: 2.16 mm mrad

RF and Related Parameters

- Synchrotron frequency has to be large enough to minimize spin decoherence within one synchrotron period but small relative to the distance to strong resonances, Q_s=0.006 was chosen (ΔQ_{SC}~0.02)
- Sum of bunch lengths, $n_b \sigma_s$, has to be as large as possible to reduce space charge tune shifts and IBS
  - Bucket height, $\Delta p/p|_{\mathrm{bucket}}$, has to be only slightly larger than the longitudinal acceptance, $\Delta p/p|_{\max}$, but linearity is still desirable => $\Delta p/p|_{\mathrm{bucket}}$ / $\Delta p/p|_{\max}$=1.5
- Main parameters
  - RF voltage: V_0=10 kV
  - Harmonic number: h=70
  - RF frequency: f_{RF}=41.81 MHz
  - Synchrotron tune: Q_s=0.006
  - Bucket height: $\Delta p/p|_{\mathrm{bucket}}=1.3\cdot 10^{-3}$
  - Bucket length: 430 cm
  - Bunch length: σ_s = 31 cm

$$Q_s = \sqrt{\frac{heV_0\eta}{2\pi mc^2\gamma\beta^2}}$$

$$\left.\frac{\Delta p}{p}\right|_{\mathrm{bucket}} = \frac{2Q_s}{h\eta}$$

$$\sigma_s = \frac{C\eta\sigma_p}{2\pi Q_s}$$

Coupling between Transverse and Longitudinal Motions

- Large dispersion in RF cavity results in coupling between x and s motions
- However for chosen RF voltage this coupling is sufficiently small
  - It has weak dependence on number of cavities => 1 cavity looks OK
  - It results in minor changes in tunes

$N_{cav} = 1$

$Q_1 = 0.32374$ $\quad Q_x = 2.32371$

$Q_2 = 0.31196$ $\quad Q_y = 0.31196$

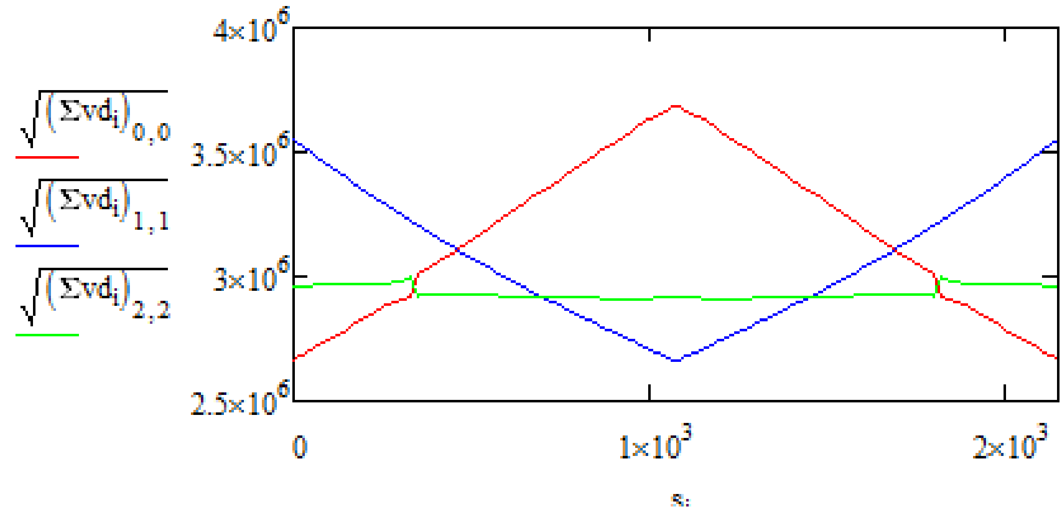
$Q_3 = 0.00601538$ $\quad Q_s = 0.00601537$

$$\frac{v_1}{v_{1_0}} = \begin{pmatrix} 1 \\ 3.431i \times 10^{-4} \\ 0 \\ 0 \\ 0.596i \\ -6.624 \times 10^{-8} \end{pmatrix} \qquad \frac{v_3}{v_{3_4}} = \begin{pmatrix} -0.017i \\ -6.624 \times 10^{-8} \\ 0 \\ 0 \\ 1 \\ -9.517i \times 10^{-6} \end{pmatrix} \qquad \frac{v_2}{v_{2_2}} = \begin{pmatrix} 0 \\ 0 \\ 1 \\ 8.683i \times 10^{-5} \\ 0 \\ 0 \end{pmatrix}$$

