Beam Measurements

T. Ieiri

Thankful contributions by:

H. Fukuma, H. Ikeda, Y. Ohnishi, K. Oide and M. Tobiyama

>Topics I : **Beam Measurement near a Half-Integer** (page 2 to16)

Topics II : **Measurement of Wake Effects using Tune Shift** (page 17 to 29)

Part I

Beam Measurement near a Half-Integer

Outline

>>>>

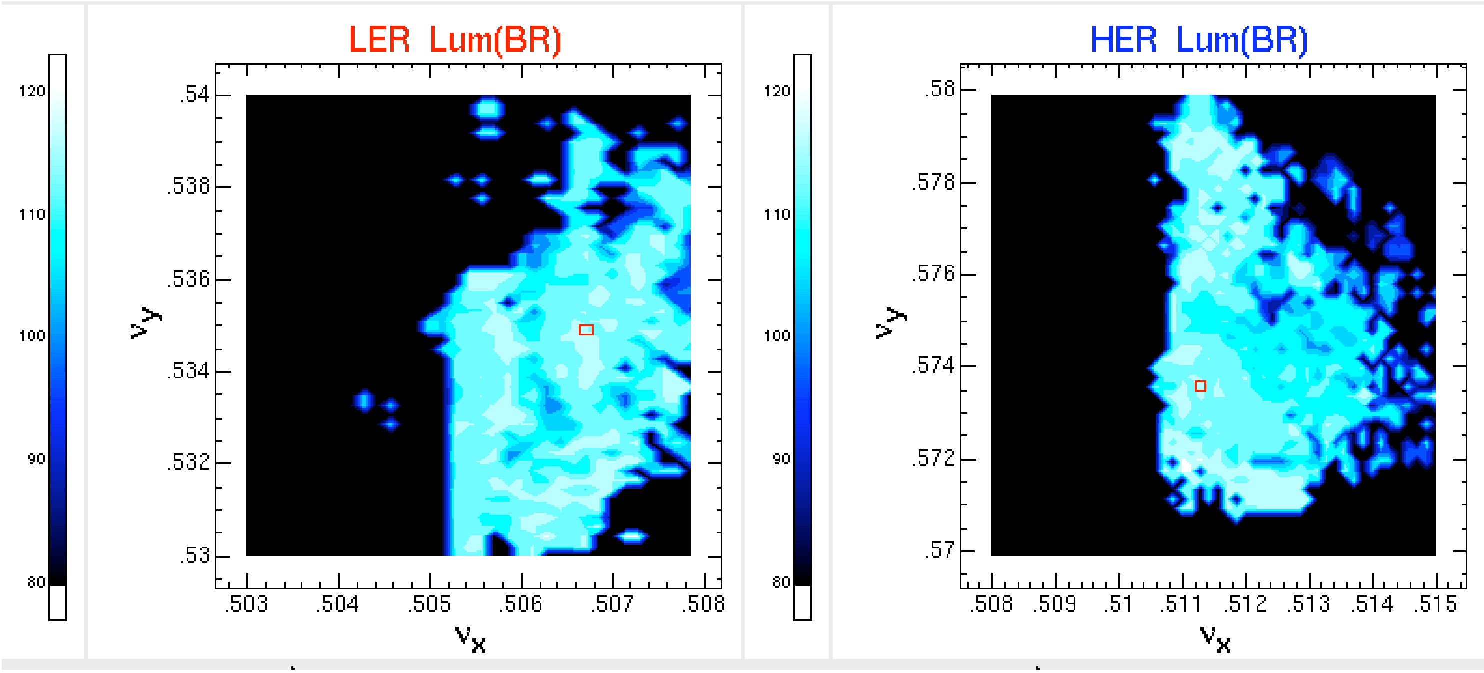
- Backgrounds
- Beam Dynamics near a Half-Integer
  - Dynamic Beam-Beam Effects
  - Half-Integer Stopband
- Measurement 1: tune spectrum
- Short Summary
- Measurement 2: beam size
- Short Summary

Backgrounds

- The beam-beam parameter reaches a high level of ξ_x=0.1.
- The operation point of the horizontal tune is set very near a half-integer.
- Dynamic beam-beam effects result in heavy distortion in optics, emittance growth and beta beat.
- On the other hand, approaching a half-integer, we would encounter the stopband, beta beat, and synchro-beta resonance.

  No machine exists without errors.
- These are attractive issues from viewpoint of beam dynamics.

Tune Diagram in Operations



- The operating points are crucial for tuning the luminosity.
- Severe wall in the horizontal tune.

Dynamic Beam-Beam Effects

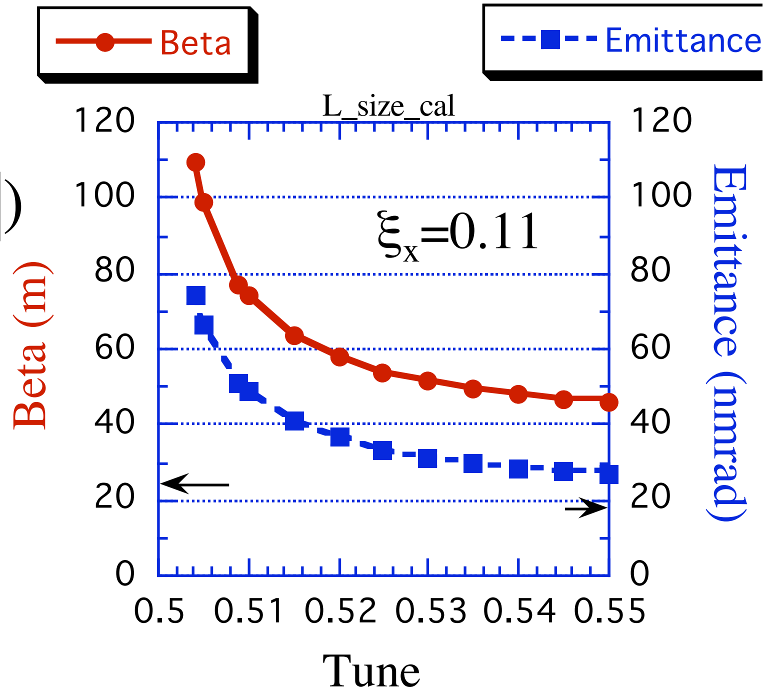
- Beta and emittance change as a function of the tune.

