Effect of the Wakes On Bunch Lengthening and Tune Shift.

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We discuss optical effects of the wakes: synchronous phase and bunch length variation along the train of bunches, effect of the beam pipe asymmetry and tune variation.

Although the main results are obtained for PEP-II DR, they can be relevant for the SuperB-factory and ILC projects.

1 Variation of the bunch length and synch. phase

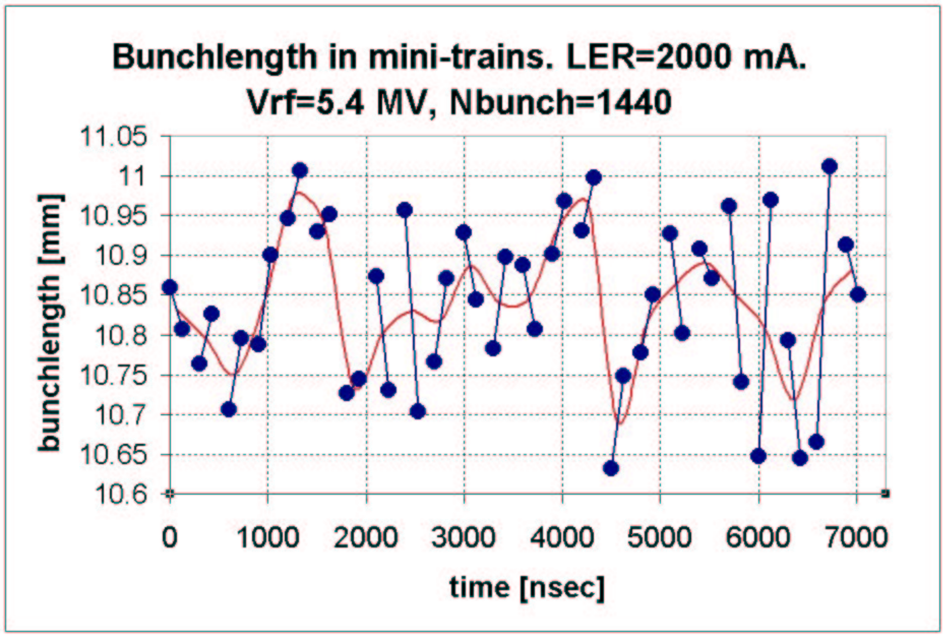


Figure 1: Variation of the bunch length along the train (S. Novokhatski).

Gap causes synchronous phase variation along the train

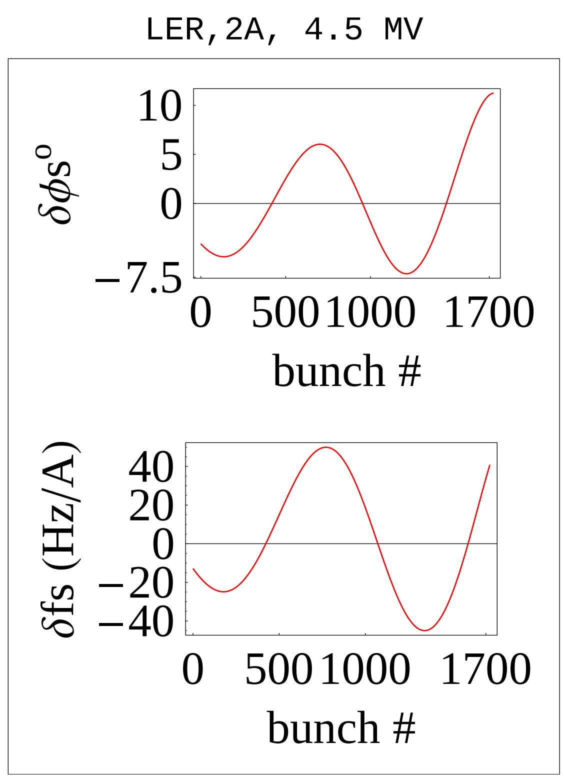


Figure 2: Synchronous phase (top) and synchrotron frequency (bottom) along the train caused by the ion gap.

