BEAM-BEAM EXPERIMENT

T. Ieiri, Y. Funakoshi, T. Kawamoto,
M. Masuzawa and M. Tobiyama

MEASUREMENT OF BEAM-BEAM EFFECTS

Outline

- Introduction
- Beam-Beam Effects
- Measurement Method
- Measurement of
  - Beam-Beam Kick with Horizontal Scan
  - Beam-Beam Tune Shift
  - Dynamic Beta
- Analysis of Results
- Summary

Motivation

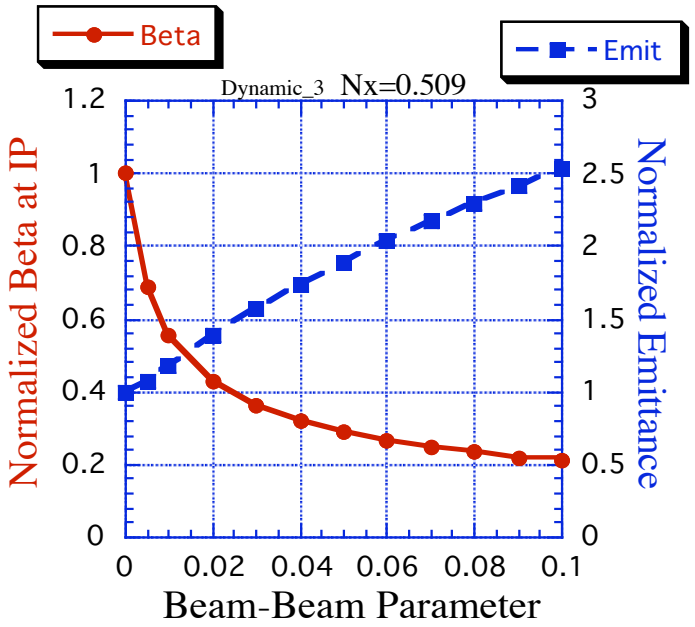
- *"Egure"* phenomena
- Effect of electron cloud
- Dynamic beam-beam effects
- Beam diagnostics with collision

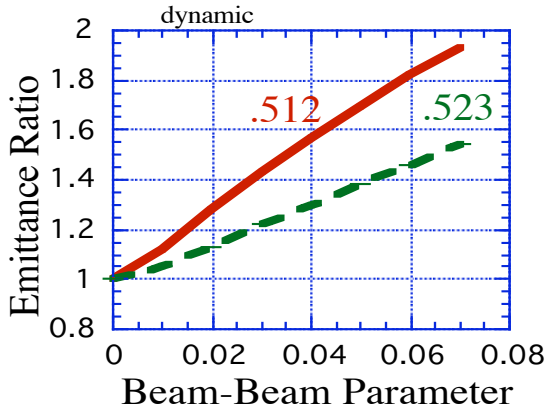
Machine Parameters

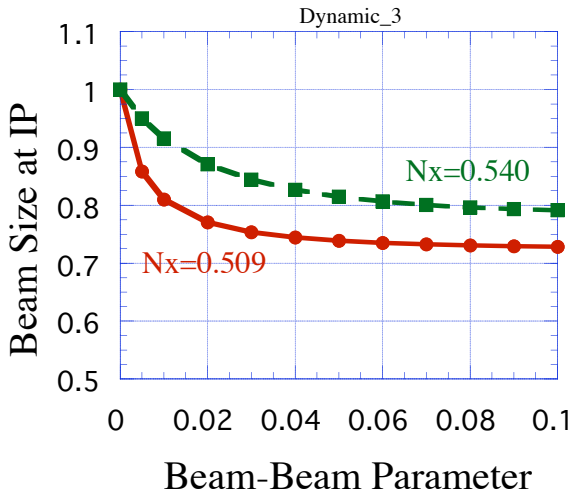
Parameter	LER	HER	
Beam Energy, E	3.5	8.0	GeV
Horizontal Emittance, ε_{x0}	18	24	nm
Betatron Tune, ν_{x0}/ν_{y0}	45.506/43.54	44.512/41.58	
Betas at IP, β_x^*/β_y^*	59/0.52	56/0.65	cm
Momentum Compaction, α	3.4	3.4	x 10^{-4}
Bunch Length, σ_l	6.5 to 8.0	6.5 to 7.0	mm
Synchrotron Tune, ν_s	0.025	0.022	
Particles per Bunch, N_b	3.7 to 7.1	3.1 to 5.1	x 10^{10}
Bunch Spacing, S_b	1.8 to 2.4		m

Dynamic Effects

- Beam parameters change with beam intensity and size, depending on betatron tune.