- Dynamic Beta

$$\Delta\beta(s) = \frac{\beta_0(s)\ \beta^*}{2 sin(2\pi\nu)} \Delta k^* \cos(2\pi\nu - 2|\Delta\varphi_s|)$$

- Dynamic Emittance

$$\varepsilon_x \approx \frac{1 + 2\pi\xi_x \cot 2\pi\nu}{\sqrt{1 + 4\pi\xi_x \cot 2\pi\nu - 4\pi^2\xi_x^2}} \varepsilon_{x0}$$

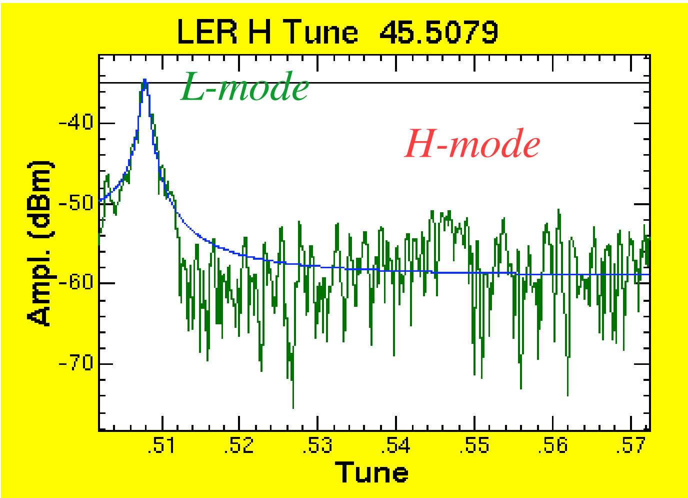


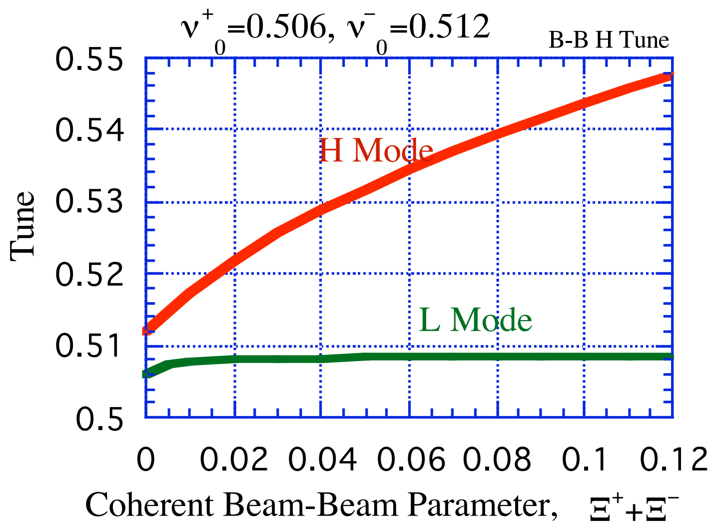
at LER SRM
β_{x0}=24.15 m
ε_{x0}=17.8 nmrad

Beam-Beam Tune Shift

- Beam-beam interaction produces a new set of two tunes.
- We call two modes the *H-mode* and the *L-mode*.
- Coherent beam-beam tune shift: $\Delta\nu_{bb} = \nu_H + \nu_L - \nu_0^+ - \nu_0^-$
- Coherent beam-beam parameter: $\Xi_q^+ + \Xi_q^- = \bar{\xi}_q = \dfrac{\kappa(\nu_0^+, \nu_0^-)}{Y}\Delta\nu_{bb}$

A measurement





Half-integer Stopband

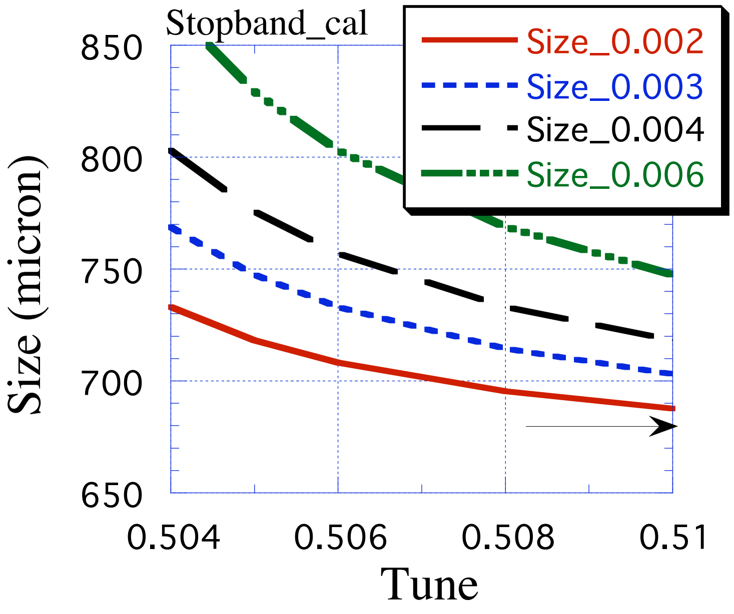
- Gradient errors cause the half-integer stopband and beta beat.
- The beta beat might be estimated from variations of the beam size.

$$\frac{\Delta\beta_{ge}}{\beta_0} = -\frac{\nu}{4\pi}\sum_p \frac{J_p e^{i\nu\phi}}{\nu^2 - (p/2)^2}$$

$$\nu \approx \frac{p}{2} \qquad p \text{ : integer}$$

$$\Delta\beta_{ge} \approx -\frac{1}{2}\frac{|\Delta\nu_{sb}|}{(\nu - p/2)}\cos(p\phi+\delta)\cdot\beta_0$$