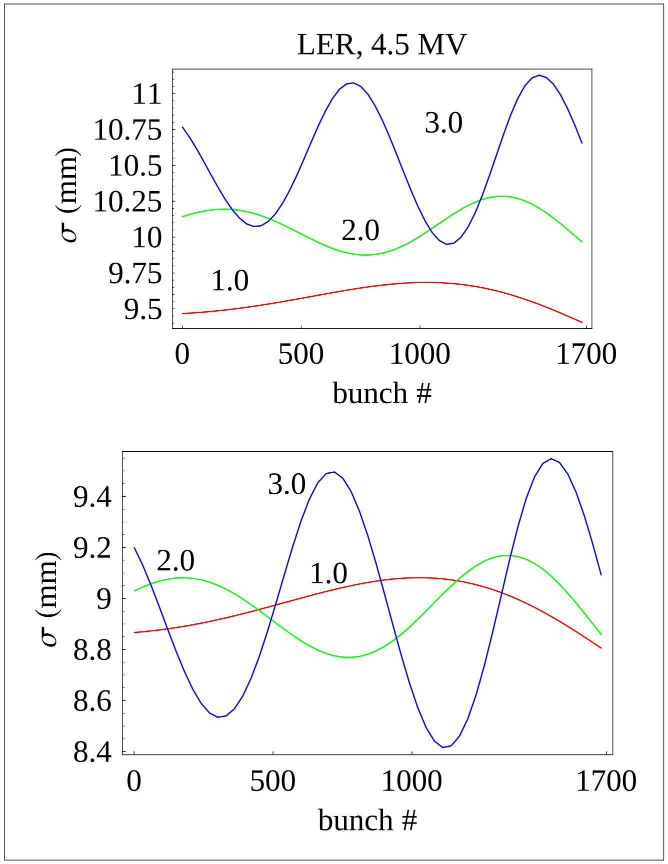


Figure 3: Calculated variation of the bunch length along the train. Bottom plot: results of only gap transients. Upper plot: variation due to the gap transients and the PWD. Beam current is indicated in the figure. LER, $V = 4.5MV$. Note increase of the variation with the detuning.

1.1 Effect on luminosity

- Synchronous phase shift along the train affects L

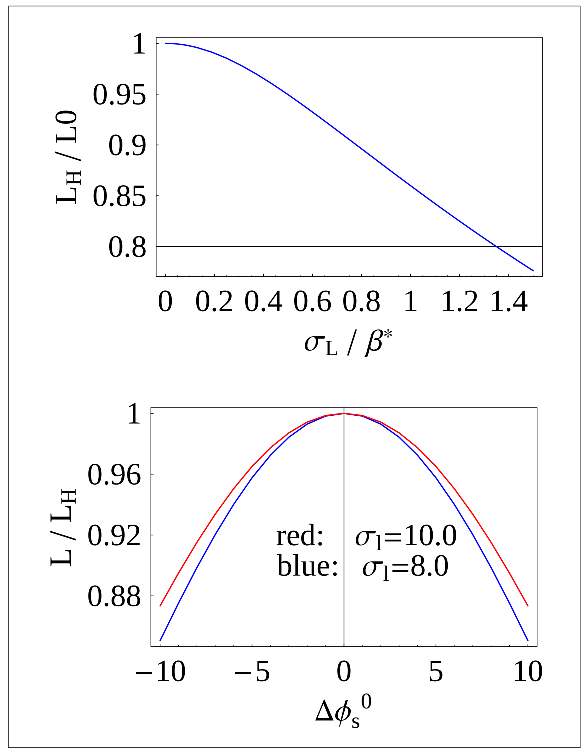


Figure 4: Hour-glass effect (left) and variation of the luminosity with the synchronous phase error (right) normalized to nominal L_0. $\beta_y^* = 1.0$ cm. a) hour-glass due to σ_l variation, b) gap transients due to syn. phase variation.

- Effect may be more important for large crossing angles.

- Synchronous phase shift along the train can be responsible for the variation of the tune along the train due to parasitic crossings for head-tail collisions.

