Impedance Measurement at KEKB

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OUTLINE

(1) Introduction
- Basic formulas for measuring the impedance

(2) Longitudinal Impedance
- Synchronous phase shift ->Loss factor, Resistive impedance
- Bunch lengthening -> Inductive impedance

(3) Transverse Impedance
- Betatron tune shift -> Imaginary part of Impedance

(4) Multi-bunch effects
- Remarkable Phenomena

(5) Summary

(1) Introduction

1 LONGITUDINAL

1.1 Loss Factor: related to real part of longitudinl impedance

defined as $K(\sigma)=\frac{1}{\pi}\int_0^{\infty} Z_r(\omega)e^{-(\omega\sigma)^2}d\omega$ using $k(\sigma)=\frac{V_c\cos\varphi_{s0}}{T_0}\frac{\Delta\varphi_s}{I_b}$

1.2 Bunch Lengthening: related to imaginary part, assuming $\Delta\varphi_s \approx 0$

$$(\frac{\sigma}{\sigma_{L0}})^3-(\frac{\sigma}{\sigma_{L0}})=\frac{\sqrt{\pi}I_b}{2hV_c\cos\varphi_s}(\frac{R}{\sigma_{L0}})^3(\frac{Z_i(\omega)}{n}) \qquad \frac{Z_i(\omega)}{n}=\omega_0 L$$

2 TRANSVERSE

$$\{Z_\perp\}=\frac{\sum_{p=-\infty}^{\infty} Z_\perp(\omega_p)h_m(\omega_p-\omega_\xi)}{\sum_{p=-\infty}^{\infty} h_m(\omega_p-\omega_\xi)}$$, depend on chromaticity

2.1 Tune Shift : related to imaginary part of transverse impedance

$$\Delta\nu_\beta=\frac{\langle\beta\rangle R I_b\{Z_{\perp i}\}}{4\sqrt{\pi}\sigma_l E/e}$$

2.2 Threshold of Mode-Coupling Instability, related to tune shift

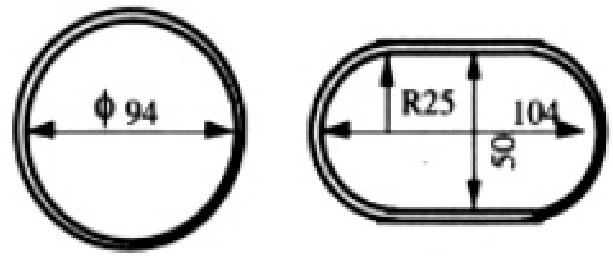
$$I_{th} \approx \frac{8}{\sqrt{\pi}} \frac{\nu_s \sigma_l E/e}{\langle\beta\rangle R\{Z_\perp\}}$$

3 Simple Relation between longitudinal and transverse

$$Z_{\perp 1}(\omega) = \frac{2c}{b^2\omega} Z_{\| 0}(\omega) \quad \text{or} \quad Z_{\perp 1}(\omega) = \frac{2R}{b^2}\left|\frac{Z_\|}{n}\right|$$

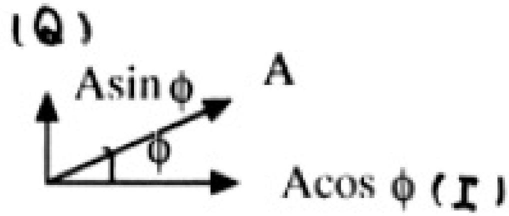
<<< Features of KEKB >>>

- Electron with 8 GeV (HER), Positron with 3.5 GeV (LER)
- **Low α, an order of 10^{-4} -> short bunch length of 4 mm in design**
- **Cross section of the chamber**



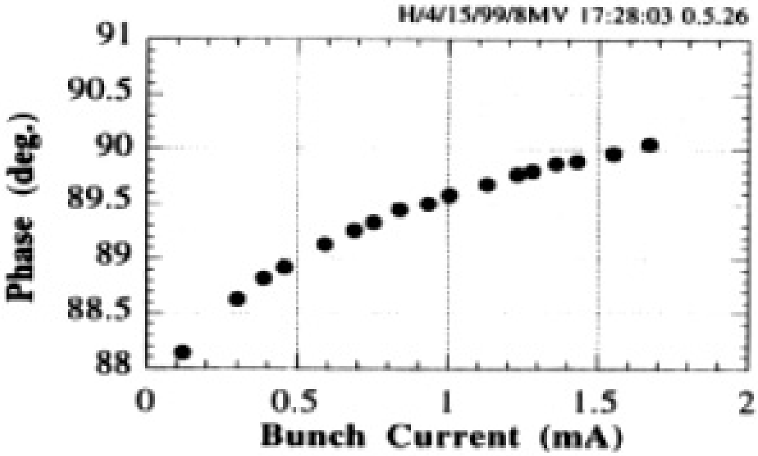
LER HER

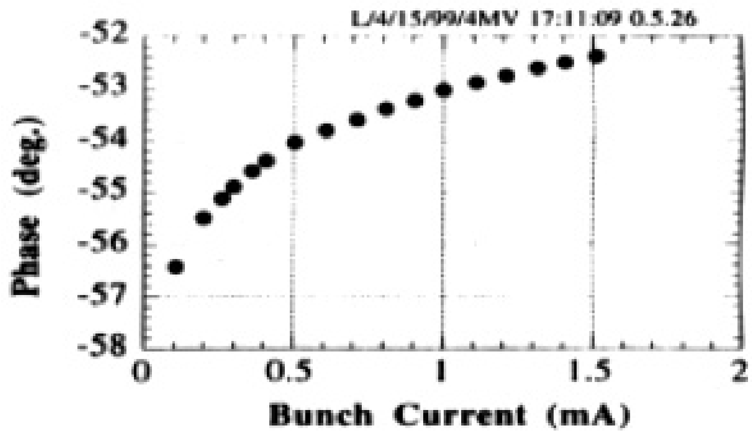
(2) Longitudinal Impedance



The bunch phase was measured using an I/Q demodulator.

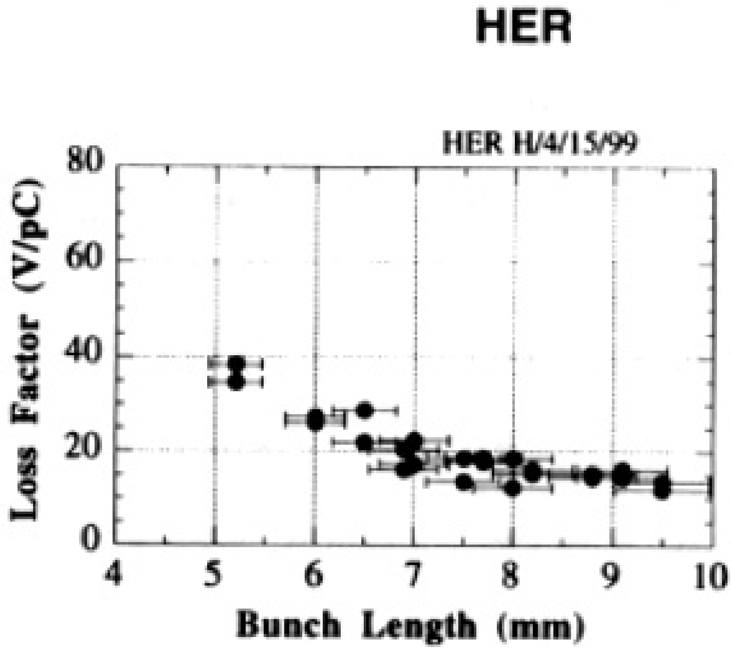
HER σ0=5.0mm @Vc=8MV   **-measured in April '99 -**   **LER** σ0=5.1mm @Vc=4MV