$$|\Delta\nu_{sb}| \approx |J_p|/2\pi \text{ : Stopband Width}$$

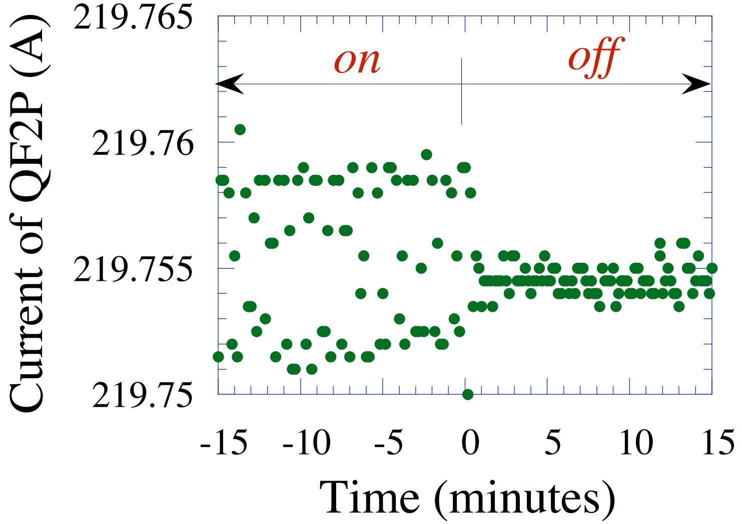


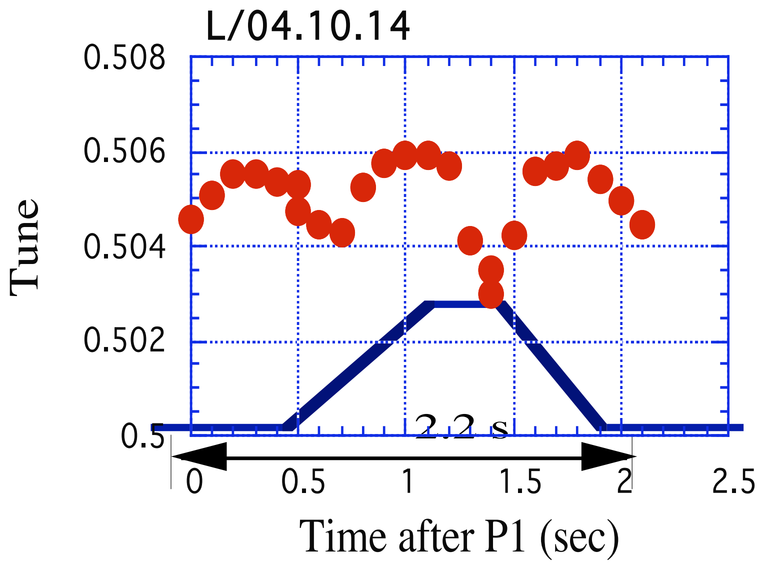
$$\phi = \int \frac{ds}{\nu\beta}$$

Measurement 1 : Distortions by KEK-PS

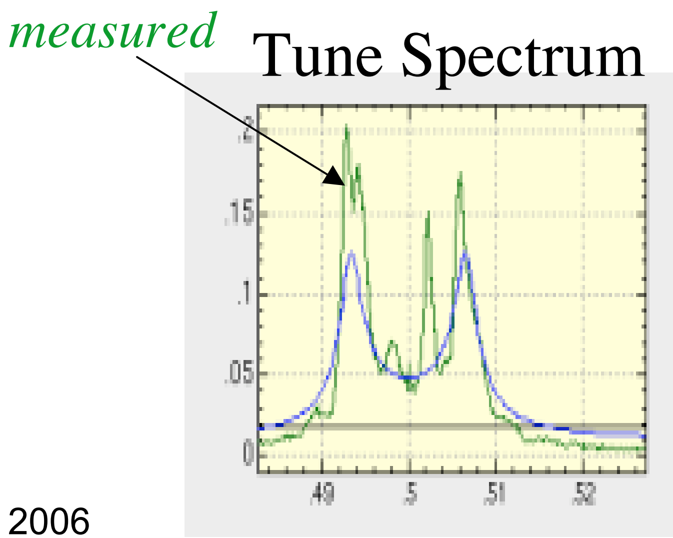
- Power supplies of KEKB was affected by KEK-PS operation.
- Tune varied, synchronized with KEK-PS cycle.
- Tune spectrum was distorted.

Power Supply for Q-Magnets





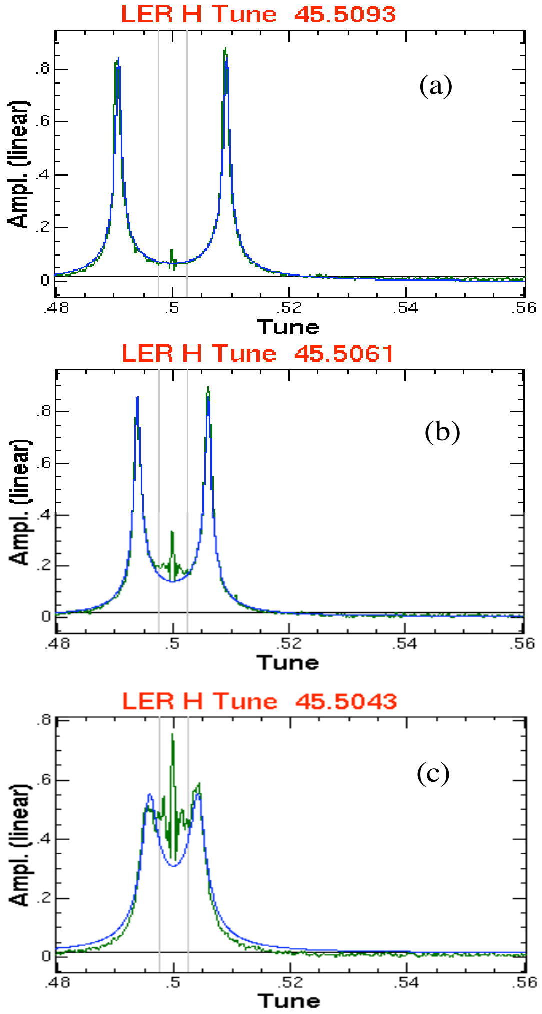
Tune Spectrum



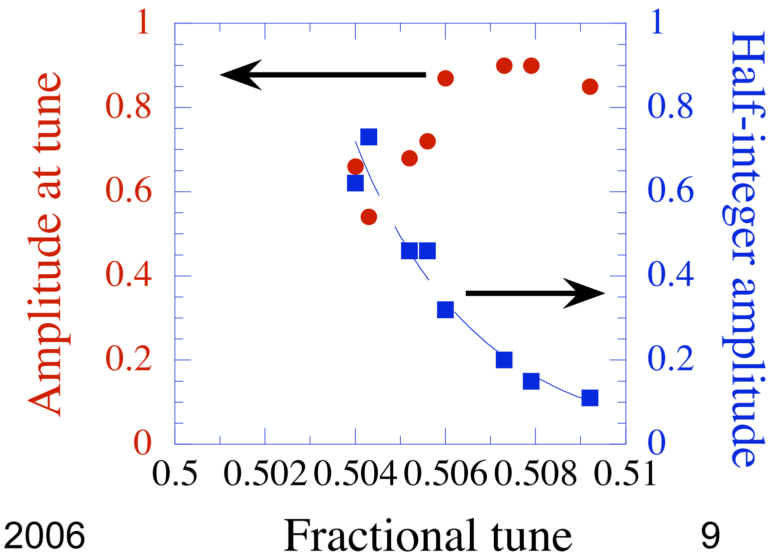
Tune Spectrum (1/2)

The influence of KEK-PS was almost fixed.
We made the tune closer to a half-integer, ---

- A sharp spectrum was observed just on a half-integer.
- As the tune approached a half-integer, the amplitude grew exponentially and the betatron amplitude reduced.

