Longitudinal Single Bunch Instability by CSR

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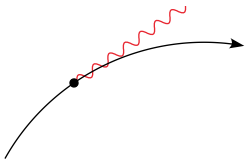
1. Introduction to CSR
2. CSR Effects in KEKB and SuperKEKB
3. Investigation by Particle Tracking Simulation
4. Summary

KEKB Review Committee, 2/22, 2005

1. Introduction to CSR

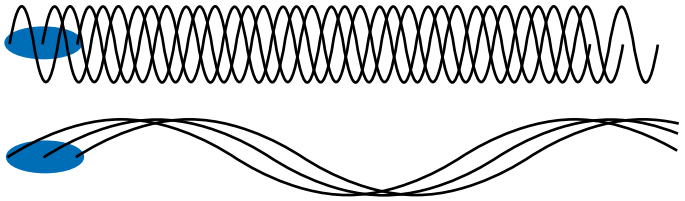
- Electrons moving in a bending magnet emit Synchrotron Radiation.



- In the spectrum of synchrotron radiation the components such that $\lambda \gtrsim \sigma_z$ produce Coherent Synchrotron Radiation. (CSR)

Incoherent

Coherent



$\sigma_z = 3\text{mm} \Rightarrow \lambda \sim 3\text{mm}$

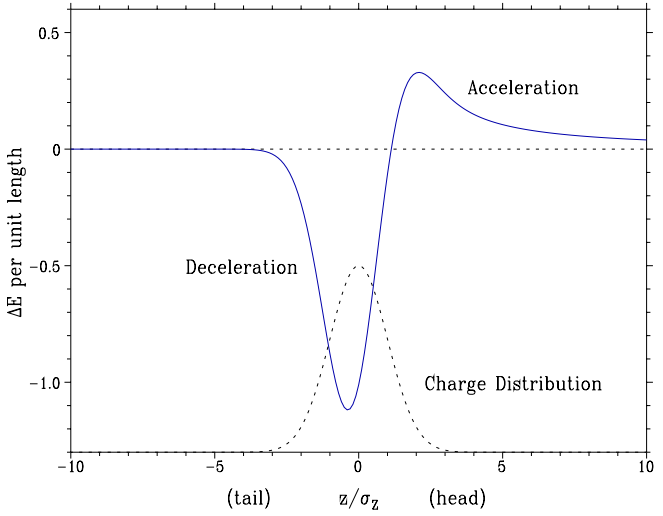
$\nu \sim 100\text{GHz}$

- Energy Change of Particles

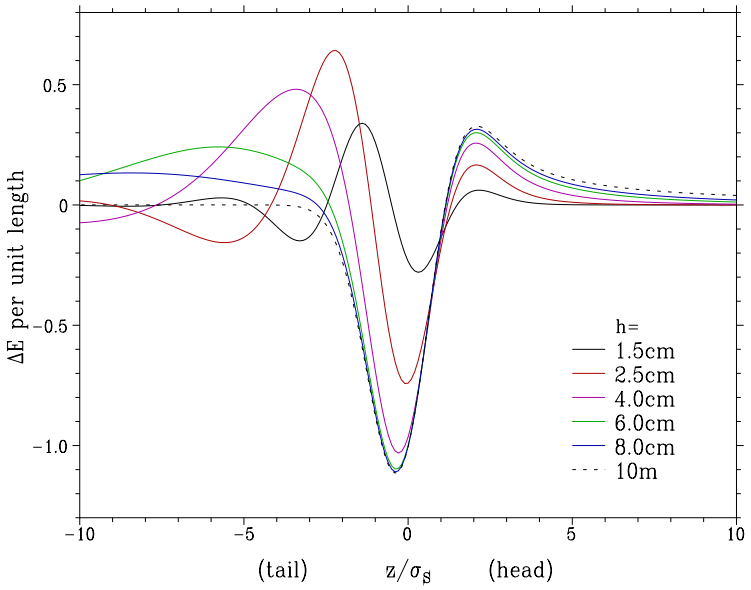
Short Range Interaction

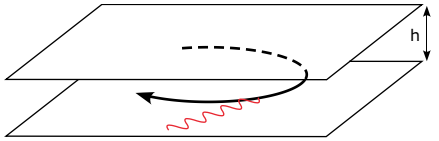
$\Rightarrow$ Energy Spread

$\Rightarrow$ Single Bunch Instabilities



- Shielded CSR by parallel plates





Typical scale length of CSR
in the transverse direction

$$\ell_\perp \sim (\rho\sigma_z^2)^{1/3}$$

$$= \begin{cases} 8.4\text{cm} & (\sigma_z = 6\text{mm}) \\ 5.3\text{cm} & (\sigma_z = 3\text{mm}) \end{cases}$$

If the shielding is strong: $h \lesssim \ell_\perp$

CSR can be suppressed with proper vacuum chambers.

$\Longleftrightarrow$ CSR depends on the chamber size.

