OBSERVATION OF BEAM SIZE FLIP-FLOP IN PEP-II*

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Abstract

The asymmetric *B*-factory, PEP-II, has delivered a peak luminosity of 4.6×10^{33} cm^{-2} s^{-1} with less than half the design number of bunches, requiring a luminosity per bunch crossing more than three times larger than the design. As a result, strong beam-beam effects are present. The strong beam-beam forces between colliding electron and positron bunches can result in a "flip-flop" of the transverse beam size of some bunches. Focusing on one positron-electron colliding bunch pair, a flip-flop occurs when the transverse size of the positron bunch shrinks and the electron bunch grows. The flip-flop accounts for a reduction in luminosity, a lower positron lifetime, and increased background in the *BABAR* detector. The flip-flop phenomenon occurs not for all of the colliding bunches, but for the bunches at the front of a mini-train. Once a colliding pair has flipped to its reduced luminosity state it can be changed back to its normal state by raising the horizontal tune in the low-energy ring (LER, positrons) by 0.01. Afterwards the LER x-tune can be reduced nearly back to its original point, resulting in higher luminosity. These observations were verified and quantified with a new time-gated camera with a resolution of 2 ns, making it possible to observe single bunches.

1 PEP-II OPERATING CONDITIONS

The PEP-II accelerator complex consists of two rings, a high-energy ring (HER) with 9-GeV electrons and a low-energy ring (LER) with 3.1-GeV positrons. We obtained our highest luminosity, 4.6×10^{33} cm^{-2} sec^{-1}, by colliding 1.75A in the LER with 1.05A in the HER. This luminosity is well over the design value of 3.0.

One obstacle to higher luminosity has been the electron-cloud instability in the LER [1,2]. To achieve this peak luminosity the following steps were taken to reduce the LER bunch size blow-up due to the electron cloud instability: (i) solenoid windings were wrapped around the arc and straight-section vacuum chambers in the LER [2], (ii) bunch spacing was optimized and short gaps were inserted in the bunch pattern [3]. The peak luminosity was achieved when we collided with 8.4-ns bunch spacing (every 4^{th} RF bucket) and evenly spaced mini-gaps. This pattern reduces the electron cloud build-up and provides no parasitic beam-beam kick in the interaction region.

The single bunch luminosity display gives a detailed picture of the colliding bunch pattern (Fig. 1). For this pattern, there are 21 colliding bunches in each train, followed by a mini-gap of 3 missing bunches. Several of the colliding bunches have a lower luminosity which is a signature that the beam size has flipped or the lifetime is poor.

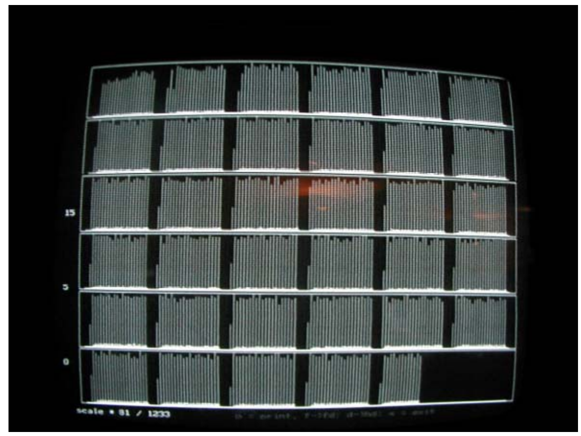

Figure 1. The bunch-by-bunch luminosity monitor for the colliding bunches in the PEP-II ring. Each bunch is 4 rf buckets apart. At the end of the pattern, a long gap allows for ion clearing and for the abort kicker's rise time.

2 EXPERIMENTAL APPARATUS

To observe the details of individual bunch blow-up, a camera with a two-nanosecond gate was used [4]. The gated camera images synchrotron radiation from a dipole magnet in the LER. The radiation is relayed by several mirrors and lenses to a radiation-safe measurement area. The camera's trigger is synchronized with the revolution frequency of the ring and can be delayed to measure any bunch. A video signal from the camera is digitized using SLAC control-system software, which fits the vertical and horizontal profile of the image to a Gaussian distribution and determines the transverse width, peak, and mean. By using the control-system digitizer, we can correlate the transverse beam size in the image with other parameters such as beam current or luminosity. Figure 2 is a vertical profile of a single bunch in the LER.

