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Observation of the Dynamic Beta Effect at CESR with CLEO

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Abstract

Using the silicon strip detector of the CLEO experiment operating at the Cornell Electron-positron Storage Ring (CESR), we have observed that the horizontal size of the luminous region decreases in the presence of the beam-beam interaction from what is expected without the beam-beam interaction. The dependence on the bunch current agrees with the prediction of the dynamic beta effect. This is the first direct observation of the effect.

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In a high energy colliding beam storage ring when two beams of oppositely charged particles pass through each other there is an attractive force between them. Under certain circumstances this beam-beam interaction can lead to a reduction in the transverse beam size at the interaction point. This "dynamic beta" effect is potentially important since a smaller beam size corresponds to a higher luminosity.

The dynamic beta effect has been long predicted [1]. It has been observed indirectly through its effect on luminosity at CESR [2]. This letter describes the first direct observation of the reduction in beam size due to the effect. The dynamic beta effect is analyzed by modeling the beam-beam interaction as a linear focusing lens. This focusing alters the beta, β, around the ring. If the tune is just above the half integer resonance there is a sharp reduction in β^*, the beta at the interaction point. This decreases the size of a single beam at the interaction point, given by $\sigma^* = \sqrt{\beta^* \epsilon}$ where ϵ is the emittance. The strength of the linear lens and therefore the reduction in β^* becomes larger with increases in the bunch current.

CESR [3] is a particularly good place to observe the dynamic beta effect. The bunch current is large, over 8mA, generating a large beam-beam interaction. There is also a large range of bunch currents during normal CESR operations as the beam lifetime is about three hours and the typical fill lasts 75 minutes. The collisions studied here have bunch currents ranging from 4 to 8mA. In the horizontal direction the CESR lattice has a tune just above the half integer contributing to a large dynamic beta effect. In the vertical direction the tune is not close to the half integer and thus bunch current dependent effects are negligible on the vertical size of the beam.

The CLEO detector has been described in detail elsewhere [4]. A recent addition is a silicon strip vertex detector [5] which is crucial to the observation of the dynamic beta effect. This consists of three layers of silicon wafers arrayed in an octagonal geometry around the interaction point. The first measurement layer is at a radius of 2.3cm and the wafers are read out on both sides by strips which are perpendicular to each other. The readout strips have a pitch of about 100μm and with charge sharing the detector has an intrinsic per point resolution of better than 20μm in both the plane transverse to the beam, the xy plane, and in the direction parallel to the colliding beams, called z.

We observe the luminous region with events of the type $e^+e^- \to$ hadrons, which are defined as events with more than two charged tracks and four or more significant energy deposits in the electromagnetic calorimeter. All the data are taken with electron-positron collisions with a center of mass energy equal or just below the mass of the $\Upsilon(4S)$ resonance. We try to form a vertex from all the tracks in the event that have hits in at least two of the three layers of the silicon in both the xy-plane and z direction. Those tracks with a contribution to the vertex chi-square of over two per degree of freedom are removed as being unlikely to share a common vertex with the other tracks. This procedure is iterated until all such tracks are removed. Finally the probability of the vertex chi-squared must be greater than 10%. Vertices formed from two or more tracks give three dimensional points in space that are used to determine the size of the luminous region. A total of 77327 such vertices are found.

For each discrete fill of CESR the average position is found in the vertical and horizontal directions. There are occasional large shifts in this average fill position that result from tuning CESR for backgrounds or luminosity with the introduction of closed orbit distortions through the interaction region. These fill averages are subtracted from all the points of the fill to correct for these shifts in the average position of luminous region. We have looked for changes in the average beam position during the course of a fill and can discern none.

The distribution of these positions in the horizontal (x) and vertical (y) directions is binned and then fit to a flat function, to account for vertices not resulting from beam-beam collisions, plus a Gaussian shape. The width of this Gaussian is taken as the observed width of the luminous region.

