BUNCH-LENGTH MEASUREMENTS IN PEP-II

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Abstract

We measured the lengths of colliding *e*+*e*− bunches in the PEP-II *B* Factory at SLAC using various techniques. First, at several RF voltages and with both single-bunch and multibunch beams, a synchroscan streak camera measured synchrotron emission through a narrow blue filter. With 3.8 MV of RF, the length of a single positron bunch was 12 mm at low current, rising to 13 mm at 1.5 mA and 14.8 mm at 3 mA. The electrons measured 12.2 mm at 16 MV with little current dependence. Both are longer than the expected low-current value of 10 mm (*e*+) and 10.5 mm (*e*−), derived from the energy spread and the measured synchrotron tune. We also determined the length for multibunch fills from measurements between 2 and 13 GHz of the bunch spectrum on a BPM button. After correcting for the frequency dependence of cable attenuation, we fitted the measured spectrum to that of a Gaussian bunch. At 3.8 MV, the positron measurement gave 13.2 mm at 1.5 mA/bunch in a full ring, shorter than the 15.6 mm found with the streak camera under these conditions, but we found 11.4 mm for the electrons at 16.7 MV and 1 mA/bunch, in good agreement with the 11 mm from multibunch streak measurements.

INTRODUCTION

The PEP-II *B* Factory at the Stanford Linear Accelerator Center [1] collides 9-GeV electrons in the high-energy ring (HER) with 3.1-GeV positrons in the low-energy ring (LER) in order to produce $B\bar{B}$ meson pairs and measure differences in their decay rates due to *CP* violation. Collisions began in 1999, and the machine presently operates with currents up to 2.55 A in the LER and 1.55 A in the HER, and a maximum luminosity of 9.2×10^{33} $cm^{-2}s^{-1}$.

The currents and the transverse beam sizes at the interaction point (IP) determine the luminosity. The longitudinal beam size—the bunch length—enters through the "hourglass effect" as the beams are focused sharply to a tight waist, with rapid convergence and divergence on either side. Shorter bunch lengths, provided by higher RF voltages, will permit higher luminosity. Bunch lengthening, due to longitudinal wakefields and instabilities, must be avoided. Here we report on a comparison of two techniques to measure the bunch lengths in the rings, and compare the results to values expected from machine parameters. One approach is optical, using synchrotron light and a streak camera. The other examines the roll-off of each beam's RF spectrum at GHz frequencies. A third approach, using the *BABAR* detector, is discussed in Ref. [2].

STREAK CAMERA

Calibration and Resolution

A dual-sweep streak camera (borrowed from the Advanced Light Source at LBNL) with a synchroscan (RF-locked sinusoidal sweep) plug-in tuned for 119 MHz (from the Advanced Photon Source at ANL) was used to measure the bunch length in the HER and LER. The streak camera was calibrated by sending synchrotron light through a narrow bandpass filter followed by a 1.5-cm-thick fused-silica etalon with 50% reflective surfaces; the separation of reflections from the surfaces determines the sweep-time calibration of the streak camera (Fig. 1), using the known index of refraction.

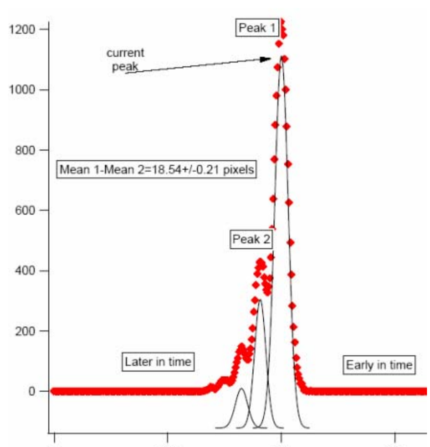

Figure 1: A streak-camera image of a light pulse transmitted through the etalon, projected onto the camera's time axis (intensity vs. pixel number). The distance between reflections provides a calibration.

Calibration was essential. Upon arrival the plug-in was found to be slow by a factor of 3, a problem later traced to a faulty amplifier inside. Compensating with our calibration, the LER data agreed closely with data taken using a triggered plug-in. After moving to the HER, we found also that the weak sweep made the calibration somewhat nonlinear with position on the screen, an effect we calibrated and included for HER, but which could not be applied retroactively to LER. However, LER data was taken at the calibrated position on the screen.

