LCLS-II Technical Note

Wakefield Effects in the Spreader of LCLS-II

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Wakefield Effects in Spreader LCLS-II

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Introduction

• In LCLS-II the trajectories of the hard and soft x-ray beam will be separated by a kicker, with one type of bunch kicked vertically in one direction, and the other type kicked in the opposite direction.

• With only one kicker chamber, both beams will on average be offset from the axis of the (round) beam pipe chamber. This will induce transverse (dipole) wakefields that generate a transverse kick that varies along the bunch, thus increasing the projected emittance. Is the problem severe enough that two separate chambers are needed?

• The chamber walls are ceramic that is copper coated, and the resistive wall wake will be excited. The chamber is round with radius $a = 5$ mm, length $L = 8$ m. The beam enter on axis, follows a vertical parabolic trajectory, and exits offset by 3 mm from the axis. The average offset is $\langle y \rangle = -1$ mm

• Here I will calculate the transverse wake effect, as well as that of the longitudinal wake

Introduction Cont'd

- In LCLS-II, after BC2, the beam (longitudinal) distribution is approximately uniform, with peak current $I = 1$ kA. The nominal bunch charge $Q = 100$ pC, the largest charge is 300 pC. The total bunch length for the two cases is 30, 90 μm

- Calculate the full rw wake, ac model with conductivity $\sigma_c = 6.0 \times 10^7\ \Omega^{-1}\mathrm{m}^{-1}$, relaxation time $\tau = 2.7 \times 10^{-14}$ s (Cu). [See e.g. K. Bane and M. Sands, AIP Conf. Proc. 367 (1996) 131]

- Currently in the optics β_y varies from 112 m to 237 m; β_y will be reduced to 33 m–Yuri N is working on it

- Another effect that needs to be investigated (–Tor) for the kicker (not a wake effect, and it will not be done in this talk), is the stay clear. When the beam leaves the chamber it passes at a distance of 2 mm from the wall. With the optics assumed here, the beam size $\sigma_y \sim 50$ μm, that distance is equivalent to $40\sigma_y$

Resistive Wall Wakes

- The rw wake scale factor

$$s_0 = \left(\frac{2a^2}{Z_0 \sigma_c}\right)^{1/3}$$

with a the beam pipe radius, σ_c the dc conductivity, and $Z_0 = 377\ \Omega$. For kicker chamber $s_0 = 13\ \mu\text{m}$

- For ac rw model, replace σ_c by $\tilde{\sigma}_c = \sigma_c/(1 - ikc\tau)$, with τ the relaxation time

- Longitudinal rw impedance as function of normalized wave number $\kappa = ks_0$:

$$Z_l(\kappa) = 2\left(\frac{s_0}{ca^2}\right)\left(\frac{2}{1-i}\frac{1}{\sqrt{\kappa}} - i\frac{\kappa}{2}\right)^{-1}$$

- Transverse (dipole) rw impedance

$$Z_{yd}(\kappa) = 4\left(\frac{s_0^2}{ca^4\kappa}\right)\left(\frac{2}{1-i}\frac{1}{\sqrt{\kappa}} - i\frac{\kappa}{2}\right)^{-1}$$

Resistive Wall Wakes Cont'd

- Longitudinal wake

$$W_l(s) = \frac{c}{2\pi}\int_{-\infty}^{\infty} dk\, Z_l(k) e^{-iks} \ .$$

Units are [V/(pC·m)]