1.2 Bunch length measurements

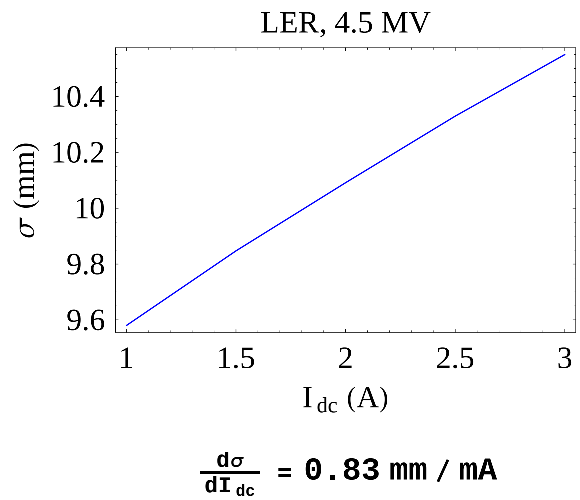


Figure 5: Averaged over the train bunch length vs beam current. Inductance $L = 80$ nH.

Measured:

(A.F.) $\sigma = (10.5/13.5)$ mm with $I_{bunch} = (0/3.0)$ mA, $d\sigma/dI = 0.8$ mm/mA.

(S.N.) $\sigma = 11.5/13.3$ mm within $I_{bunch} = (500/2500)$, $d\sigma/dI = 1.45$ mm/mA.

1.3 Bunch length calculations

The *actual* rms σ_{exp} can be calculated from Haisinskii equation:

$$\rho(x,p) = \frac{1}{|N|} e^{-\{p^2/2 + U_0(x) + \lambda \int dx' \rho(x') S[\sigma_l (x'-x)]\}}. \tag{1}$$

Here, $\sigma_l \equiv \frac{\alpha \delta_0 c_0}{\omega_s}$,

$$\begin{aligned} \lambda &= \frac{N_B r_e}{2\pi R \gamma \alpha \delta_0^2}, \quad S(z) = \int_0^z dz' W(z'), \\ p &= \frac{\delta}{\delta_0}, \quad x = \frac{z}{\sigma_l}. \end{aligned} \tag{2}$$

δ_0 is defined by SR. What is ω_s ?