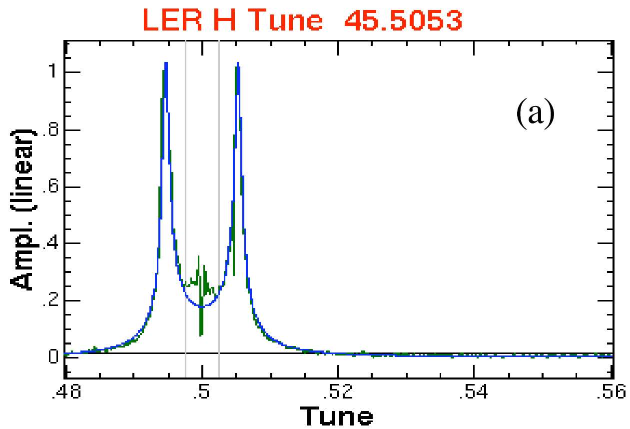


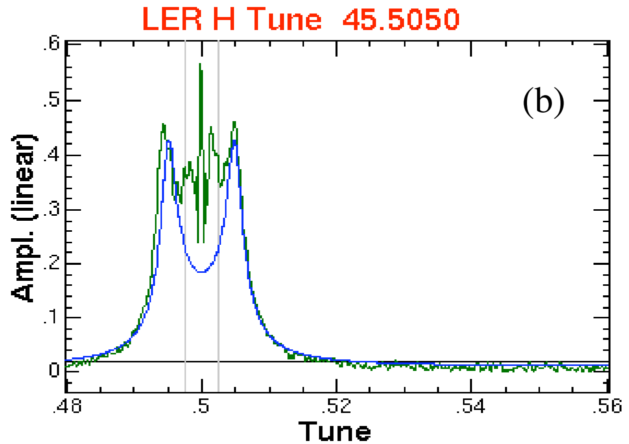
ξ_x=0.94

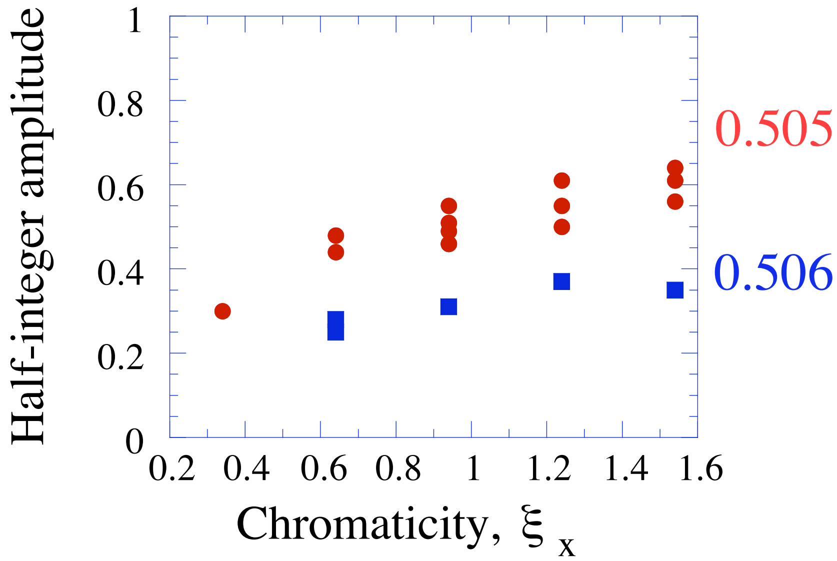


Tune Spectrum (2/2)

- The half-integer spectrum depended on chromaticity.

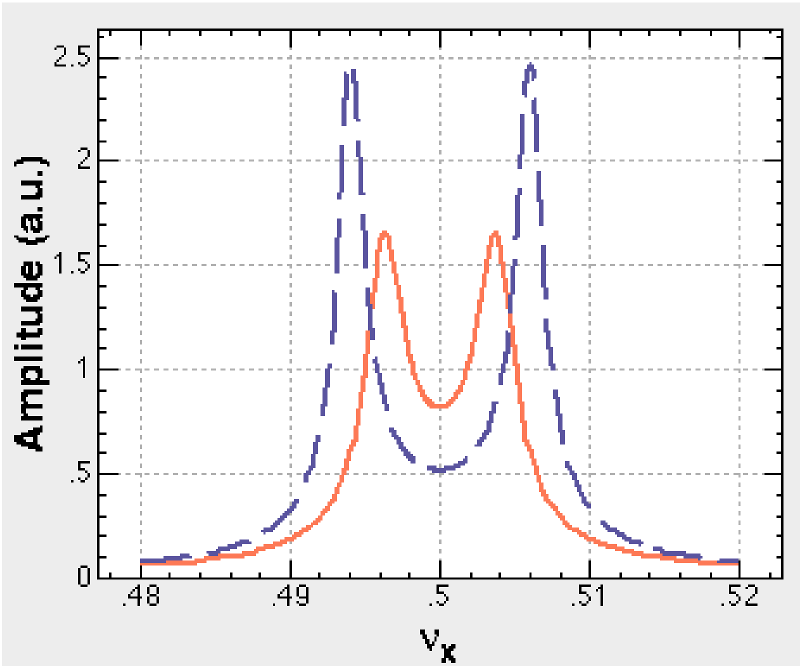






Simulating the spectrum

- The betatron tune spectrum well simulates the real one.
- But, no distortion can be seen at half-integer.



- Conditions -

- Phase relation is the same
- Assuming a single particle
- No machine error

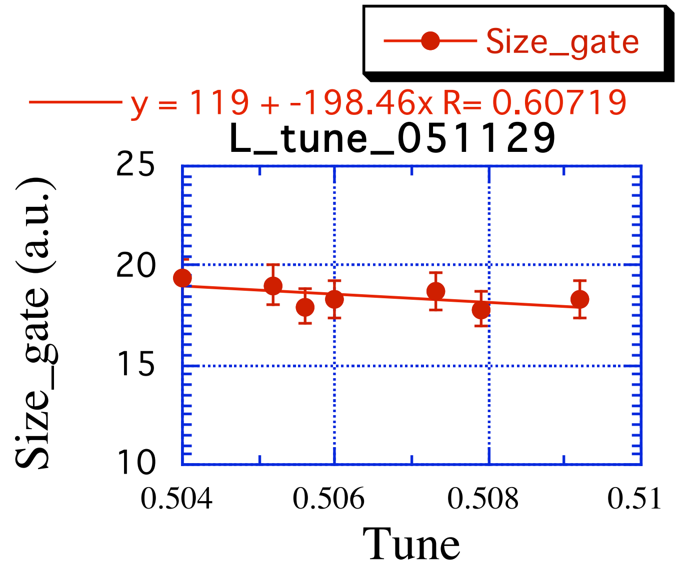
Short Summary on Tune Spectra

- Even though KEK-PS was off, the tune spectrum was distorted.
- The amplitude of the half-integer spectrum depended on the tune and chromaticity.
- However, a simple simulation did not indicate such a spectrum on a half-integer.
- The distortion in the spectrum is caused by off-momentum particles jumped into an unstable region of a half-integer resonance.
- Need to consider dynamics of off-momentum particles.

Size Measurement (1/2)

Non-colliding Bunch

Horizontal size of a pilot bunch was measured using a gated CCD camera.

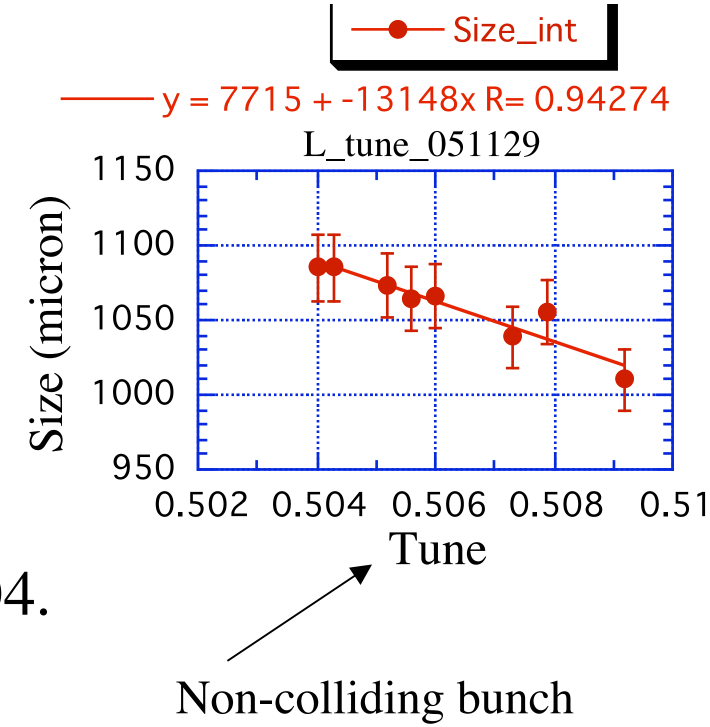


- Linearly fitting line shows horizontal size slightly increases by 6.4% with large error bars, when the tune changed from 0.510 to 0.504.

- Change in the size may suggest an **effective stoband** of $|\Delta\nu_{sb}|\cos(p\phi+\delta)= 0.002$ to 0.003.