For the data presented in this paper, to reduce pulse-to-pulse bunch size variations, each data point consists of an average of five gated-camera measurements. The beam size measurements presented here show the LER only; a similar optical transport for HER light is in preparation.

3 MEASUREMENT OF BEAM-SIZE FLIP-FLOP

The dynamics of the beam-size flip-flop were measured with 728 colliding bunches having an average current of 1.8 mA and 1.2 mA per bunch in the LER and HER

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respectively. Each mini-train had 21 colliding bunches with a 3-bunch mini-gap. The trigger of the camera was set to observe the first bunch after the ion-clearing gap and then advanced one colliding bunch at a time. This was repeated over the first four trains after the ion gap. The measurement shown here is near the bottom of the luminosity cycle after the beams have been in collision for approximately 30 minutes. Fig. 3 shows the luminosity for these bunches, and Fig. 4 shows the transverse sizes.

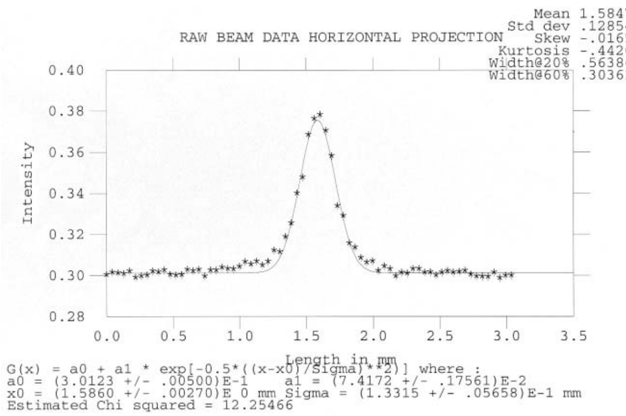

Figure 2. A vertical profile for a single bunch in the LER. The distribution is fit to Gaussian function to determine the vertical bunch size.

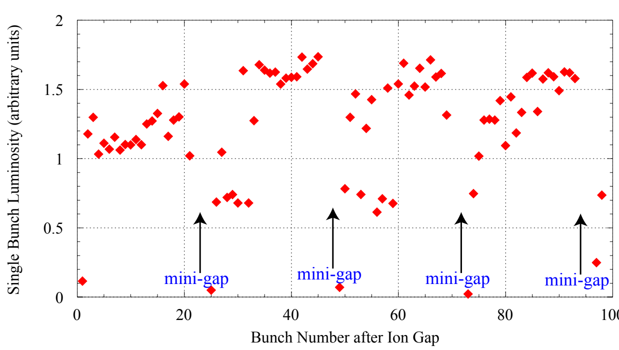

Figure 3 (Color). The luminosity of the first four mini-trains after the ion gap.

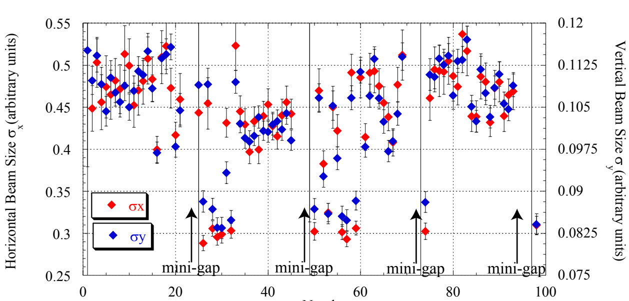

Figure 4 (Color). The horizontal and vertical beam size for the first four mini-trains after the ion gap.

There are several interesting points to be made: (i) several bunches have almost zero luminosity. These bunches had very short lifetimes and had lost much of their charge when this measurement was made. They have large error bars in beam size (Fig. 4). (ii) Several bunches have reduced beam size (by ~20%) and luminosity (by ~50%). These are the flipped bunches. (iii) The flipped bunches tend to be at the front of a mini-train.

