Unexplained Phenomena in Lepton Machines

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LARP Mini-Workshop on Beam-Beam Compensation

Half Integer and Dynamic Beta

- Modern e+e- colliders, CESR, KEKB, PEP-II, moved closer to the half integer
- Dynamic beta effects play a critical role
- Why beam-beam parameters is much higher near the half integer?

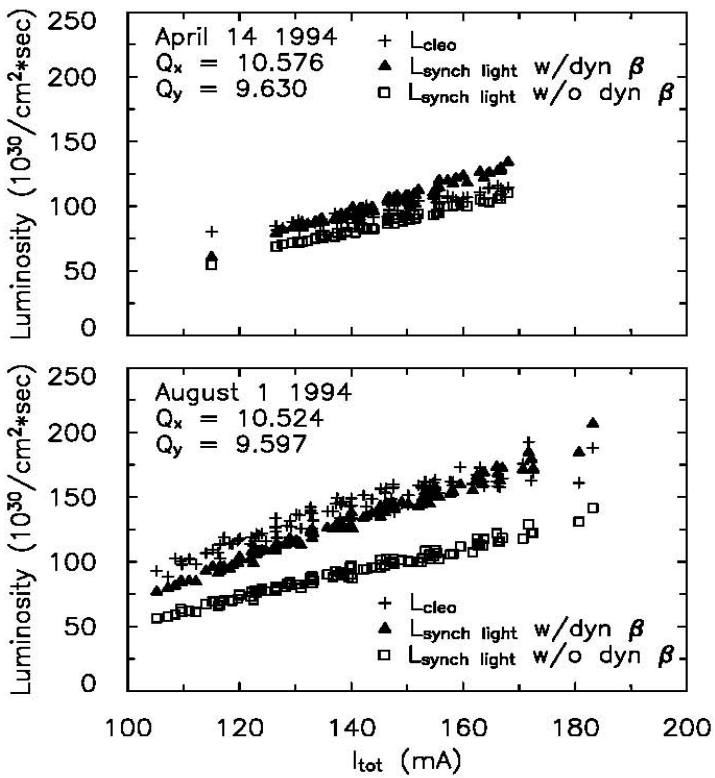


Figure 2. Luminosity as a function of total current for two days of HEP running.

David Sagan, CESR, 1996

Comparison of Simulations and Observations

M. Tawada, Y. Funakoshi, M. Masuzawa, K. Ohmi
KEKB, 2000

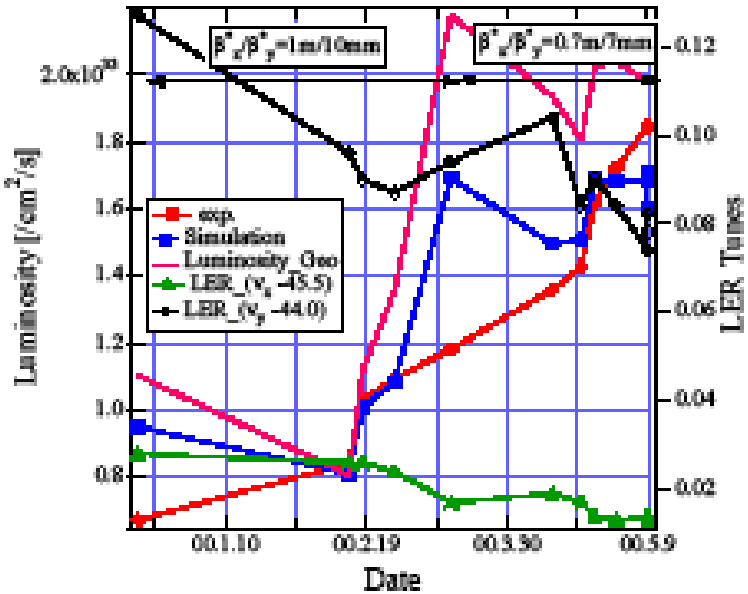


Figure 1: Luminosity history. The filled circle is the experimental peak luminosity, which was measured by the CsI luminosity monitor, the solid line is the geometrical luminosity and the filled box is the simulation result. The filled triangle and white circle is the horizontal and vertical tunes of LER.

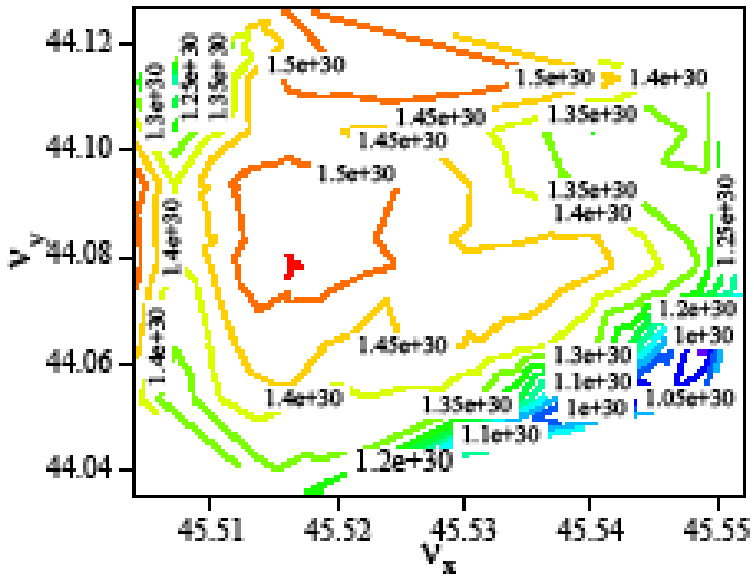


Figure 2: The result of LER tune survey by the strong-strong beam simulation around the present working point. The value on this graph is the luminosity for single bunch at the bunch current of 0.37 mA for HER and 0.58 mA for LER, respectively. The present LER working tune is $\nu_x \sim 45.52$, $\nu_y \sim 44.08$.