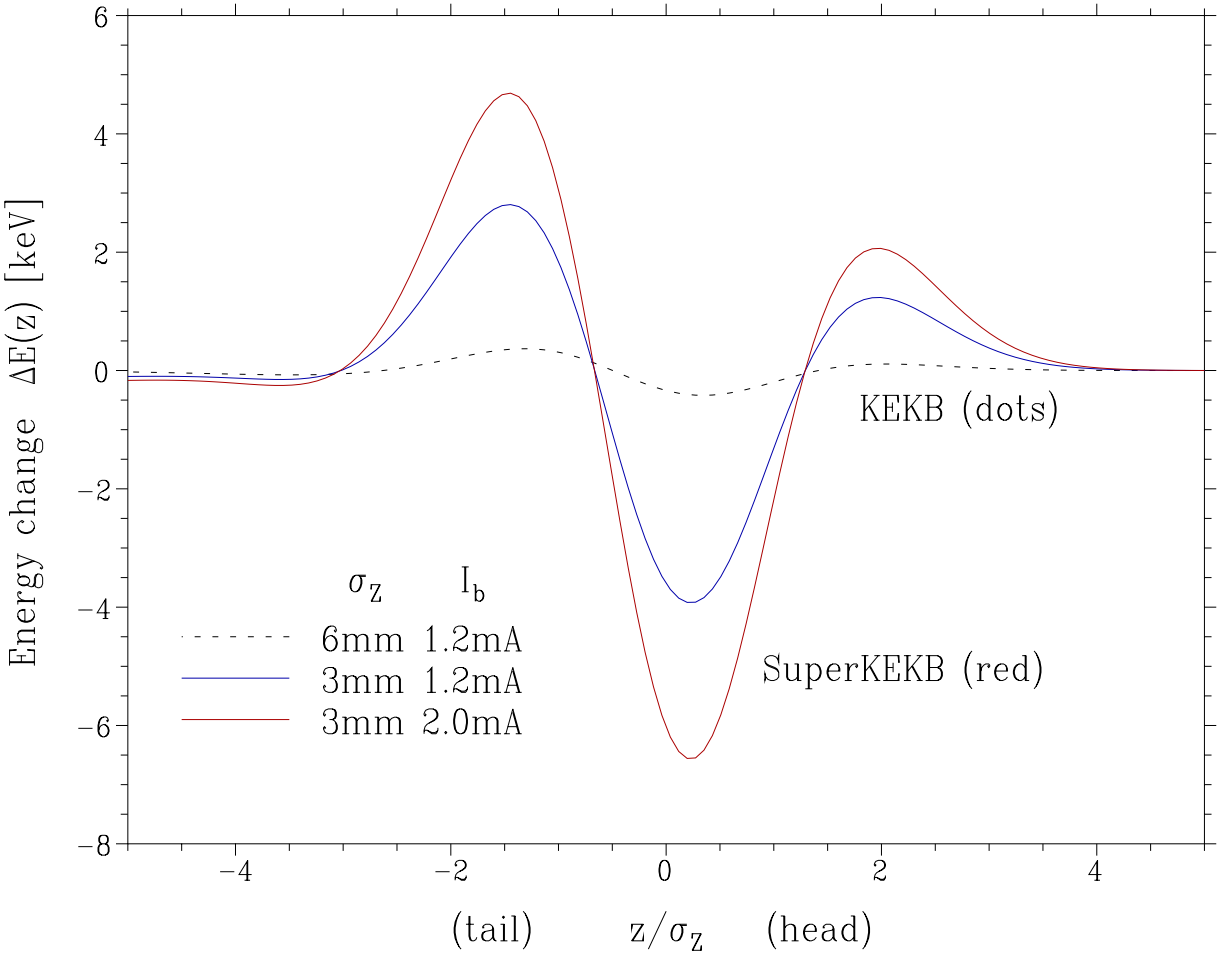
- LER is affected with CSR in SuperKEKB.

LER : $\rho = 16.3\text{m}$
HER : $\rho = 104.5\text{m}$

The bending radius in LER is very small.

2. Energy Change of Particles in KEKB and SuperKEKB

	KEKB		SuperKEKB
Bunch Length :	$\sigma_z = 6$mm	$\Rightarrow$	3mm
Bunch Current :	$I_b = 1.2$mA	$\Rightarrow$	2mA (≈ 20nC)