Another useful feature of the CESR lattice for the observation of the dynamic beta effect is the disparity of the beam size between the horizontal and vertical directions. Without considering the effect of the beam-beam interaction, the horizontal beta at the interaction point, β^*_{0x}, is 1.38m and the horizontal emittance, ϵ_x, is 2.0×10^{-7}m, giving a Gaussian width of the beam in the horizontal direction of $\sigma^*_{0x} = 525\mu$m. In the vertical direction $\sigma^*_{0y} \approx 10\mu$m. Note that when the two beams collide they create a luminous region which is the overlap of the two colliding beams. The size of this luminous region is a factor of $\sqrt{2}$ smaller than the single beam size.

Figure 1 shows the observed width of the luminous region in the horizontal and vertical directions as a function of the bunch current. The vertical width of around 120μm is much larger than the expectation of $10/\sqrt{2} = 7\mu$m. Studies with a Monte Carlo based simulation of hadronic events in the CLEO detector indicate that the vertical width of the luminous region is a measure of the technique's resolution in the xy-plane. The observed horizontal width is as small as 320μm which is smaller than the expected unperturbed value of $525/\sqrt{2} = 370\mu$m. If the observed vertical width is interpreted as the resolution these data imply an underlying horizontal width of the luminous region of $\sigma_{x\mathcal{L}} = 295\mu$m which is much below the expected unperturbed value. If we fit the observed widths as a function of the bunch current to lines, the vertical is seen to be independent of the bunch current, while the horizontal width has a negative slope of $(-5.4 \pm 1.6)\mu$m/mA. Both the observation of a significantly smaller than expected horizontal width of the luminous region in the presence of the beam-beam interaction and a significant dependence of the horizontal width on the bunch current are evidence of the dynamic beta effect.

To compare with the prediction of the dynamic beta effect we extract the horizontal beta from the width of the luminous region. We use a resolution of $118 \pm 10\mu$m. This is from a fit to the vertical distribution independent of bunch current with the error dominated by a 10μm jitter introduced by the correction for the average fill position. The horizontal emittance is taken from the expectation of the CESR lattice. It is parametrized by $\epsilon_x = (1.96 \times 10^{-7} + 1.46 \times 10^{-9}\mathrm{I_{bunch}} + 5.15 \times 10^{-12}\mathrm{I^2_{bunch}})$m, where $\mathrm{I_{bunch}}$ is the bunch current in milliAmps, which includes dynamic effects caused by the beam-beam interaction. We have measured the horizontal emittance using $e^+e^- \to \mu^+\mu^-$ events observed with CLEO. They give $\epsilon_x = (1.87 \pm 0.65) \times 10^{-7}$m where the error is dominated by the resolution on the angle between the two muons. Then using $\beta^*_x = \sigma^2_{x\mathcal{L}}/2\epsilon_x$ we calculate β^*_x as a function of the bunch current as is shown in Figure 2. The β^*_{x0} of (1.38 ± 0.07)m is taken from a single beam measurement using the observed phase advance through the interaction region.

The theory curves shown in Figure 2 also include the small effect of the beam-beam interaction at parasitic crossings away from the interaction point where the beams are separated by a pretzel orbit. This effect serves to lower β^*_x by about a 10% at a bunch current of 12mA and is essentially linear from no effect at zero bunch current. The range of the