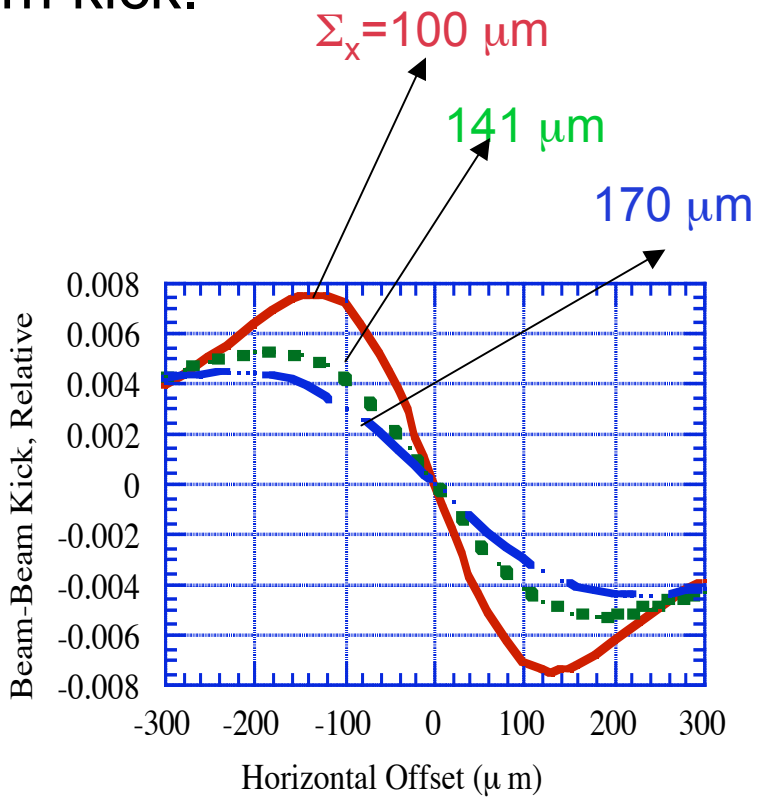
Beam–Beam Kick

- Collision with a position offset at IP distorts an orbit around the ring due to beam-beam kick.
- A position shift at a detector is:

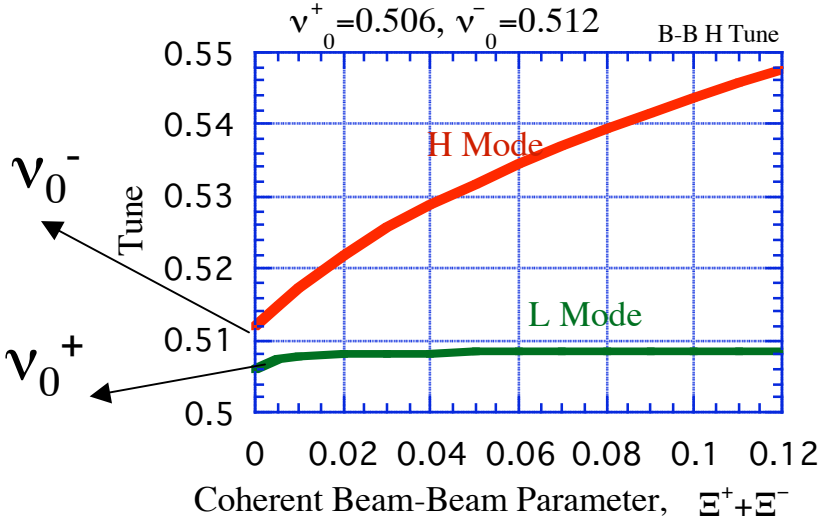
$$\Delta X_{\mathrm{det.}} = \frac{\sqrt{\beta_{\mathrm{det.}}\beta_x^*}}{2\sin(\pi\nu)}\theta_{b-b}\cos(\pi\nu - |\Delta\varphi_{\mathrm{d}}|)$$

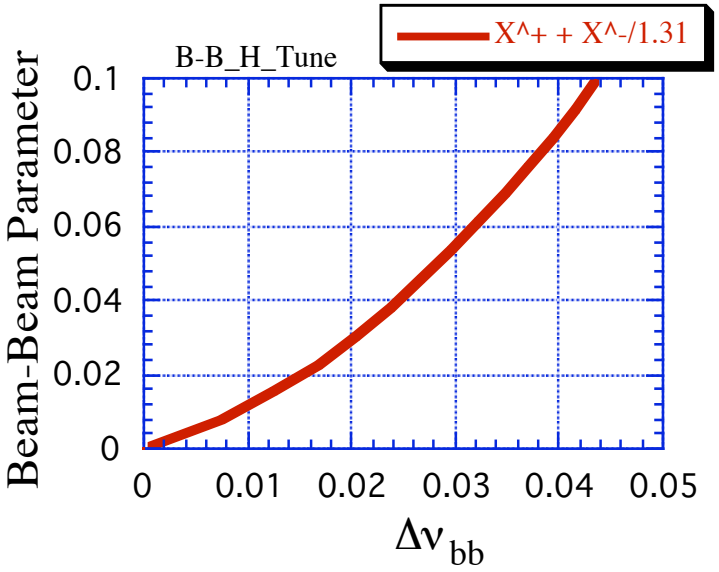
- Beam–beam kick depends on effective beam size, Σ_x.