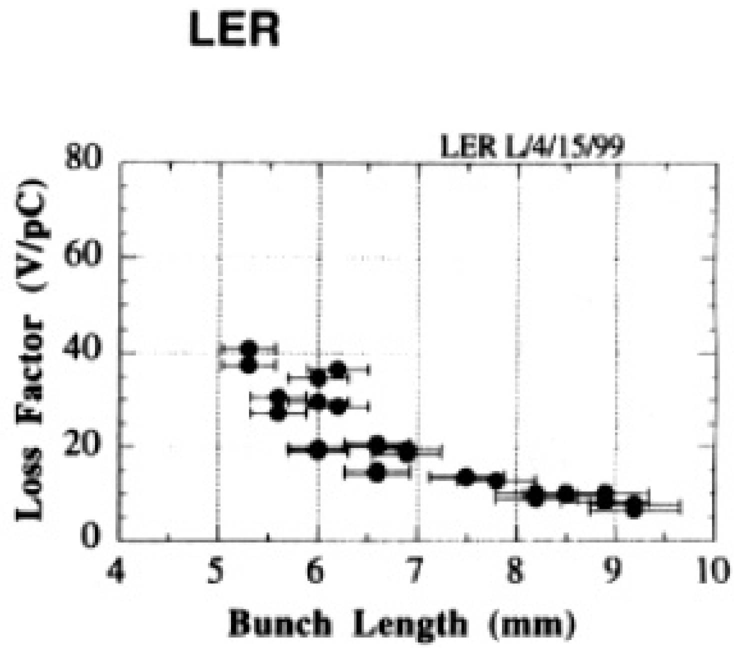




-> The slope is proportional to the loss factor.

Loss Factor vs. Bunch Length





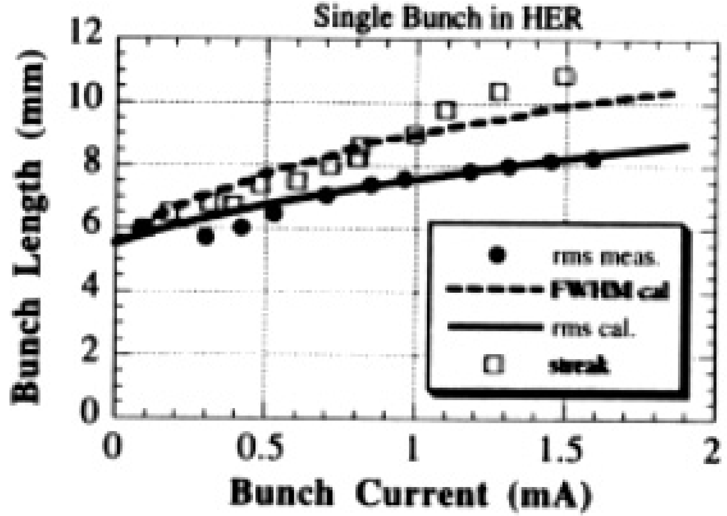
-> The loss factor is k=20 - 30 V/pC @ σ = 6 - 7 mm in both rings
Beam loss power is P_{beam} = 170 - 260 kW @ 1A

-> It is hard to estimate loss factor at σ = 4 mm.
but, would be much higher than the design!

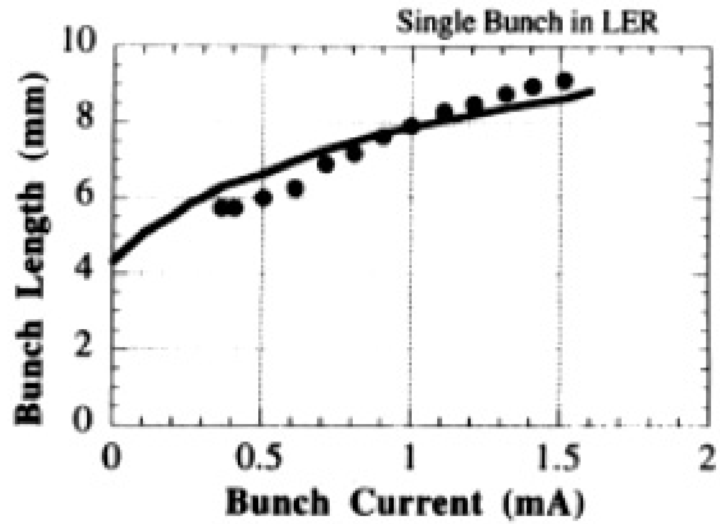
Bunch Lengthening

A ratio of two frequency components gives an rms bunch length, under $\omega\sigma$<1.

HER



LER



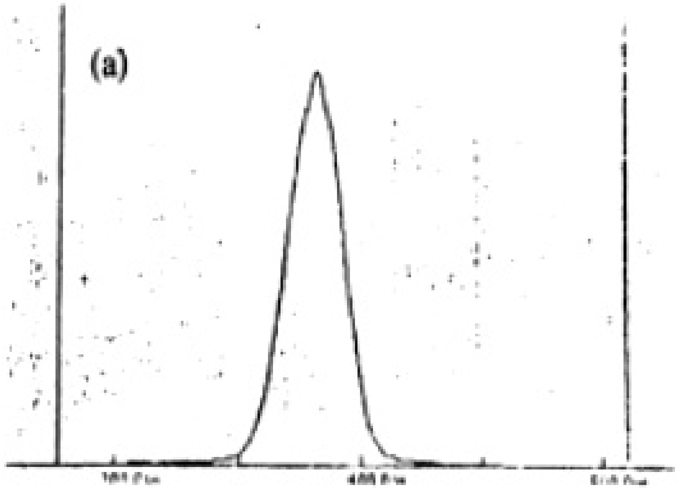
Lines are calculated bunch length, assuming $|Z_i/n|$ = 0.076 Ω for HER and $|Z_i/n|$= 0.072 Ω for LER. -> good agreement in HER -> rough agreement in LER

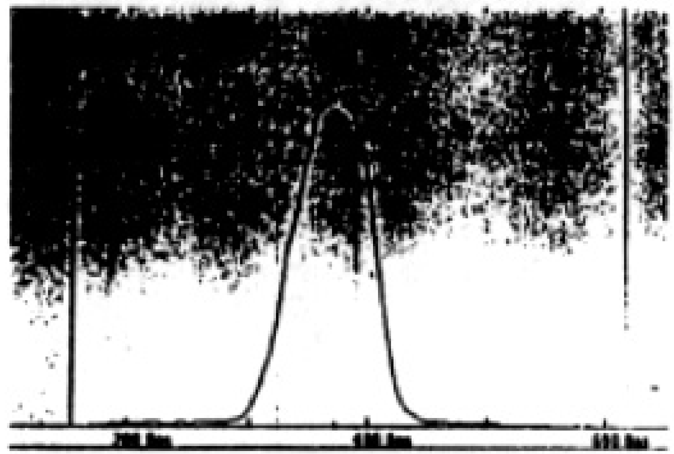
Measured impedance of both rings is 5 times larger than the design of 0.015 Ω.