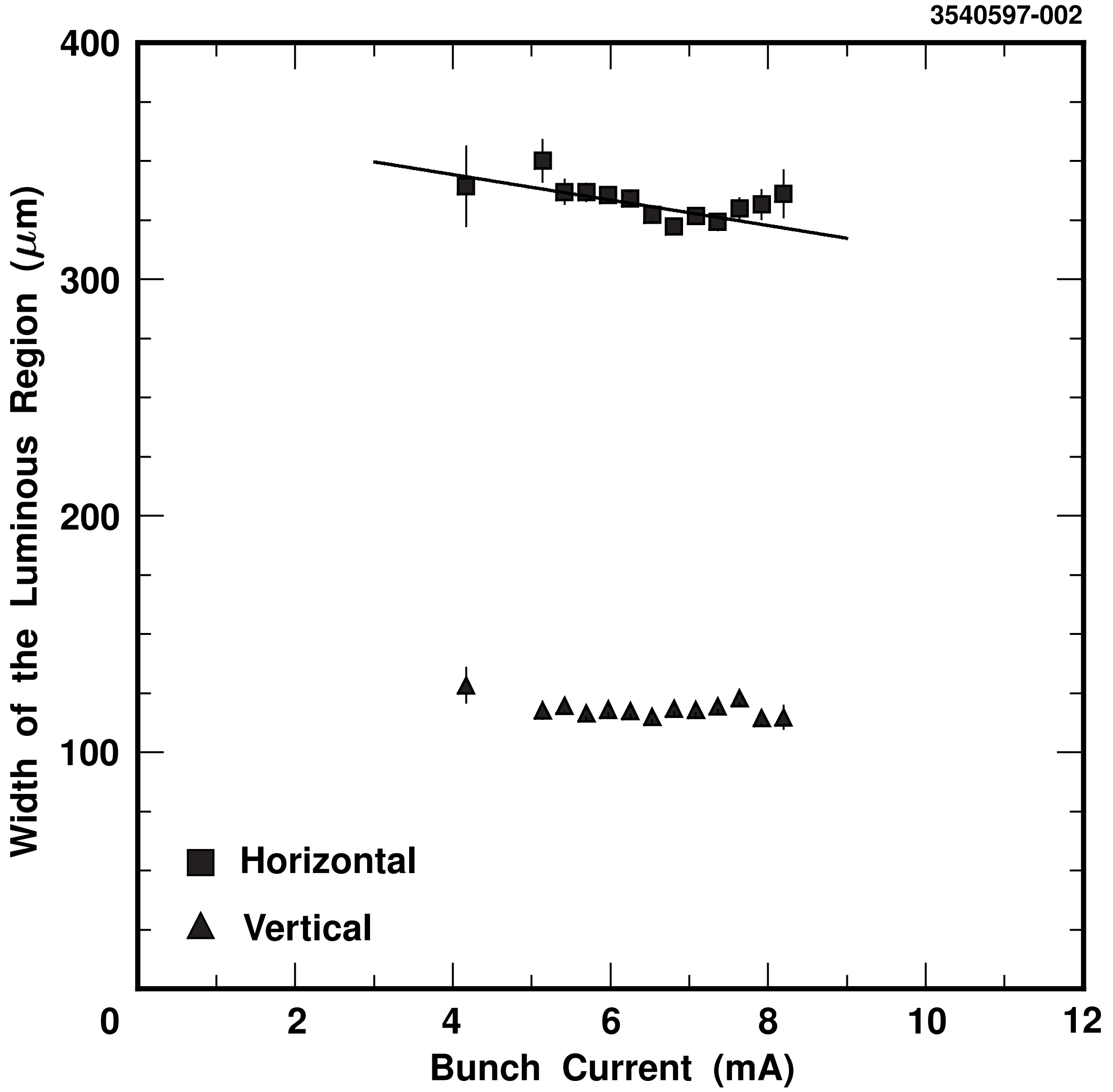

FIG. 1. The observed width of the luminous region in the horizontal and vertical directions as function of the bunch current. Also shown is the line from the fit to the horizontal widths described in the text.