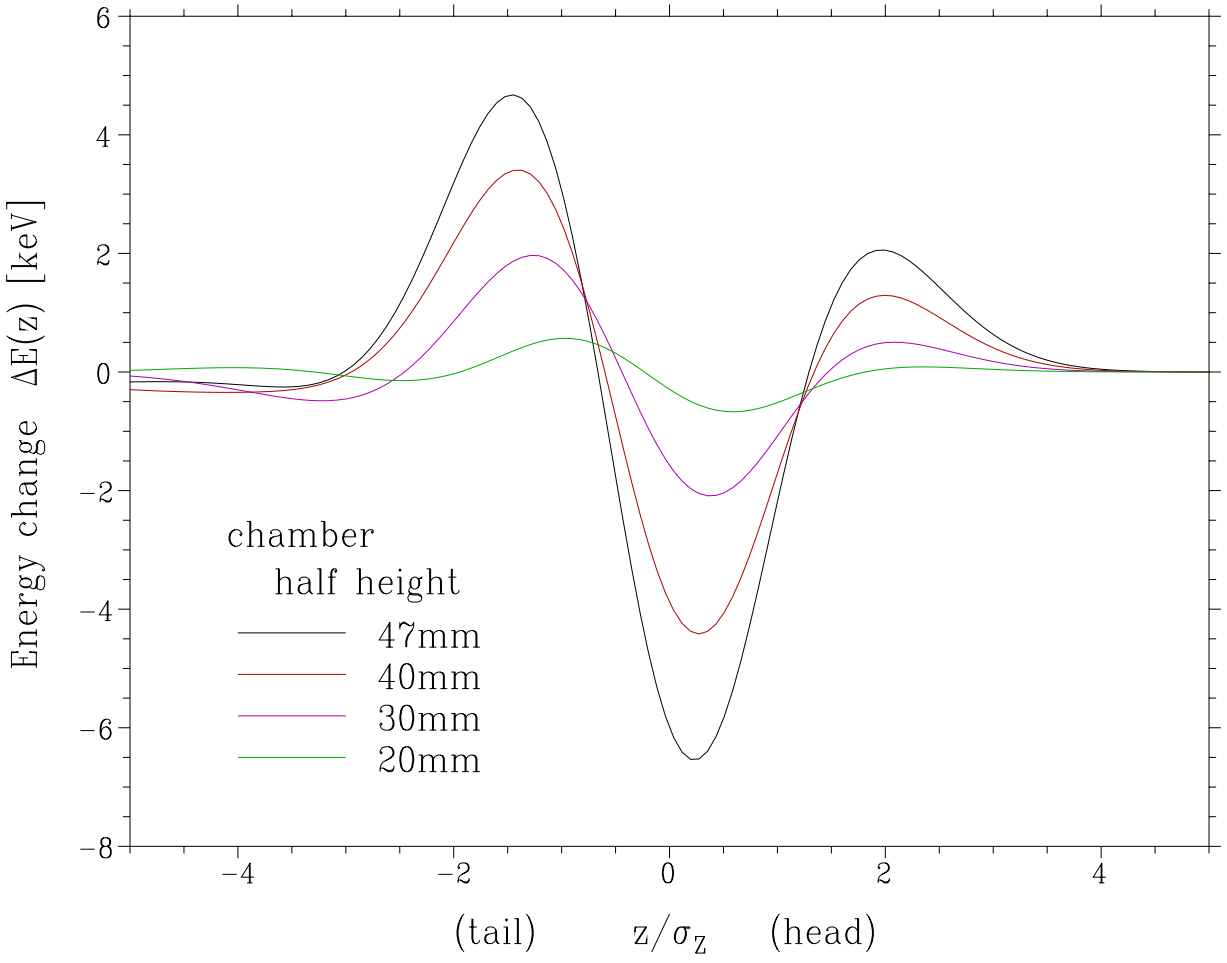
⇐ Energy change by CSR
for one particle,
for one bend.

SuperKEKB (red line)
14 times larger ΔE
than KEKB (dotted line)

Square pipe
$r = 47$mm
(half height)

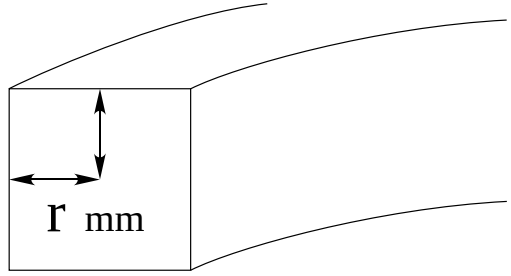
CSR Suppression by Beam Pipe

CSR can be suppressed by using chambers of small cross section.