To determine the resolution contribution due to the streak camera's slit width, we measured the image size in focus mode (no sweep). Each measurement below has the resolution subtracted in quadrature.

LER Bunch-Length Measurements

Single Bunch: The length of a single bunch in the LER was measured at several beam currents. At each, five streak-camera images were taken at our usual RF voltage of 3.8 MV and at 4.5 MV. We fit the projection along the time axis of each image to an asymmetric Gaussian:

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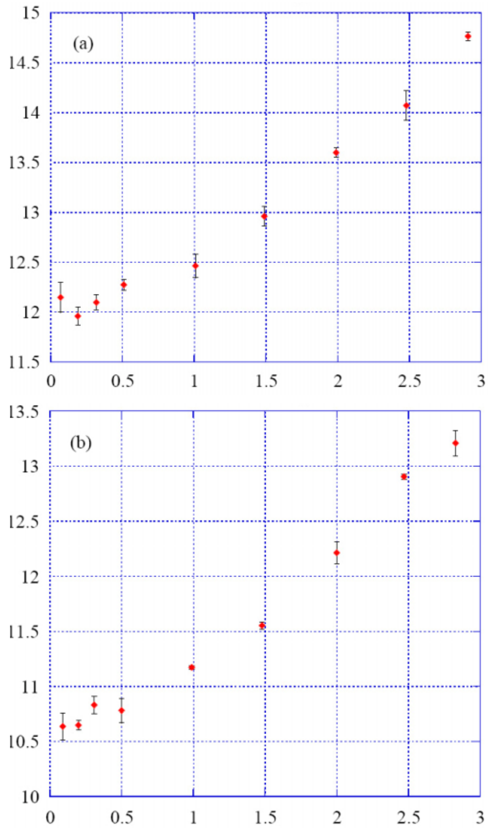

Figure 2: Streak-camera measurements of LER bunch length (mm) vs. current (mA). Single bunch at (a) 3.8MV and (b) 4.5MV.

$$A + B\exp\left[-\frac{(x-C)^2}{2D^2}\left(\frac{1}{1+E\ sign(x-C)}\right)^2\right] \qquad (1)$$

to determine its width *D* and asymmetry factor *E*. From Figs. 2 and 3, we conclude: 1) Higher RF voltage shortens the bunch length. 2) The length increased with current at ~1 mm/mA, independent of voltage. 3) There was a ~17% difference between the measurement and the expected bunch length at zero current:

$$\sigma_z = \frac{\alpha c}{2\pi \nu_s}\left(\frac{\sigma_E}{E}\right) \qquad (2)$$

where $\alpha = 1.23\times10^{-3}$ and $\sigma_E/E = 6.5\times10^{-4}$. Using the measured synchrotron tune at 3.8 MV, $\nu_s = 3.84$ kHz, Eq. (2) gives an expected length of 10 mm. 4) The distributions had tails longer than the heads, and this asymmetry grew with beam current, a signature of resistive potential-well distortion.

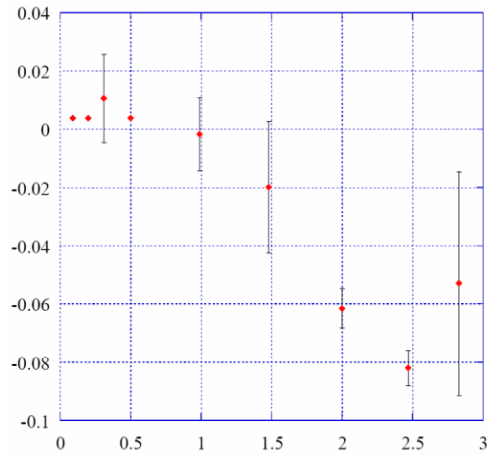

Figure 3: Streak-camera measurements of the asymmetry factor *E* (Eq. (1)) in the LER vs. current (mA). Single bunch at 4.5 MV.

Bunch Trains: We also took data while colliding 2.2 A of positrons with 1.4 A of electrons in 1561 bunches, arranged in trains of 66 [3]. The LER current corresponded to 1.4 mA/bunch, and the RF voltage was 3.8 MV. The bunch length (Fig. 4) varied along the train from 15 to 16 mm. For comparison, a single bunch with the same current (Fig. 2(a)) had a length of 13 mm.

