

# CESR STATUS AND PERFORMANCE \*

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## 1 INTRODUCTION

During the nine month running period ending in June 2001, the Cornell Electron Storage Ring delivered an integrated luminosity of just over  $11 fb^{-1}$  to the CLEO experiment at center of mass energy near the  $\Upsilon_{4s}$ . CESR is a symmetric energy collider operating in a bunch train mode. The counterrotating beams share a common vacuum chamber and electrostatic separators displace the closed orbits of the two beams so that the bunches collide only at a single IP[1]. The total beam current, typically 750mA at the start of a fill, is supported by 4 single cell SRF cavities[2]. Beam current is limited by the long range beam-beam interaction associated with the bunch train - pretzel separation scheme. Machine performance for the running period is reviewed with an emphasis on phenomena associated with the large number of parasitic crossings peculiar to a single ring collider with multi-bunch beams.

The permanent magnet final focus quadrupoles will be replaced in the summer of 2001 by superconducting magnets and the beam energy range over which CESR can operate will be dramatically increased. Beginning in the fall of 2001, CESR will run at  $\Upsilon$  resonances below the  $\Upsilon_{4s}$ , and during machine studies periods at  $J/\Psi$  resonances[3].

## 2 TUNED OPTICS

During machine tune up after installation of the CLEO III detector, beam based measurement of betatron phase and coupling errors[4] were found to be inconsistent with the modelled layout of the machine elements. The measurements indicated that the final focus quads were 2mm closer to the IP than specified in our machine model. With this correction to the model, an excellent fit to measured data was achieved. The machine optics were redesigned based on the corrected layout.

Initial design values for interaction region parameters were  $\beta_v^* = 18mm$ , consistent with a bunch length of  $\sim 18mm$ , and  $\beta_h^* = 1m$ . Groups of quadrupoles defined to vary machine parameters such as  $\beta_v^*$  and  $\alpha_v^*$  were used to tune luminosity. After specific luminosity was optimized, we measured  $\beta_v^* = 21 \pm 0.5mm$  and  $\alpha_v^* = 0.2 \pm 0.05$ . The nonzero  $\alpha_v^*$  corresponds to a displacement of the minimum  $\beta$  by 4mm.

## 3 TRAINS OF BUNCHES

In CESR, the electron and positron orbits are displaced electrostatically so that the trains of bunches are horizontally separated at the parasitic crossing points. However the separation is insufficient to eliminate the effect of long range beam beam interactions. The transverse separation,  $\beta$ -functions and beam sizes are different at each of the parasitic crossings, and temporal spacing of the bunches is not uniform, (the bunches are arranged in trains). The optical distortions due to the multiple parasitic interactions vary from bunch to bunch. The resulting spread in tunes and closed orbits degrades lifetime and luminosity.

The closed orbit beyond the separators is

$$x(s) \sim a \sqrt{\beta_h(s)} \sin(\phi_h(s) - \phi_0) \quad (1)$$

and the beam-beam tune shift

$$\Delta Q_h \sim \frac{I_b \beta_h}{x^2} = \frac{I_b}{\sin^2(\phi_h(s) - \phi_0)} \quad (2)$$

The tune shift is smallest for parasitic crossings near the peak of the pretzel lobe where  $\phi_h(s) - \phi_0 \sim \pi/2$  corresponding to bunches near the center of the train, and increases for bunches at the beginning and end of the trains. This effect limits the train length. The tune shift for each of the temporally spaced bunches in three consecutive trains, computed by a detailed strong-strong simulation[5] is shown in Fig. 1. The pattern repeats for each set of 3 trains. The calculated bunch dependence of the tunes has been verified by direct measurement. For reference, note that the width of the working point in the tune plane is  $\sim 100Hz$  horizontally and  $\sim 1kHz$  vertically. Evidentially, the bunch to bunch variation in horizontal tune is a current limiting effect.