Square Pipe

r = Half height



SuperKEKB Parameters

$\sigma_z = 3\text{mm}$

$I_b = 2\text{mA}$

$(Ne = 20\text{nC})$

3. Investigation by Particle Tracking Simulation

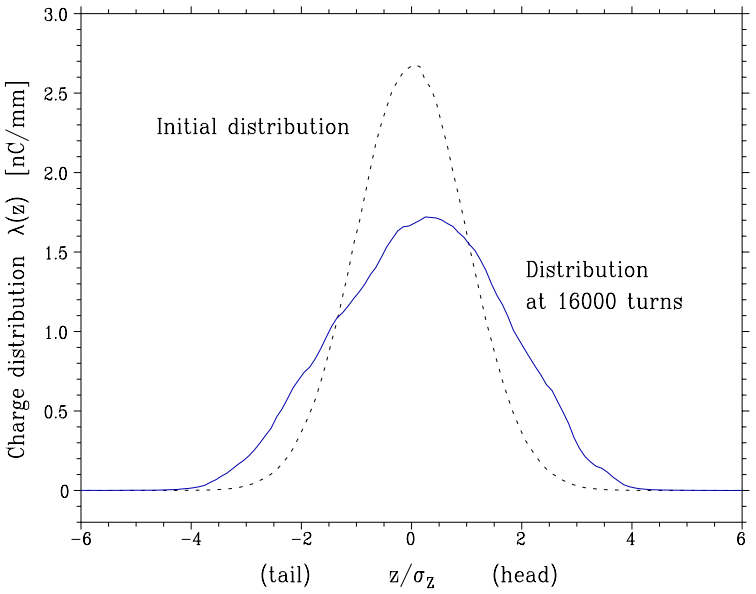
- Equations of Longitudinal Motion

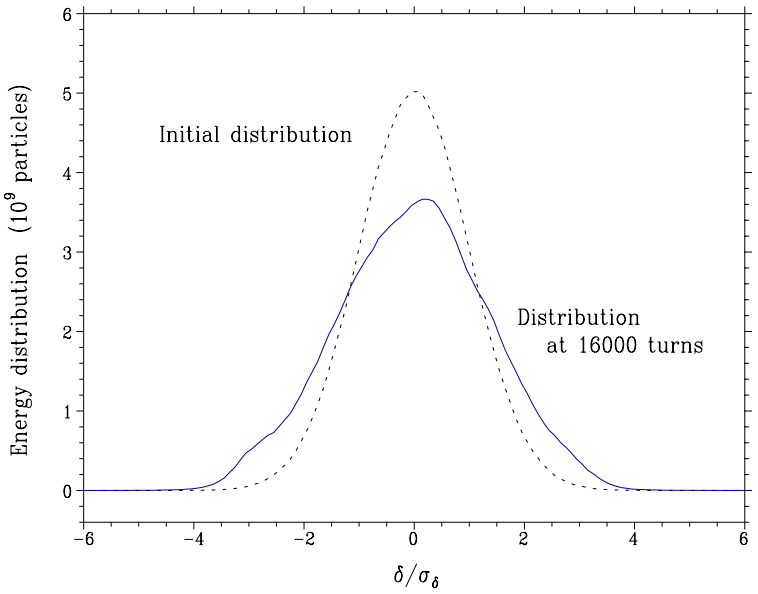
$$\begin{cases} z' = -\eta\delta \\ \delta' = \dfrac{(2\pi\nu_s)^2}{\eta C^2} z - \dfrac{2U_0}{E_0}\delta + \text{Quantum Excitation} + \text{CSR} \end{cases}$$

- 134 Arc-Bends are considered for CSR,
  but CSR in wiggler is ignored.
  (Wiggler is taken in the radiation damping U_0.)
- Copper pipe of square cross section
  (Actual one is round.)

- SuperKEKB parameters:
  σ_z=3mm, $\sigma_\delta = 7.1\times10^{-4}$
  $V_{\rm rf} = 15$MV, $\omega_{\rm rf}$=509Hz, $h = 5120$, $\alpha = 2.7\times10^{-4}$
  $U_0 = 1.23$MeV/turn, τ_s=28msec, ν_s=0.0306

- Charge distribution and Energy spread in SuperKEKB ($r = 47$mm)