The lifetime in the HER and LER for this measurement was approximately 500 and 200 minutes respectively. The current per bunch in the HER was fairly uniform, whereas in the LER it varied greatly between bunches. Figure 5 is a correlation between the single-bunch luminosity and LER current. The correlation points out that some LER bunches have short lifetimes and the flipped bunches have low luminosity with nominal current per bunch.

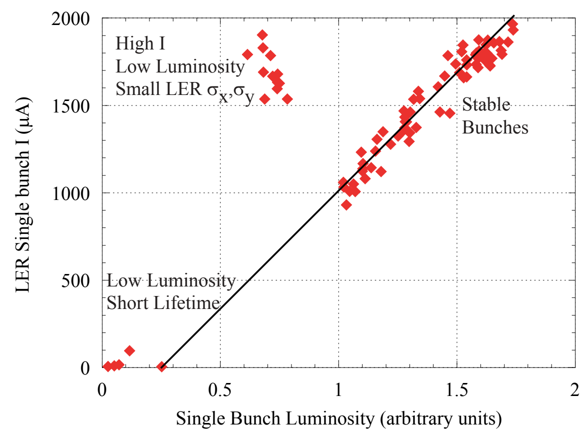

Figure 5 (Color). The luminosity correlated with the LER current for the bunches shown in figures 3 and 4.

The trigger advance was increased by a factor of 4 in order to measure every 4th colliding bunch. Figure 6 is the single bunch luminosity for every fourth colliding bucket over the whole train and Fig. 7 is the transverse beam size as a function of location in the train. It is evident in Fig. 7 that the flipped bunches are at the front of the mini-train which suggests that the electron cloud and/or beam-beam tune shift is the culprit behind the beam size flip-flop.

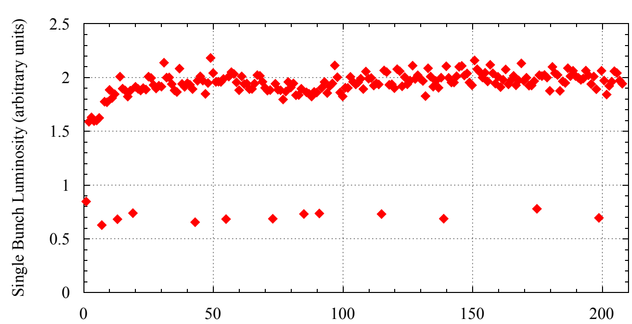

Figure 6 (Color). The single bunch luminosity for every fourth colliding bunch in the PEP-II ring.

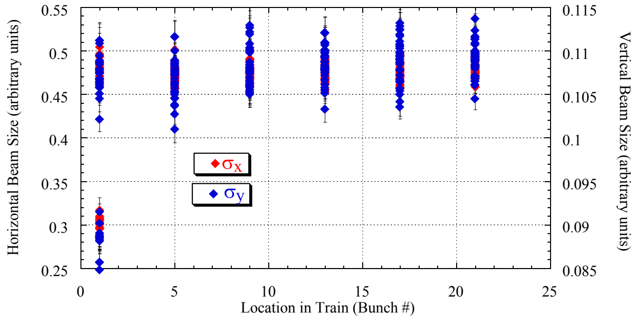

Figure 7 (Color). The beam size dependence on the location in the mini-train for all the trains in the PEP-II ring.

4 BEAM SIZE FLIP-FLOP TRANSITION

The triggering mechanism for the beam size flip-flop was examined in greater detail by measuring the beam size of a bunch at the front of a mini-train that flip-flops frequently. During this measurement the bunch changed state once during injection and once in the middle of the store. Figures 8 and 9 show the correlation between the luminosity, current, and beam size for this one colliding bunch.

