Design Study for Sub-picosecond Pulse at 2.5 GeV PLS

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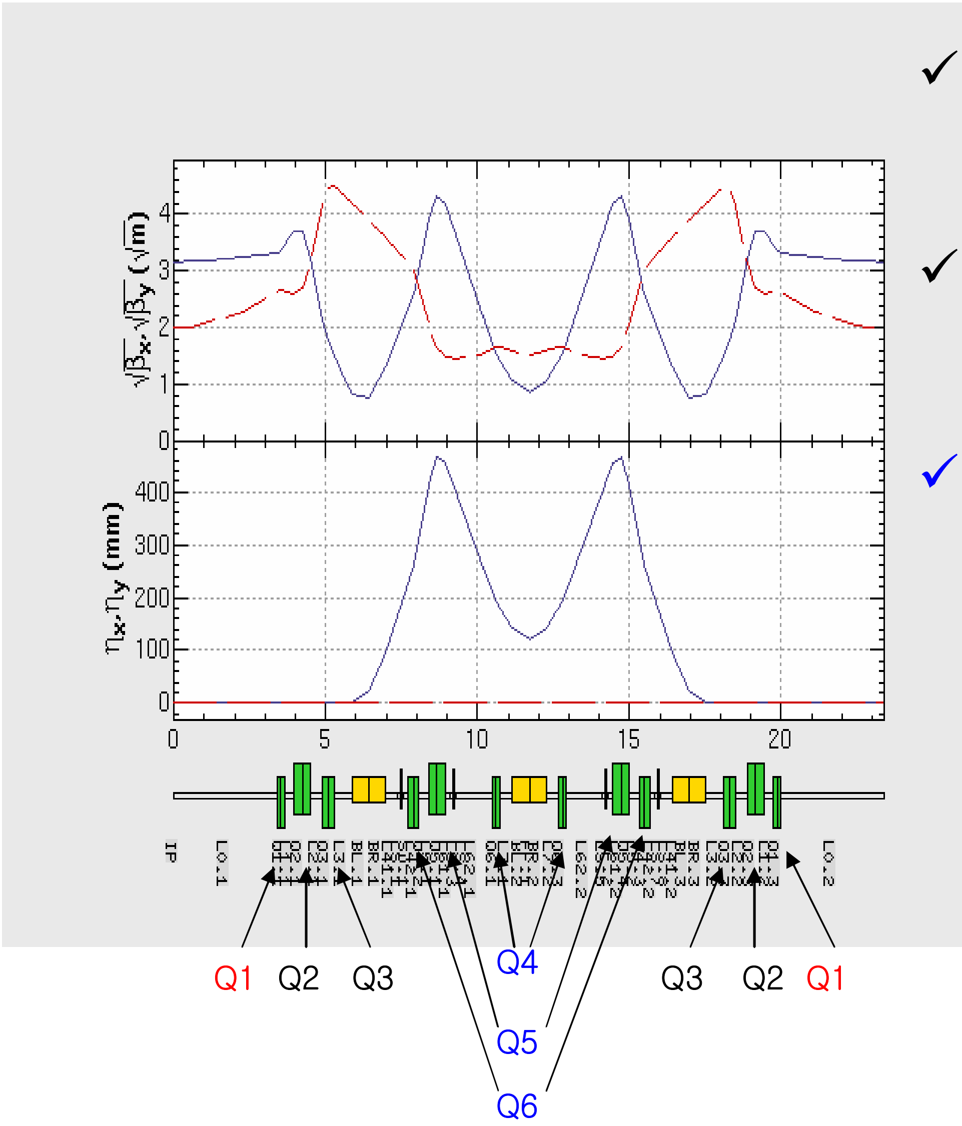
Introduction