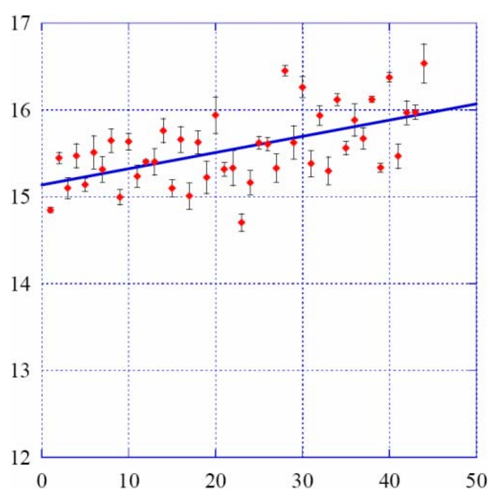

Figure 4: Streak-camera measurements of LER bunch length (mm) vs. bunch number along the 20th bunch train. 1.4 mA/bunch and 3.8 MV.

HER Bunch-Length Measurements

Single Bunch: For the HER, the length for a single bunch was also measured as a function of current, at 12, 13.4, 14.6, 16, and 18 MV. Fig. 5 shows the bunch length as a function of current at 16 MV.

Unlike the LER, the HER exhibited no significant bunch-length growth with current for all RF voltages. For the HER, $\alpha = 2.41\times10^{-3}$ and $\sigma_E/E = 6.1\times10^{-4}$. The measured synchrotron tune at 16 MV, 6.694 kHz, gave a zero-current bunch length of $\sigma_z = 10.5$ mm, 14% smaller then the measurement. The other four RF voltages showed a similar discrepancy.

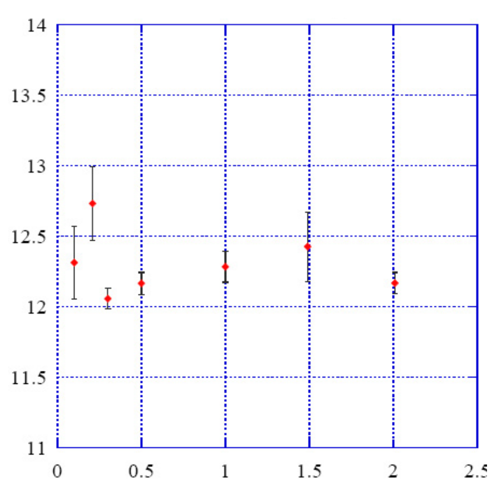

Figure 5: Streak-camera measurements of HER bunch length (mm) vs. current (mA). Single bunch at 16 MV.

Bunch Trains: As with the LER, we studied colliding bunch trains, using the same pattern but with slightly more current, 2.3 A in the LER and 1.45 A in the HER, corresponding to 0.93 mA/bunch in HER. Fig. 6 shows the size along the 20th train, almost a constant 11 mm, closer to the expected zero-current value, and 11% shorter than the single-bunch measurement.

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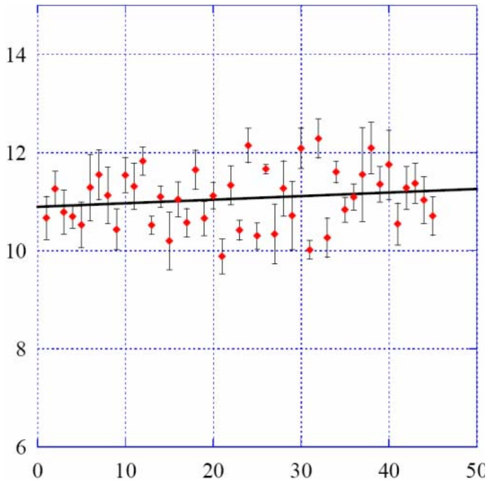

Figure 6: Streak-camera measurements of HER bunch length (mm) vs. bunch number along the 20th bunch train. 0.93 mA/bunch and 16 MV.

BUNCH SPECTRUM

The bunch length was also determined from the RF spectrum of a BPM-button signal. To get an adequate signal, the spectra were measured with multibunch fills in collision. Fig. 7 shows a typical HER spectrum between 1.655 and 13.57 GHz. The main frequency lines are harmonics of 238 MHz, half of PEP's 476-MHz RF, since we typically fill every second bucket, except for small gaps between long trains [3].

