Measurements of Tune, Bunch Length and Bunch-by-Bunch Position

Outline

- **Tune Measurement**
  - Beam-Beam Tune Shift
- **Bunch Length Measurement**
  - Monitor based on Beam Spectrum
  - Bunch Lengthening and Shortening
- **Bunch-by-Bunch Position**
  - BPM System
  - Bunch-by-bunch Orbit
- **Summary**

Beam-Beam Tune Shift

- **Tunes in Beam-Beam Collision (H- & L- modes) :**

$$(\cos\mu_H + \cos\mu_L) - (\cos\mu_0^+ + \cos\mu_0^-) = -2\pi\{\Xi_q^+ \sin\mu_0^+ + \Xi_q^- \sin\mu_0^-\}$$

- **Coherent Beam-Beam Parameters:**

$$\Xi_q^\pm = \frac{N_\mp r_e}{\gamma_\pm} \frac{\beta_q^{0\pm}}{2\pi\Sigma_q(\Sigma_x + \Sigma_y)} R_q^\pm \qquad \xi_q \approx \Xi_q^+ + \Xi_q^- \qquad \Sigma_q = \sqrt{(\sigma_q^+)^2 + (\sigma_q^-)^2}$$

- **Luminosity:**

$$L = \frac{f_0 N_b^+ \gamma^+}{r_e} \cdot \frac{T}{1+T} \cdot \left[\frac{\Xi_y^+ + \Xi_y^-}{\beta_y^*}\right] \cdot \frac{R_L}{R_y^*} \qquad T = \frac{I^- \gamma_-}{I^+ \gamma_+}$$

- **Emittance:**

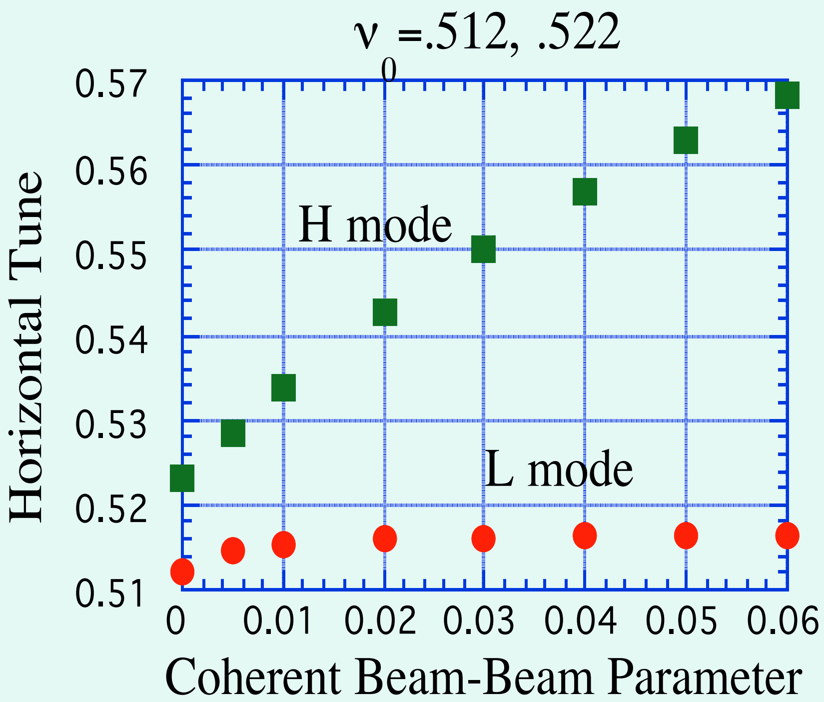
R_q^* : reduction factors

$$\varepsilon_x^+ + \varepsilon_x^- = \frac{r_e}{\Xi_x^+ + \Xi_x^-} \cdot \frac{N^+}{2\pi\gamma^-}(1+T) \cdot R_x^*$$

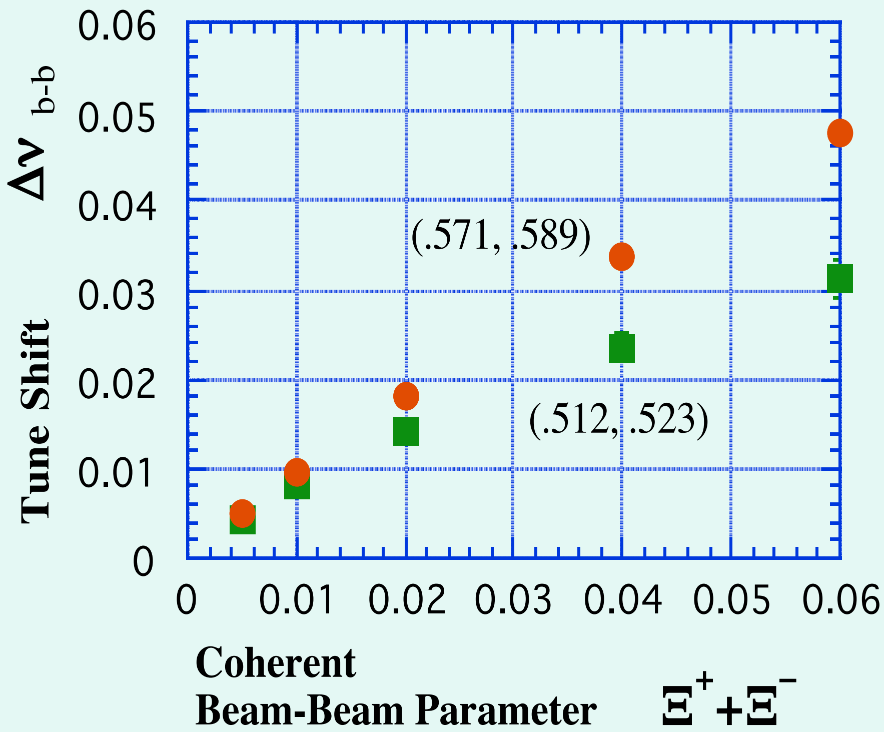
Assuming a flat beam and $\beta_x^+ \approx \beta_x^- = \beta_x^*$

Beam-Beam Tune Shift (cont'd)