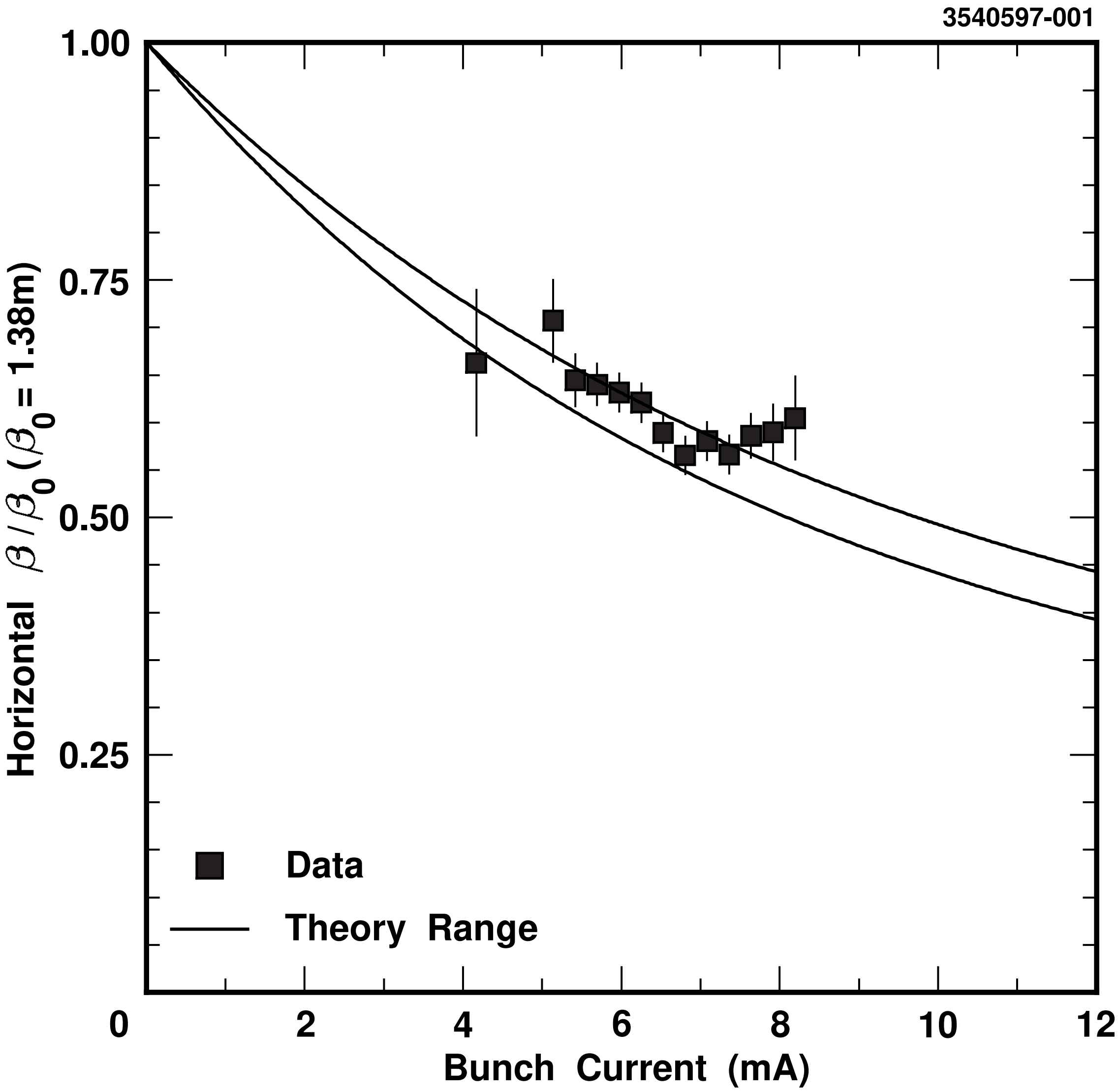

FIG. 2. The horizontal beta as function of bunch current. Note that the error on β^*_{x0} of 5% of its value is not included in the error bars on the data.

theory comes from the observed variation in the fractional integer tune from 0.537 to 0.544 from fill to fill.

In conclusion, we have directly observed the dynamic beta effect at CESR with the silicon strip detector of the CLEO experiment. We have seen that the horizontal size of the luminous region is smaller than expected when there is a beam-beam interaction, and that it decreases in size with increasing bunch current as the dynamic beta effect predicts. When we extract the horizontal beta as a function of the bunch current it is seen to agree very well with the expectation of the dynamic beta effect. This is the first direct observation of this effect.

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REFERENCES

[1] B. Richter, Proceedings of the International Symposium on Electron and Positron Storage Rings, Saclay, 1966 and *Physics of Collective Beam Instabilities in High Energy Accelerators*, A. Chao, Wiley, 1993.

[2] David Sagan in *Proceedings of the 1995 Particle Accelerator Conference and Interanational Conference on High Energy Accelerators Dallas 1995*, IEEE, 1995.

[3] David L. Rubin for the CESR Operations Group in *Proceedings of the 1995 Particle Accelerator Conference and Interanational Conference on High Energy Accelerators Dallas 1995*, IEEE, 1995.

[4] Y. Kubota, *et al.* (CLEO Collaboration), Nuclear Instruments and Methods, **A820**, 66 (1990).

[5] W. R. Ross, Proceedings of the Vertex 96 Conference, Chia, Sardinia, Italy, July 1996.