Where bunches are displaced vertically at parasitic crossings, the long range beam-beam kick has a vertical component that distorts the vertical closed orbit. This occurs in the interaction region and at the crossing point diametrically opposite the IP. In the interaction region, the experimental solenoid couples the crossing horizontal orbits to differential displacements of the vertical trajectories. At the parasitic crossings nearest the IP, the bunches are offset vertically as well as horizontally and there is a vertical component to the beam-beam kick. The bunch at the start(end) of the train experiences a parasitic interaction only as it approaches (leaves) the IP. Bunches in the middle of the train will be kicked on entrance and exit. The situation is similar opposite the IP where the beams

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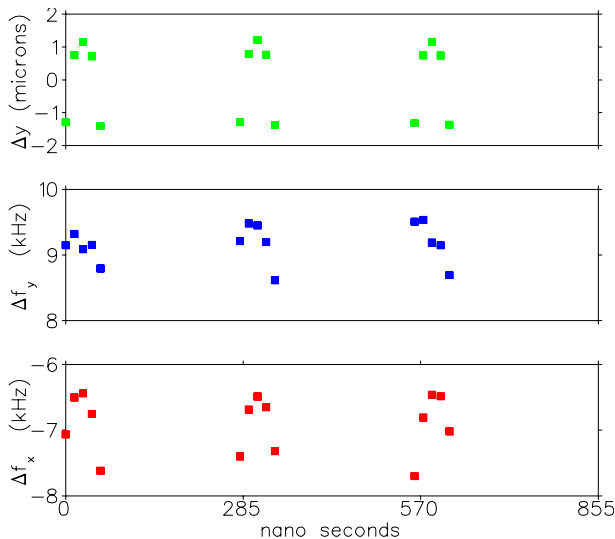


Figure 1: Tune shift in one beam due to long range interaction with the opposing beam. There are 9, 5-bunch trains with 7.5mA/bunch in each beam. Bunch spacing within each train is 14ns.  $f_{rev} = 390.1\text{kHz}$ . The difference in the vertical orbits at the IP for the two beams is shown above.

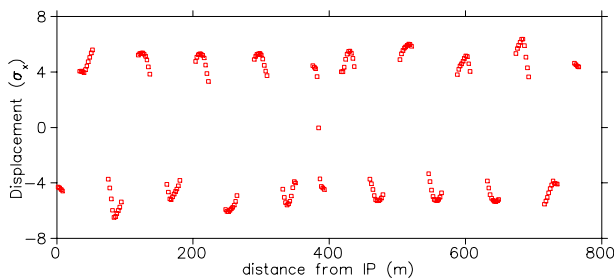


Figure 2: Horizontal separation at each of the parasitic crossing points in units of rms beam size. At the very center of the plot, beams are separated vertically.

are displaced by vertical electrostatic separators. The resulting bunch dependent difference in vertical position at the IP for the electrons and positrons is shown in the upper plot of Fig. 1. The vertical beam size at the IP is about  $4\mu$ .

Particles in the horizontal tail of one beam that approach the core of the opposing beam experience strong vertical kicks that diminish lifetime[6]. The separation of the bunches in units of horizontal beam size is shown in Fig. 2. The lifetime is limited by the most poorly separated bunches. Lifetime improves (and luminosity declines) if transverse coupling is adjusted to decrease horizontal beam size.

#### 4 BEAM-BEAM LIMIT

That parasitic long range interactions limit performance is evidenced by the fact that the beam-beam tune shift parameter decreases as the number of bunches in the train is increased. Having surveyed and aligned all of the ring quadrupoles and dipoles, reduced corrector magnet nonlin-

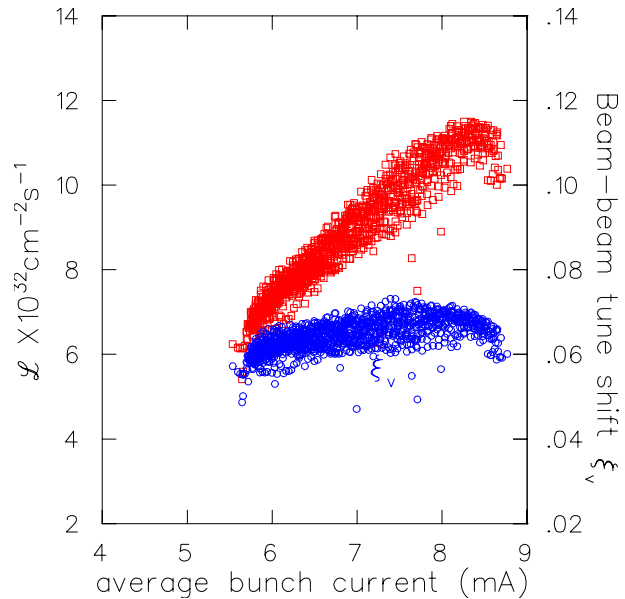


Figure 3: Average beam-beam tune shift  $\xi_v$  and luminosity versus bunch current with nine, 4-bunch trains/beam.

earities, diagnosed and corrected quadrupole coupling and sextupole errors, and devoted many hours to empirical tuning, we measured an average vertical beam-beam tune shift parameter of nearly 0.07 with nine 4-bunch trains in each beam and  $\beta_v^* = 21\text{mm}$ . The spacing of the bunches within each train is 14ns. The dependence of beam-beam tune shift and luminosity on bunch current is shown in Fig. 3. The tune shift appears to saturate at bunch current of about 7.5mA. Attempts to further increase the bunch current in the 4-bunch/train configuration were frustrated by deteriorating lifetime as well as declining specific luminosity.