-> Transverse impedance is expected to be 31 kΩ/m in LER.

by courtesy of J. Flanagan

Bunch Profile taken by a streak camera at HER





(a) Ib=0.2 mA

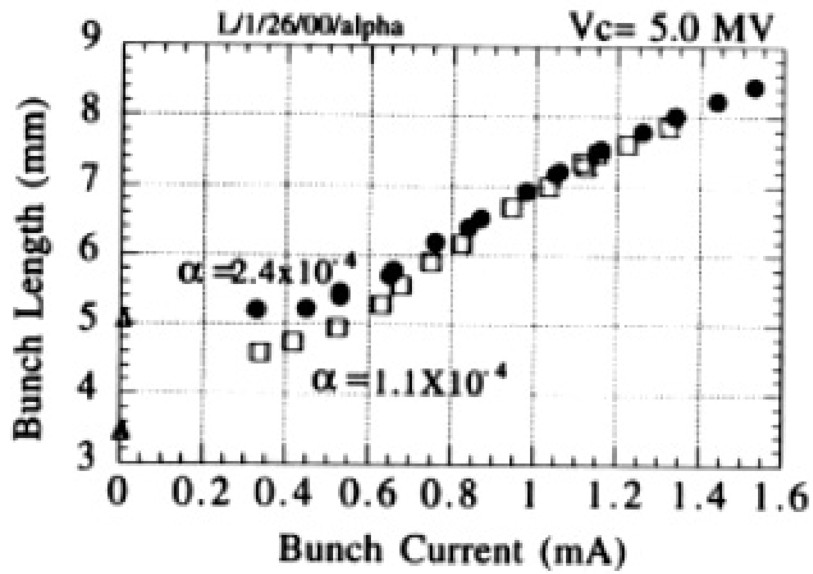
sharp peak (Gaussian)
symmetric distribution
FWHM=51.0 ps