- **Beam-Beam Tune Shift, calculation**

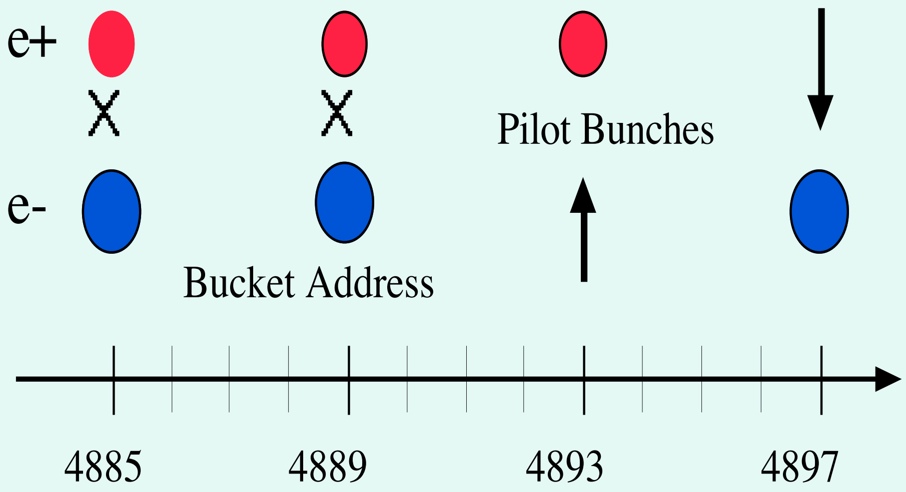


$$\Delta\nu_{b-b} = \nu_H + \nu_L - \nu_0^+ - \nu_0^-$$



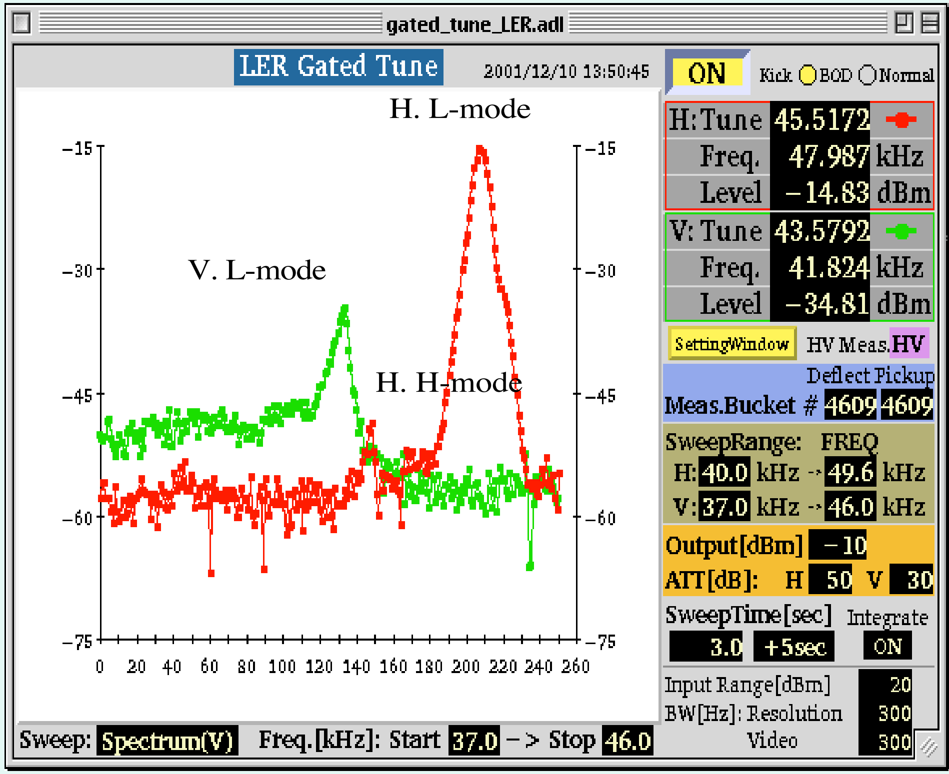
Measurement of Beam-Beam Tune

- **Measurements of pilot bunch and collision bunches are useful for beam-beam study.**
- **Beam-beam tune shift is studied by measuring both tunes.**