Initial

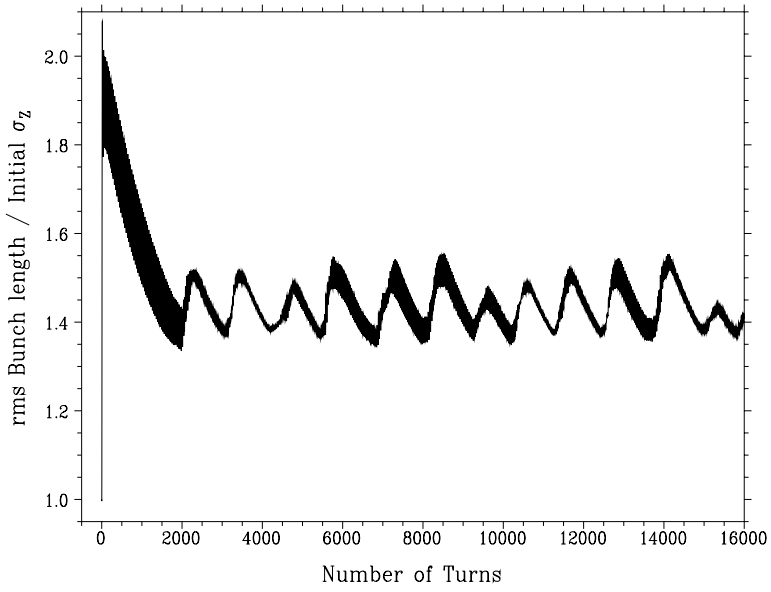
Bunch Length

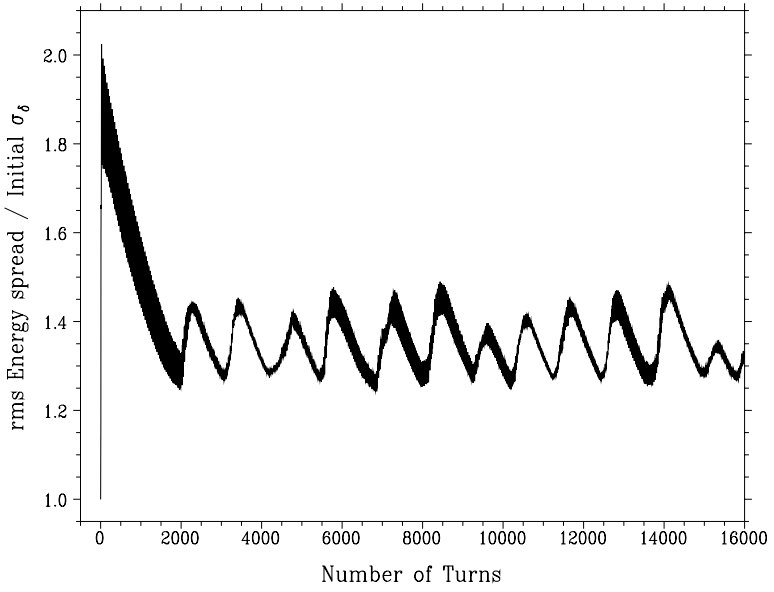
$\sigma_z = 3.0$mm

Initial

Energy Spread

$\sigma_\delta = 7.1 \times 10^{-4}$





Bunch Length

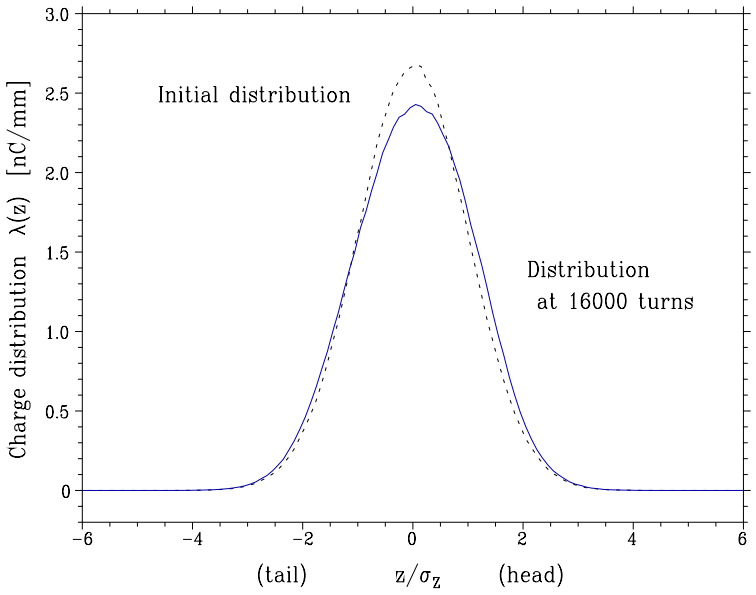
$\sigma_z \sim 4.3$mm

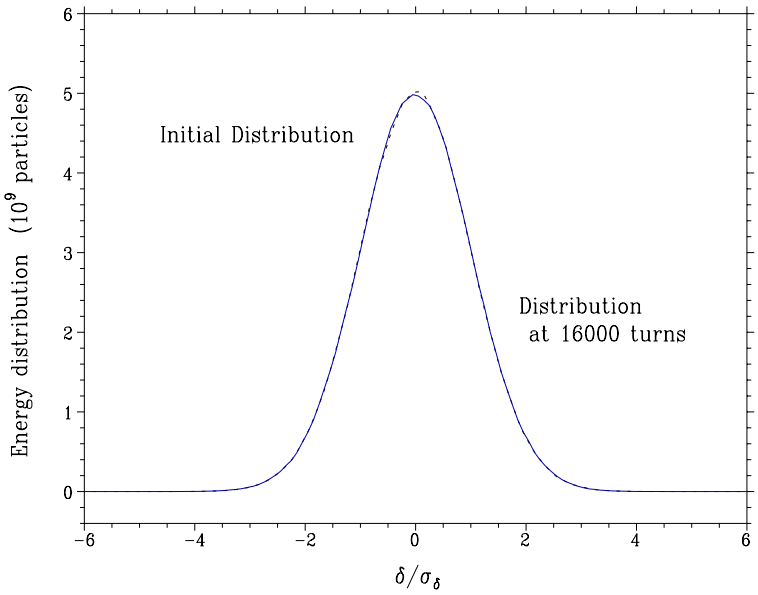
Energy Spread

$\sigma_\delta \sim 9.0 \times 10^{-4}$

UNSTABLE

- Charge distribution and Energy spread in SuperKEKB ($r = 25$mm)