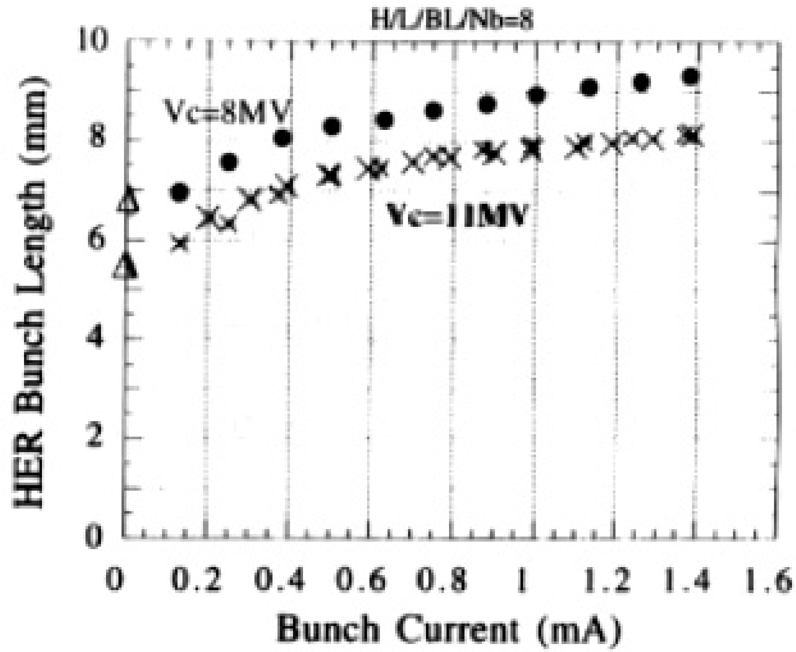
(b) Ib=1.1 mA

roundish peak (parabolic)
a small asymmetry
FWHM=76.9 ps

To make a shorter bunch length

Reducing α | **Raising RF voltage**

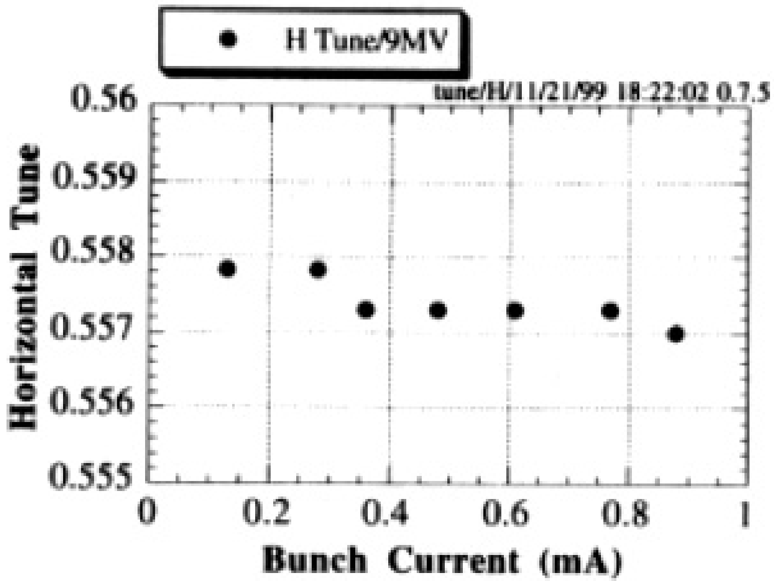


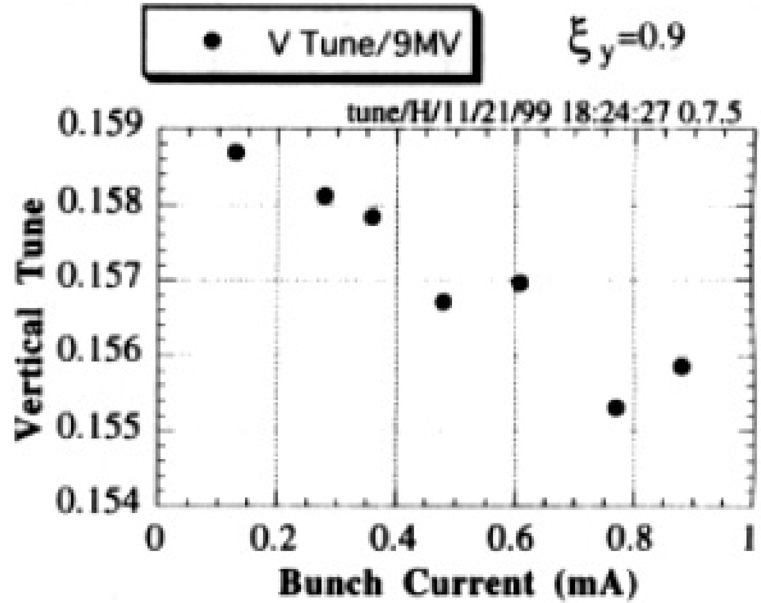


-> **Raising the RF voltage is more effective than reducing α.**

(3) Transverse Tune Shift

Horizontal　　　　HER　　　　Vertical



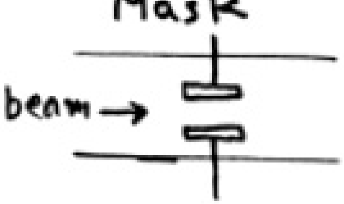


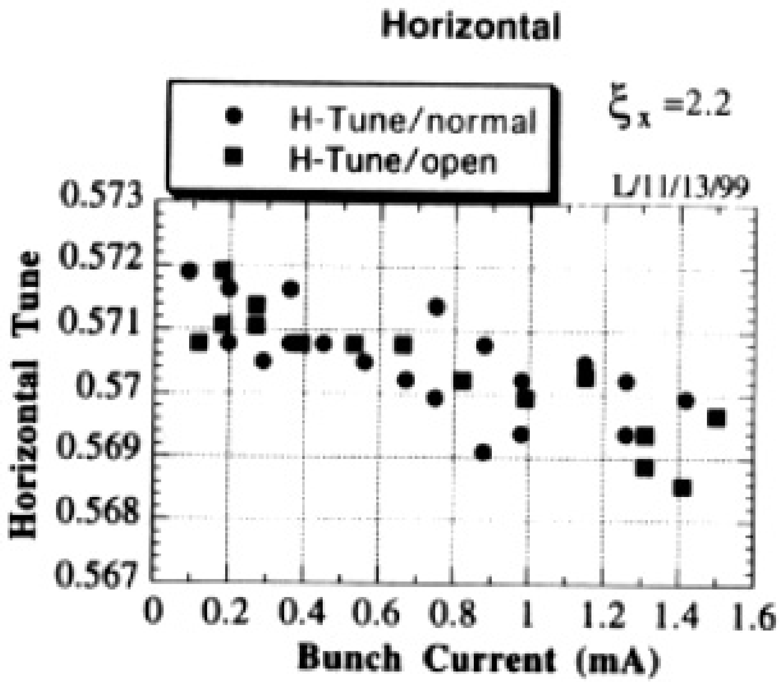
$\Delta\nu x$ -0.001 /mA　　　　**$\Delta\nu y$ -0.004 /mA**

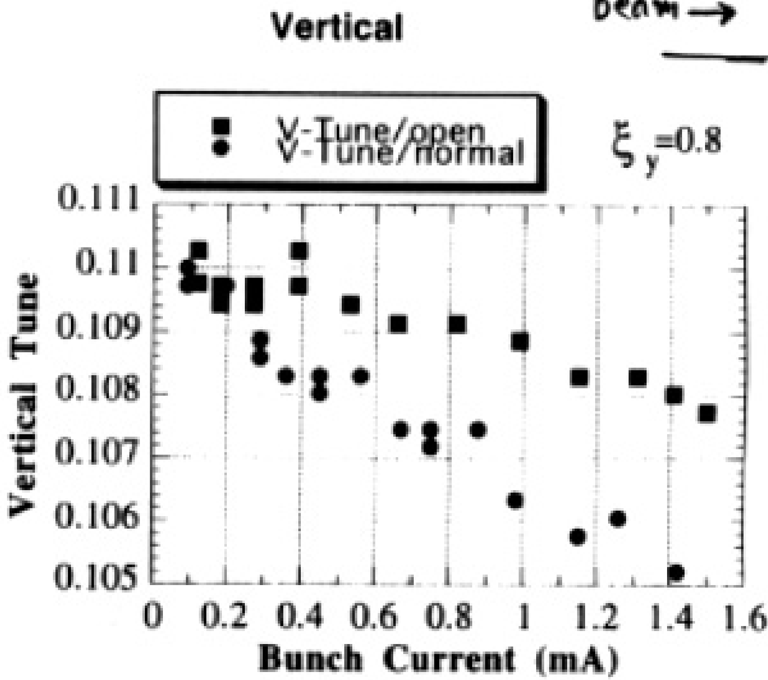
Impedance ($Z_\perp$) : **25 - 34** $k\Omega/m$ **<<** **243 - 283** $k\Omega/m$

,depends on bunch length.

Transverse Tune Shift at LER







$\Delta\nu x$ = -0.001 ~ -0.0015 /mA **$\Delta\nu y$ = -0.0014 /mA open -0.0034 /mA normal**

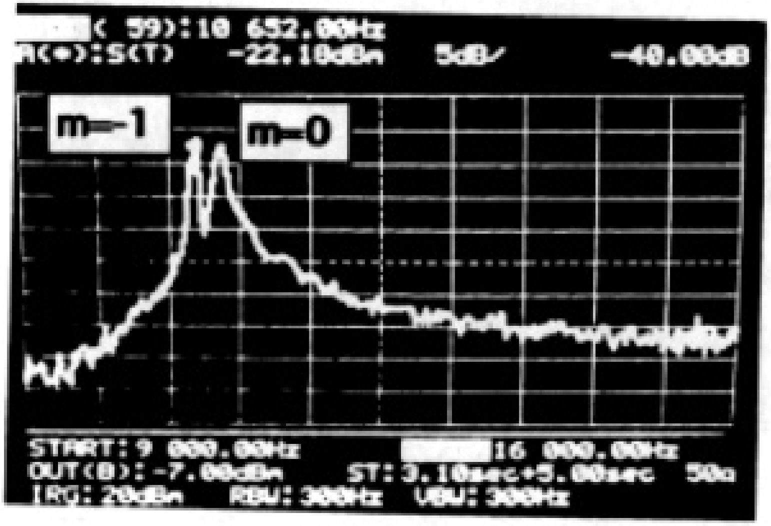
Design : -0.0004 /mA from KEK report 95-7 p.5-12

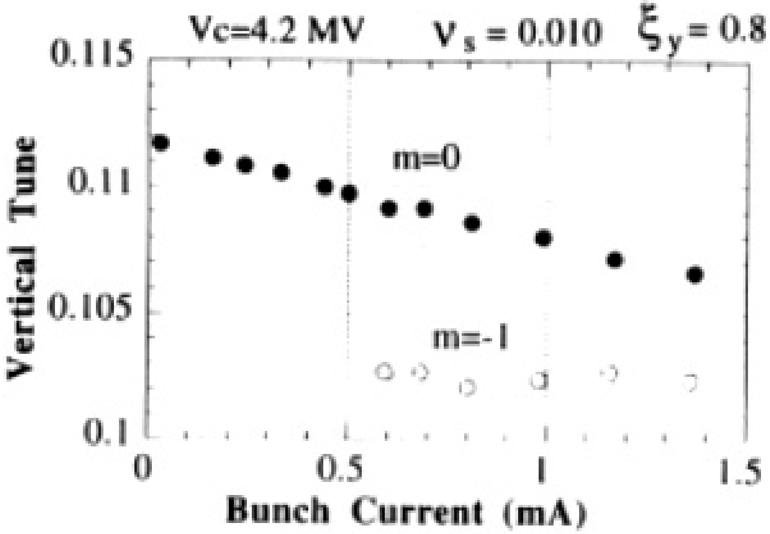
Impedance ($Z_\perp$) : H: 25 - 51 $k\Omega/m$

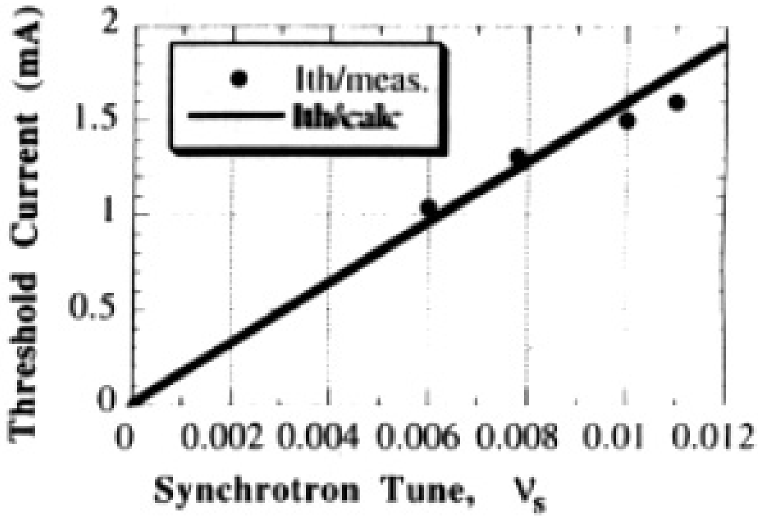
V: 33 - 46 $k\Omega/m$ /open,
V: 80 - 139 $k\Omega/m$ /normal

Measured tune shift is 3 to 4 times in fully opened masks (movable collimators) and 9 times in normal condition larger than the design value.