$$\Sigma_x = \sqrt{(\sigma_x^+)^2 + (\sigma_x^-)^2}$$



Beam-Beam Tune Shift





- Coherent Beam-Beam Parameter

$$\Xi_q^{\pm} = \frac{N_{\mp} r_e}{\gamma_{\pm}} \frac{\beta_q^{0\pm}}{2\pi\Sigma_q(\Sigma_x + \Sigma_y)}$$

- Beam-Beam Tune Shift

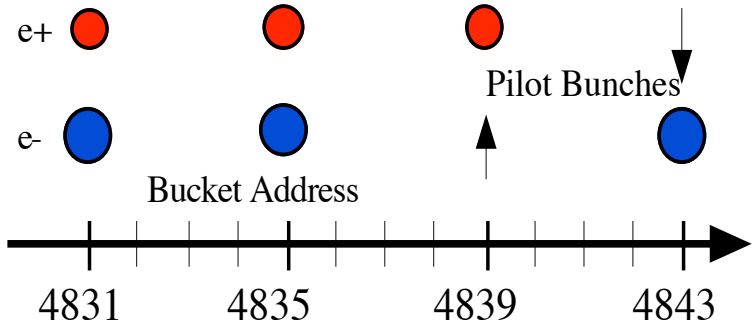
$$\Delta\nu_{bb} \equiv \nu_H + \nu_L - \nu_0^+ - \nu_0^-$$

$$\xi_q \approx \frac{\kappa(\nu_0^+, \nu_0^-)}{\mathrm{Y}} \Delta\nu_{bb}$$

Y: Yokoya Factor

Measurement Method

Comparing beam parameters of colliding bunches with those of a non-colliding pilot bunch



- Advantage
  - Measurement is not affected by an orbit correction.
  - Monitors are not required to install near IP.
  - Imbalance in gains of a detector is cancelled out due to subtraction.
  - An effect of the wake may be compensated by considering the measurement in a single beam.
- Disadvantage
  - Not simultaneous measurement.
  - Difference in the intensity of bunches may make an error.

Gated Beam Position Monitor

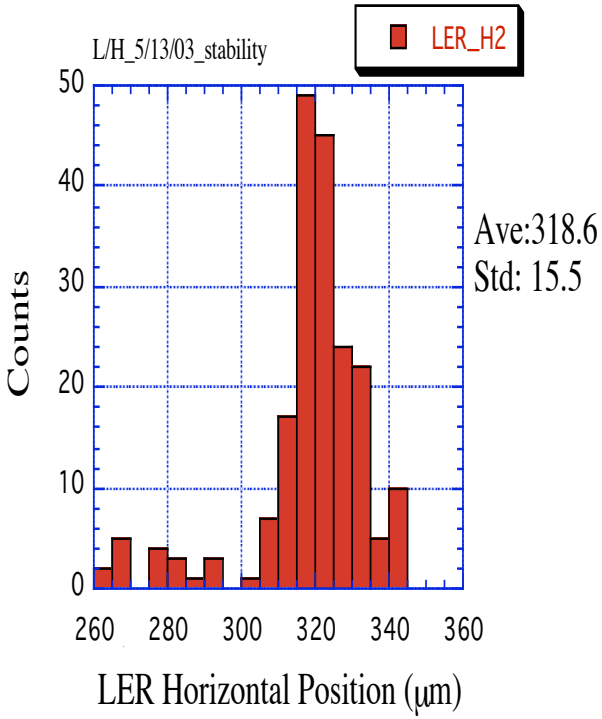
- Two detectors are installed in each ring .

Optics Parameter at Detector w/o Beam-Beam Effect

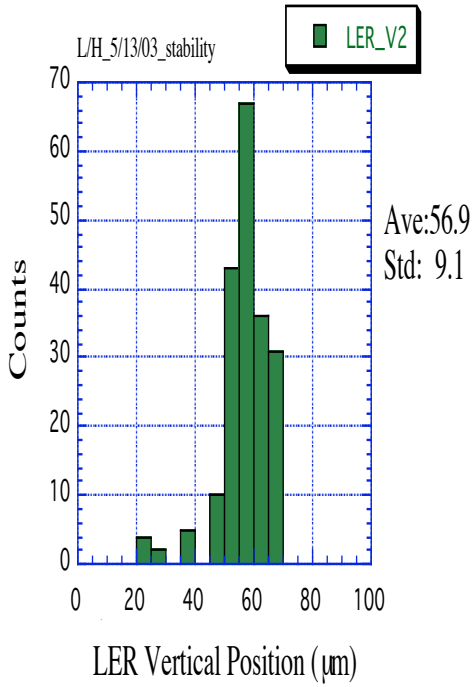
	LER-1 BPM_098	LER-2 BPM_104	HER-1 BPM_097	HER-2 BPM_100
Nx	9.34	9.77	35.35	35.12
Bx(m)	39.29	73.14	21.14	31.89
Sensitivity_x	-0.64	1.00	0.45	0.42
Ny	9.03	9.79	32.83	32.59
By(m)	13.35	5.94	12.56	15.98