Bunch Trains and Effects of Close Orbit

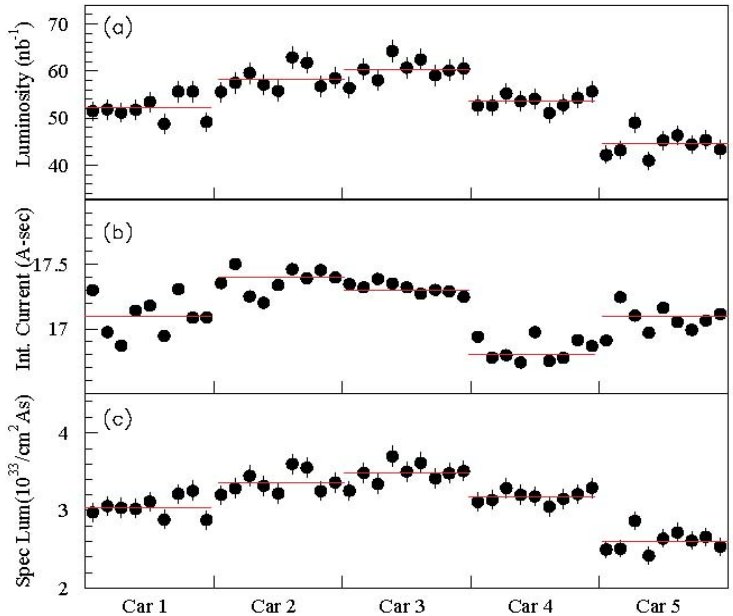


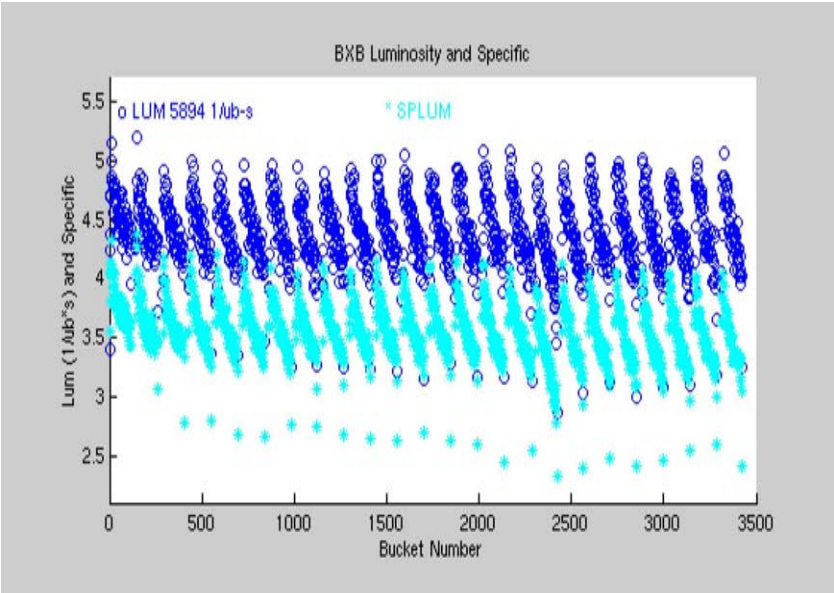
Figure 2: The (a) integrated luminosity, (b) integrated current, and (c) run-averaged specific luminosity of an HEP run where there were 9 trains of 5 bunches. The points represent the performance for individual cars while the lines indicate the average over all trains for each car.

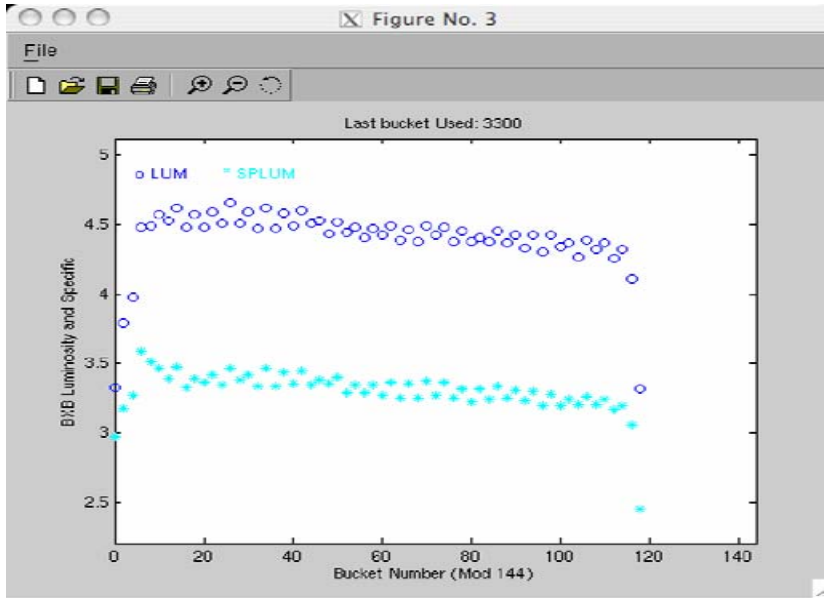
D. Sagan, M. Billing, M. Palmer, CESR, 2001

Figure 2. Electron and positron closed orbits in crossing angle operation. The crossing angle is $\pm 2.3 mrad$. Tic marks along the circumerence indicate parasitic crossings with 9 trains with the 2 bunches/train spaced 28ns apart.

- Different bunches in a train experience a difference collision sequence
- Beam-beam kick from parasitic collisions cause the change of orbit
- The difference in orbit causes the difference in optics as well
- Self-consistent simulation?

Luminosity Droop in a Short Train





W. Colocho, PEP-II, 2005

normal situation

- "Pacman" effect was clearly seen in the nominal case
- The droop lasted several months and decreased as the machine optics was tuned better, especially after a fix of a shorted quadrupole magnet

Flip-Flop Along Bunch Train

R. Holtzapple et al, PEP-II, 2002

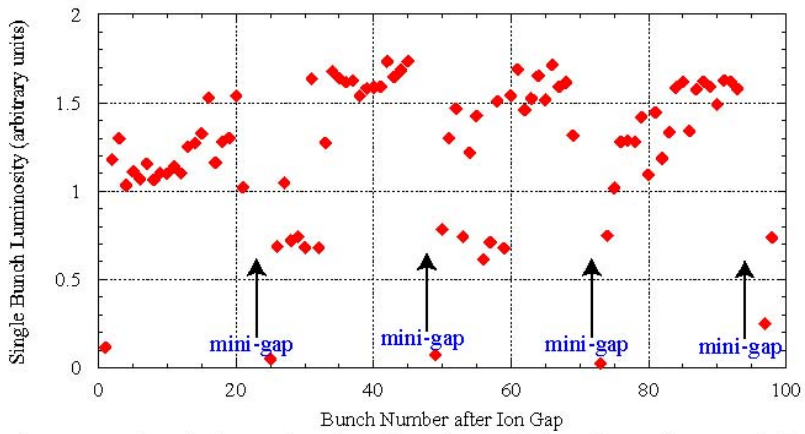


Figure 3 (Color). The luminosity of the first four mini-trains after the ion gap.

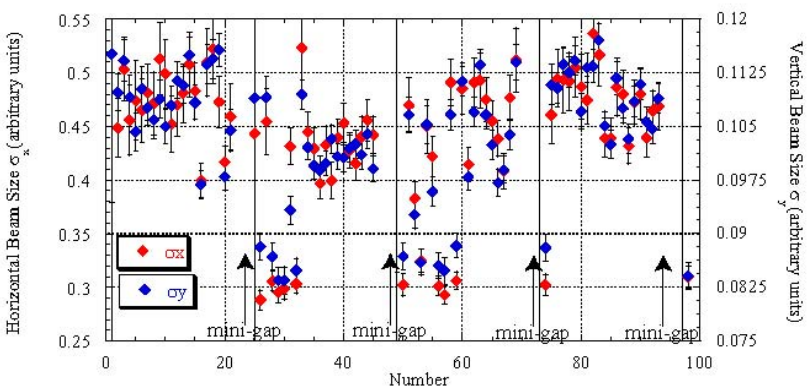
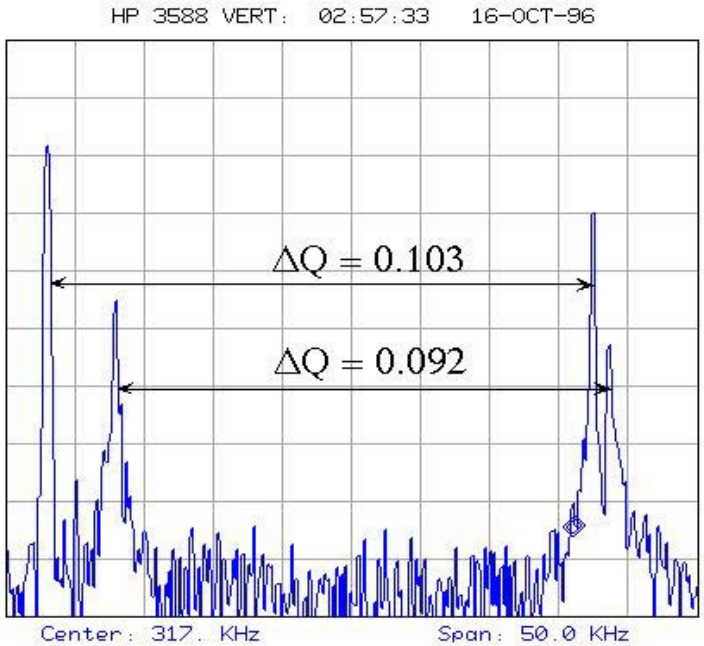


Figure 4 (Color). The horizontal and vertical beam size for the first four mini-trains after the ion gap.