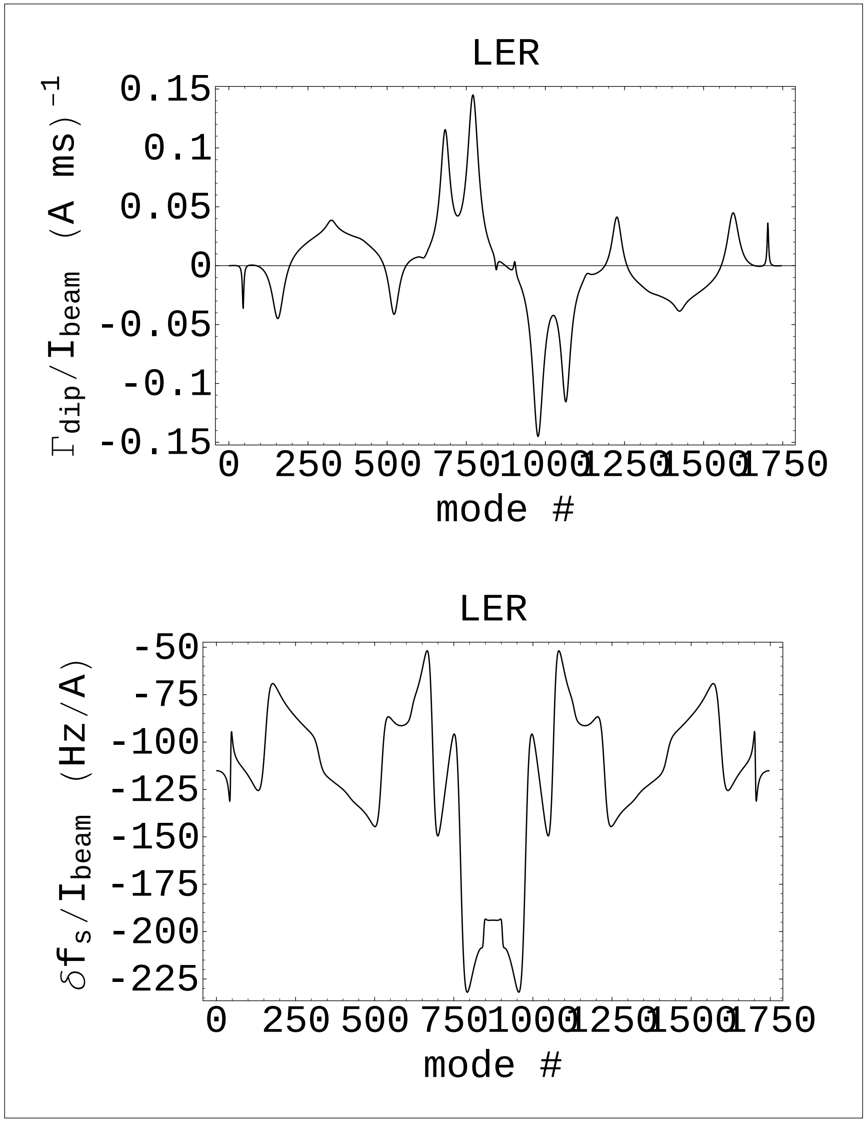


Figure 6: CB longitudinal dipole modes.

* Observation ω_s of the bunch centroid is *not* the same as ω_s in Haissinski formalism.

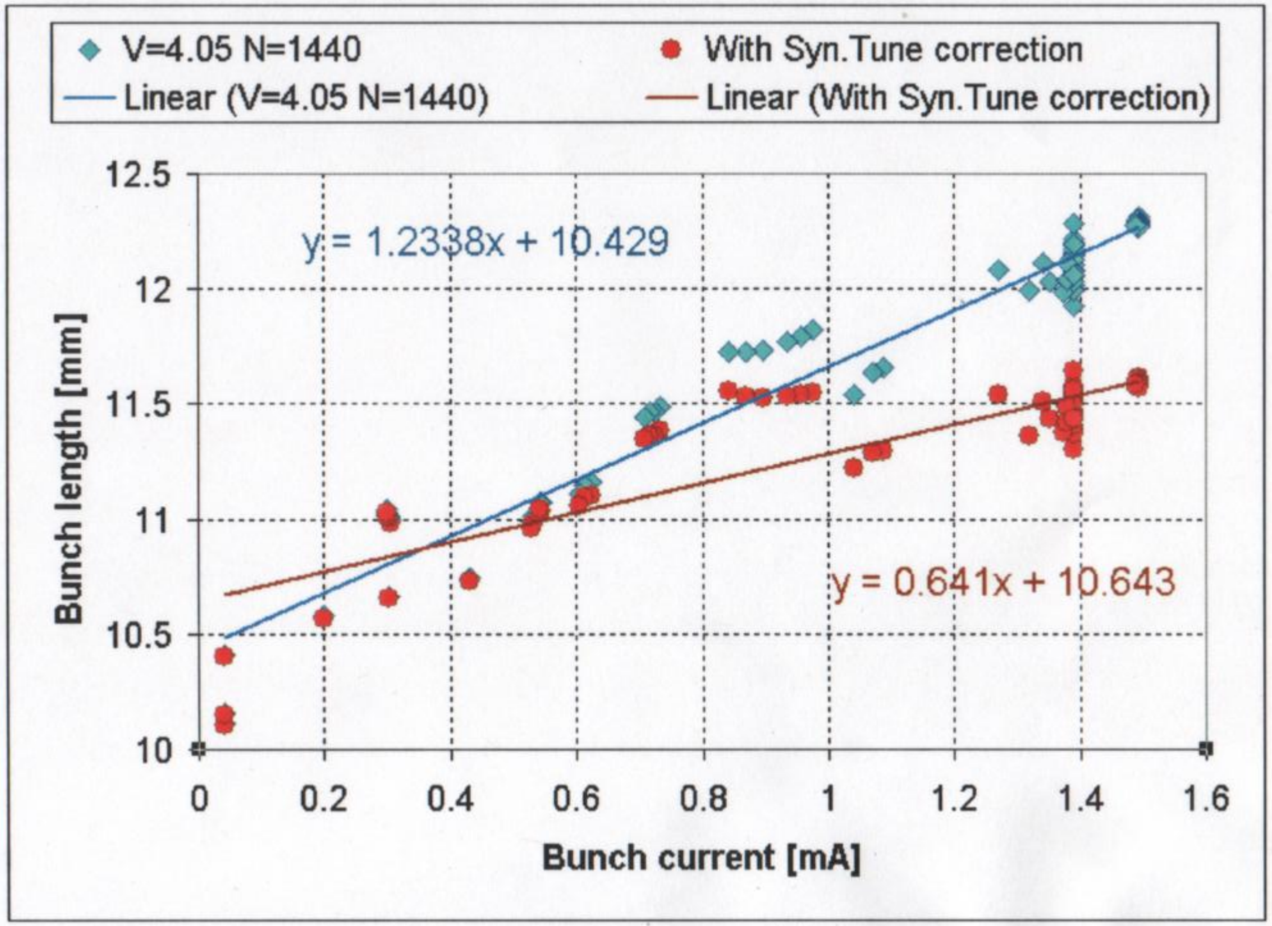
Example: HT oscillations.