Reproducibility of Measured Position

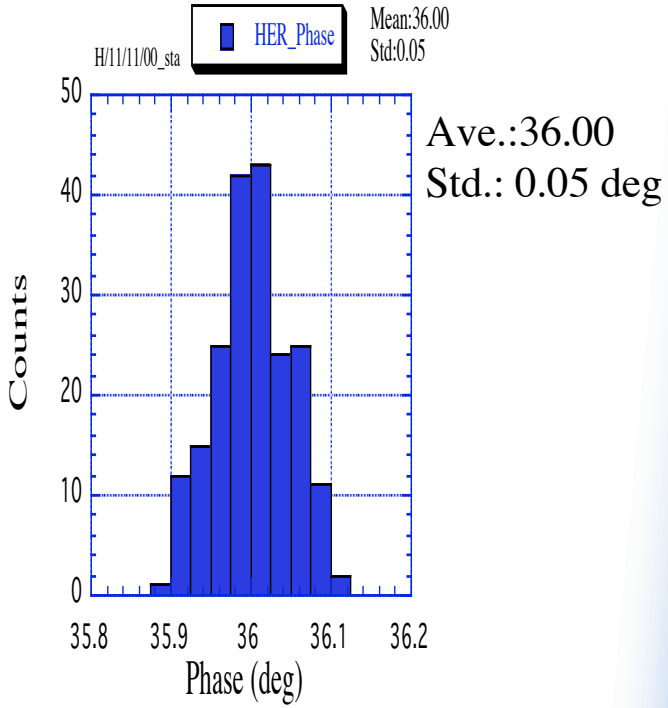
Horizontal



Vertical



Phase



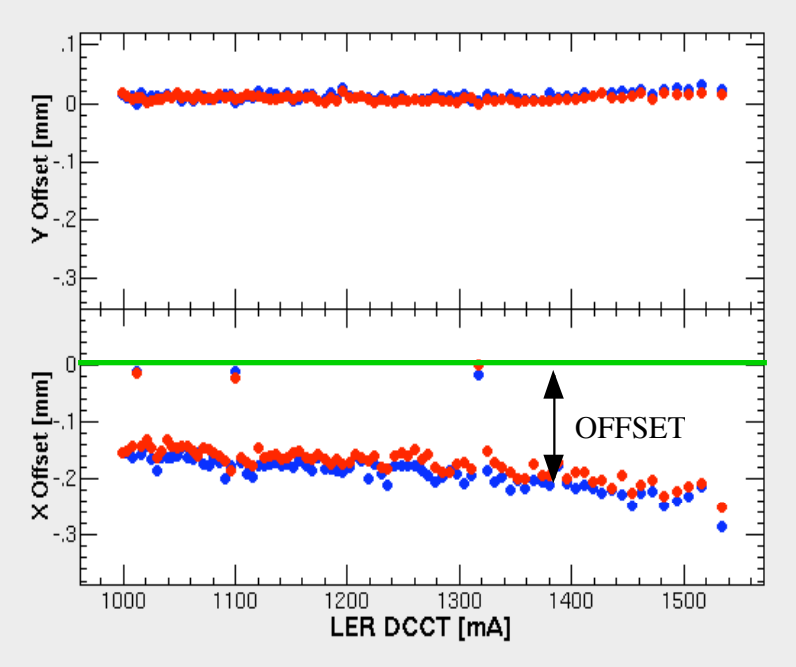
- Resolution is about 10 μm in position and 0.05 deg in phase.

Measurement in Normal Run

- Collision is normally performed with a horizontal offset !