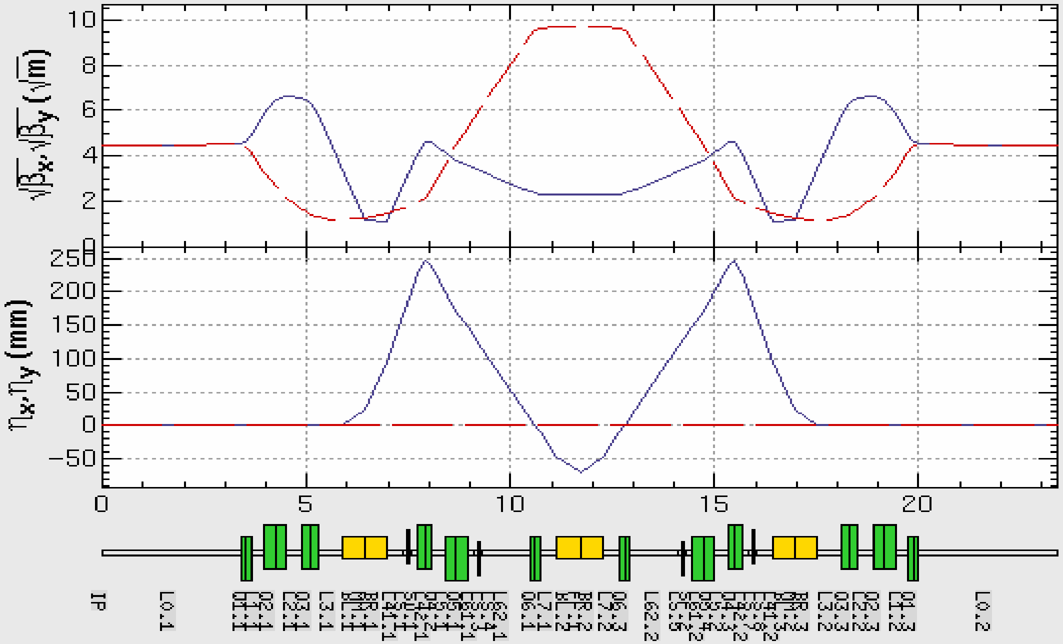
- The recent interest on sub-picosecond beam in quasi-isochronous rings makes the proposal of rings for experimental of terahertz.
- Since these rings have a small α, higher order terms of α may be important and they require careful analysis in particle dynamics.
- We show results of design study to produce sub-picosecond beam at PLS.
- We also present effects of second-order momentum compaction factor on particle motion and beam instability.

Lattice of PLS ring



- ✓ **PLS ring has 12 symmetry cells with TBA structure.**
- ✓ **Each arc is made as achromatic and each cell has 12 quadrupoles.**
- ✓ **<u>One method to obtain small α is to make η to be negative value in bending magnets</u> so that negative η part cancels or exceeds positive η part and so α can be reduced.**