* Dependence on current of ω_s is due to losses and through NB wake due to gap transients.

* For multibucnh case, Haissinski exponent should be understood as the sum over CB modes.

* $2\omega_s$ sideband is result of $m = 2$ CB modes and of anharmonicity of a single particle motion.

Real bunch lengthening



Bunch lengthening is determined (almost in half) by the synchrotron tune shift at higher currents.

2 Effect of the RW wake on tunes

2.1 Tune dependence on bunch number

RW gives the dominant contribution to transverse dynamics, see Fig.

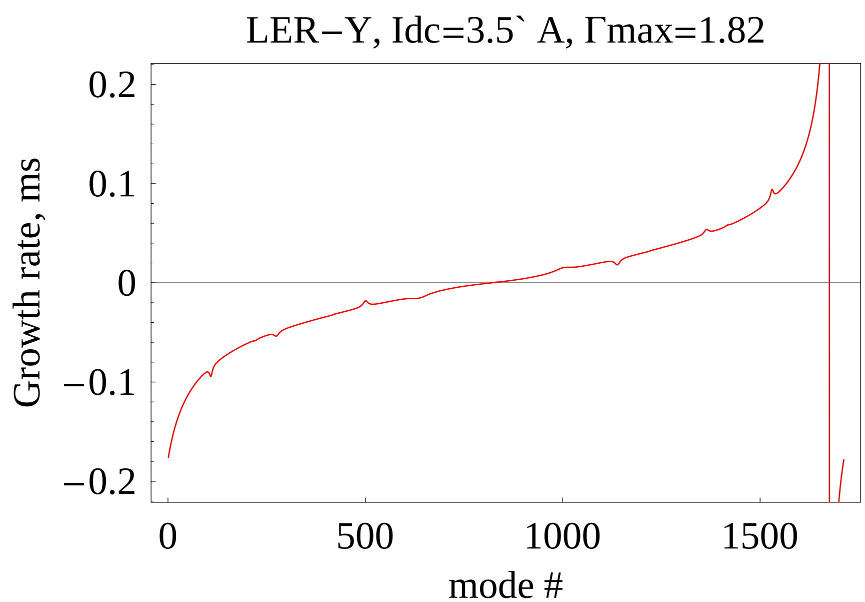


Figure 7: Growth rate vs CB mode number.

Corresponding tune variation is $\delta Q_x = 0.46\,10^{-2}$.

Experiment (A. Fisher, gated tune measurements) gives variation *along the train* $\delta Q_{x/y} = 0.4\,10^{-2}$ which is monotonic for y-plane and oscillatory in x-plane.

2.2 Discussion

* Do all bunches have the same frequencies?

* For CB motion, the tunes of all bunches have to be the same even with a gap.

* CB modes: when they exist?