Vertical
Position Shift

Horizontal
Position Shift



Detected at LER-2 on Dec. 11, 2003

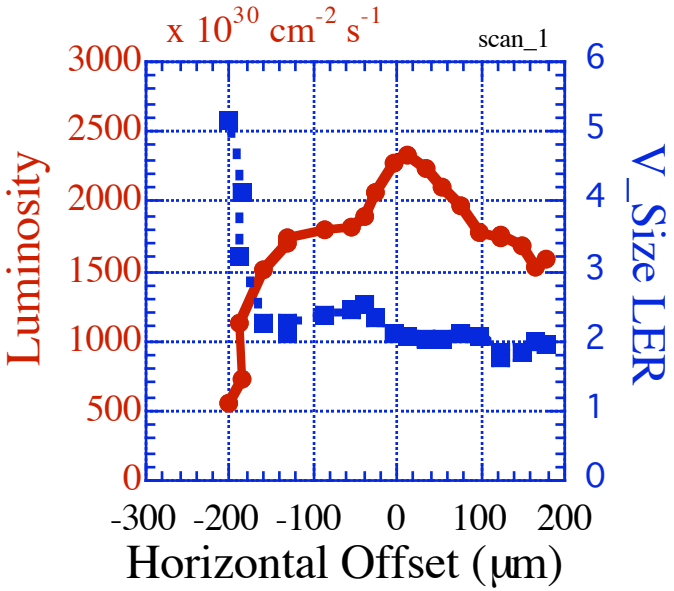
Measurement with Horizontal Scan

- Scanning Conditions

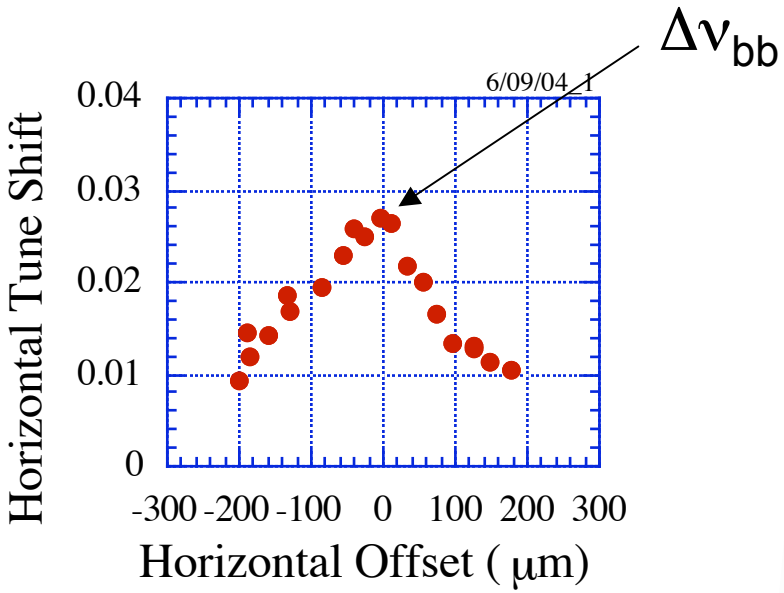
Scan No.	Bunch Spacing S_b (bucket)	Bunch Current I_b^+/I_b^-(mA)	Number of Bunches	Tune ν_{x0}^+/ν_{x0}^-	Memo
1	3.77	0.43/0.29	1289	0.511/0.514	Low Current
2	3.77	0.78/0.67	1289	0.511/0.512	High Current
3	24	0.62/0.52	203	0.510/0.508	Wide Spacing