Designed lattice for a quasi-isochronous mode



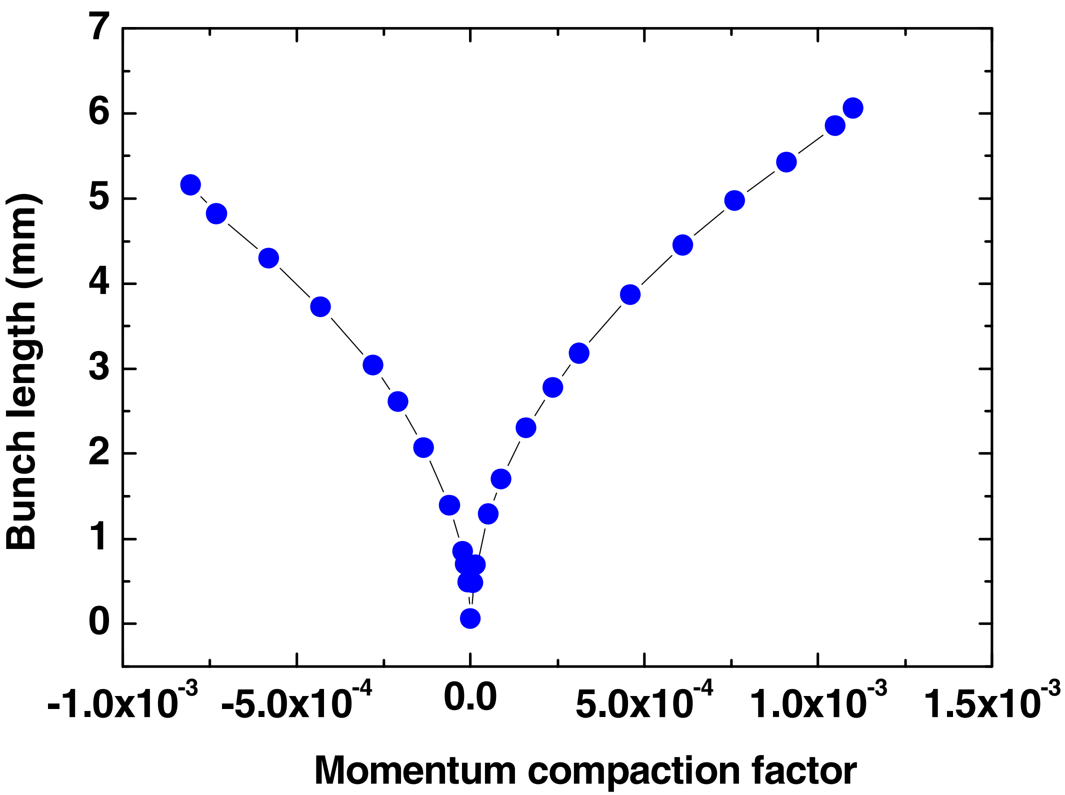
α_1 =6.8x10^{-6}

- We keep the betatron tune at constant value and remain a value of the dispersion function in the straight section as zero.
- It makes continuous transfer possible from the normal mode to the quasi-isochronous mode without crossing resonance lines in tune space.

Main parameters in PLS ring

Normal mode		Quasi-isochronous mode
2.5 GeV	Beam energy	2.5 GeV
18.9 nm	Emittance	37.7 nm
8.5E-4	Energy spread	8.5E-4
1.8E-3	Mom. compaction factor	6.8E-6
468	Harmonic number	468
14.28/8.18	Betatron tune	14.28/8.18
1.6 MV	RF voltage	1.6 MV

Bunch length vs. α_1 in quasi-isochronous mode



We can reduce α by a factor of 1000 as compared to the normal mode($1.8x10^{-3}$).

This make reduce the bunch length by a factor of about 30.

Analysis of transverse motion in the quasi-Isochronous mode

- In a quasi-isochronous mode with $\alpha_1 \sim 0$,
  higher-order terms of α have to be considered.

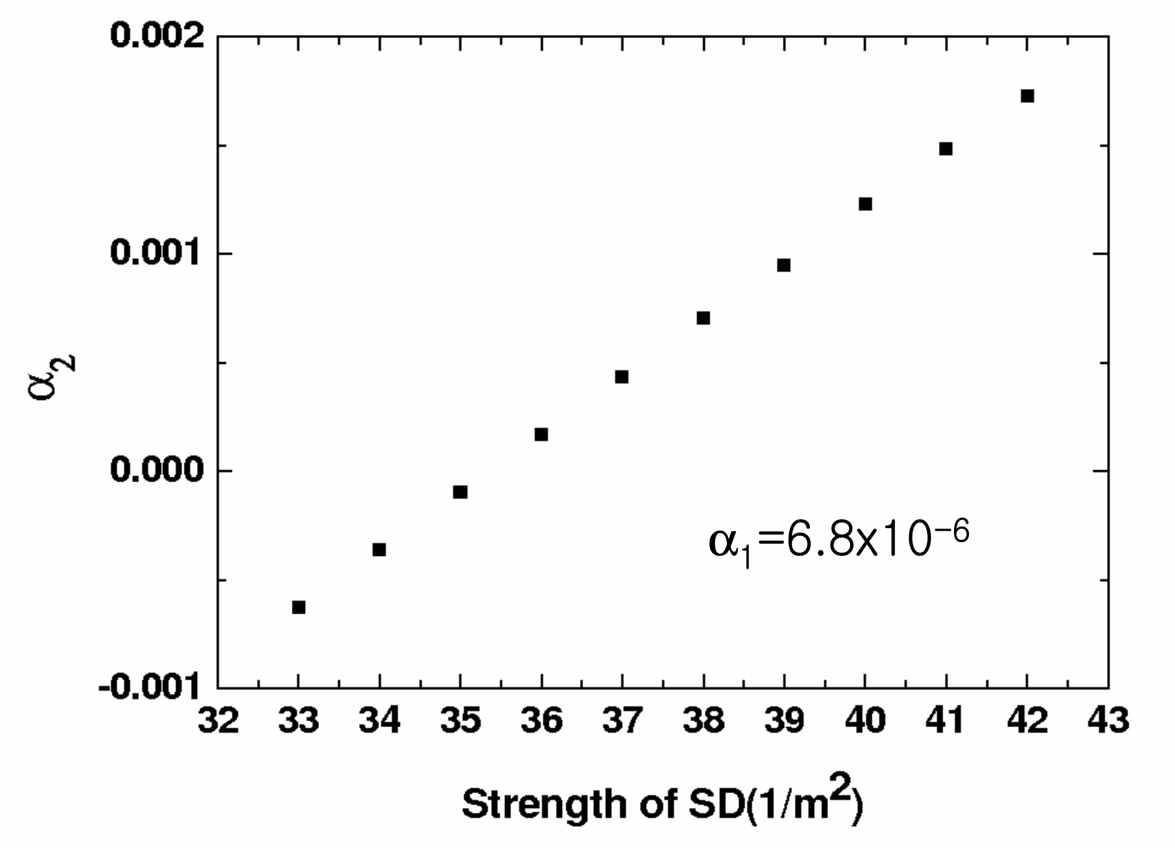
$$\alpha = \alpha_1 + \alpha_2 \delta + \ldots\ldots.$$