- Several bunches have very short lifetime. As a result, their luminosity was nearly zero
- Several bunches have reduced beam size and luminosity. There were flipped bunches
- Flipped bunches tended to be at the front of bunches
- Most likely cause was the electron cloud in addition to the beam-beam force

Round Beam Colliders: Mobius Rings



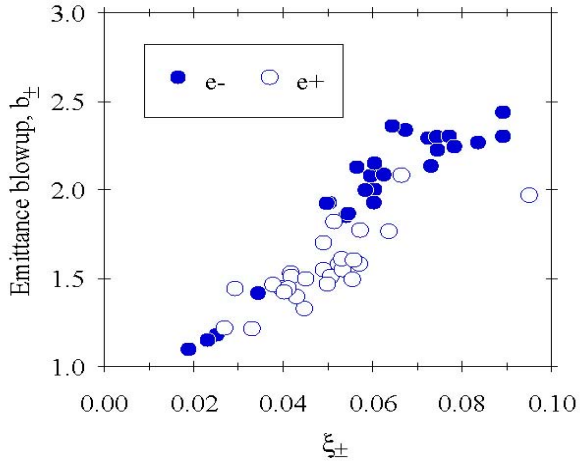


Figure 3: The emittance blowup of each beam, $b_\pm$ as a function of the tune shift parameter which it experienced, $\xi_\pm$.

E. Young, et al, CESR, 1998

- Why there are two sets of coherent peaks?
- Why electron beam tends to blow-up more the positron beam?
  - CESR regular operation with flat beam as well
  - Electron beam is always weaker than in the simulation

Beam-Beam Deflection

C. Bovet, et al. LEP, 1995

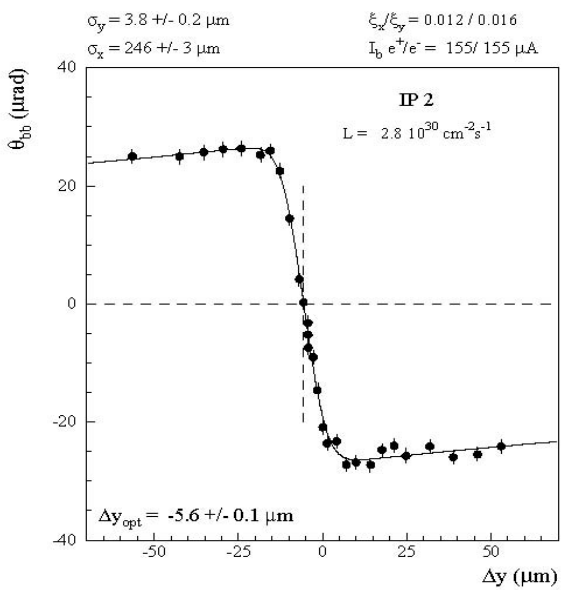


Figure 1: Beam-beam deflection scan for a beam energy of 65.1 GeV. θ_{bb} is shown as a function of the electrostatic separator bump amplitude Δy. The systematic offset θ_0 is already subtracted from the data. The line is the result of the fit. The luminosity L and the beam-beam tune shifts ξ_x and ξ_y have been calculated from the fitted beam sizes and the bunch currents I_b. Δy_{opt} is the optimum separator setting.

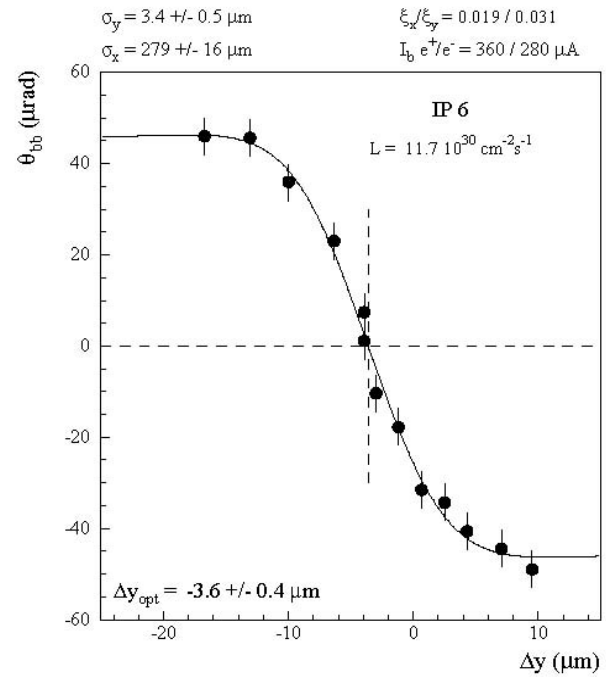
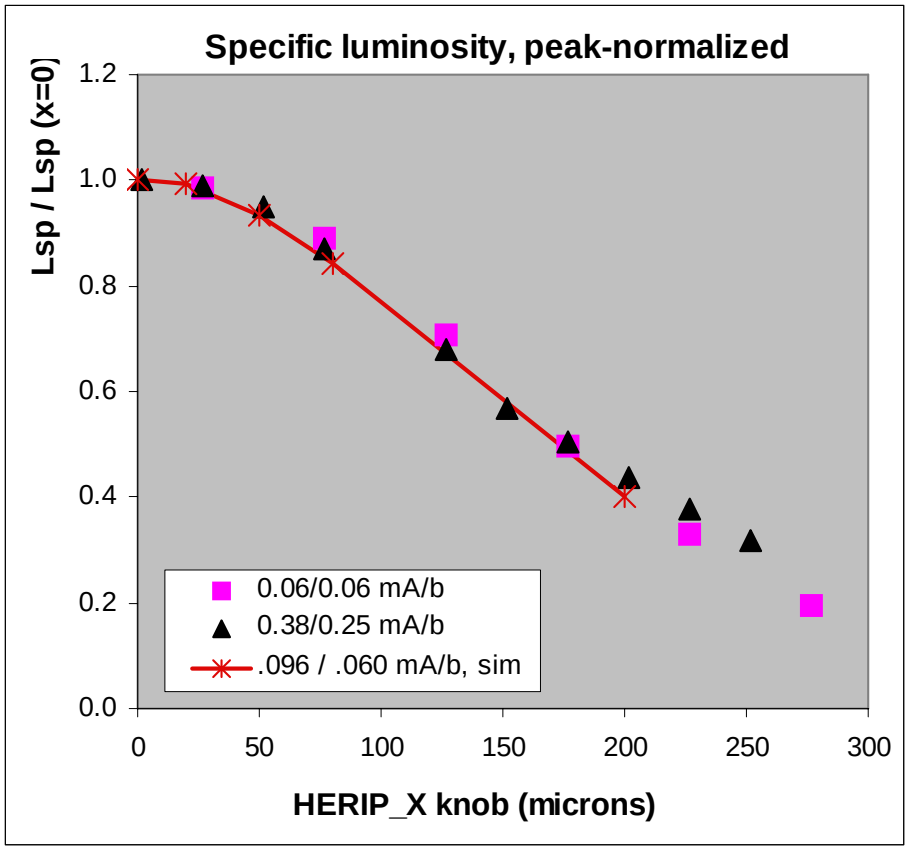
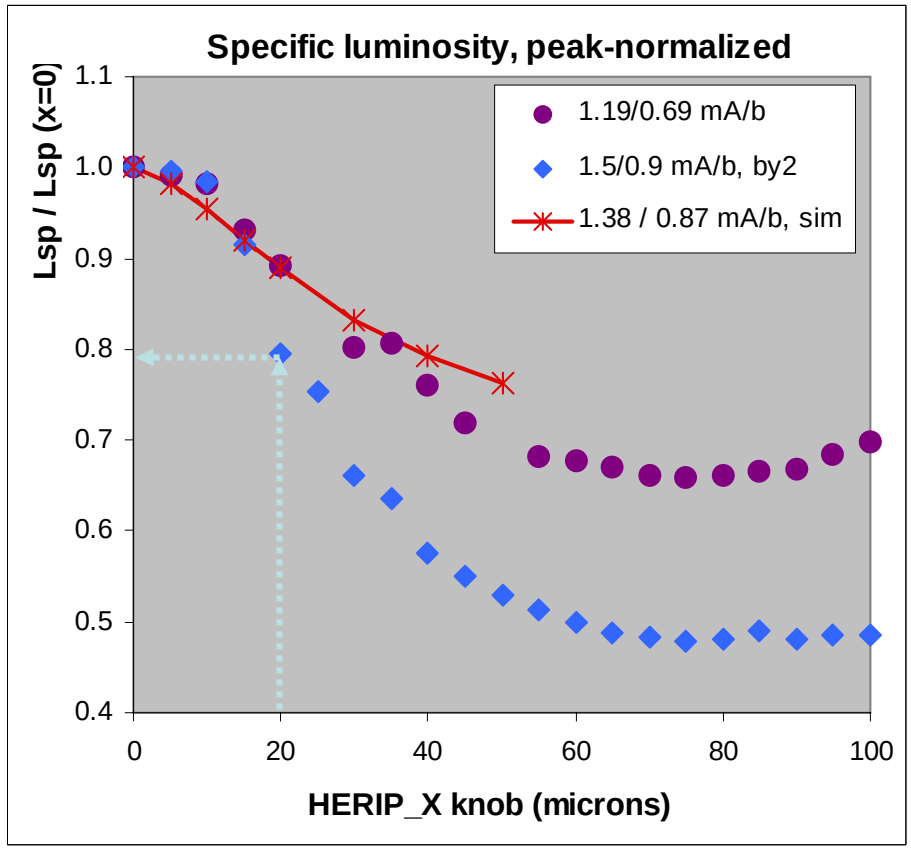