Scan-1/ low current, normal spacing

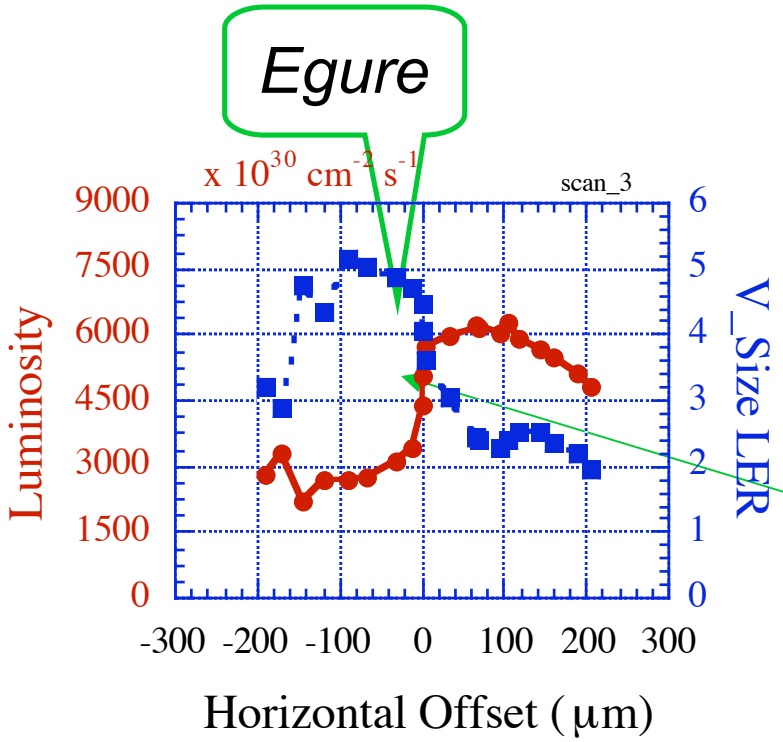
Luminosity and LER Vertical Beam Size

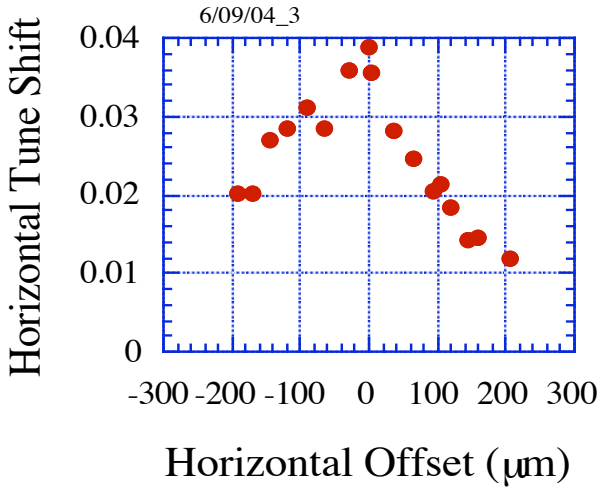


Beam-Beam Tune Shift

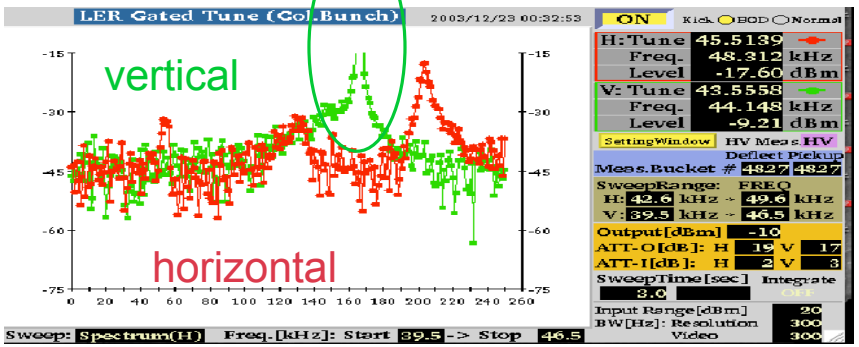


Scan-2/ high current, normal spacing



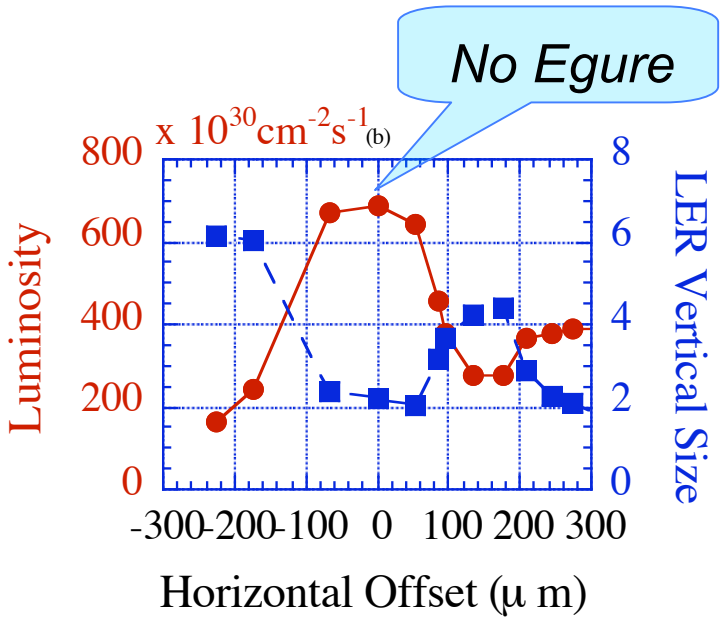


Tune Spectrum

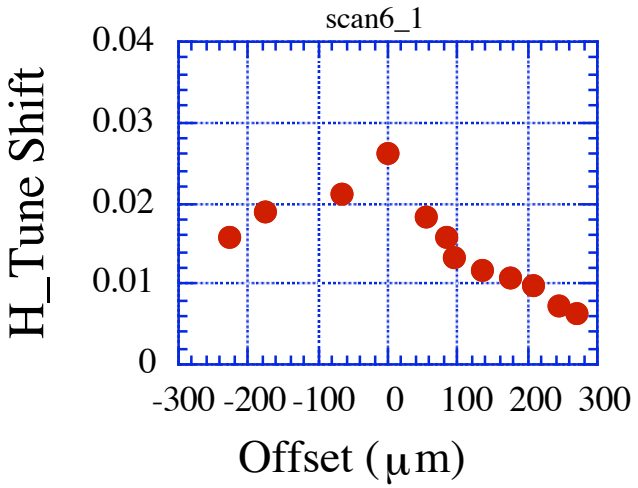


Scan-3/wide spacing

Luminosity and LER Vertical Beam Size

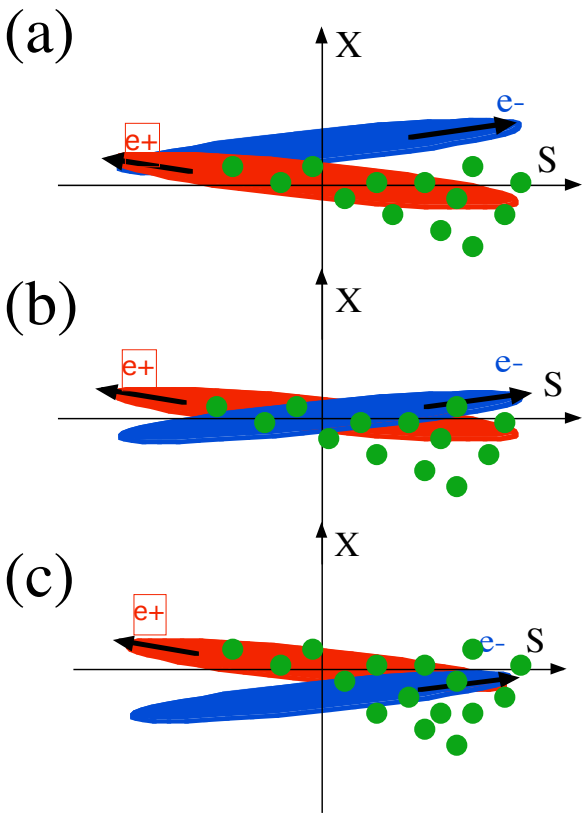


Beam-Beam Tune Shift



- Luminosity curve is almost symmetrical.