Size Measurement (2/2)

Horizontal size of colliding bunches were measured using the interferometer.



- Horizontal size increased by 7.6% when tune changed from 0.510 to 0.504.

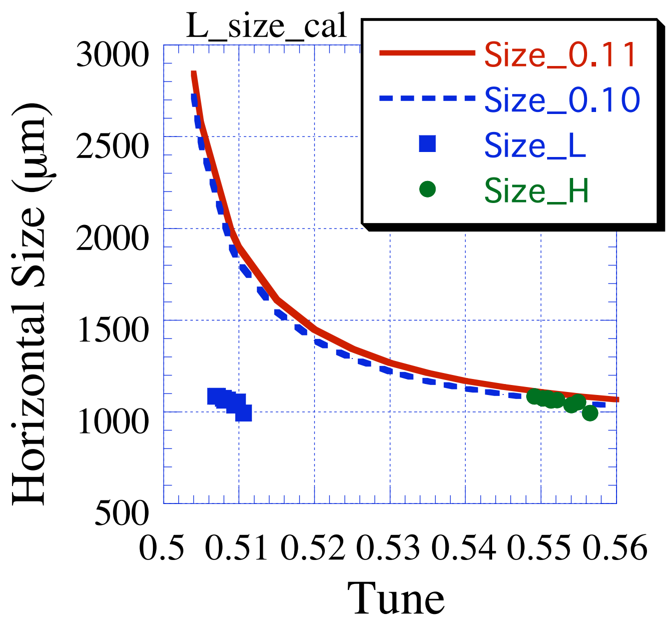
- The measurement might be affected by both dynamic beam-beam and stopband effects

Note:
Tune of colliding bunches is different from that of pilot bunch.

Consideration for Size Measurement in Collision

- Colliding bunches have two modes of tune; L-mode and H-mode.
- Assuming ξ_x=0.11 or 0.10, two tunes can be estimated from unperturbed tunes.
- By using the H-mode tune, measured size agrees with calculated one.
- Effect of stopband would be small.

Dynamic Size at SRM



σ_{x0}=656 μm

Short Summary on Beam Size

- Horizontal size of non-colliding bunch slightly increased when the tune approached to a half-integer.
- The increase of the size might affect the distortion in the tune spectrum at a half-integer.
- However, quantitative evaluation is difficult due to large error bars in size measurement, needs more precise measurement.
- Colliding bunches is mainly caused by dynamic beam-beam effects.
- The tune in the *H-mode* should be used to evaluate the dynamic beam-beam effects, not that in the *L-mode*.

Part II

Measurement of Wake Effects using Tune Shift

Outline

- Motivation
- Tune Shift
- Gated Tune Monitor
- Measurement Method
- Results
- Summary

Motivation

- The LER suffers from an increase of the vertical beam size.
- Caused by a strong head-tail instability due to electron clouds.
- A resonatorlike wake is proposed to explain the sideband.
- Can the tune shift catch the wake?
- The detection is an integrated value over a whole bunch.

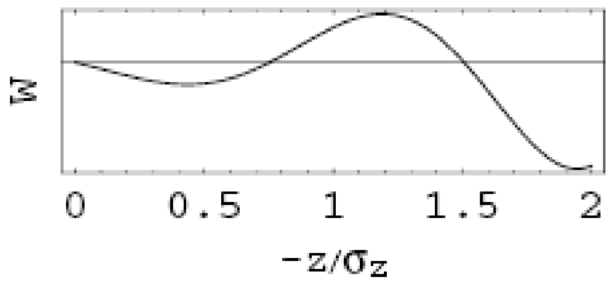


FIG. 5. Model focusing wake. The horizontal axis is the longitudinal coordinate in units of the bunch length.

From J. Flanagan et al., PRL 94 054801(2005)

Tune Shift

- Dipole fields acting a bunch change the tune.

$$\Delta\nu_y = \frac{1}{4\pi E}\oint \beta \frac{dF_y}{dy} ds$$

F_y: Forces acting a bunch
$\Delta\nu>0$: focusing, $\Delta\nu<0$: defocusing

- Head-tail wake makes a negative tune shift.

$$\Delta\nu = -\frac{T_0 I_b}{4\pi E/e}\sum_i \beta_i k_i$$

k_i : kick factor V/(Qm)

- Space charge due to electron cloud causes a positive tune shift.

$$\Delta\nu_y = \frac{r_e}{2\gamma}\int \rho\beta_y ds$$

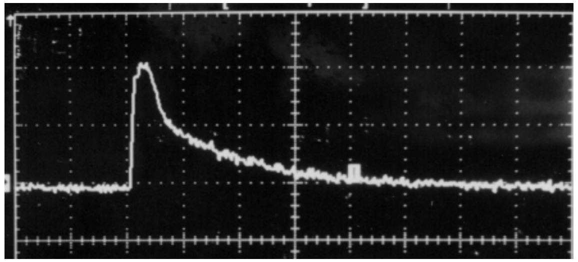
ρ: cloud density /m^3

Gated Tune Monitor

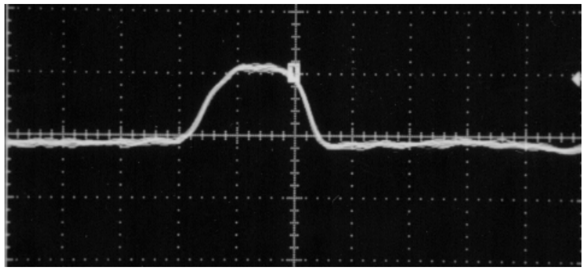
Some improvements were carried out in last year.

- New Spectrum Analyzer
  - Sweep Time, 8 to 1.5 sec
  - Data Points, 250 to 1000
- Shorten Deflection Pulse
  - Width: 50 ns + long tail to 10 ns
    -> bunch-by-bunch deflection
- Stabilizing the oscillation detector
- Adding 2nd Monitor
  - Simultaneous measurement for two bunches

Deflection Pulse



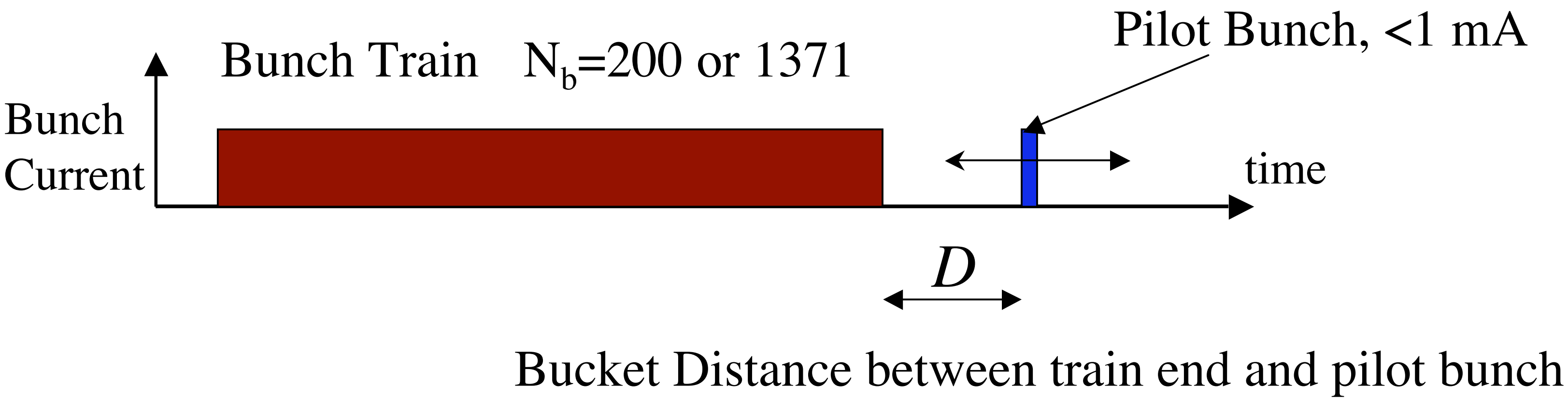
100 ns/div.