Figure 2: Beam-beam deflection scan performed at a beam energy of 68.1 GeV. The bunch currents are more than twice as large as for the scan shown in Figure 1.

Why the vertical beam size appeared smaller at higher currents?

X offset and specific luminosity





Low current:

excellent agreement between data & simulation

Medium/high current:

qualitative agreement betw. data & simulation on Lsp out to ΔX~40 μ (but: sizes!). Simulation underestimates L_{sp} drop.

Measured by W. Kozanecki, PEP-II, 2004

Effect of Radiation Damping

Table 1: Overview of achieved beam energies, ξ_y, bunch currents, and transverse damping times in LEP.

Year	Beam energy [GeV]	Maximum ξ_y	Damping time [turns]	Bunch current [μA]
1994	45.6	0.045	721	320
1995	65.0	0.050	249	400
1996	86.0	0.040	107	525
1997	91.5	0.055	89	650
1998	94.5	0.075	81	750
1999	98.0	0.083	73	780
2000*	102.7	0.055	63	550

R. Assmann and K. Cornelis, LEP, 2000

$$\xi_y \propto \lambda^{-0.4}$$ (Similar to S. Peggs, LHC99)

Where λ is the damping decrement. Why such scaling law?

Beam-Beam Tail and Lifetime

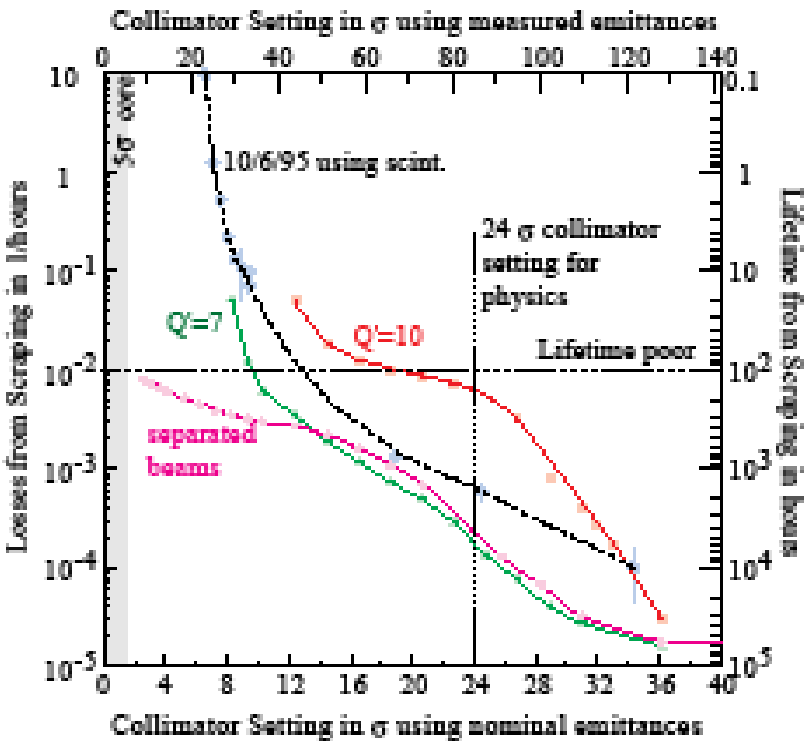


Figure 2: Measured beam tails in the vertical plane.

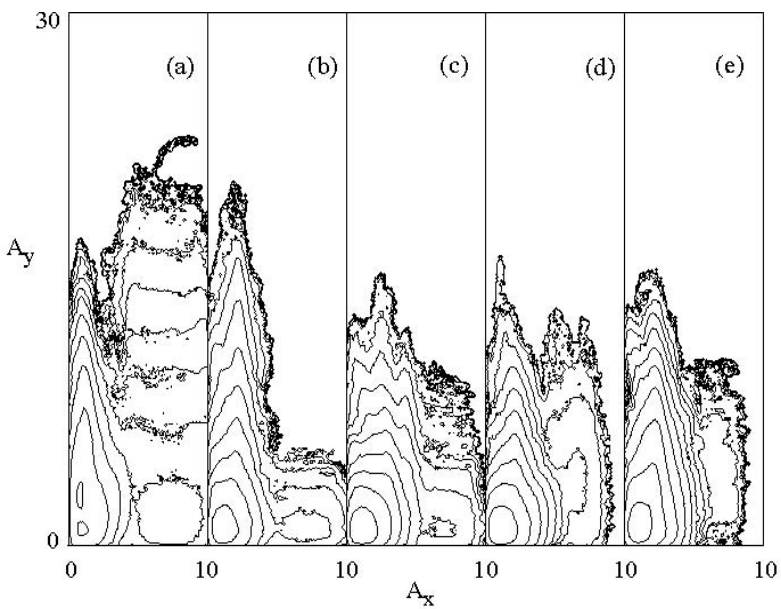


Figure 3: Beam tail distributions in transverse amplitude space: a) q_x=0.6236 for p=8 resonance, b) q_x=0.5986 for p=10 resonance, c) q_x=0.5819 for p=12 resonance, d) q_x=0.57 for p=14 resonance, and e) q_x=0.5611 for p=16 resonance.