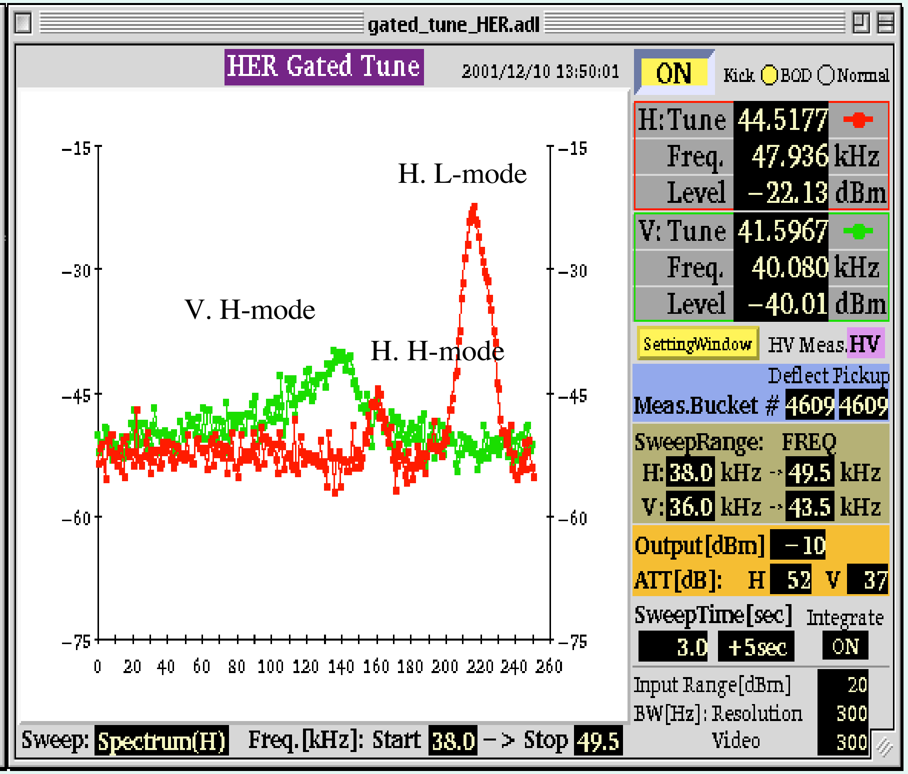


Measurement of Beam-Beam Tune (cont'd)
- Two beam-beam modes

LER

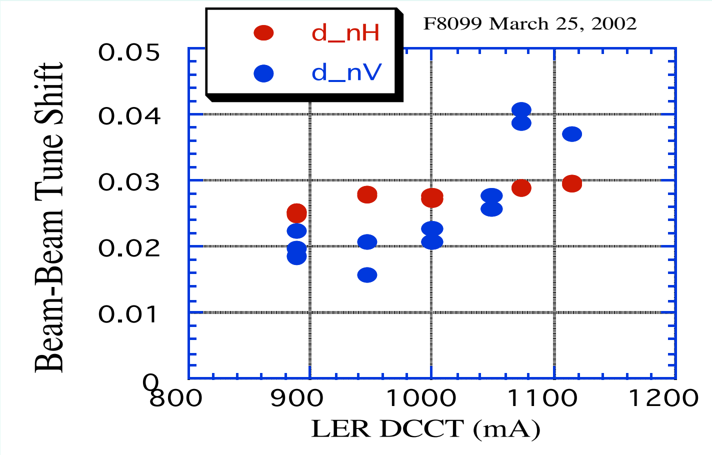


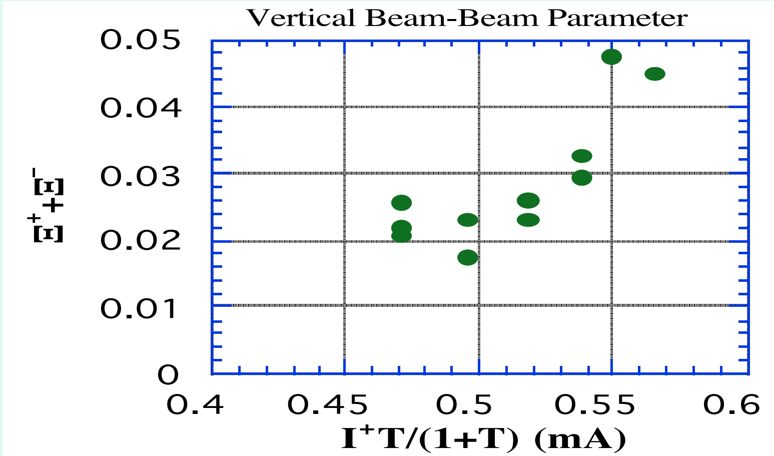
HER

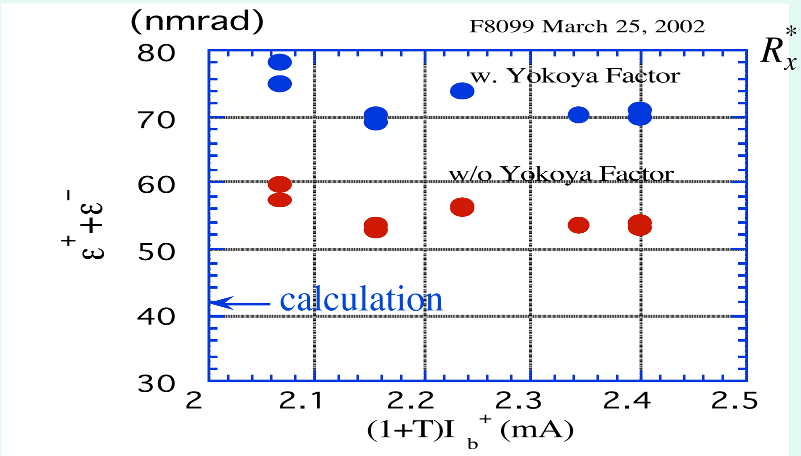


Non-Collision Tunes are .5124, .5712 .5221, .5903

Measurement of Beam-Beam Tune (cont'd) - Current dependence

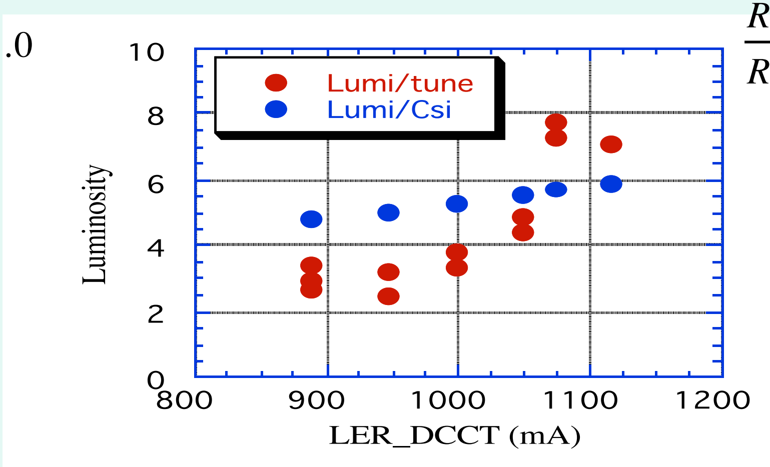






$R_x^* = 1.0$

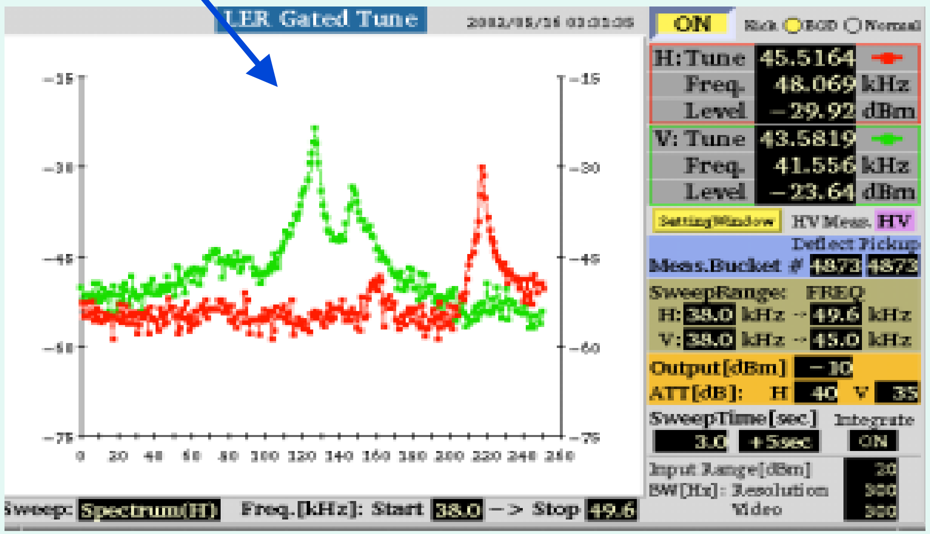
$\frac{R_L}{R_y^*} = 1.0$

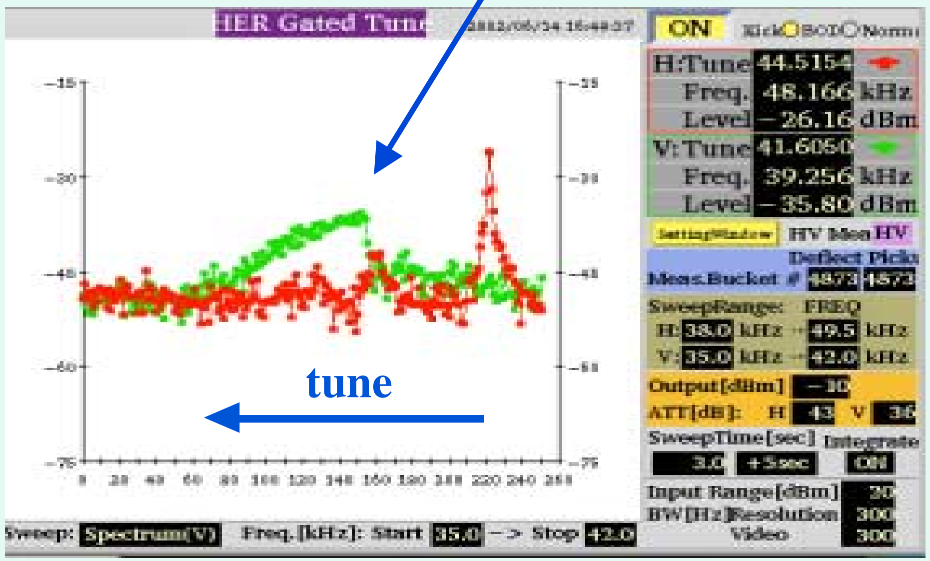