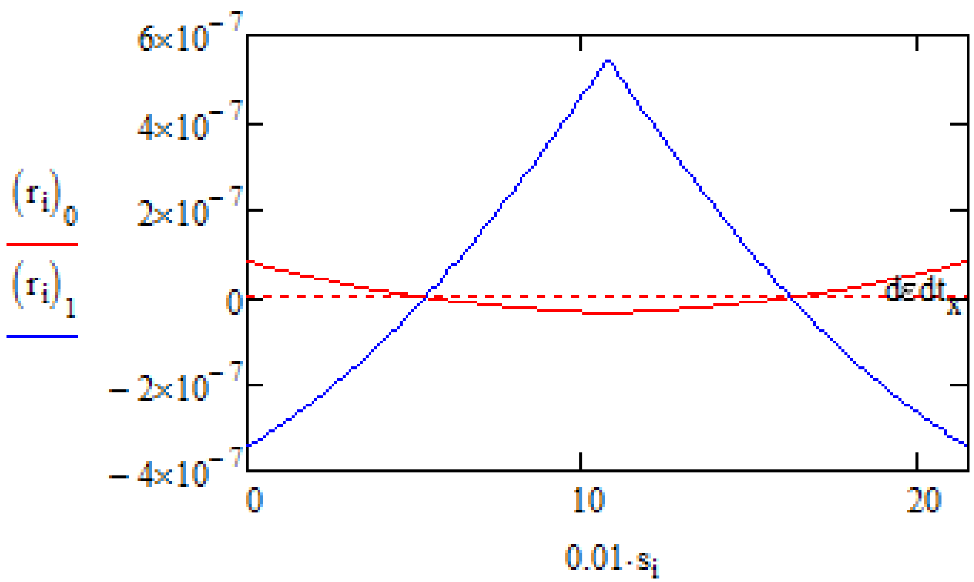
  - and a change in the horizontal beta-function from β_x= 29.16 m to β_{x1}=29.14 m (in Mais-Ripken representation)
- As one can see from the above eigen-vector corresponding to horizontal betatron oscillations, v_1, the betatron motion is accompanied by the longitudinal motion
  - at the cavity location the motions are shifted in phase by 90 deg.

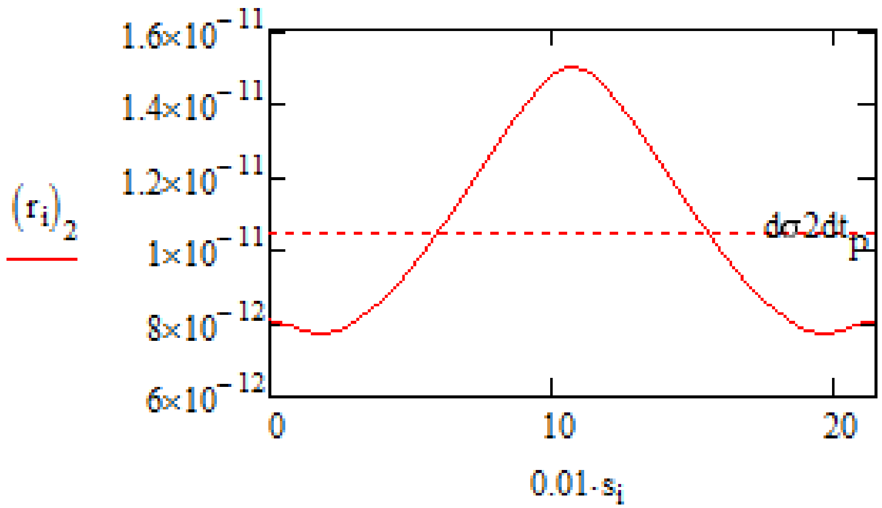
Space Charge Tune Shifts and IBS Growth Rates

- Operation below transition greatly reduces IBS growth rates for operation in vicinity of thermal equilibrium: $\tau_{x,y,s} \approx 7500$ s



- In this case the initial particle number of $7 \cdot 10^8$ per bunch is set by Coulomb tune shifts of ΔQ_x=0.015 and ΔQ_y=0.027





- Controlled vertical emittance blowup can lead to a controlled beam loss

Conclusion

- Judged on pure acceleration physics grounds the strong focusing ring looks better than the soft focusing ring
  - Larger momentum acceptance and particle number
  - Suppressed IBS rates
- Analysis of spin decoherence is required to see its potential for EDM
  - In particular, the sensitivity of spin decoherence to sextupoles

	Soft focusing	Strong focusing
Circumference, m	263	300
Qx/Qy	1.229/0.456	2.32/0.31
Particle per bunch	$1.5\cdot10^{8}$	$7\cdot10^{8}$
Coulomb tune shifts, $\Delta Q_x/\Delta Q_y$	0.0046/0.0066	0.0146/0.0265
Rms emittances, x/y, norm, μm	0.56/1.52	0.31/2.16
Rms momentum spread	$1.1\cdot10^{-4}$	$2.9\cdot10^{-4}$
IBS growth times, x/y/s, s	300/(-1400)/250	7500
RF voltage	13	10.3
Synchrotron tune	0.02	0.006