H. Burkhardt, et al. LEP 1995

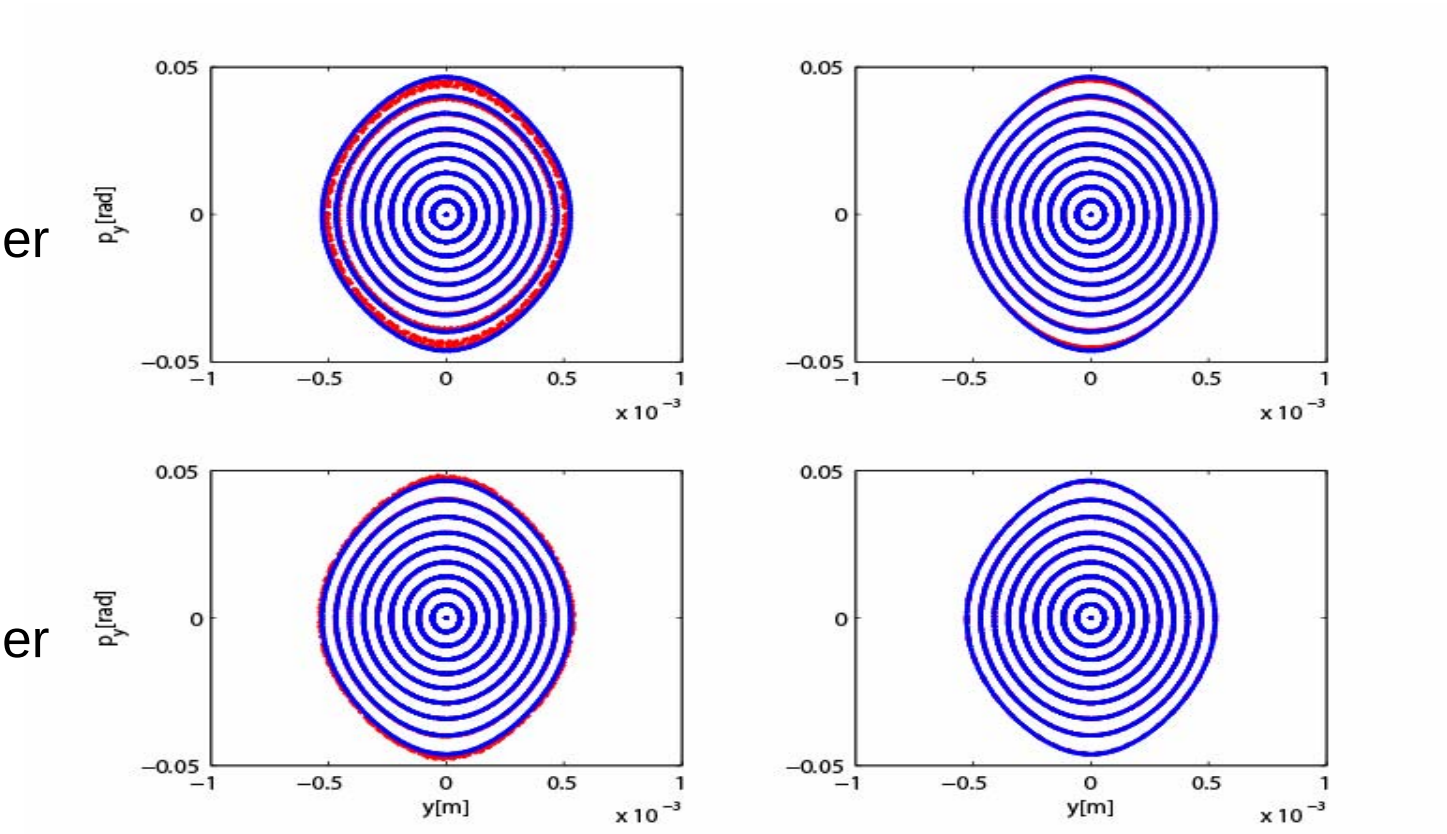
T. Chen, J. Irwin, R.H. Siemann, PEPII 1996

Why the simulation and measurement were so far apart? Do we need a detailed Information of nonlinearity in the machine?

Symplecticity in Hamiltonian System

6th order

8th order



Increment : $5\sigma_y$

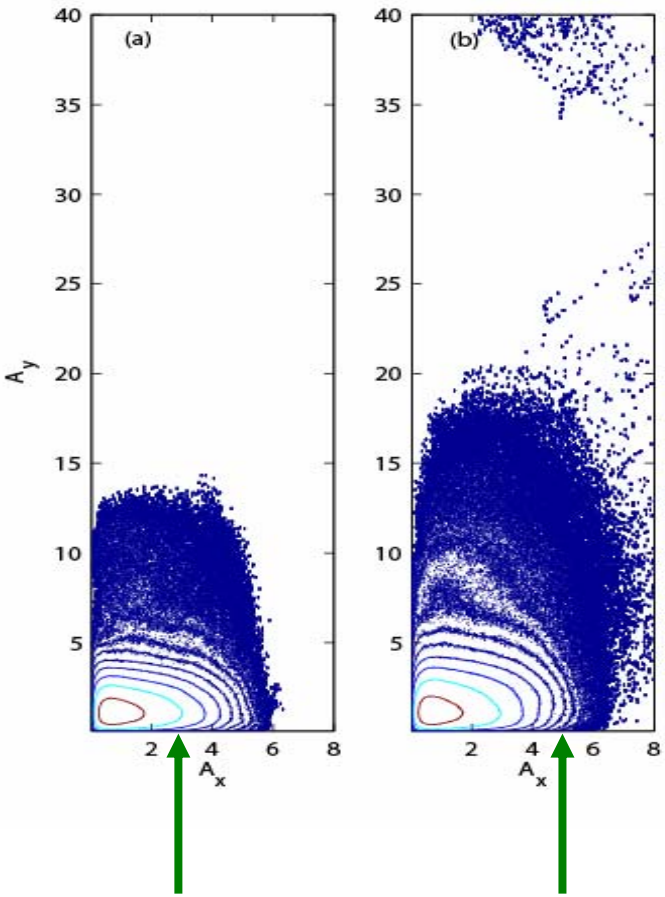
Taylor map (Zlib)

Mix-variable generating function (Zlib)

element-by-element tracking (LEGO)

Positron Beam Distributions with Beam-Beam Interaction

$\tau = \infty$ $\tau = 16\,\mathrm{min}$



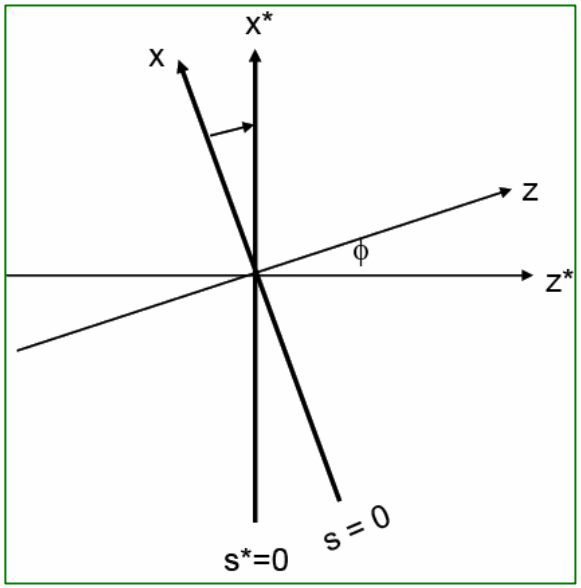
The distributions are averaged after 40,000 turns to improve the statistics.

Contours started at value of peak/sqrt(e) and spaced in e. Labels are in σ of the initial distribution.

The core distribution is not disturbed much by the nonlinearity in the ring while the tail is strongly effected.

With a linear matrix or 8th order Taylor map (ν_x^+=0.5125). Nonlinear map is important because it defines the dynamic aperture.