Transverse Mode-Coupling Instability





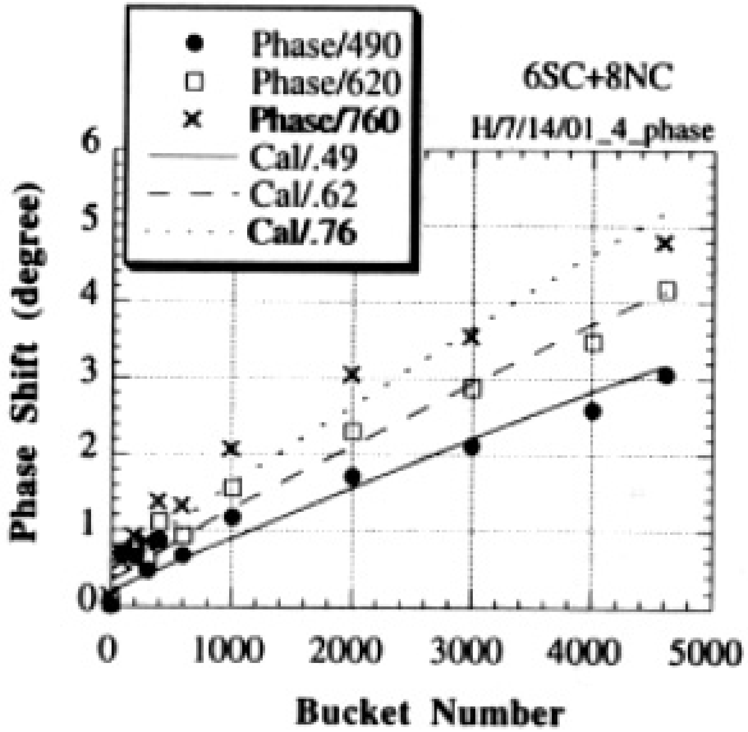


(4) Multi-bunch Efffects

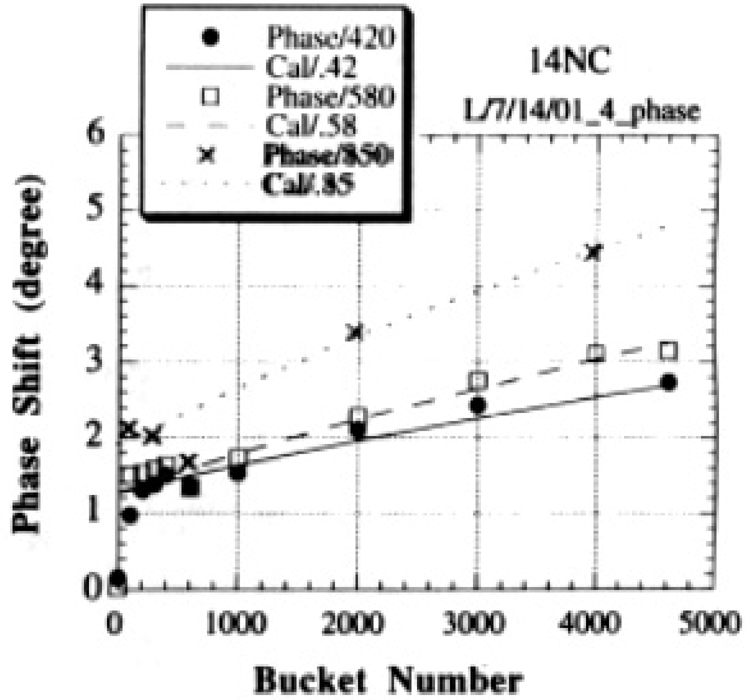
Usually 4-bucket spacing (8ns), Nb=1153

4.1 Transient Beam Loading with 10% Gap

HER

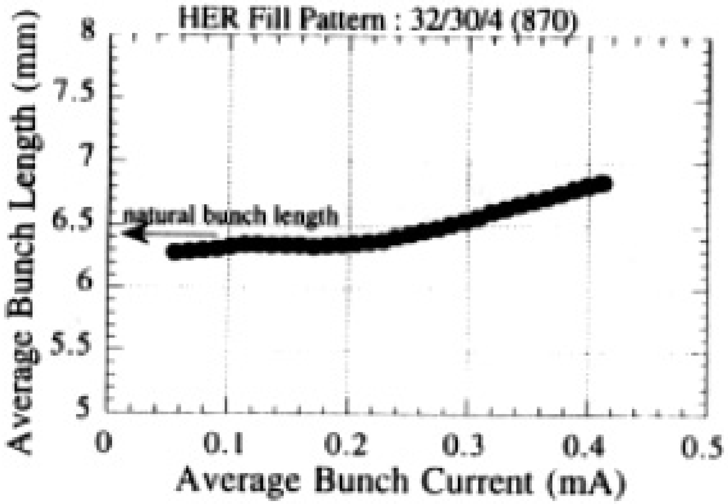


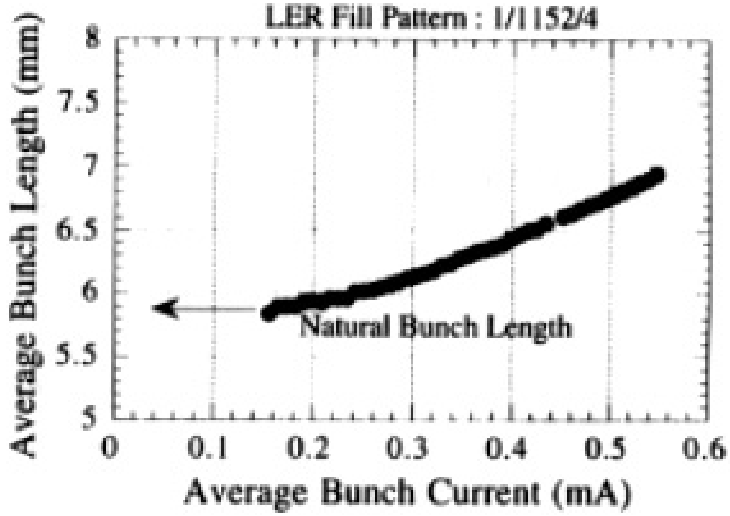
LER



-> Good agreement with calculation except in the leading part of train.