= $1/L$ ✐ $\eta ds/\rho + 1/L\ \delta$ ✐ $(\eta/\rho + \eta'^2/2)$
ds…….

So, we **can control** α_2 **by varying strengths of sextupoles, keeping** α_1 **to be constant value.**

: We investigate dependence of α_2 on strengths of sextupoles in quasi-isochronous mode.

α_2 vs. strength of SD in quasi-isochronous mode



Variation of 1/m^2 in SD makes a change of 2.32x10^{-4} in α_2

Analysis of longitudinal particle motion in the quasi-Isochronous mode

- **We investigate aspect of longitudinal phase space in small $\alpha_{1.}$**

  $H = 1/2h\alpha_1\delta^2 + 1/2h\alpha_2\delta^3 + eV_{rf}/2\pi E_o[\cos(\varphi+\varphi_o) + \varphi\cos(\varphi_o)]$

- **Fixed points $dH/d\varphi = 0$ and $dH/d\delta = 0$.**
- **For $\alpha_2 = 0$, stable fixed point $(\varphi, \delta) = (0,0)$**

  unstable fixed point $(\varphi, \delta) = (\pi - 2\varphi_o, 0)$

- **For $\alpha_2 \neq 0$, additional fixed points exist.**

  stable fixed point $(\varphi, \delta) = (\pi - 2\varphi_o, -\alpha_1/\alpha_2)$

  unstable fixed point $(\varphi, \delta) = (0, -\alpha_1/\alpha_2)$

α_{2o} that determines rf and alpha buckets

- $\alpha_{2o} = \sqrt{(E_o T_o \omega_{rf} |\alpha_1|^3 / 12 e V_{rf} \{-\cos\varphi_o + (\pi/2 - \varphi_s) \sin\varphi_o\}}$

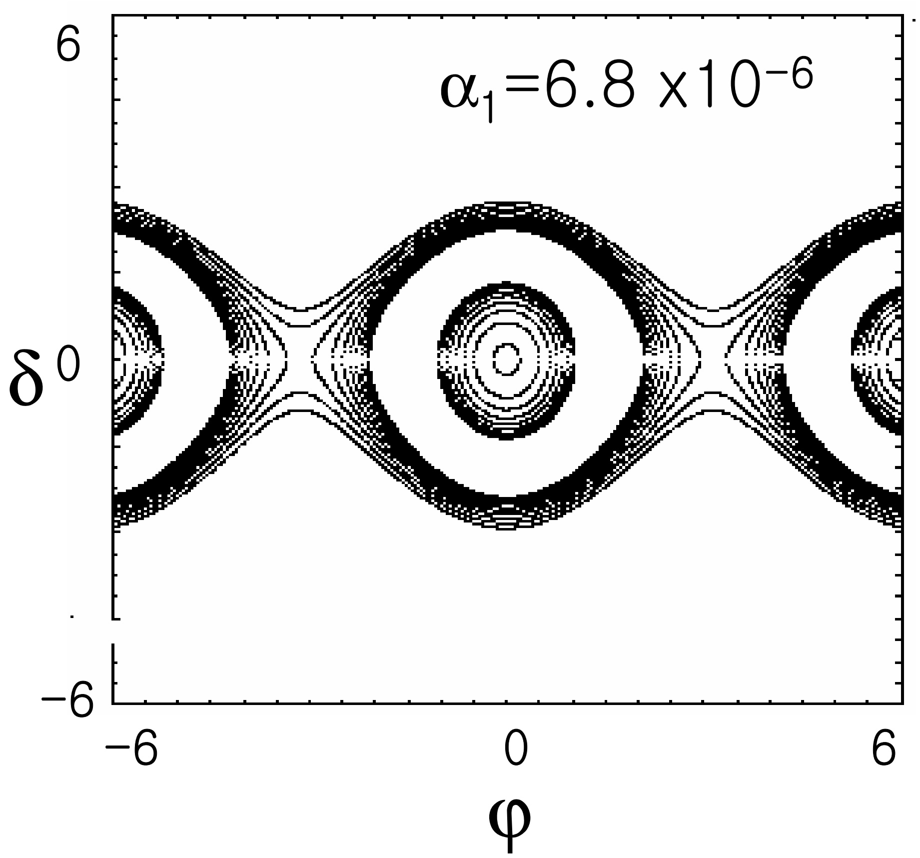
✓ $|\alpha_2| < \alpha_{2o}$: **Buckets have the same buckets as the linear case.**