Symplectic Treatment of a Finite Crossing Angle



Rotation around Y axis

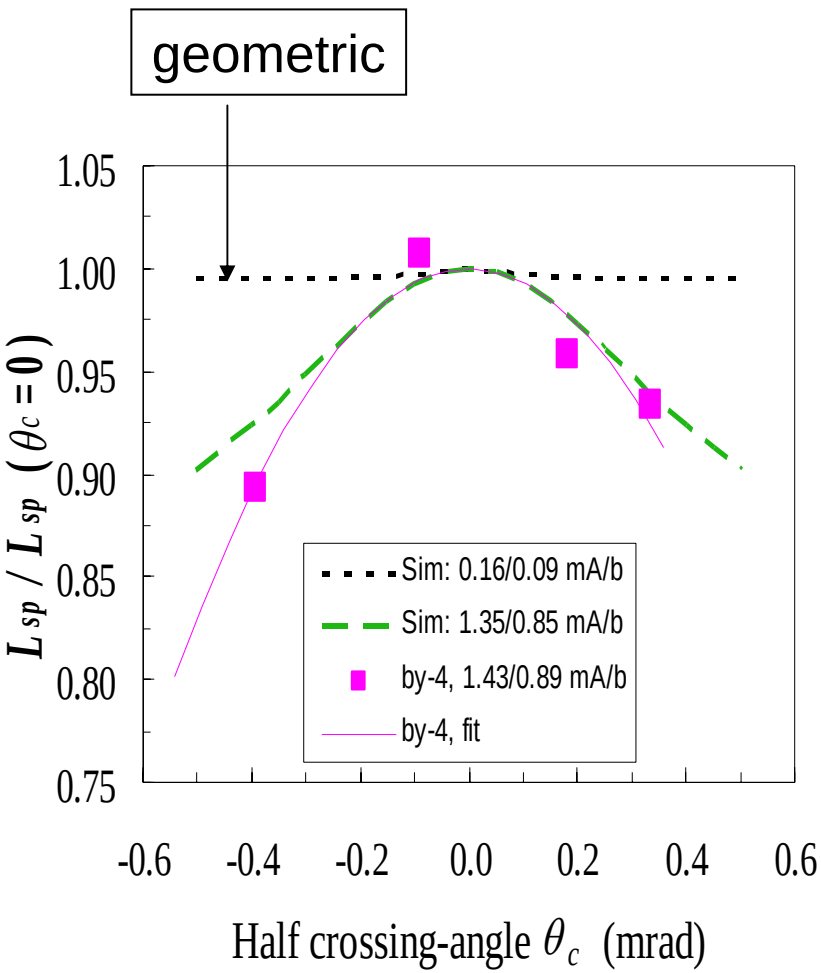
Lie transformation: $e^{:xp_s:\phi}$

$$x^* = xp_s/[\cos\phi(p_s - p_x\tan\phi)],$$
$$p_x^* = p_x\cos\phi + p_s\sin\phi,$$
$$y^* = y + xp_y\tan\phi/(p_s - p_x\tan\phi),$$
$$p_y^* = p_y,$$
$$\delta^* = \delta,$$
$$l^* = l + x(1+\delta)\tan\phi/(p_s - p_x\tan\phi),$$

where, $p_s = \sqrt{(1+\delta)^2 - p_x^2 - p_y^2}.$

It is a symplectic transformation contrast to Hirata's Lorentz boost, which is quasi-symplectic.

Crossing Experiments at PEP-II



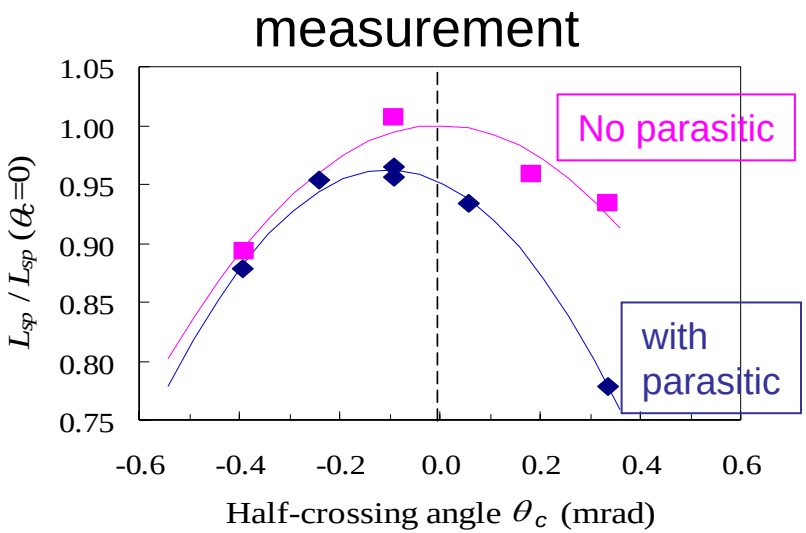
Measured by W. Kozannecki, PEP-II, 2006

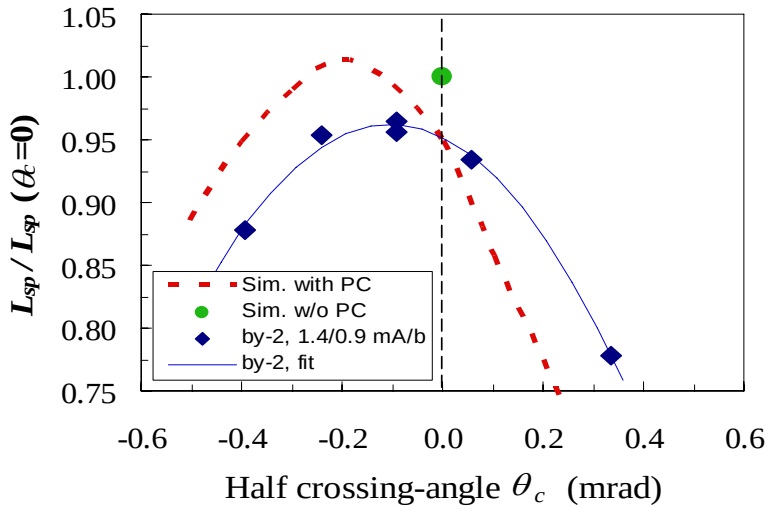
- Simulation was carried out prior to the experiments to make sure there was enough sensitivity.
- 'By-4' bunch pattern to avoid parasitic collision (30 σ_x^- separation).
- The orbit bump used to change the angle. The knob was carefully calibrated against a pair of BPMs next to the IP.
- Luminosity feedbacks were on to align beams transversely after each change.
- Tune changes were necessary to compensate the optical errors introduced from the nonlinearity of the fringe field and magnets inside the bumps.

Experiment of Crossing Angle and Parasitic Collisions

- 'By-2' bunch pattern was used to include parasitic collisions (3.2 mm or $11\sigma_x^-$ nominal separation)
- Crossing angle and the separation of parasitic collisions are related: $\delta x = \delta x_0 - 2\theta s_c$. The corresponding range of separation is 3.6 to 2.7 mm.
- Both simulation and experiment showed small nonzero crossing angle are preferred to move away from the parasitic collisions.
- It is not clear why the optimum luminosity is actually better when both parasitic collisions and crossing angle are present than the head-on collision without the parasitic collision.

Measured by W. Kozanecki, PEP-II, 2006



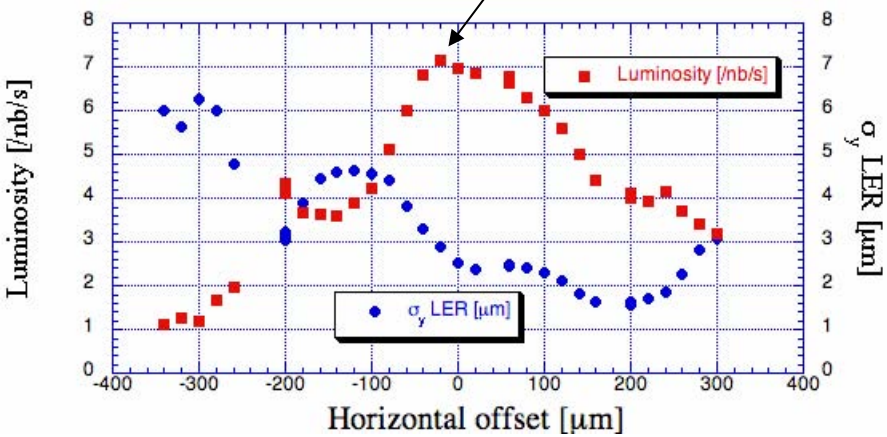


Horizontal offset scan (Y. Funakoshi, KEKB,2004 June 9)

Scan with high current (940mA/1200mA)