Measurement of Beam-Beam Tune (cont'd) - Complexity

Two peaks appears, when vertical offset is given.

Nonlinearity in vertical spectrum





Bunch Length Monitor
based on Beam Spectrum

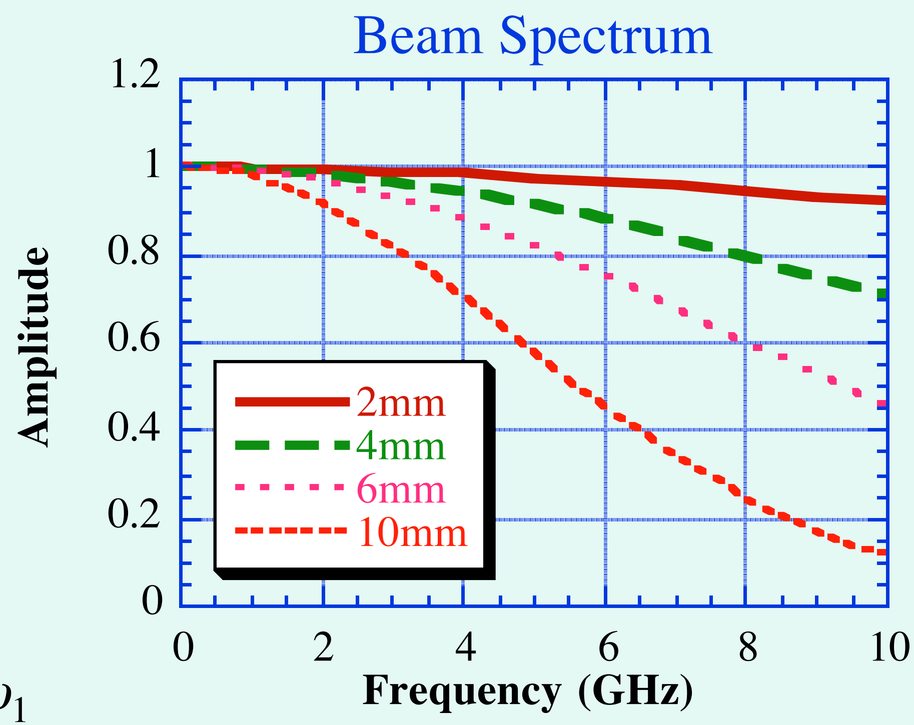
- **Amplitude of Spectrum :**

$$|F(\omega)| \approx I_0\left\{1-\frac{1}{2}\langle t^2\rangle\omega^2\right\} \qquad \omega t < 1$$

- **Rms Bunch Length :**

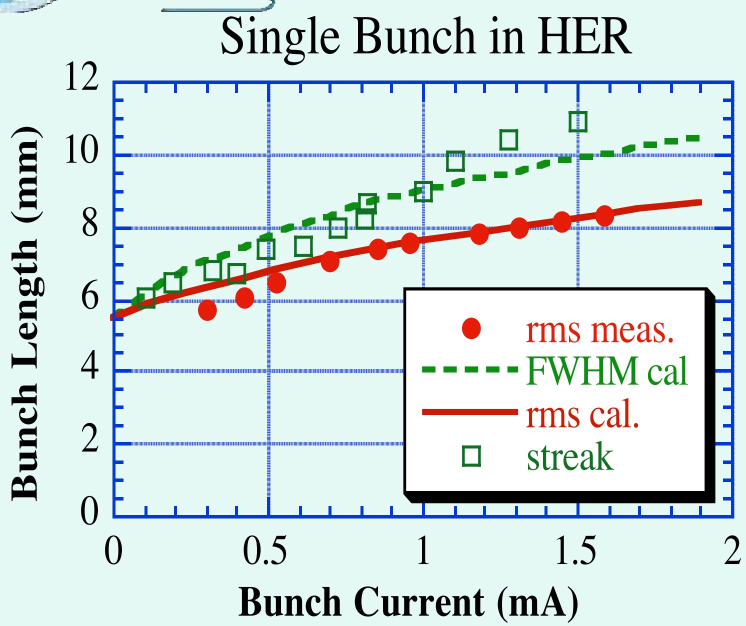
$$\sigma \equiv \sqrt{\langle t^2\rangle} = \sqrt{\frac{2}{\Delta\omega^2}\ln\left|\frac{F(\omega_1)}{F(\omega_2)}\right|}$$