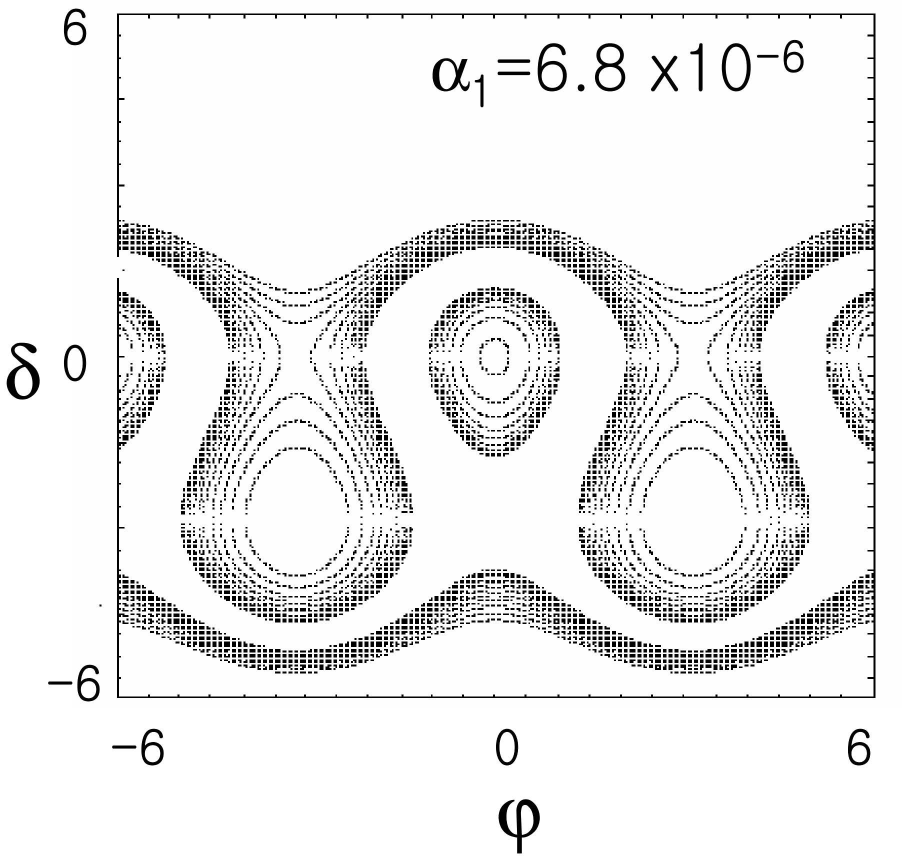
✓ $|\alpha_2| > \alpha_{2o}$: **Buckets become α-like.**

✓ $|\alpha_2| = \alpha_{2o}$: **Transition between the two cases.**

α_{2o} is 1.78×10^{-6} for quasi-isochronous PLS mode.