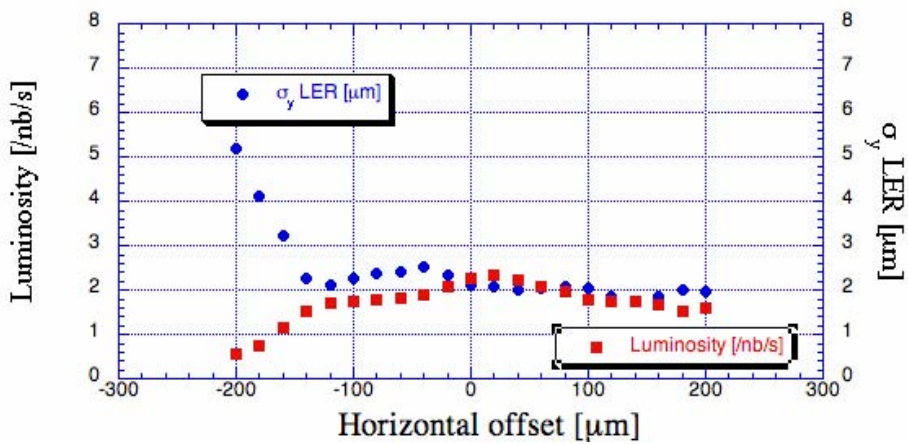
← scan

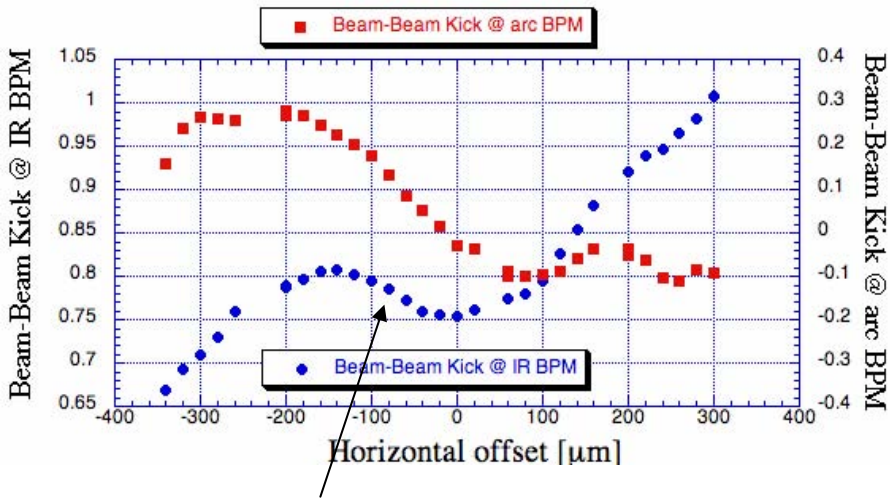
Lumi peak(H_{set} ~ -20μm)



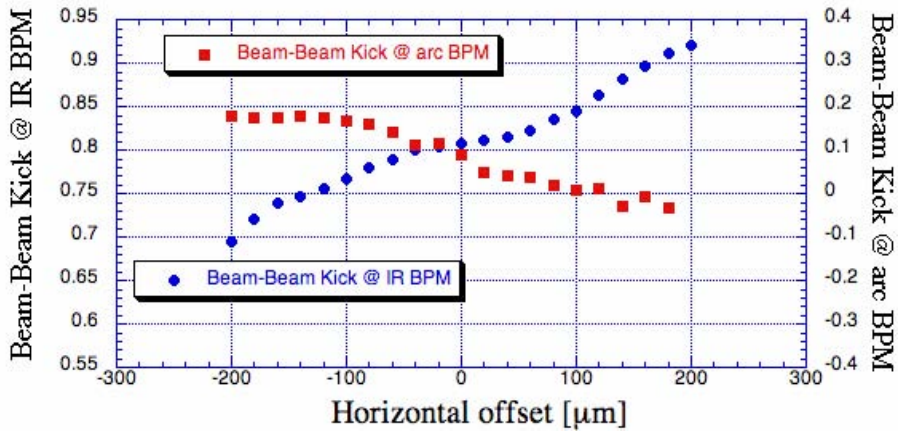
Scan with low current (~400/600mA)

← scan



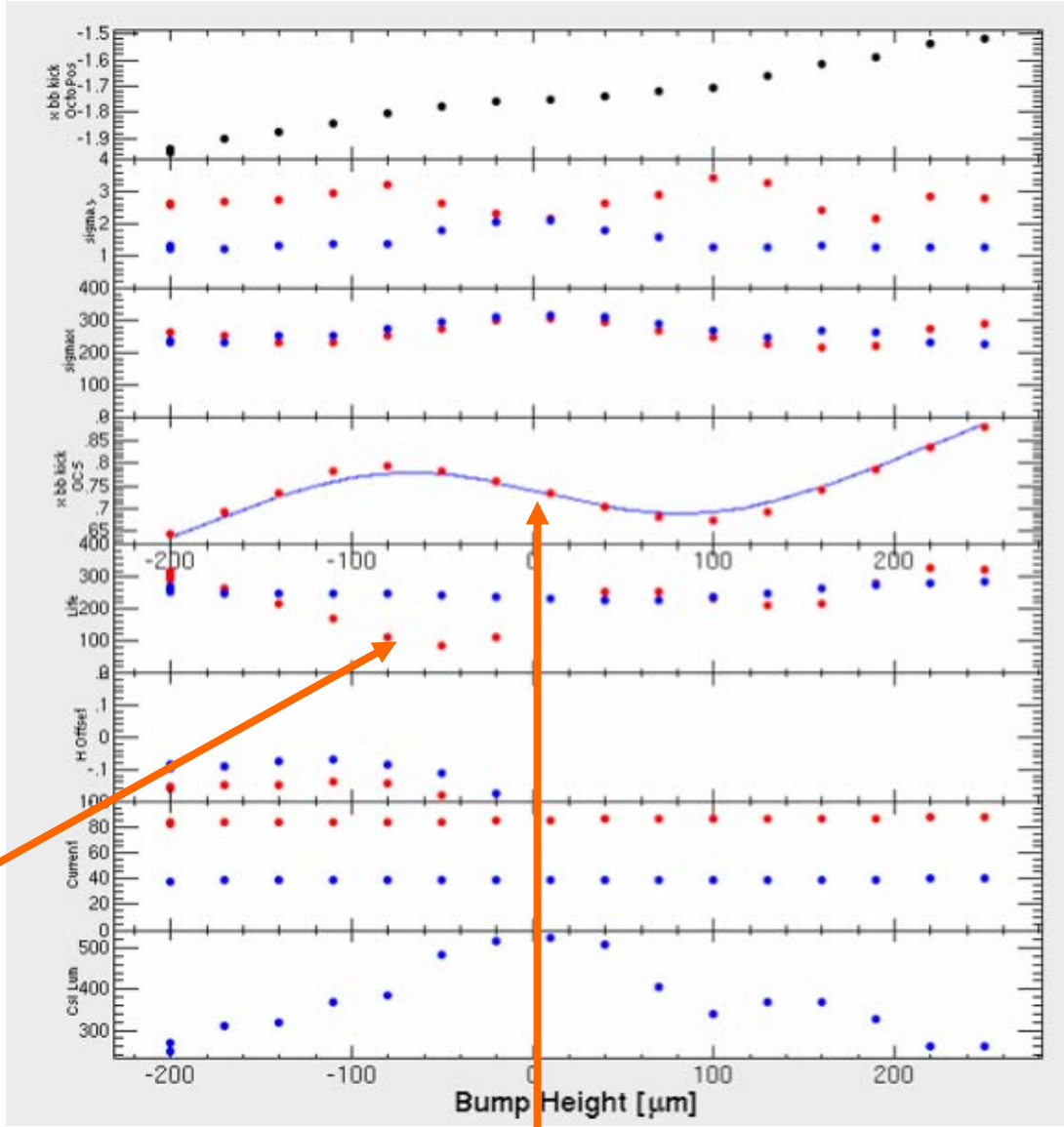


zero-offset (H_{set} ~ -70μm)



Horizontal offset scan

- The (HER) beam current seems to be limited by the short life time of the LER beam.
- The (LER) beam lifetime is very asymmetric with respect to H offset.