Initial

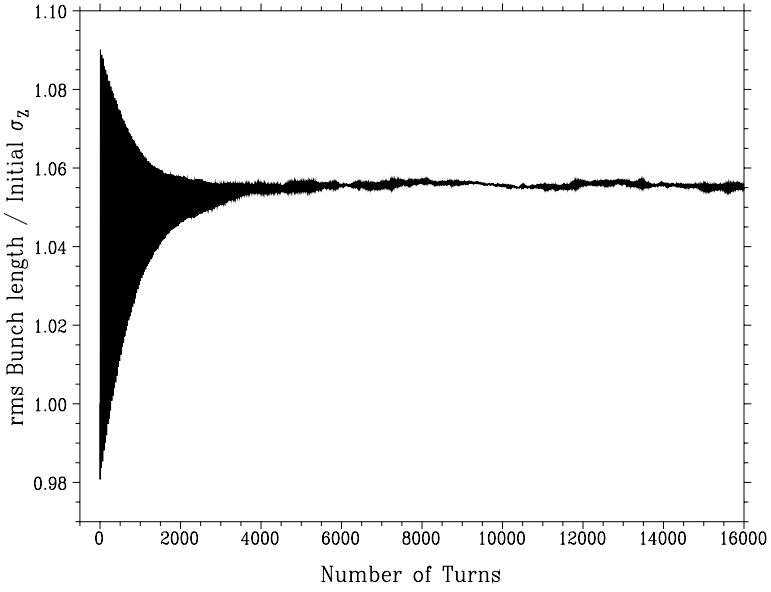
Bunch Length

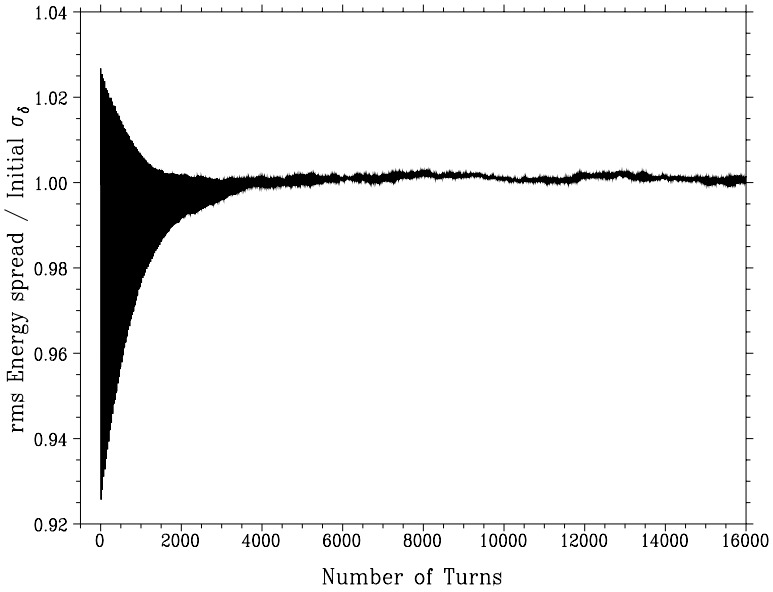
$\sigma_z = 3.0$mm

Initial

Energy Spread

$\sigma_\delta = 7.1 \times 10^{-4}$





Bunch Length

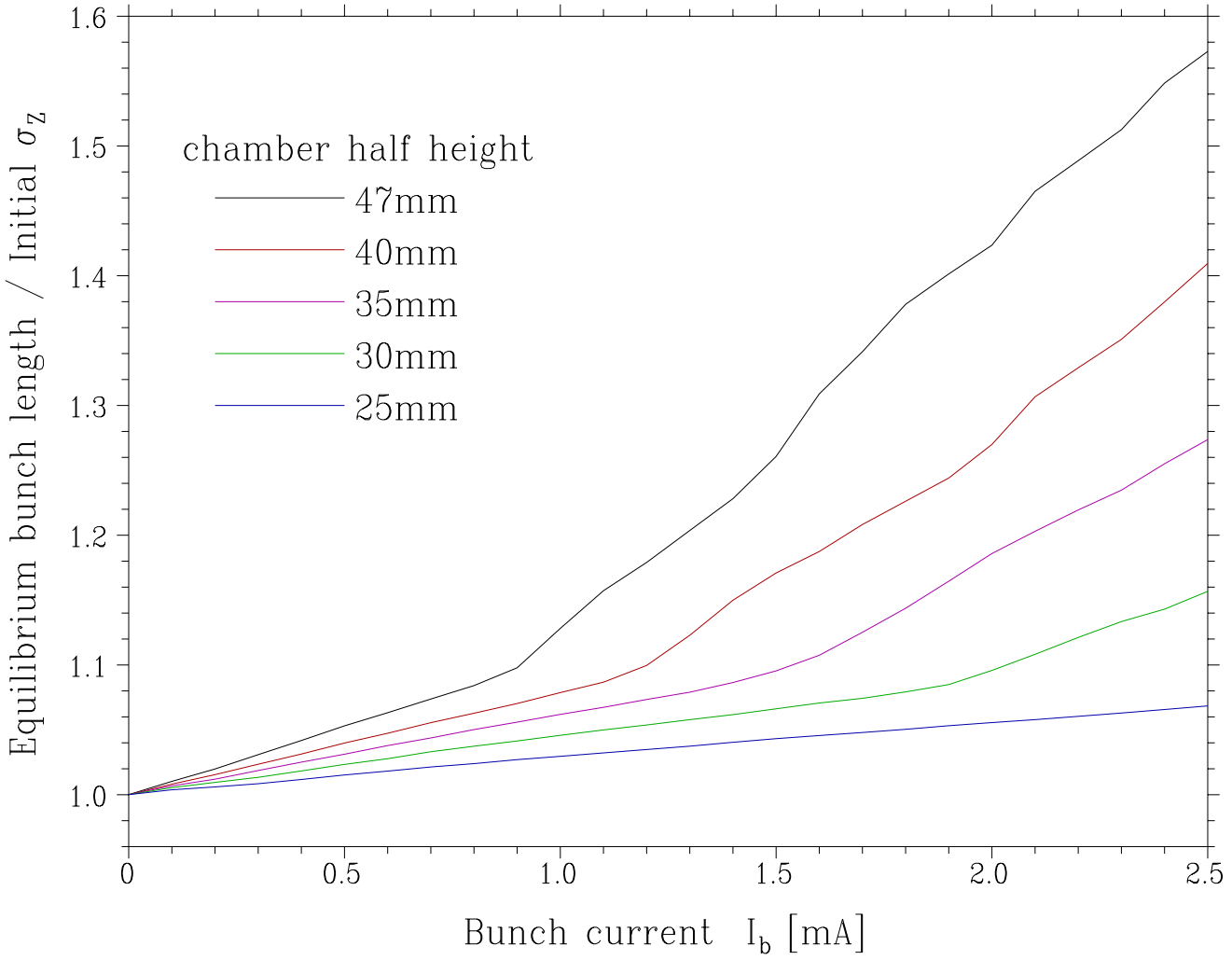
$\sigma_z \sim 3.17$mm

Energy Spread

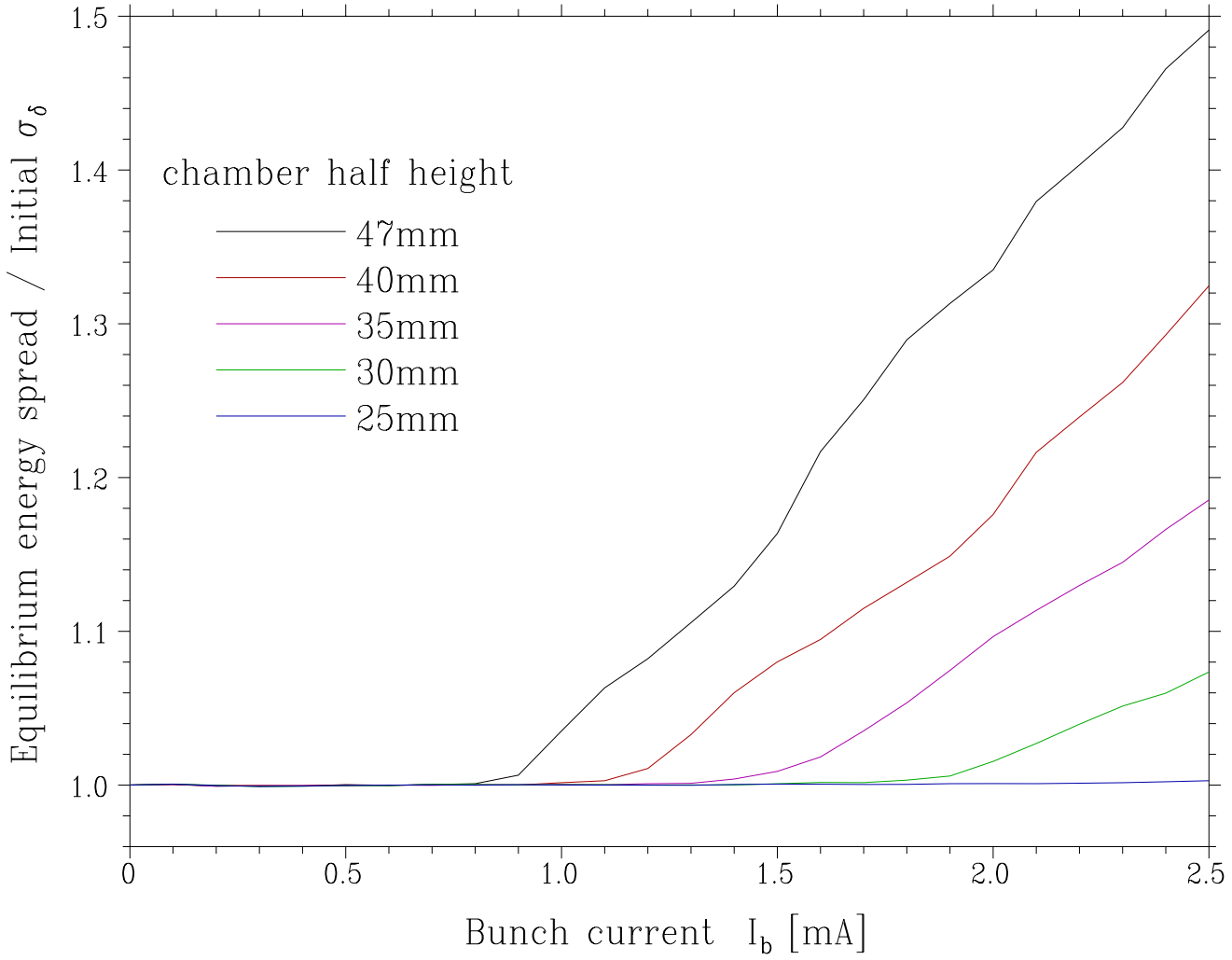
$\sigma_\delta \sim 7.1 \times 10^{-4}$

STABLE

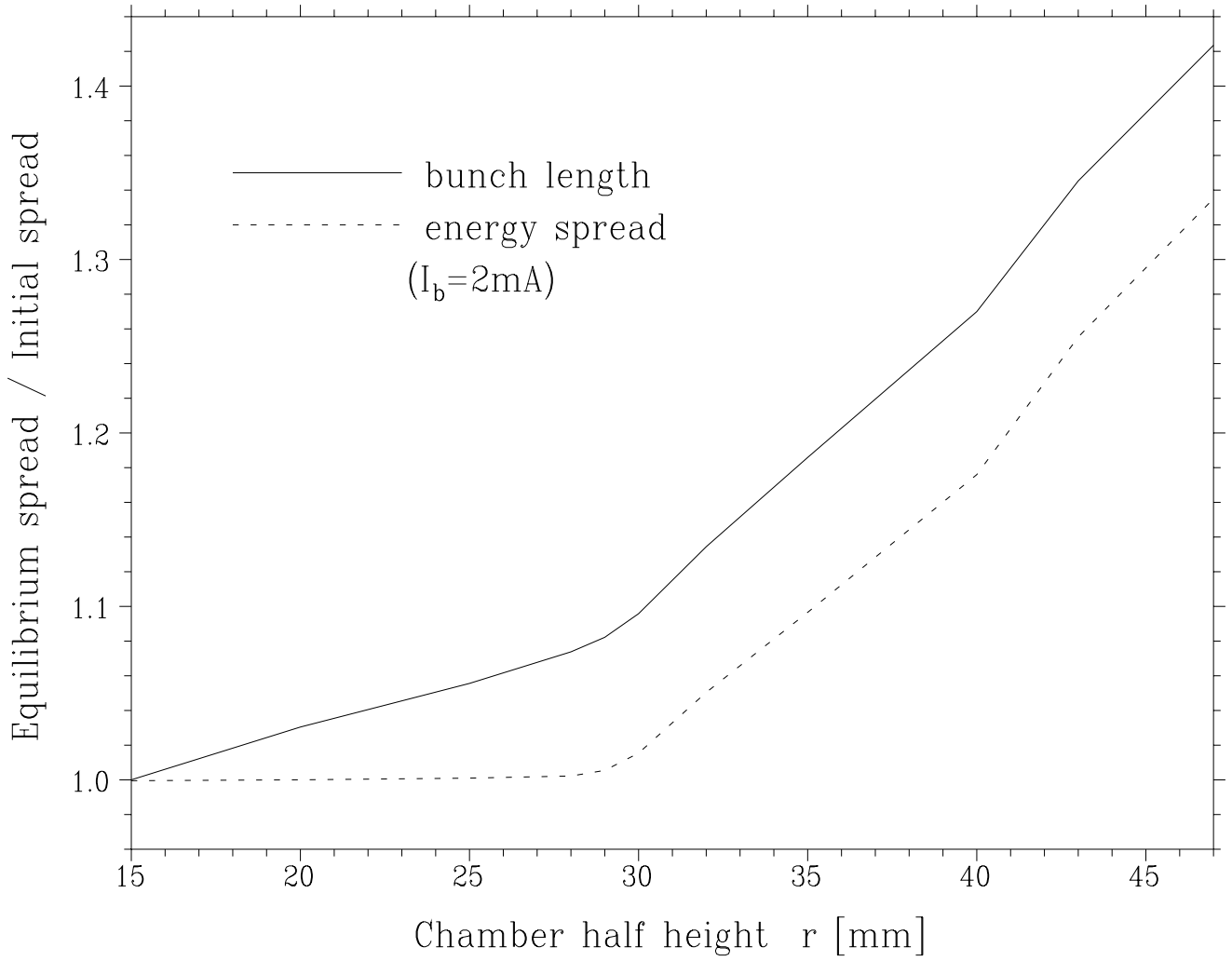
- Bunch length vs Bunch current



- Bunch length vs Bunch current



- Bunch length, Energy spread vs Chamber size



4. Summary

- LER is affected with CSR because of (1) short bunch length, (2) high bunch charge, (3) small bending radius.

- The bunch of 3mm length and 2mA current is unstable due to CSR in the present design.
  It is lengthened by CSR and cannot maintain its length of 3mm.
  Oscillation: SR Damping $\Leftrightarrow$ CSR Lengthening

- The threshold bunch current is $I_b = 0.7$mA ($Ne \approx 7$nC) in the present chamber $r = 47$mm.

- Small chambers substantially reduce CSR.
  The threshold half height (radius) is 28mm for $I_b = 2$mA.
  (It must be smaller for safety margin.)

- But small chambers may induce side effects.
  Microbunching by other wakefields can generate intense CSR.
  We need further studies.