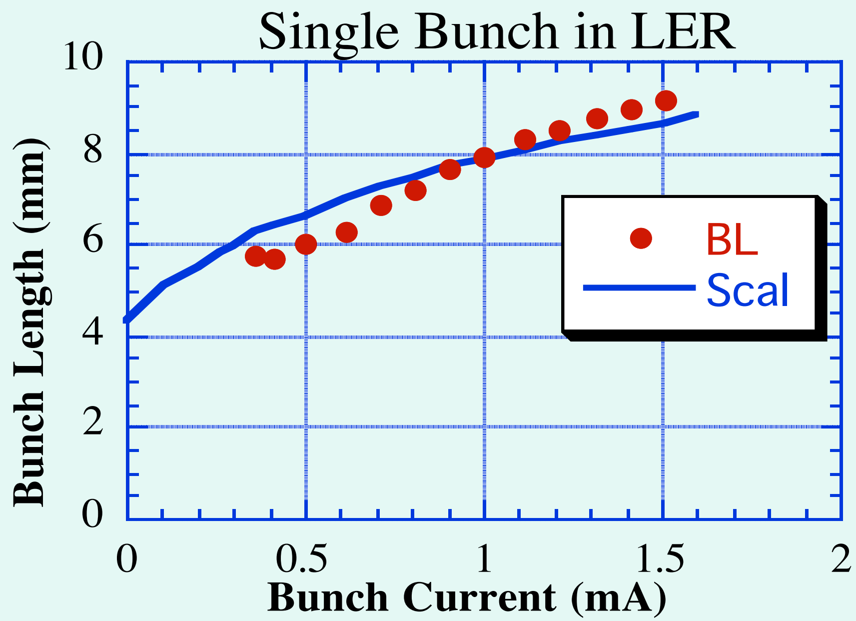
$$\Delta\omega = \omega_2 - \omega_1$$



Note: This measurement does *not* depend on bunch structures.

Bunch Lengthening



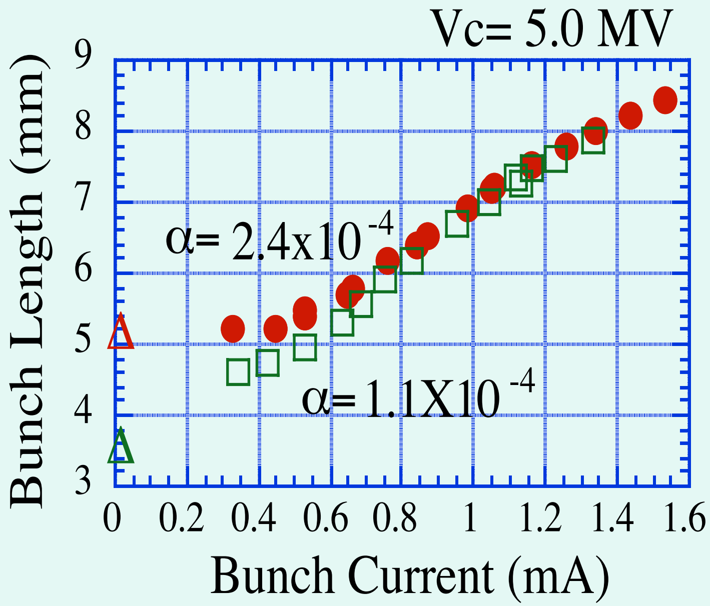


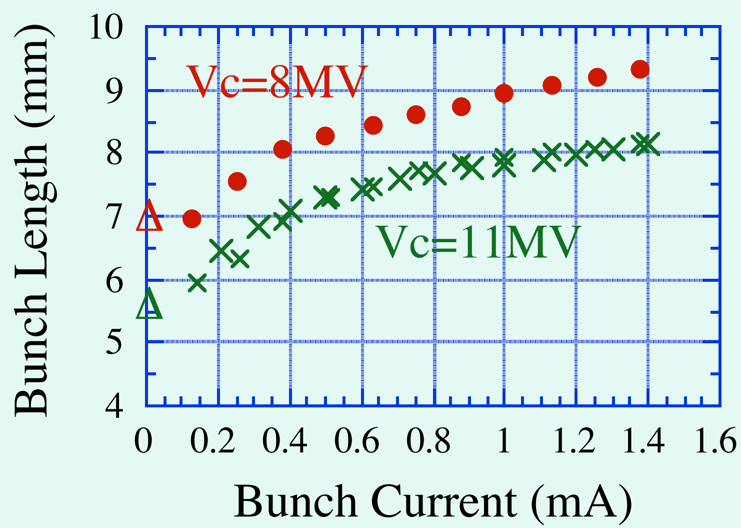
- **Lines are calculated rms bunch length assuming purely inductive impedance, results in $|Z_i/n|$ = 0.076 Ω for HER and =0.072 Ω for LER.**
- **Estimated impedance is 5 times larger than the design of 0.015 Ω.**
- **Need to resolve the disparity between measurement and design.**