LER lifetime

Collision center given by the beam-beam kick

with crab crossing

Y. Funakoshi, KEKB, 2007

Coupling and Beam Size at the Interaction Point

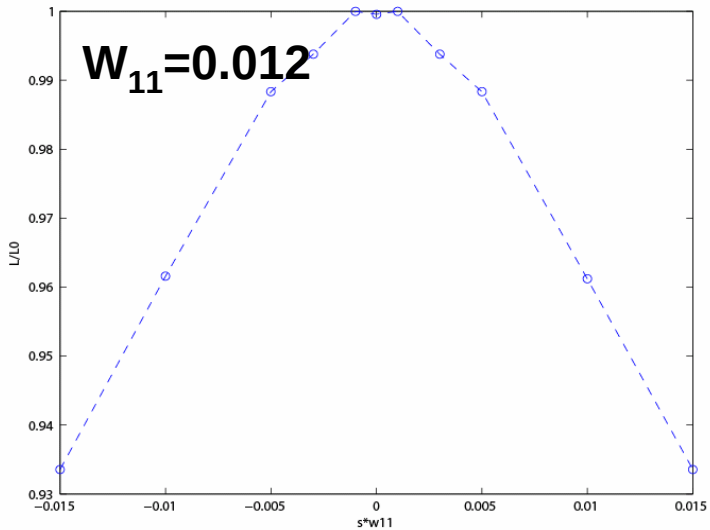
In general coupled lattice, we have

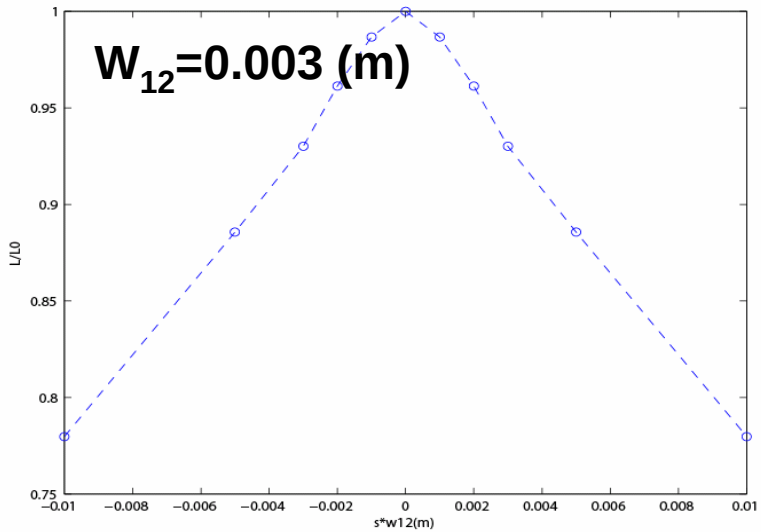
$$\sigma_x{}^2 = \Sigma_{11} = \beta_1 \varepsilon_1 g^2 + (\beta_2 w_{22}{}^2 + 2\alpha_2 w_{22} w_{12} + \gamma_2 w_{12}{}^2)\varepsilon_2,$$
$$\sigma_y{}^2 = \Sigma_{33} = (\beta_1 w_{11}{}^2 - 2\alpha_1 w_{11} w_{12} + \gamma_1 w_{12}{}^2)\varepsilon_1 + \beta_2 \varepsilon_2 g^2,$$

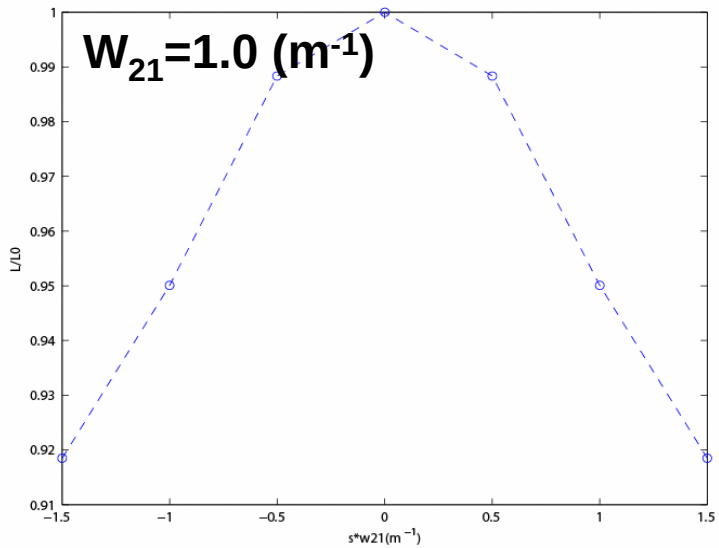
where α,β,γ are Courant-Snyder parameters in the eigen modes, $w_{11}, w_{12}, w_{21}, w_{22}$, are four coupling parameters, and ε is eigen emittance.

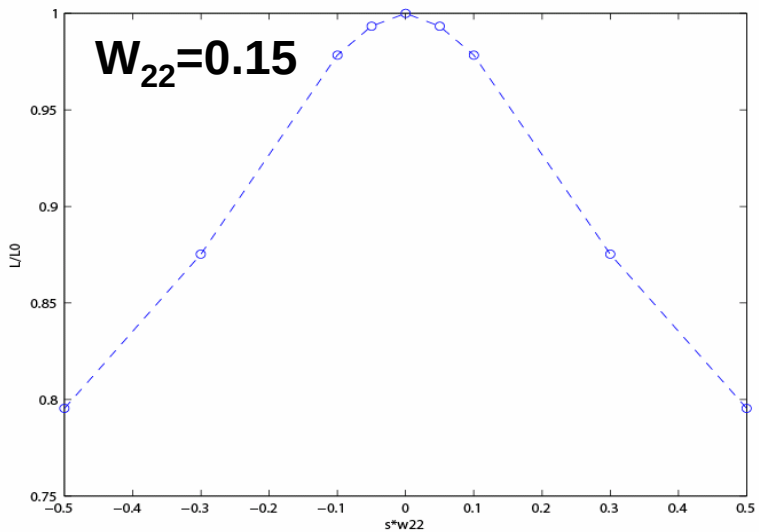
1. In an electron storage ring, usually $\varepsilon_1 >> \varepsilon_2$
2. ε_1 and ε_2 are invariant in a ring.
3. w_{21} does not appear in the beam size directly.
4. Most time, $\alpha_1=0$, $\beta_1<1.0$, the most sensitive parameter to luminosity is w_{12}.

Simulation of Luminosity Degradation due to Coupling at the IP









MIA/LEGO Models

- High energy ring:
  $w_{11} = 1.27\text{x}10^{-2}$, $w_{12} = 8.48\text{x}10^{-3}$
  $w_{21} = -0.924$, $w_{22} = 0.262$
- Low energy ring:
  $w_{11} = 6.13\text{x}10^{-3}$, $w_{12} = 1.50\text{x}10^{-2}$
  $w_{21} = -2.07$, $w_{22} = -0.82$
- Why the luminosity reduced by a factor of two if we used these coupling values in the simulation?
- Why the final empirical tuning based on the luminosity monitor are always necessary?

Conclusion

- Many progresses in the understanding of beam-beam effect in the lepton machine has been made over the past decay, largely due to the ever increasing of computer power and improvement of new algorithms.
- As usual, it is always a constant struggle to understand the operating accelerators even with good simulation tool.
- It seems that single-bunch effects are quite well understood at least in terms of simulation. The future improvement are most likely come from the subjects that relates to the multiple bunches, parasitic collisions, compensation, and other things that beam encounters in the circular accelerators, such as ions, electron cloud and nonlinearity.