Example 1: Train with a large gap.

Example 2: Gap transients give bunch ω_s variation and can kill longitudinal CB modes.

*CB modes disappear and there is the tune variation along the train if

a) there is a perturbation with revolution period, b) perturbation depends on the test particle offset (FB/e-cloud/asymmetry)

which give bunch detuning comparable with the CB mode splitting.

2.3 Variation of the tune with current

$$\frac{dQ_\perp}{dI_{beam}} \propto \frac{1}{n_b}\sqrt{\frac{R}{\sigma_B}} + \frac{\Gamma(1/4)}{\sqrt{1-Q_\perp}} + A, \tag{3}$$

where the 1st term is the single bunch effect, the second is mutibunch effect, and the last is the asymmetry effect.

The last term gives the dominant contribution for PEP-II.

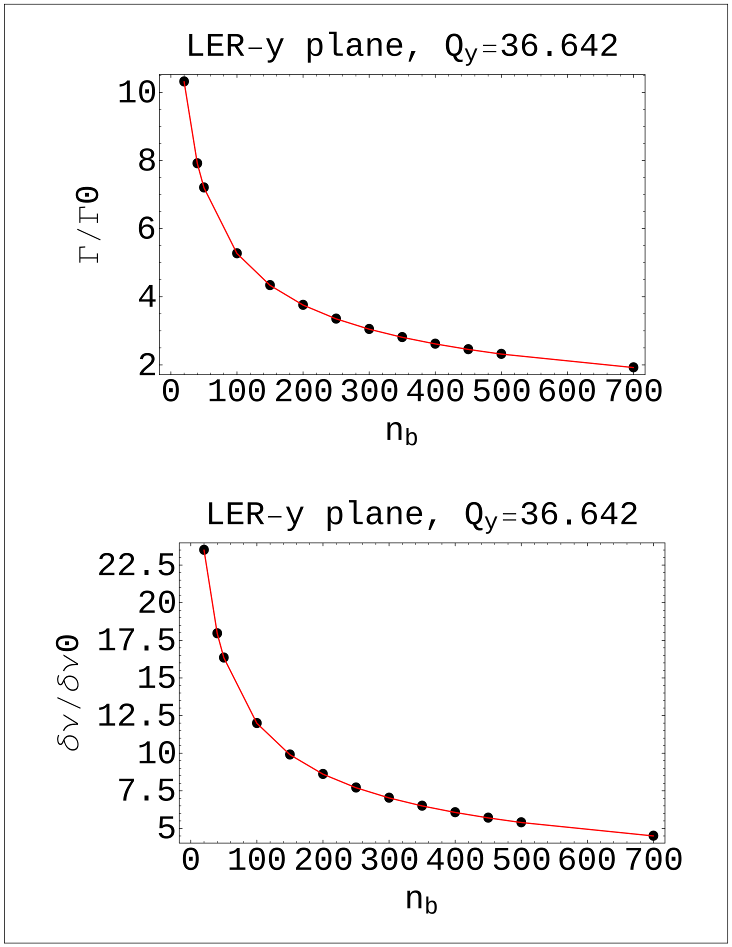


Figure 8: Growth rate and the tune shift as function of the number of bunches for a fixed beam current and bunch spacing.