Reducing the bunch length

Natural bunch length : $\sigma_0 = \dfrac{c\alpha\delta_\varepsilon}{\omega_s}$

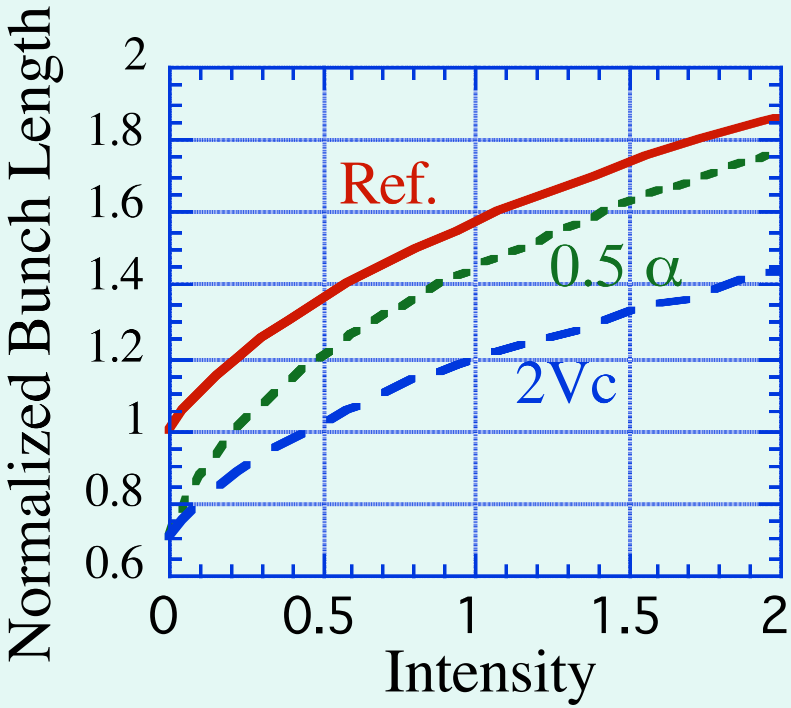
- **(1) Reduce momentum compaction, α**
- **(2) Raise cavity voltage, Vc**





Bunch Length Calculation with P.W.D.

- **Both methods reduce B.L. to 70% at zero intensity.**
- **Higher Vc makes shorter B.L. at high intensity.**



Note:

- **Higher Vc has advantage of beam loading.**
- **Short bunch length produces high HOM power.**

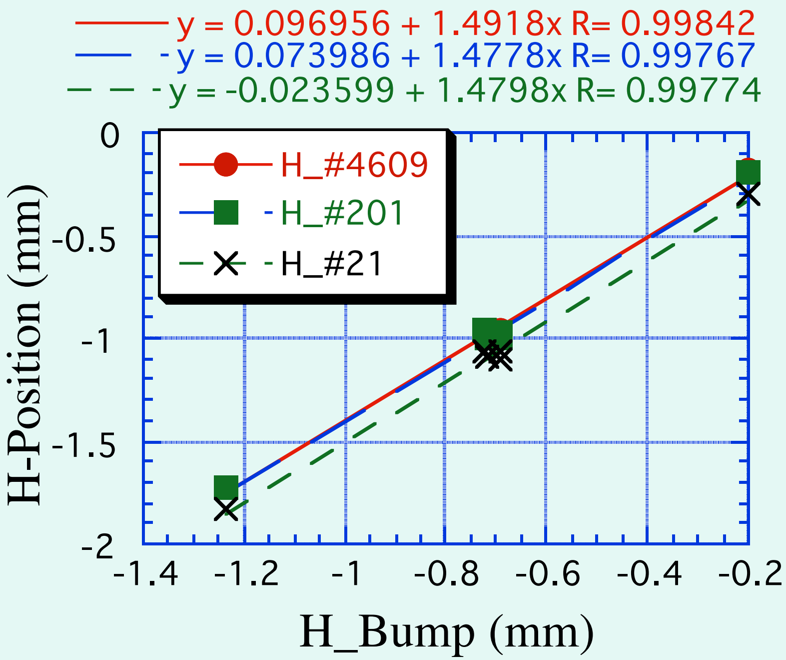
Turn-by-Turn & Bunch-by-Bunch Beam Position Monitor

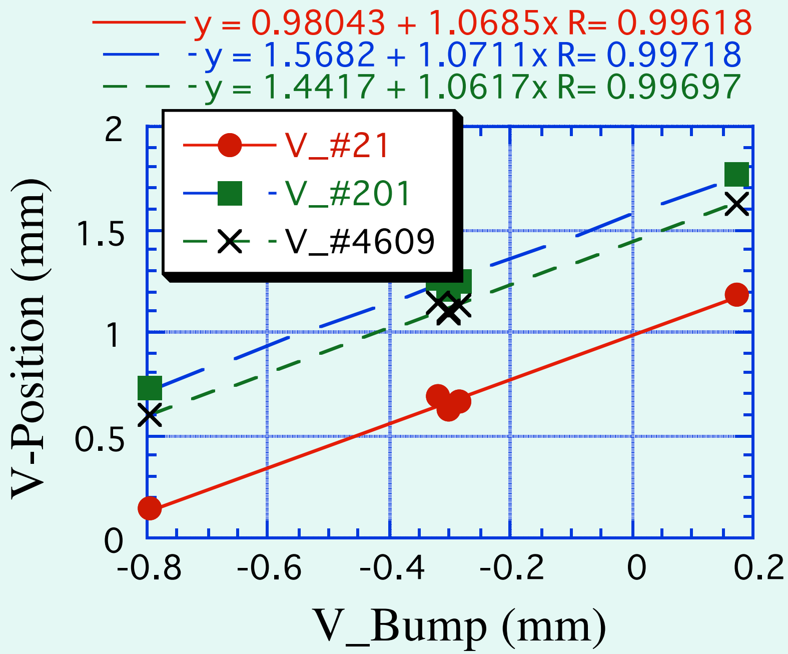
features

- **Share the button signal with the COD measurement.**
- **Intensity, orbit and synchronous phase are measured using an I/Q demodulator working at the rf frequency.**
- **The gate enables to measure the bunch-by-bunch parameters.**
- **Resolution : < 0.1 degrees in phase, < 10 μm in orbit with averaging.**