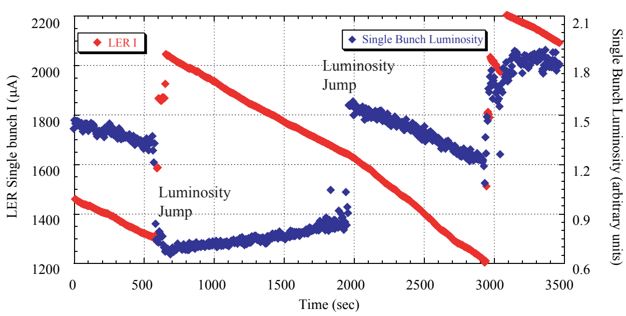

Figure 8 (Color). The luminosity and LER current as a function of time for a single colliding bunch during transition between the flip-flopped states.

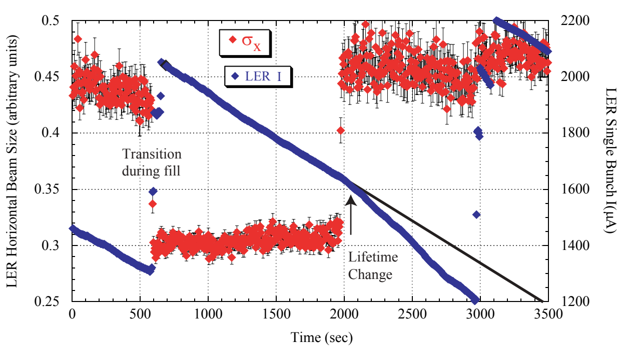

Figure 9 (Color). The LER current and horizontal beam size as a function of time for a single colliding bunch during transition between the flip-flopped states.

Several conclusions can be made from observing these flip-flop transitions: (i) The LER lifetime changes when the bunch goes from its flipped state to the flopped state. (ii) This change in state has been noticed when the tune is changed in the LER, which could be explained by a difference in tune shift that moves the bunch closer to a resonance. The transition between states can be forced by changing the LER x tune. (iii) The gated camera can also be run in a mode that acquires data at speeds up to 100 Hz, allowing a more detailed look at the transition between states. These have been observed on a 100-ms time scale (Fig. 10).

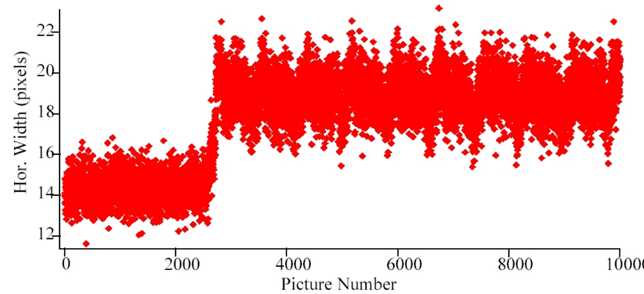

Figure 10 (Color). The LER horizontal beam size when the gated camera data was acquired at 100 Hz. The data shows an abrupt transition between states and a small oscillation in beam size after transition.

5 SUMMARY

The beam size flip-flop has been observed in the PEP-II low energy ring. Measurements have shown that when the beam size flips: (i) the horizontal and vertical beam size for the LER decreases by ~20%, (ii) the luminosity drop by ~50%, (iii) the transition is rather fast and occurs usually at the top of a store when the LER x-tune is optimized for high luminosity, (iv) it occurs primarily for bunches in the front of a mini-train, which might be a result of bunches at the start of mini-trains having a different beam-beam tune shift due to the electron cloud in the LER, and (v) it is assumed that the HER transverse beam size must blow up when the LER shrinks in size.

A more detailed study of the beam size flip-flop is planned using two gated cameras, one per ring, which will be correlated with our new gated tune tracker.

6 REFERENCES

[1] Cai, Y. et al., "New Simulation Results for the Electron-Cloud Effect at the PEP-II Positron Ring," SLAC, June 2001. Presented at the Particle Accelerator Conference, Chicago, IL, June 2001.

[2] Kulikov, A. et al., "The Electron Cloud Instability at PEP-II", SLAC, June 2001. Presented at the Particle Accelerator Conference, Chicago, IL, June 2001.

[3] Decker, F.-J., et al., "Complicated Bunch Pattern in PEP-II", SLAC, June 2001. Presented at the Particle Accelerator Conference, Chicago, IL, June 2001.

[4] The gated camera is a PI-MAX Intensified CCD Camera manufactured by Princeton Instruments.