Effect of α_2 on the longitudinal phase space

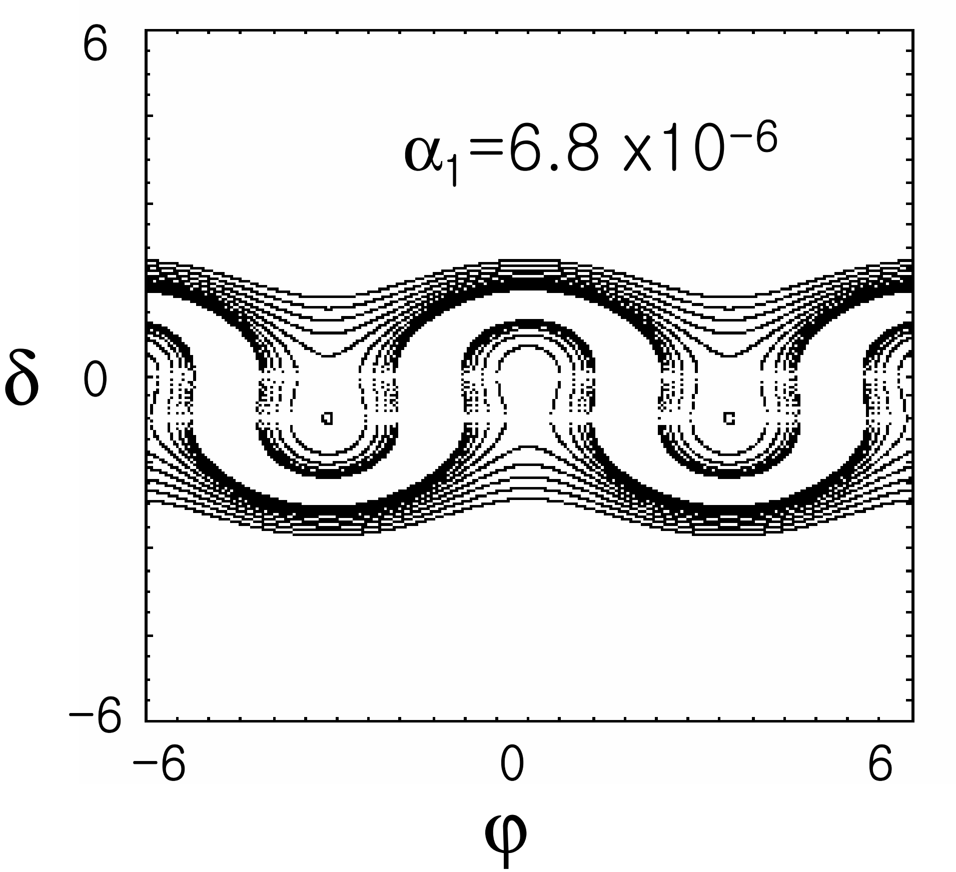




α_2=1.78 x10^{-7}

α_2=1.78 x10^{-6}

Increasing of α_2/a_1 shows that stable phase space have both up and down directions, that is, alpha-bucket.



α_2=6.8 x10^{-6}

Longitudinal beam instability by a Multi-particle tracking in quasi-isochronous mode

❑ Longitudinal macroparticle's motion of equation

$$\Delta\varepsilon_i = -2T_o/\tau_d + 2\sigma_{\varepsilon o}\sqrt{(2T_o/\tau_d})r_i + V'_{rf} z_i + W_o(z_i)$$

$$\Delta z_i = (\alpha_1 + \alpha_2\delta)/E_o c T_o(\varepsilon_i + \Delta\varepsilon_i)$$

✓ **Approximation of wake force in the ring by broad-band impedance**

$$W_o(z) = \omega_R R_s/Q e^{\alpha z/c}\{\cos\varpi z/c + \omega_R/(2Q\varpi)\sin\varpi z/c\}$$

$$\varpi = \sqrt{\omega^2{}_R - \alpha^2}\,,\quad \alpha = \omega_R/2Q$$

Binning method to calculate wake function

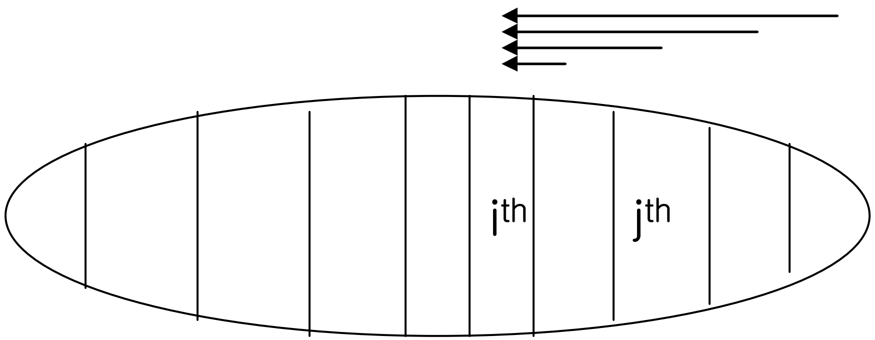
- $W_o(z_i(n)) = -(N_b r_o/N_p \gamma) \Sigma^{zi(n)<zj(n)} N_j W_o' (z^i(n) - z^j(n))$