Bunch-by-bunch Orbit
- Effect of Orbit Bump

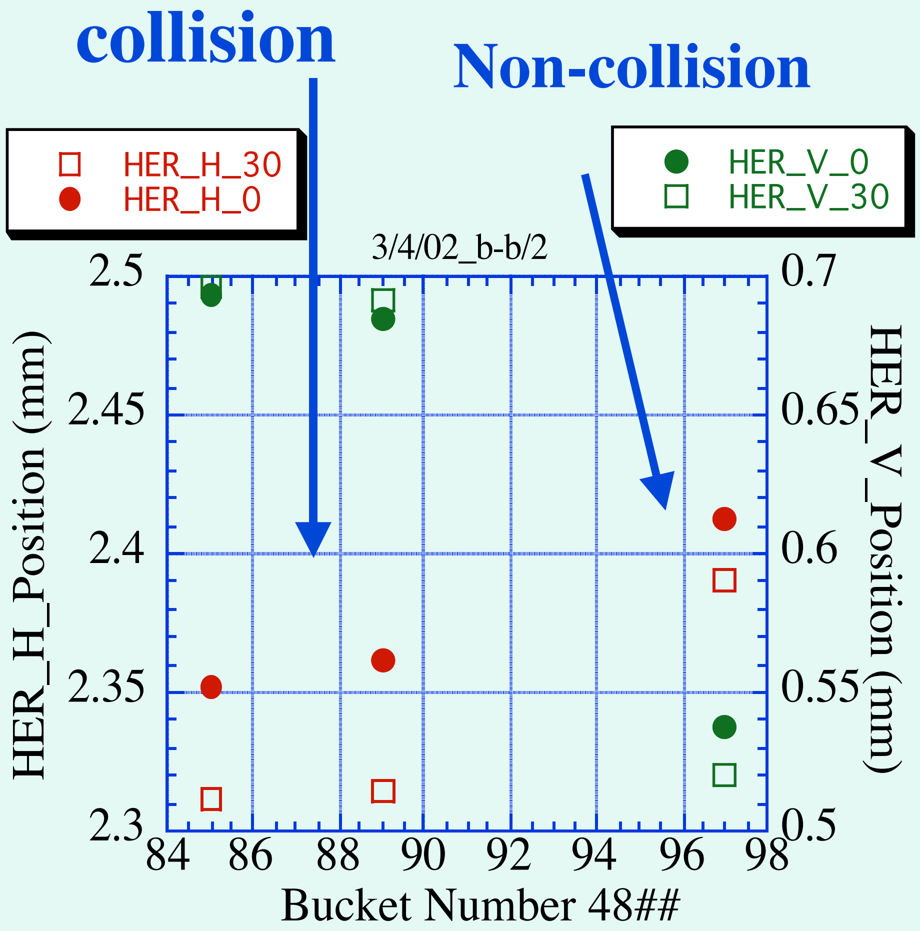
◆ **Bunch-by-Bunch Position Sensitivity**





Position Sensitivity for each bunch is consistent within 1%.

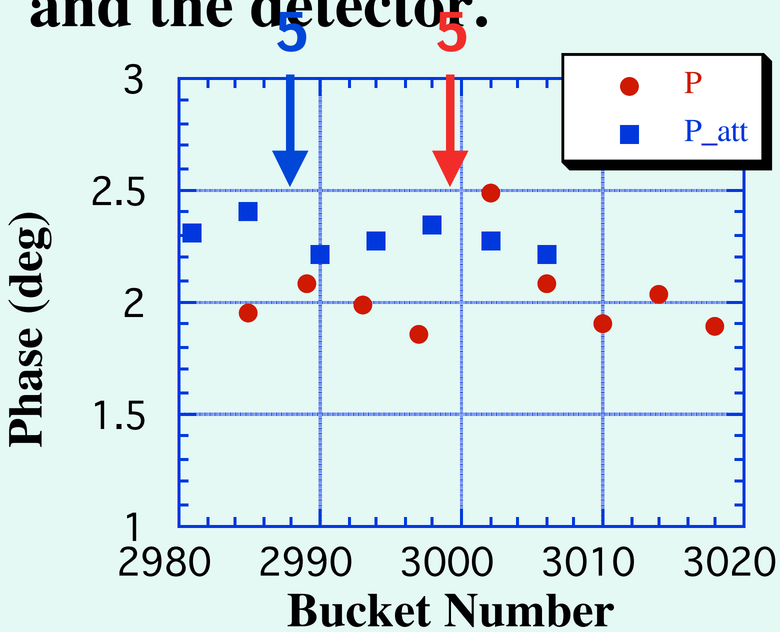
Bunch-by-bunch Orbit
- Effect of IP Horizontal Bump, *Preliminary*

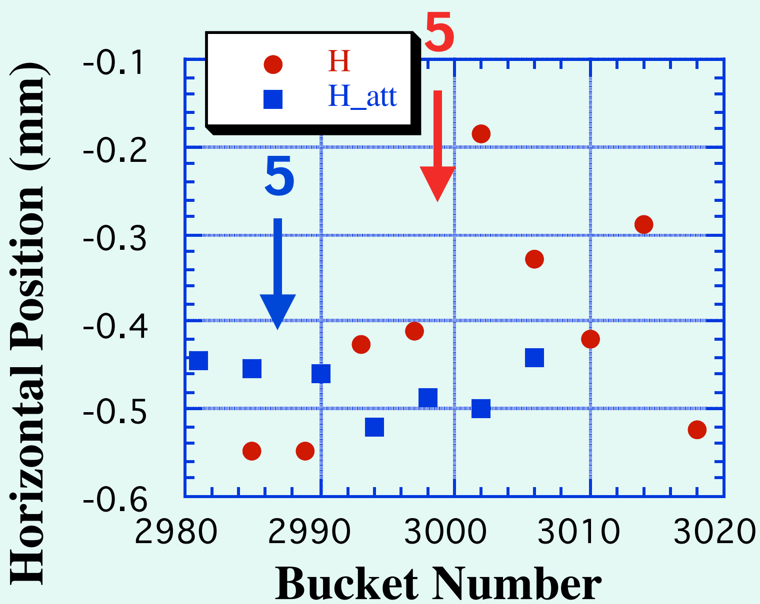


- **Orbit displacement exists between collision and non-collision bunches. real ?**
- **Collision offset makes an orbit displacement around the rings.**
- **Beam-beam effect can be estimated from an orbit difference between collision and non-collision bunches.**