2.4 Tune dependence on the beam pipe symmetry

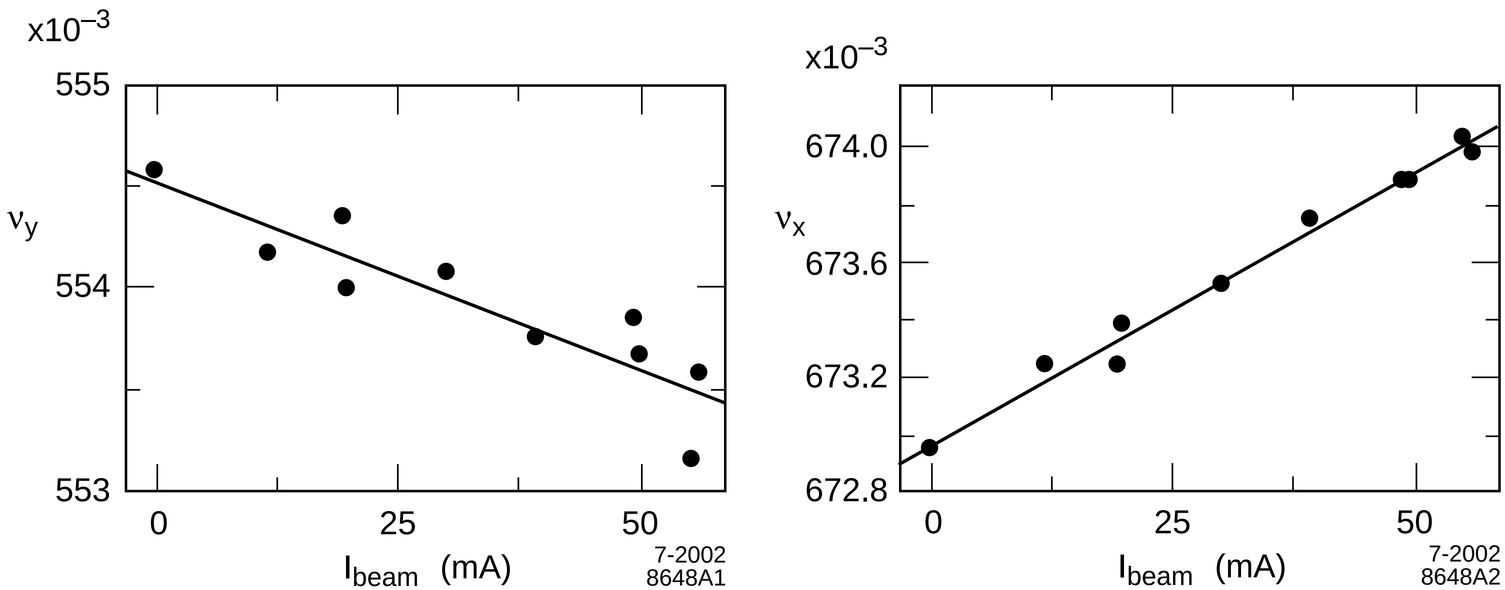


Figure 9: Measured tune variation with current

Without Quadrup. Field :

Theory : $d\nu / dI$, (1 / mA)	LER	HER
x	$-0.036\ 10^{-5}$	$-0.015\ 10^{-5}$
y	$-0.103\ 10^{-5}$	$-0.041\ 10^{-5}$

With Quadrup. Field, Fe + Cu :

Theory : $d\nu / dI$, (1 / mA)	LER	HER
x	$1.62\ 10^{-5}$	$0.80\ 10^{-5}$
y	$-1.41\ 10^{-5}$	$-2.45\ 10^{-5}$

Experiment :

Exper : $d\nu / dI$, (1 / mA)	LER	HER
x	$2.1\ 10^{-5}$	$2.0\ 10^{-5}$
y	$-1.5\ 10^{-5}$	$-2.0\ 10^{-5}$

Compare with LER single bunch (J. Turner) :

$d\nu_y / dI = -0.00226$, (1 / mA)

$d\nu_x / dI = -0.00131$, (1 / mA)

Figure 10: Resuts of the calculations with the model of the quadrupole wakes.

2.5 Variation of the β-function and dispersion

Effect of the tune variation on the L (MAD calculations, $Q_x = 38.518$):

$$\begin{aligned} \frac{dD_x^*}{dQ_x} &= 4.\,10^{-2}, \\ \frac{1}{\beta_x^{max}}\,\frac{d\beta_x^{max}}{dQ_x} &= 1.62, \\ \frac{1}{D_x^{max}}\,\frac{dD_x^{max}}{dQ_x} &= 0.15. \end{aligned} \tag{4}$$

3 Conclusion

• The optical effects of the wake fields are needed to explain some experimental observations.

• At large currents, their effect is not reduced to the growth rate only.

• Wake can affect the beam dynamics in the non-resonant way

We appreciate discussions with A. Chao and Y. Nosochkov