5 ns/div.

How to measure

Use a pilot bunch as a probe.



1. A bunch train was stored on ahead.
2. A pilot bunch was injected one by one from behind.
3. The tune was measured as a function of pilot-current during each injection under constant train-current.

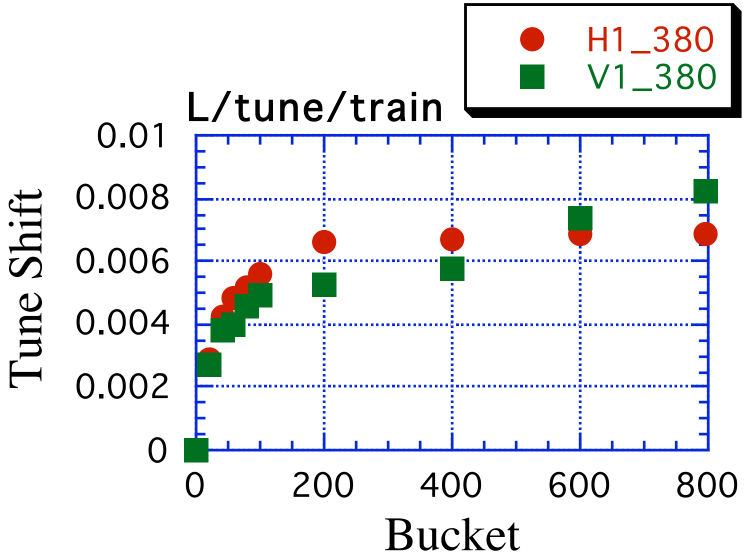
Machine Conditions

	Measurement 1	Measurement 2
Beam	Positron	Positron
Bunch Structure	4/200/4	1/1371/3.5
Bunch Current	0.5 ~ 0.7 mA	1.0 mA
Solenoid	OFF	ON
Vc, ν_s	8 MV, 0.025	8 MV, 0.025
ξ_x, ξ_y	1.6, 4.6	0.9, 3.2

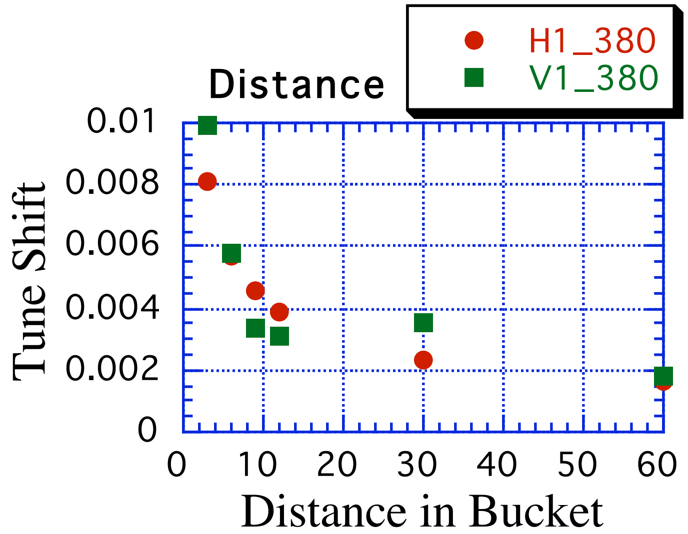
Measurement 1 : Bucket-Dependent Tune-Shift (BDTS)

Without Solenoids

Along Train



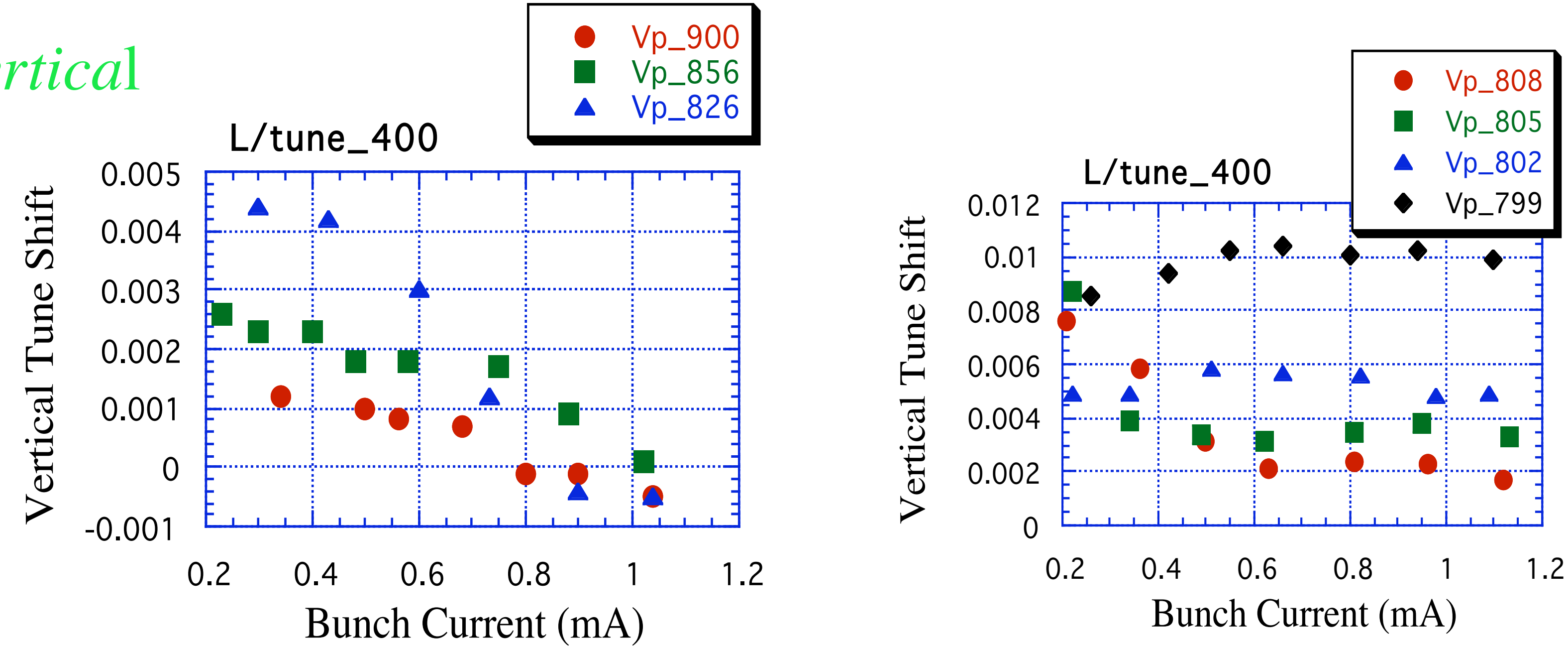
After Train



Note: The tune of the leading bunch of a train is used as a reference.