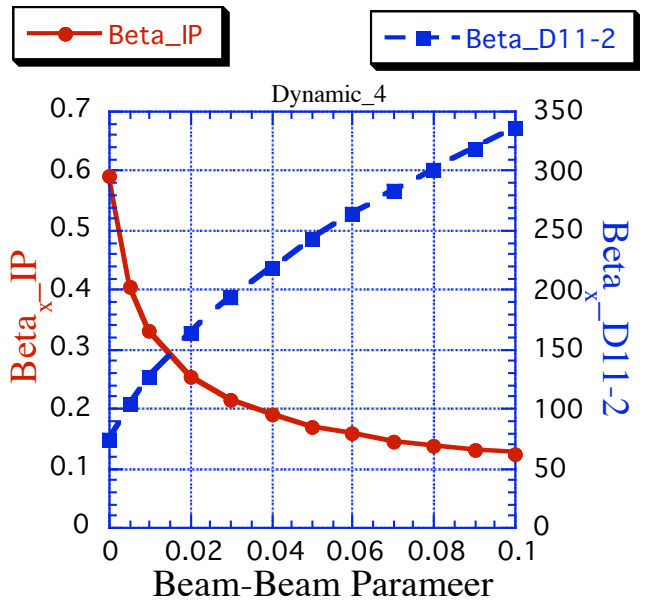
Why is the luminosity asymmetrical in the horizontal scan ?



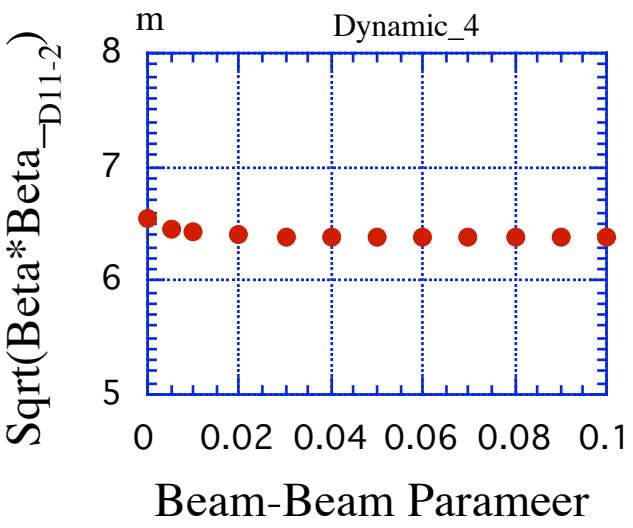
- The tail part of a positron bunch is vertically unstable due to e^- cloud.
- For the sake of a finite crossing angle, longitudinal colliding position shifts, depending on the horizontal offset.
- The electron beam may stimulate the electron cloud in offset (c).
- The vertical size of the positron beam increases due to synchro-beta coupling.
- Therefore, the luminosity reduces in (c).

Position Shift and Beam-Beam Kick

- Position shift depends on the beta function, the beta changes due to dynamic effects.



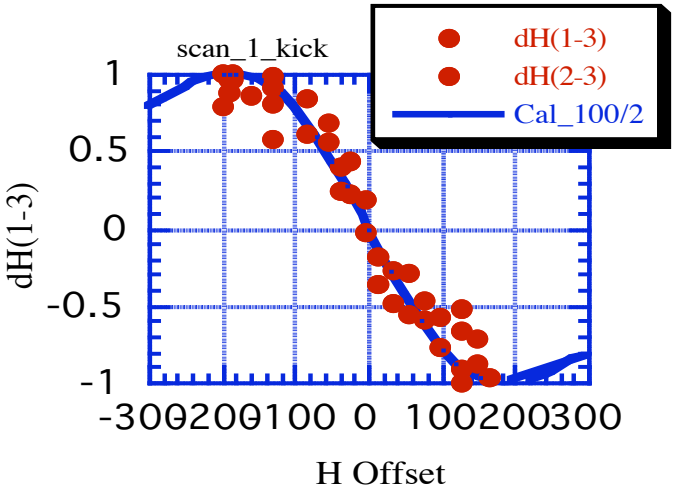
- But, $\sqrt{\beta_{D11\text{-}2}\beta^*}$ is almost constant.



- We can obtain beam-beam kick from position shift.