4.2 Bunch Lengthening in Multi-Bunch Mode



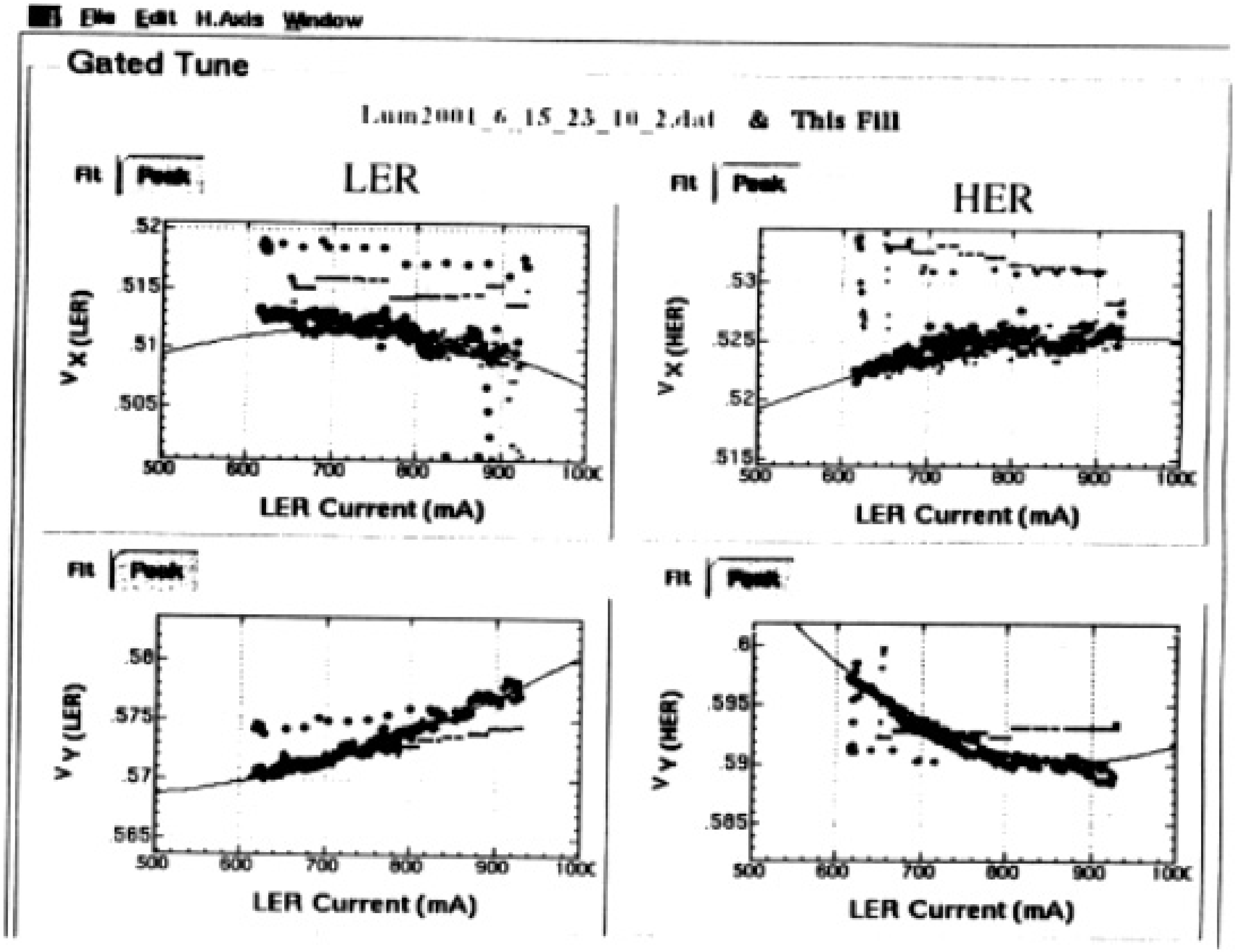


-> Bunch lengthening is similar to that in a single bunch.

-> No dfference between collision and non-collision.

> No significant dfference between 3- & 4- bucket spacing.

4.3 Tune Shift for non-collision bunches



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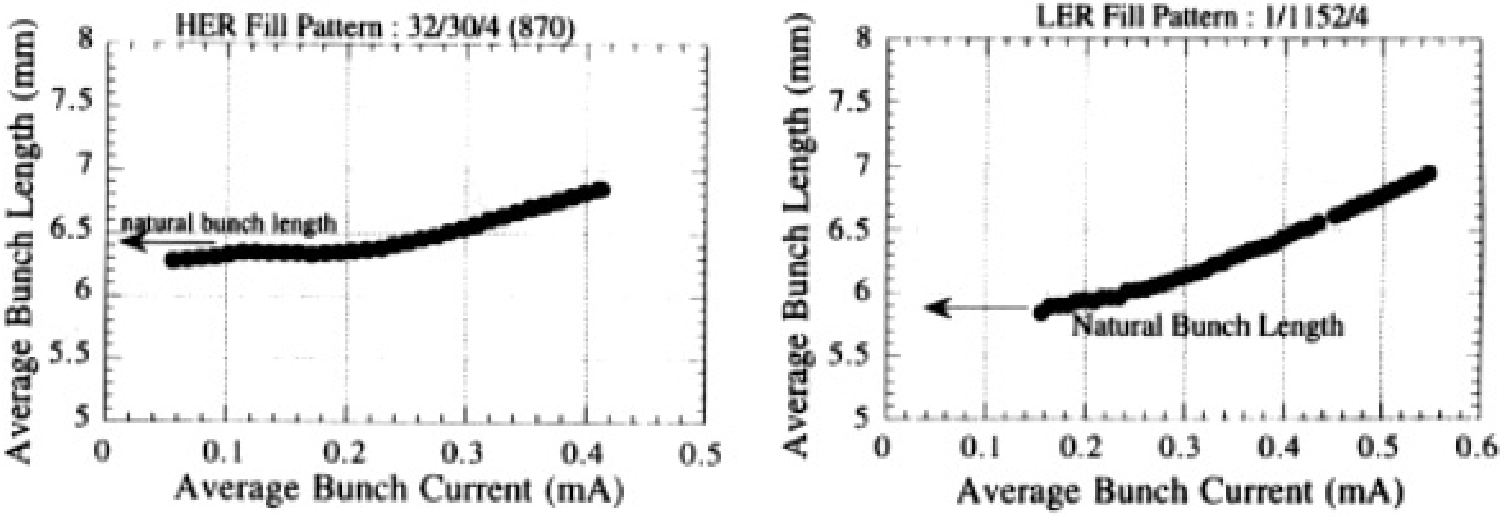