Bunch-by-bunch Orbit in irregular 4-bucket spacing

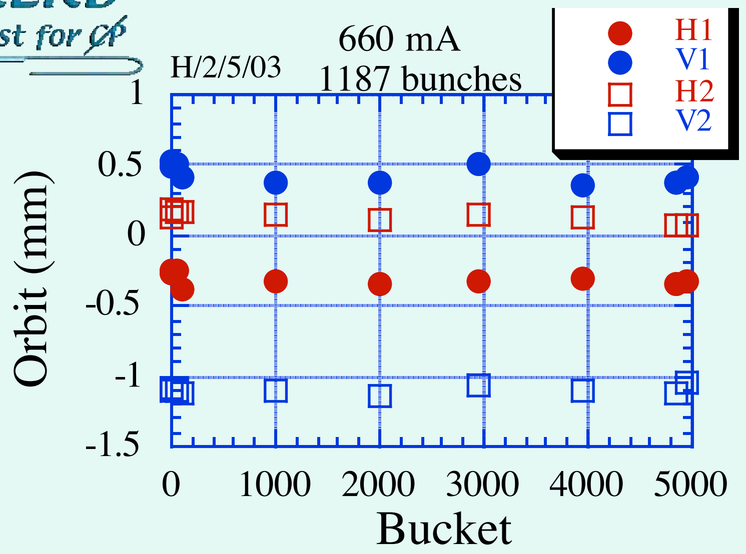
- We observed jumps in phase and in orbits at 5-bucket spacing.
- Attenuators inserted near the buttons reduced the jumps.
- Measurements are influenced by mismatch between buttons and the detector.

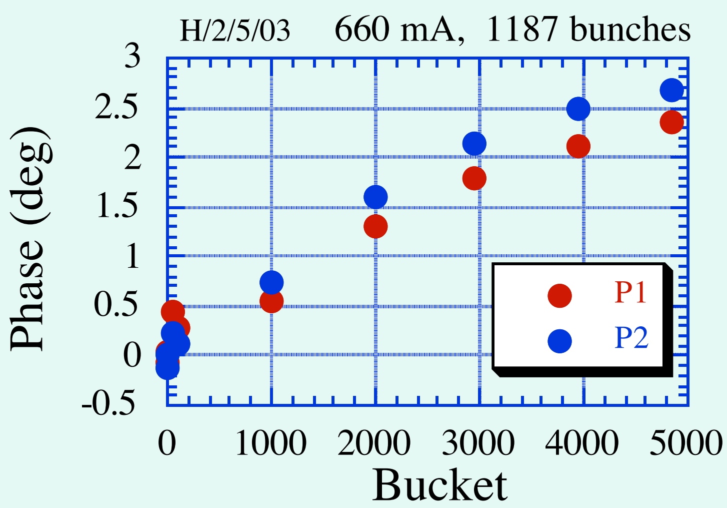




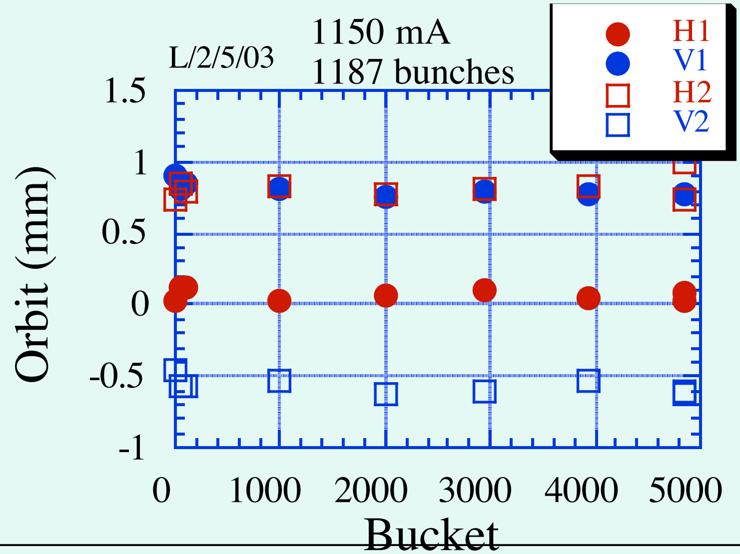
Positions along Train

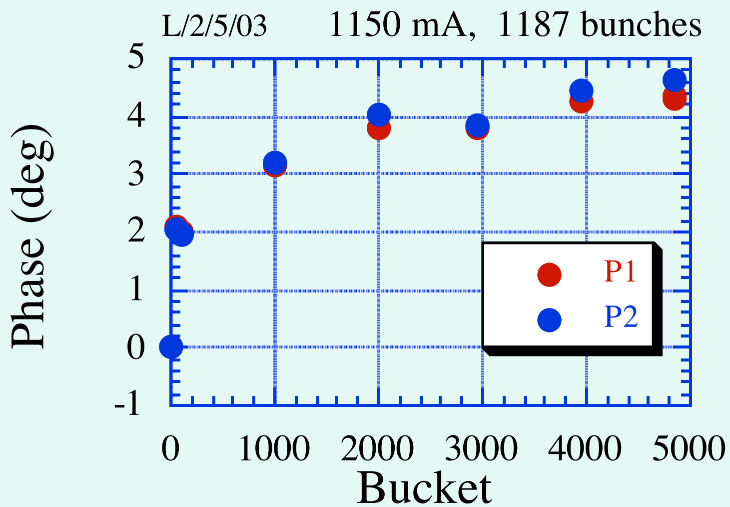
HER





LER





Summary

- **Beam-beam tune shift**
  - Detected beam-beam modes under unequal tunes.
  - Estimated luminosity is roughly consistent with the luminosity monitor.
  - Estimated emittance is larger than calculation, suggests the dynamic effect.

Summary (cont'd)

- **Bunch lengthening**
  - **We need to check the impedance sources, to explain the unexpected bunch lengthening.**
  - **Raising Vc is more effective than reducing α, to make the bunch length short .**

- **Bunch-by-bunch position**
  - **Beam-beam offset could be measured from an orbit displacement.**
  - **Orbit along train stays within +/- 0.1 mm.**