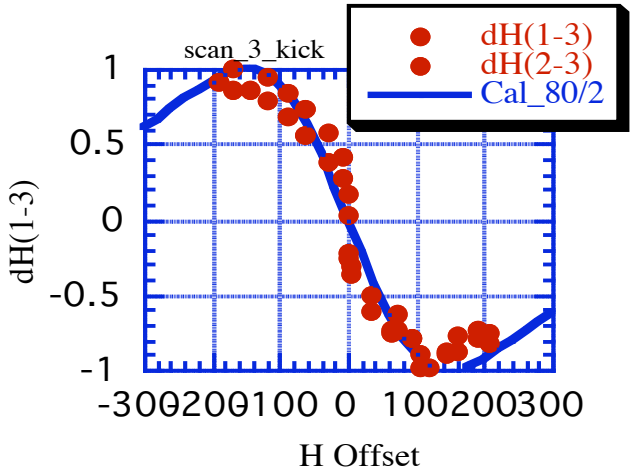
Dynamic Horizontal Beam Size at IP

- Intensity normalized beam-beam kick curves with different current



$0.43 \times 0.29\ mA^2$

$\Sigma_x = 141\ \mu m$



$0.78 \times 0.67\ mA^2$

$\Sigma_x = 113\ \mu m$

- Beam size reduces as the current increases.

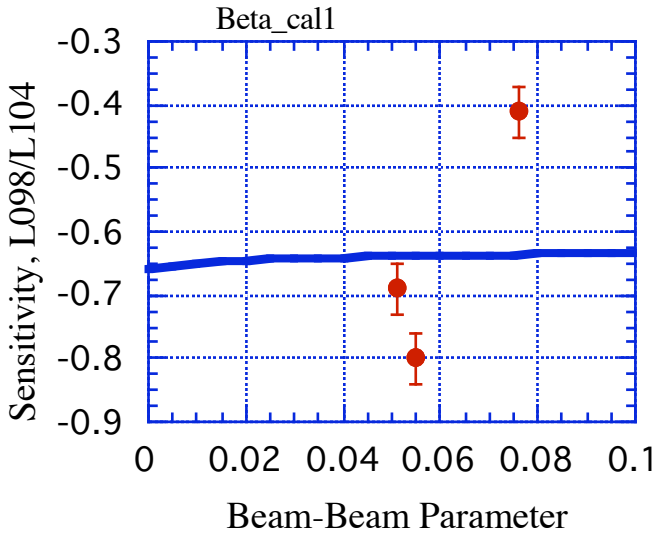
Effective size w/o dynamic effect : $\Sigma_{x0} = 155\ \mu m$

Ratio of Beta Function for Two Locations

- A ratio of position shift for two locations provides

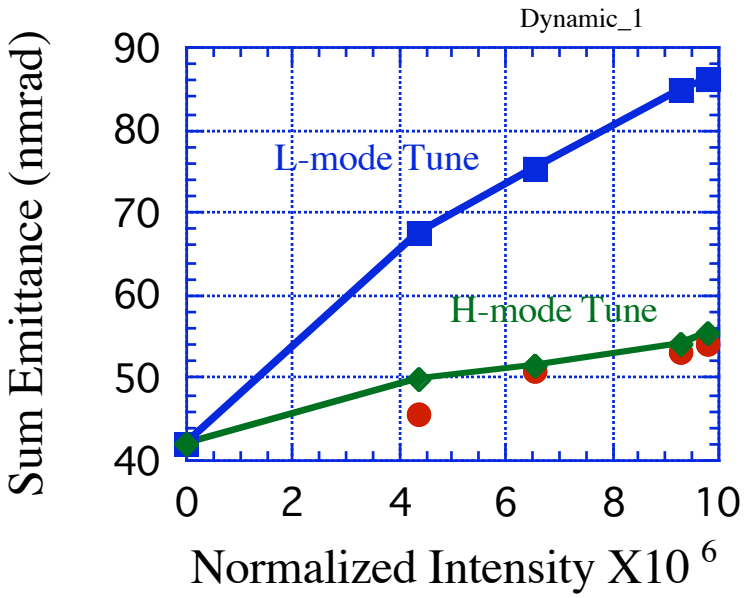
a beta function ratio there, regardless of beam-beam kick.

$$\frac{\Delta X_2}{\Delta X_1} = \sqrt{\frac{\beta_2}{\beta_1}} \cdot \frac{\cos(\pi\nu - |\Delta\varphi_2|)}{\cos(\pi\nu - |\Delta\varphi_1|)}$$



- A measured ratio is different from calculation.

Dynamic Emittance



- Sum emittance is obtained from beam-beam tune shift

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

Normalized Intensity

- Sum emittance measured agrees with calculation using H-mode tune, not L-mode tune.

Summary

- Collision at KEKB is performed with a horizontal offset to avoid the “Egure”.
- The “Egure” phenomena should be caused by electron cloud.
- Horizontal beam size at IP agrees with expectation.
- A measured ratio of beta function for two locations is different from calculation.
- Dynamic emittance agrees with calculation using *H*-mode tune.
- The presence of dynamic effects was demonstrated by these experiments.