- For uniform bunch distribution with peak current I, in pipe of length L, voltage within bunch is given by

$$E_w(s) = -\frac{IL}{c}\int_0^s ds'\, W_l(s')$$

- The transverse wake is obtained similarly from Z_{yd}. The kick angle, for a beam of energy E, offset by y_0, at the end of a pipe of length L is

$$\Delta y'(s) = \frac{eILy_0}{cE}\int_0^s ds'\, W_{yd}(s')$$

Longitudinal Effect

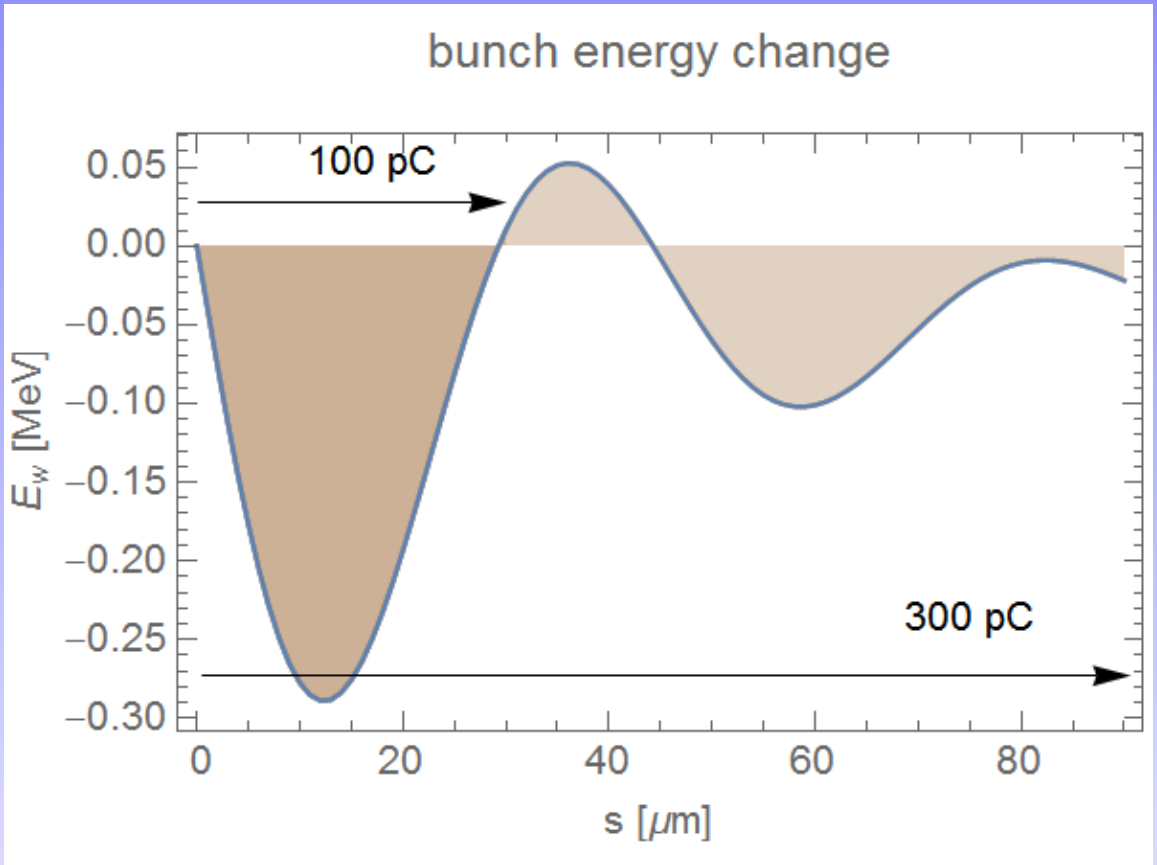

Figure: Rw wake induced energy change in LCLS-II spreader kicker chamber for a bunch with a uniform distribution, with peak current $I = 1$ kA. The bunch head is located at $s = 0$

At $E = 4$ GeV, the total spread in induced relative energy variation is $\delta E_w = 7\,(9) \times 10^{-5}$, for $Q = 100\,(300)$ pC