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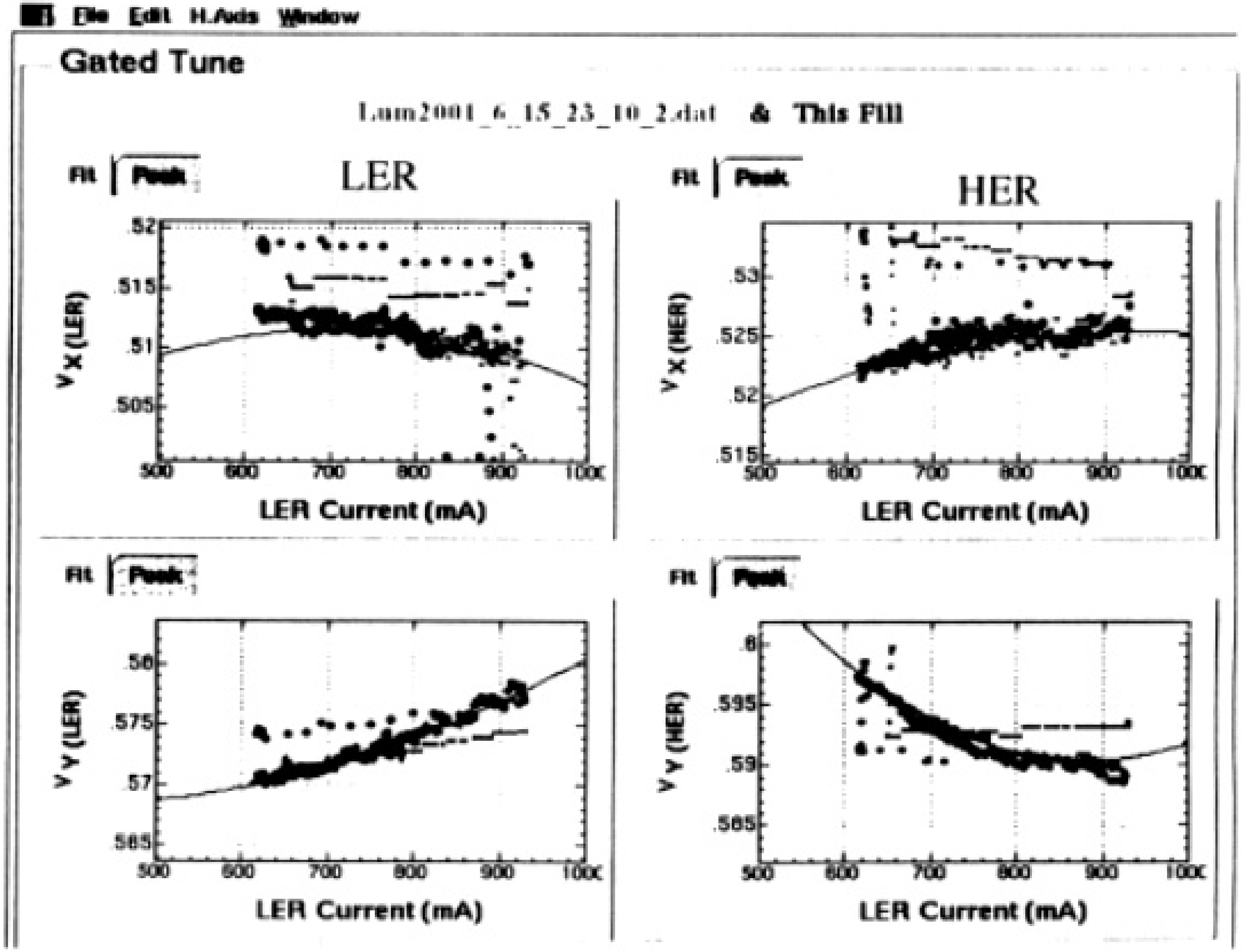
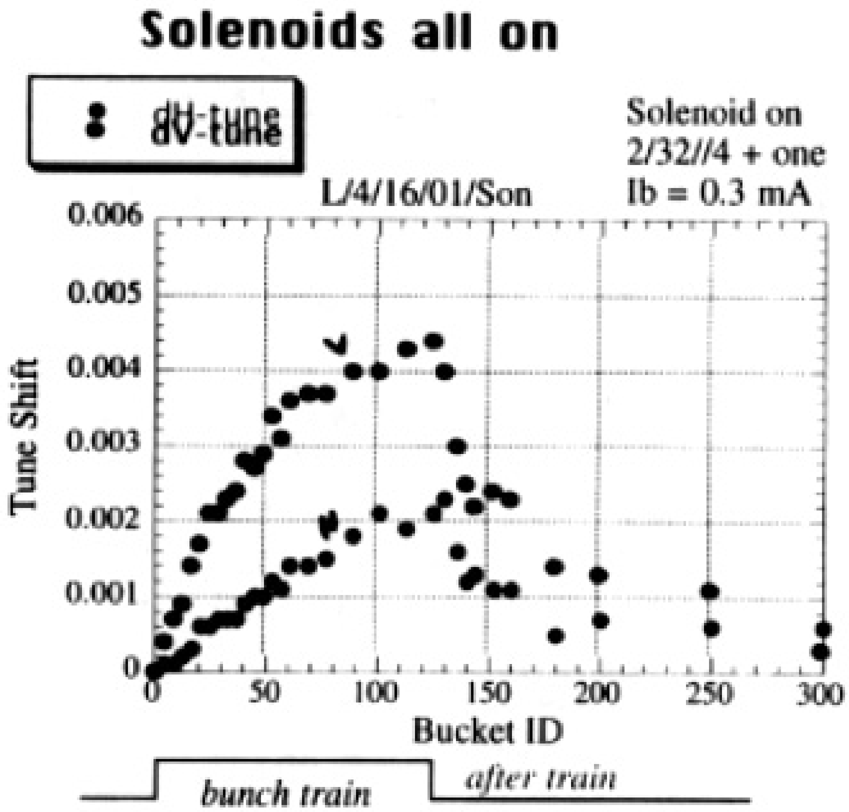
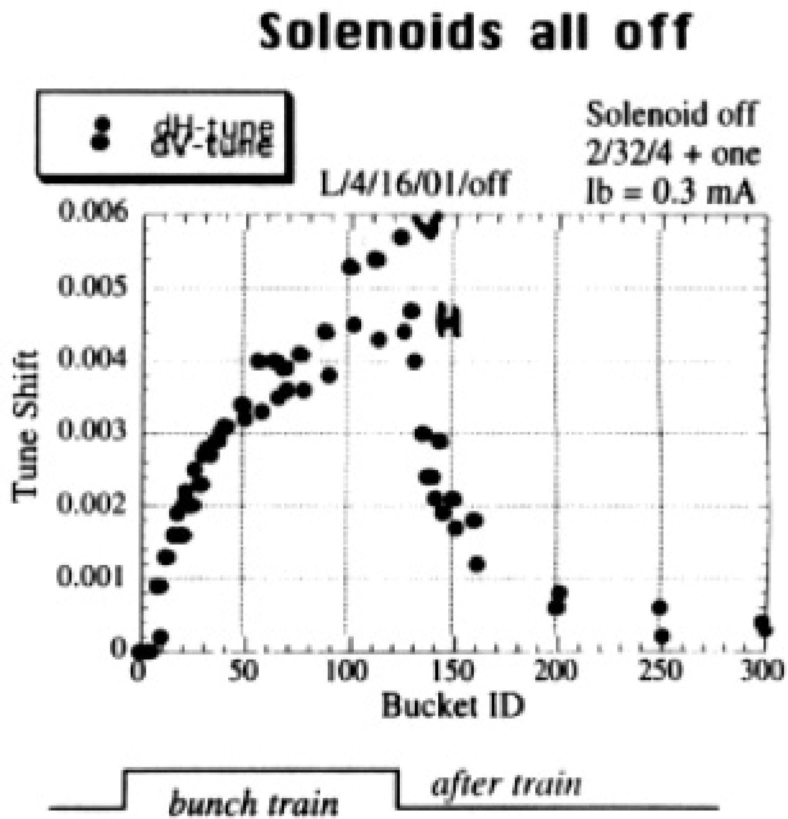


Tune Shift in LER





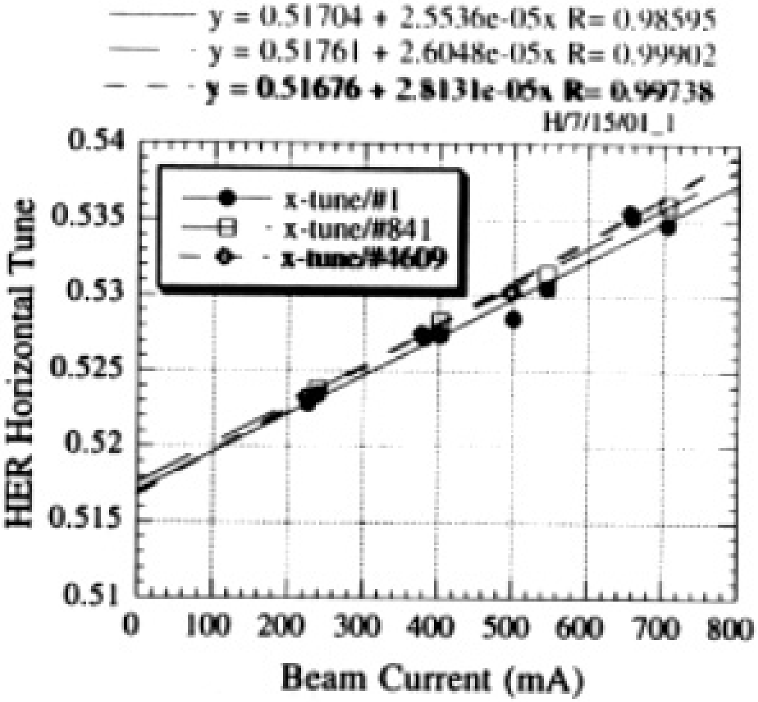
measured in April 2001

-> The tune depends on where a bunch is placed, which is affected by the electron cloud.