Measurement 1 : Current-Dependent Tune-Shift (CDTS)

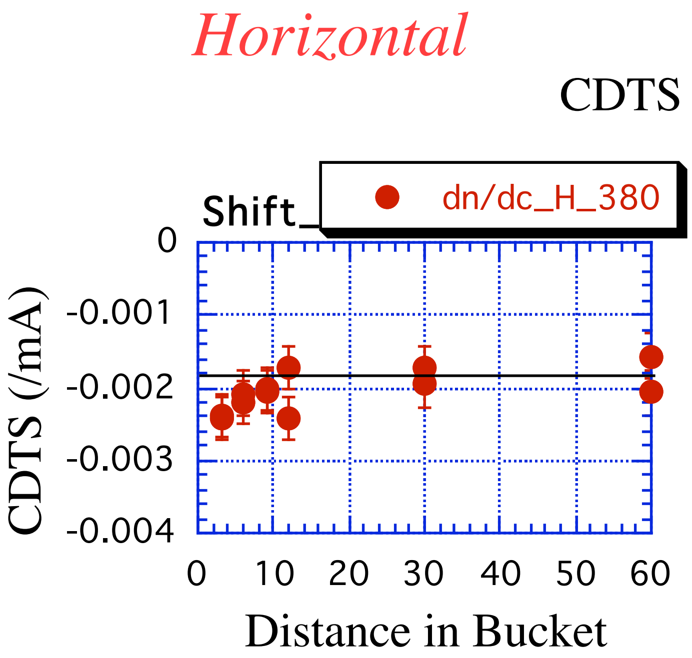
Vertical

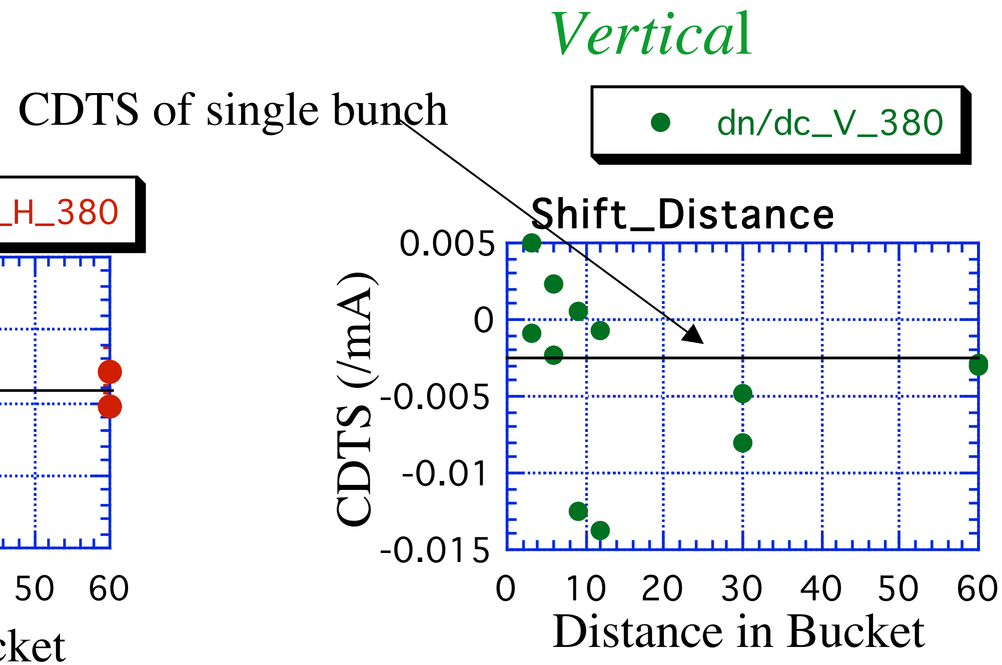


- The CDTS is not linear.
- Approximated by two lines.

Measurement 1 : Current-Dependent Tune-Shift (CDTS)

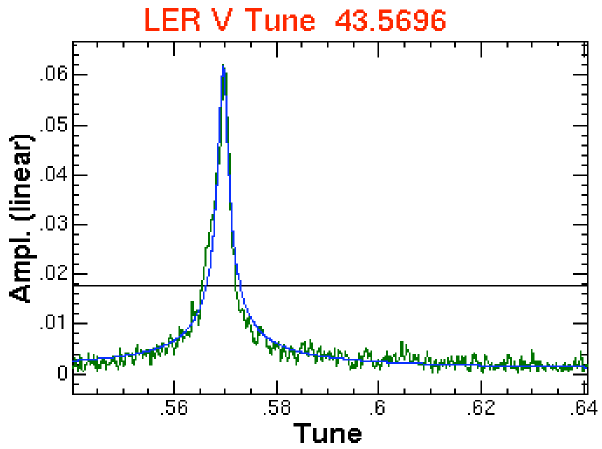
- Two values correspond to the CDTS around 0.4 mA and 0.8 mA.

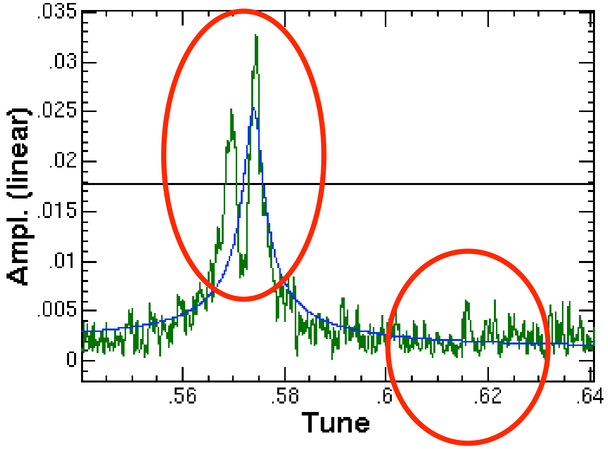




- The vertical CDTS abruptly changed around D=10.
- Positive CDTS at D<10.

Measurement 1 : Tune Spectra at short distance





- Observed two-peak spectrum and Flanagan sideband (?) at a short distance of 3 under high train-current.