Transverse Wake

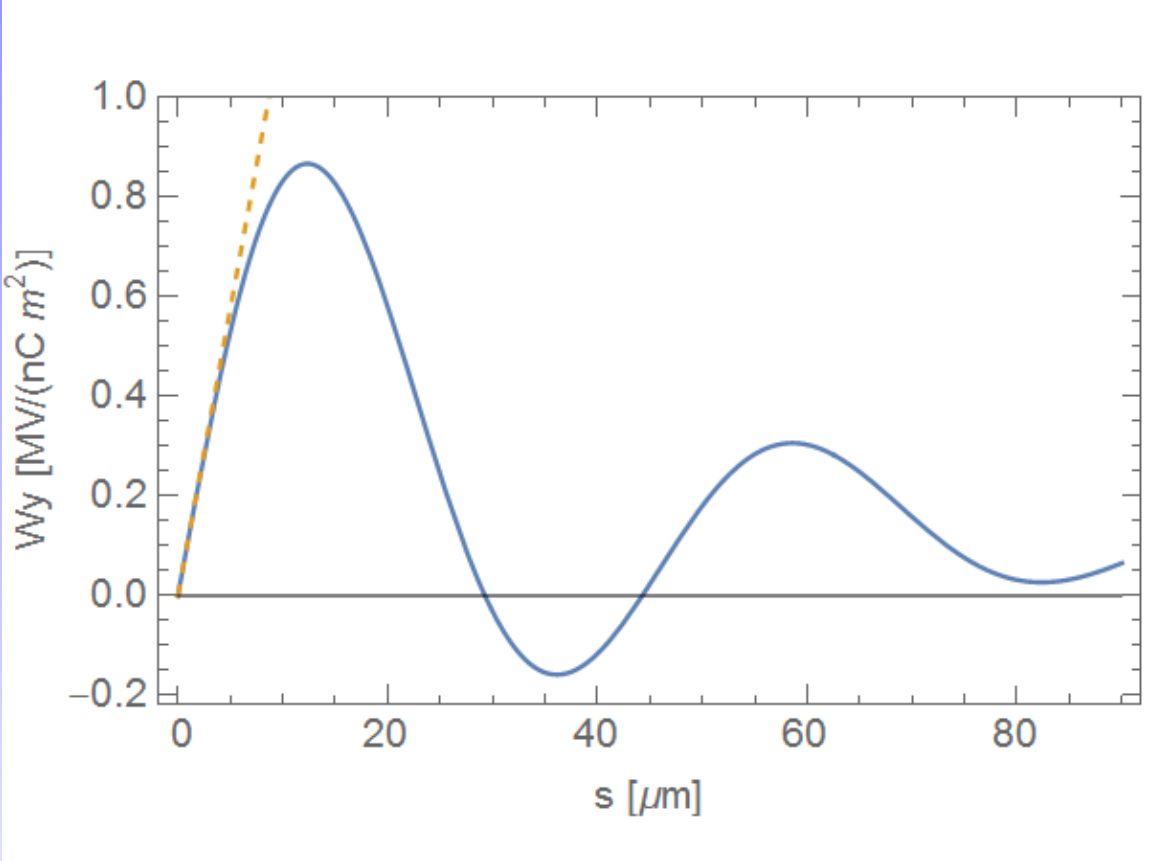

Figure: Transverse rw (point charge) wake in LCLS-II spreader kicker chamber. Slope at origin is $W_y'(s) = 2Z_0c/\pi a^4$

Transverse Effect

- Calculate vertical kick for a bunch passing through the pipe offset by $y = 1$ mm: Here $E = 4$ GeV, $\beta_y = 33$ m, $\epsilon_n = 0.5$ μm