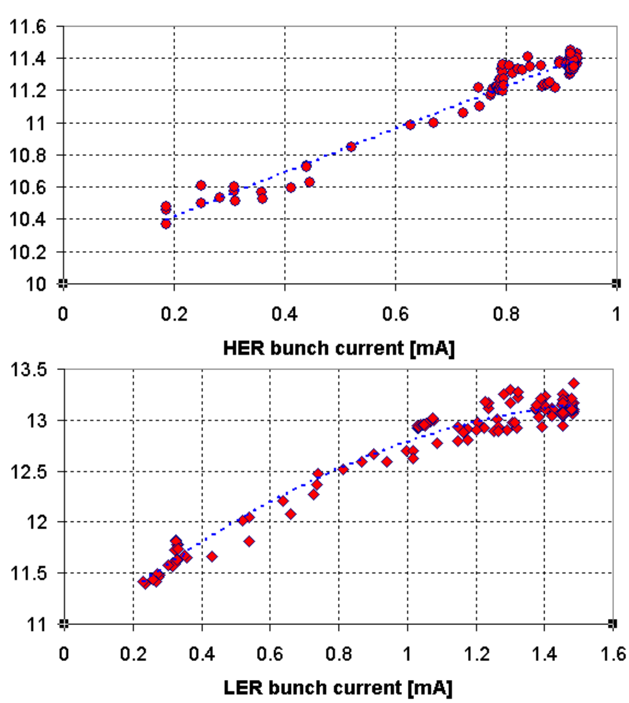

Figure 8: Bunch length (mm) measured from the RF spectrum, for (a) HER at 16.5 MV and (b) LER at 3.8 MV, as a function of bunch current (mA). Colliding multibunch fill.

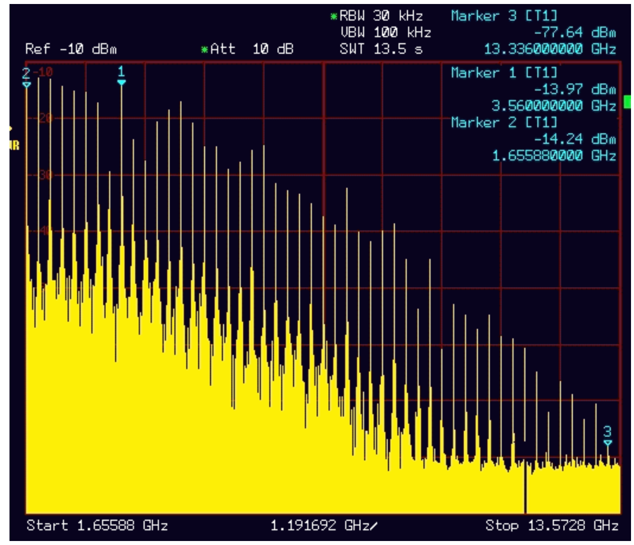

Figure 7: HER power spectrum on a 10 dB/division scale, from 1.655 to 13.57 GHz. Multibunch fill at 1.48 mA/bunch.

We first corrected the spectrum for the frequency dependence of cable attenuation, using a fit to the manufacturer's data for LDF2-50 Heliax:

$$\alpha_{[\text{dB/100ft}]} = 0.054 f_{[\text{MHz}]}^{0.6} \tag{3}$$

Then we fit the envelope of the main lines, with their logarithmic power scale, to a quadratic

$$y(f) = 10\left(\log_{10} e\right)\left[y_0 - \left(\frac{2\pi f}{c}\sigma_z\right)^2\right] \tag{4}$$

by varying two parameters, the amplitude y_0 and the bunch length σ_z.

Fig. 8 shows the results for the two rings. At 3.8 MV, the positron measurement gave 13.2 mm for 1.5 mA/bunch, shorter than the streak-camera result for these multibunch conditions, but we found 11.4 mm for the electrons at 16.7 MV and 1 mA/bunch, in good agreement with the streak measurement.

ACKNOWLEDGMENTS

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[1] U.S. Dept. of Energy contract DE-AC03-76SF00515.
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