Train:380 mA
around threshold
D=3

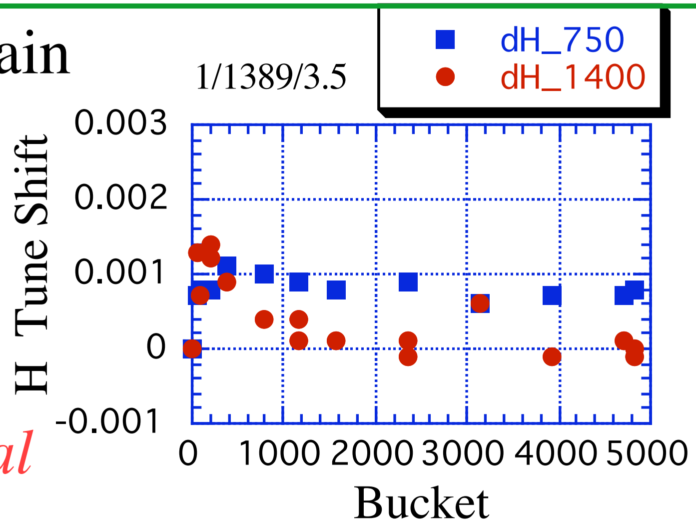
Train:580 mA
above threshold
D=3

Measurement 2 : Bucket-Dependent Tune-Shift (BDTS)

Along Train

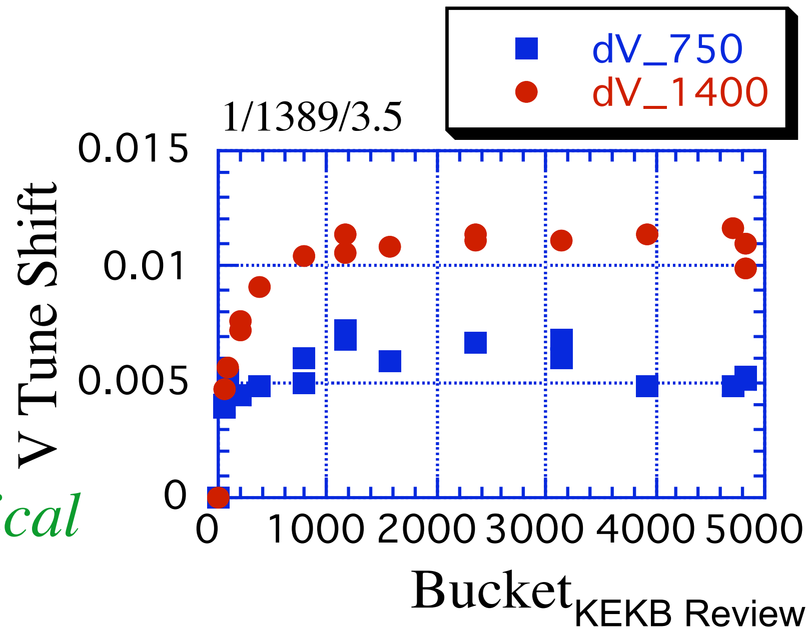
With Solenoids

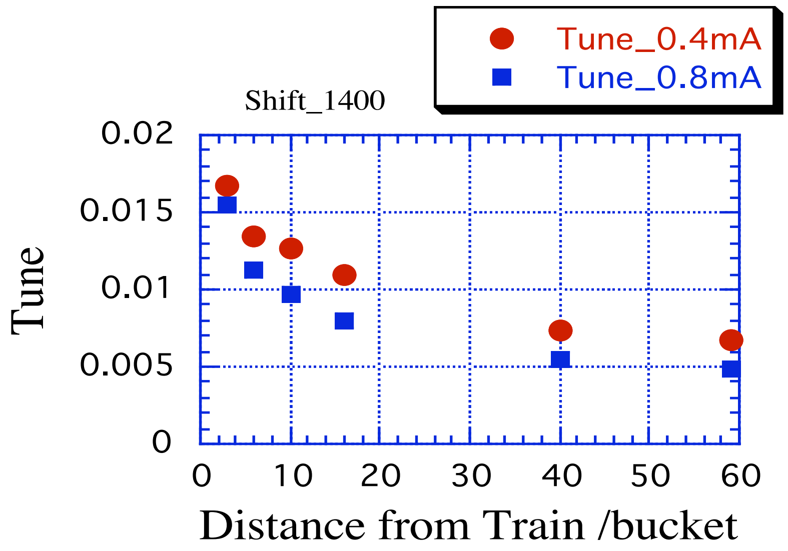
Horizontal



After Train

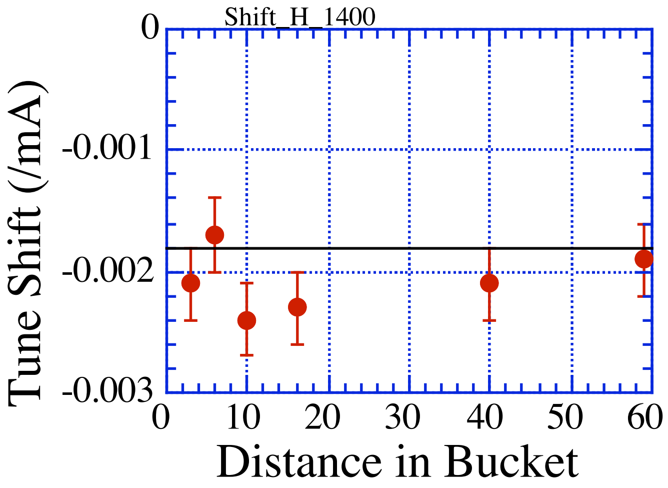
Vertical



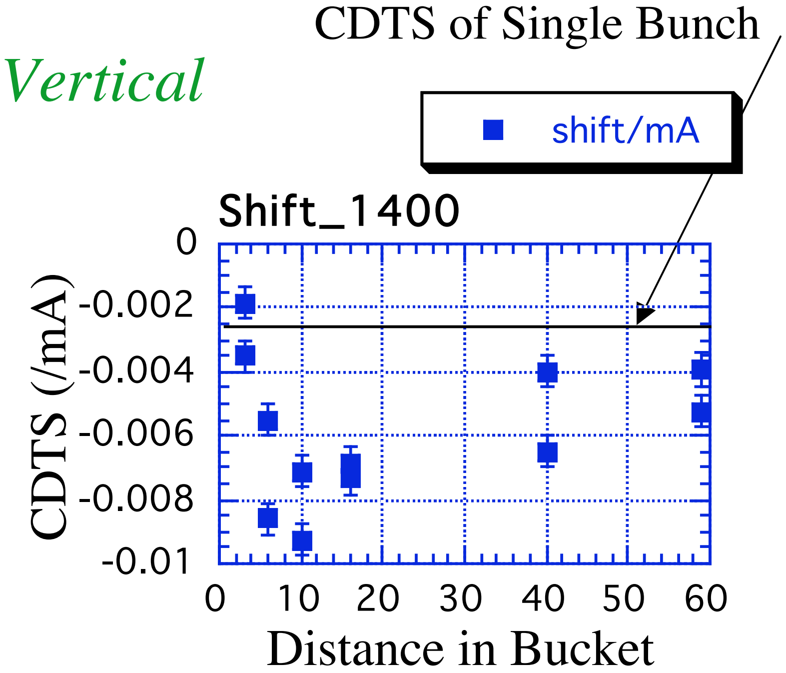


Measurement 2 : Current-Dependent Tune-Shift (CDTS)

Horizontal



Vertical



- Horizontally, completely damped by solenoids.
- Vertically reduced, but the structure is preserved.

Summary of Tune Shift

- The CDTS (Current-Dependent Tune-Shift) was measured after a bunch-train in the LER with and without the solenoids.
- As a pilot bunch approached a train, the vertical defocusing force was stronger, but changed to a focusing force within a bucket distance of around 10.
- The change may suggest a direct effect of electron clouds.
- At a short distance of 3 with a high train-current, the tune spectrum was heavily distorted, two peaks with the sideband(?).
- Though the BDTS is almost the same between horizontal and vertical directions without the solenoids, the CDTS is quite different, which might suggest a strong wake vertically.
- Horizontal CDTS was small and completely damped by the solenoids.