  :from macroparticles in preceding bins

  $- (N_b r_o/N_p \gamma) \Sigma^{zi(n)<zj(n)} W_o' (z_i(n) - z_j(n))$

  :from macroparticles in the same bin

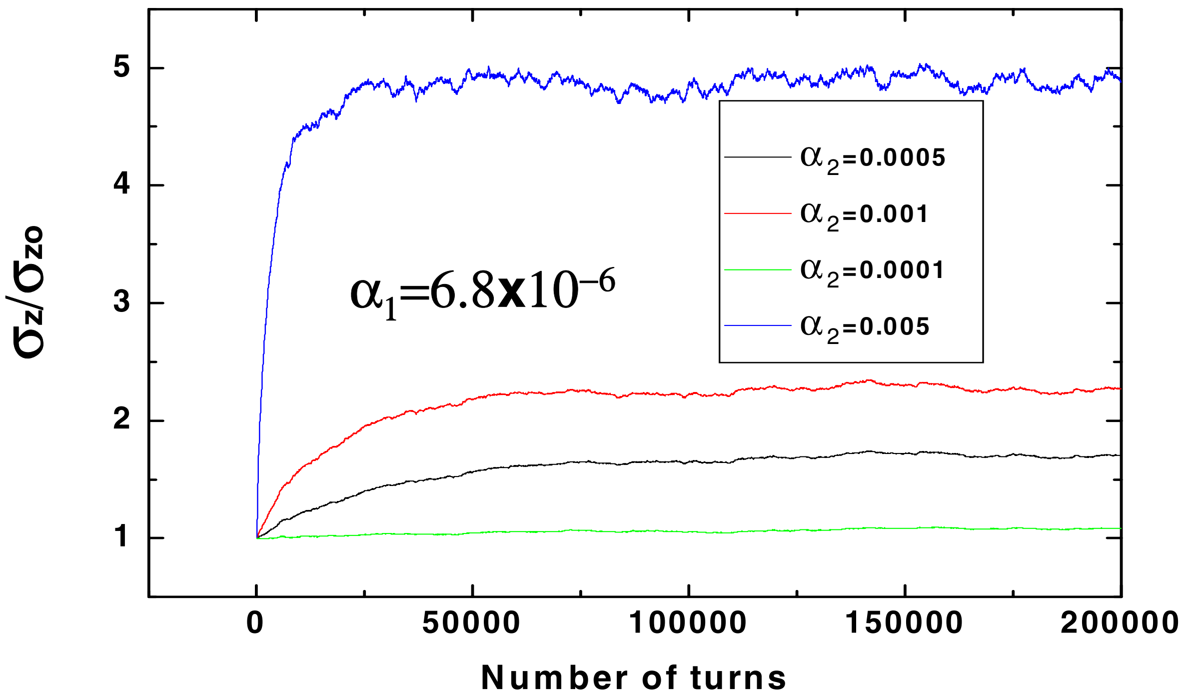
  $- (N_b r_o/N_p \gamma) W_o'(0)$: from macroparticle itself



$z^i(n) < z^j(n)$

Bins of variable width(=constant number of particles in each bin)

Sensitivity of α_2 on the longitudinal beam instability



The importance of control of α_2 in the quasi-isochronous mode

Summary

- **We show design of lattice for a quasi-isochronous ring that may produce sub-picosecond bunch length at PLS.**

- **Small momentum compaction factors at the PLS could be obtained by varying the dispersion function to be negative values in the position of bending magnet.**

- **The effects of second-order momentum compaction factor on the particle dynamics in the quasi-isochronous ring are investigated.**

- **From these studies, it was shown that a quasi-isochronous ring at PLS makes it possible to produce bunch length in sub-picosecond range.**