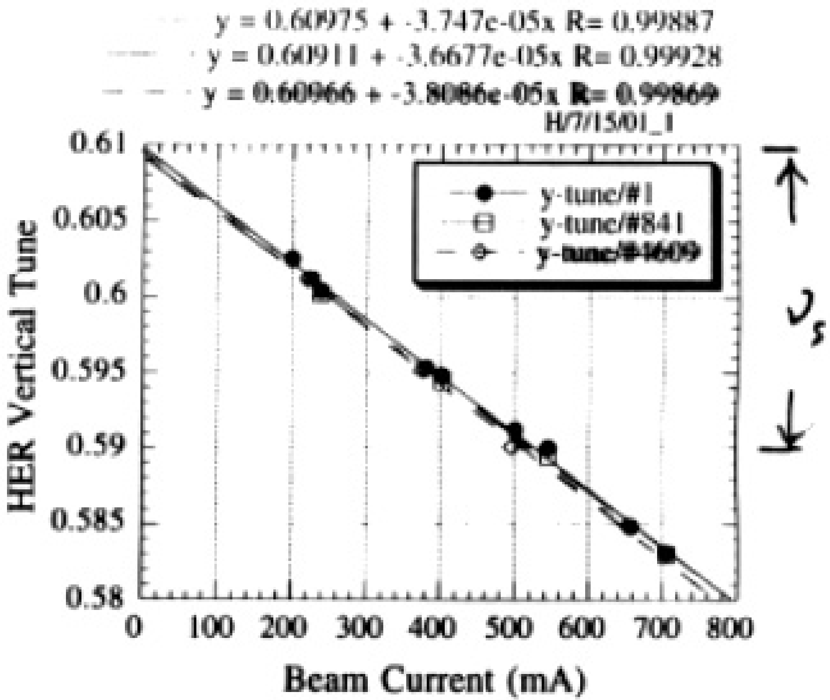
Tune Shift in HER (Multi-bunch)

ξx=0.97 ξy=5.41

Horizontal



Vertical

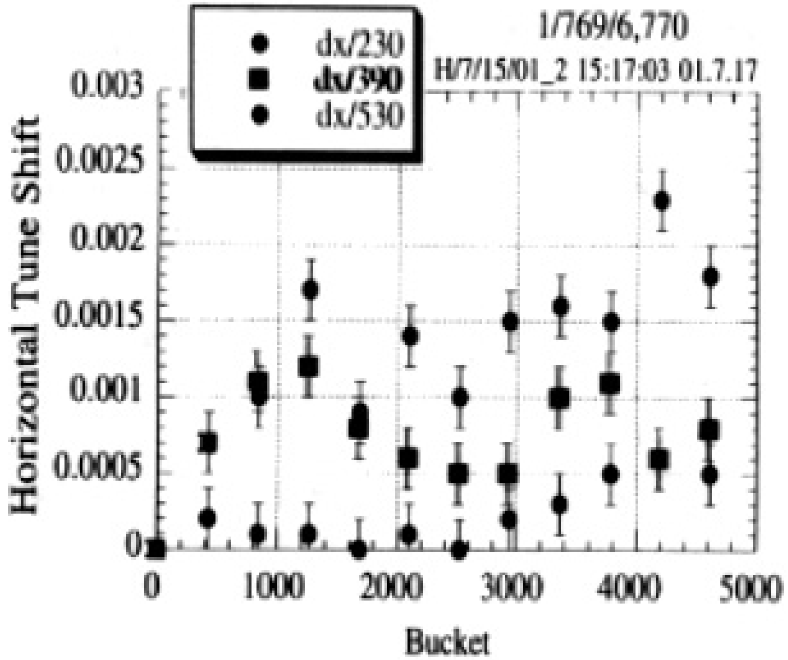


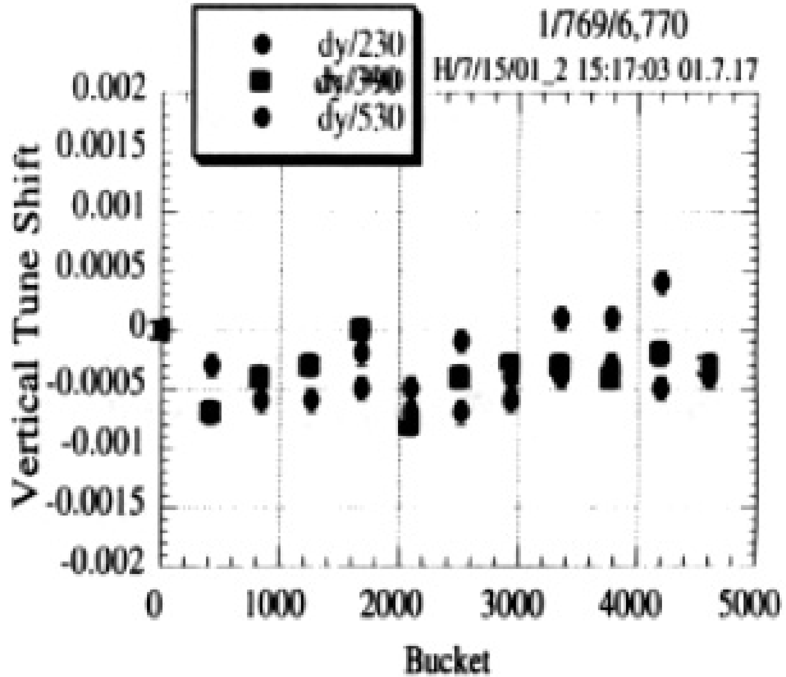
-> Tune shift depends on the beam current.

-> Focusing in horizontal and defocusing in vertical.

-> A quadrupole field is induced by the beam.

Tune Shift along Train at HER





-> No sign of ion effects.

-> Similar results to the ESRF.

Summary

Impedance:

- Measured longitudinal impedance $|Z_{\|i}/n|$ is 5 times higher than the design. This unexpected high impedance affects the transverse tune shift. The mode-coupling instability was observed in a small ν_s.

- The measured loss factor is 20 to 30 V/pC, an expected value. This is because the bunch length is longer than the design.

- Tune shifts show all negative slopes, Masks in LER dominate vertical impedance, *i.e.*, 33-46 kΩ/m /open and 80-139 kΩ/m /normal.

- Transverse impedance with fully opened masks in LER is consistent with the value estimated from longitudinal impedance

Multi-Bunch Effects:

- No significant change in the bunch length.
- Transient beam loading was measured, rapid increase in the leading part.
- The tune in LER is affected by the electron cloud.
- The tune shift in HER should be affected by an induced quadrupole field.