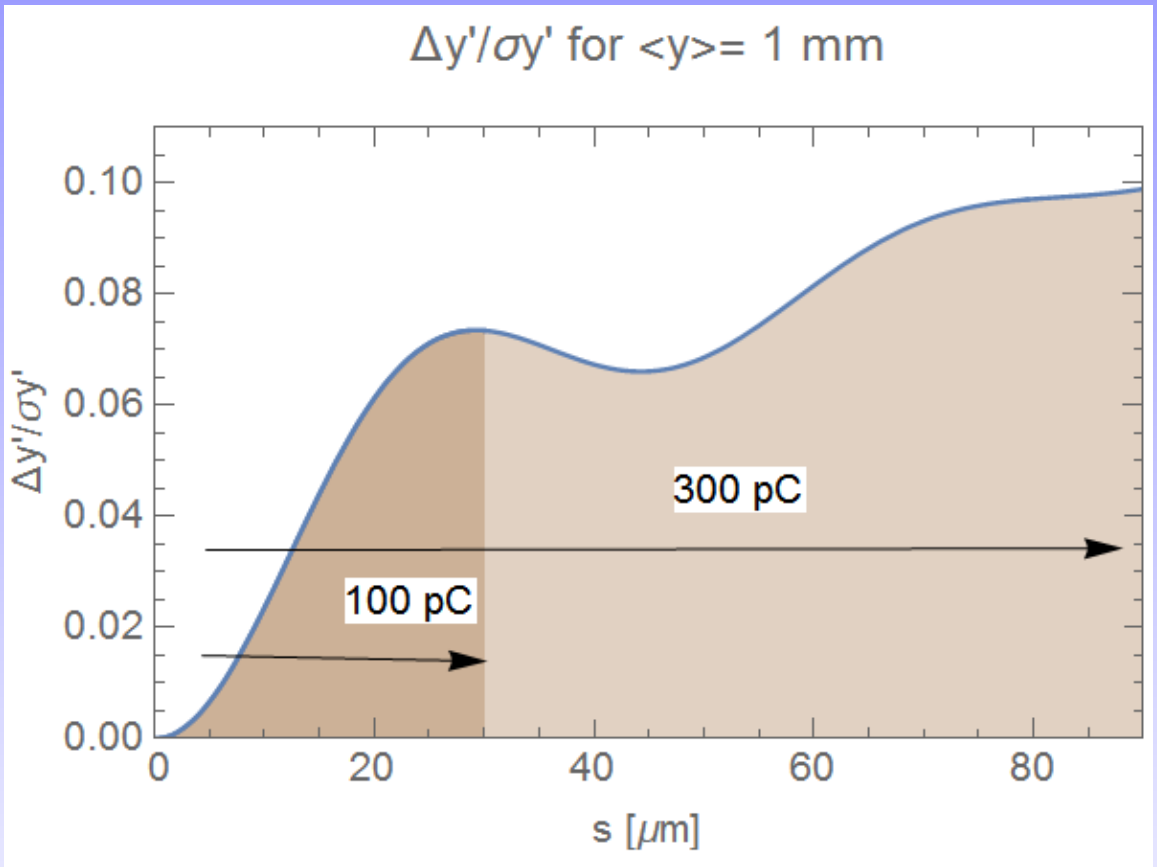

Figure: Rw wake induced transverse (dipole) kick in LCLS-II spreader kicker chamber for a bunch with a uniform distribution with peak current $I = 1$ kA that is moving on the design orbit. Plotted is $\Delta y'/\sigma_{y'}$

Discussion

- Due to the off-axis orbit, the last slice in the 100 pC or 300 pC bunches will be displaced by $\sim 10\%$ of $\sigma_{y'}$ at the end of the kicker, assuming $E = 4$ GeV, $\beta_y = 33$ m, $\epsilon_n = 0.5$ μm. For larger β_y the effect will grow by $\beta_y^{1/2}$
- Paul E. pointed out that this a small effect in terms of the emittance. The effective emittance growth for the last slice is $\Delta\epsilon_y/\epsilon_y = \frac{1}{2}(\Delta y'/\sigma_{y'})^2 = 0.5\%$
- The longitudinal effect is a wake-induced total energy variation, for both the 100 pC and 300 pC cases, of $\Delta E_w/E \sim 10^{-4}$. The chirp is very non-linear and probably cannot be corrected