In order to increase total beam current, we added a fifth bunch to each train. The current dependence of tune shift and luminosity in the 5-bunch/train configuration are shown in Fig. 4. Careful comparison of the data indicates that the beam-beam tune shift is consistently 10% higher with the four bunch train versus the five bunch train. Indeed we measure nearly 25% higher specific luminosity for the bunch at the center of the five bunch train compared to the bunch at the end of the train [7]. The bunch dependence of the luminosity is presumably a result of the tune and closed orbit differences described above.

#### 5 INTEGRATED LUMINOSITY

A significant increase in the ratio of integrated to peak luminosity has been achieved by reducing injection time, through extension of the topping off procedure to include positrons as well as electrons, improvements in the injector and transfer lines, and elimination of unnecessary steps changing conditions[8]. Beam current and luminosity over a 24 hour period are shown in Fig. 5. Non HEP time is about six minutes per fill. Fig. 6 shows the monthly integrated luminosity history for CESR to date.

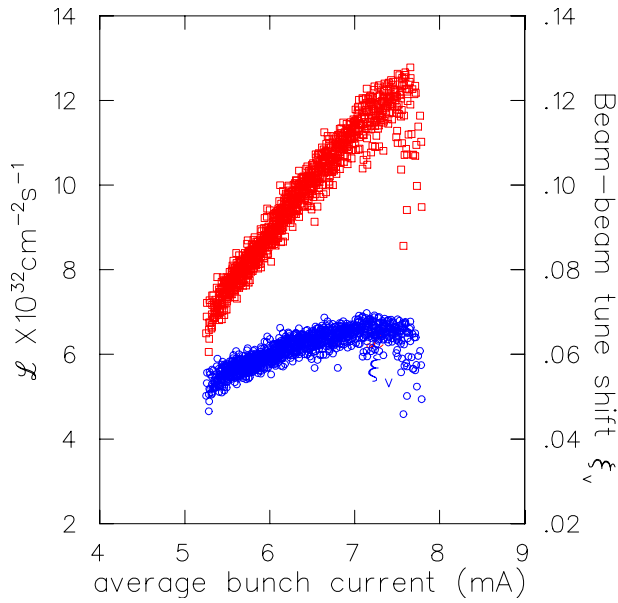


Figure 4: Beam-beam tune shift and luminosity vs bunch current with nine 5-bunch trains/beam.

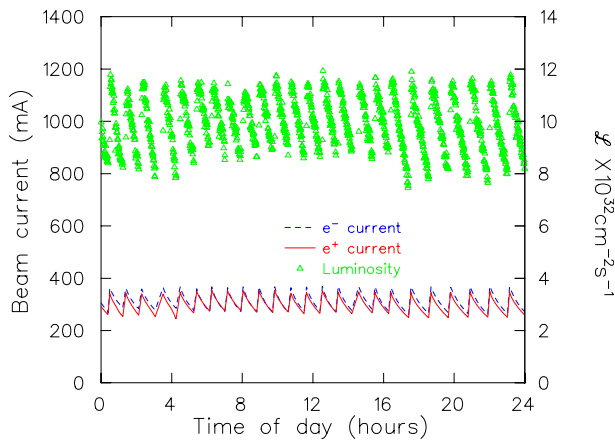


Figure 5: Beam current and luminosity during a 24 hour period. Total luminosity for the day is  $73pb^{-1}$

## 6 $\Upsilon$ AND $J/\Psi$ RESONANCE RUNNING

During the summer of 2001, the permanent magnet final focus will be replaced with superconducting quadrupoles in anticipation of operation at  $\Upsilon$  resonances below the B-meson threshold (4.7 - 5.17GeV/beam) and then  $J/\Psi$  resonances (1.55 - 2.5GeV/beam)[3]. The layout of quadrupoles in the present and future interaction region is shown in Fig. 7. The  $\beta$ -functions in the new IR are relatively small, especially at low energy, allowing for the possibility of reducing the temporal spacing between the bunches. That spacing is now limited by the high value of  $\beta_v$  at the parasitic crossing points nearest the IP.

## 7 REFERENCES

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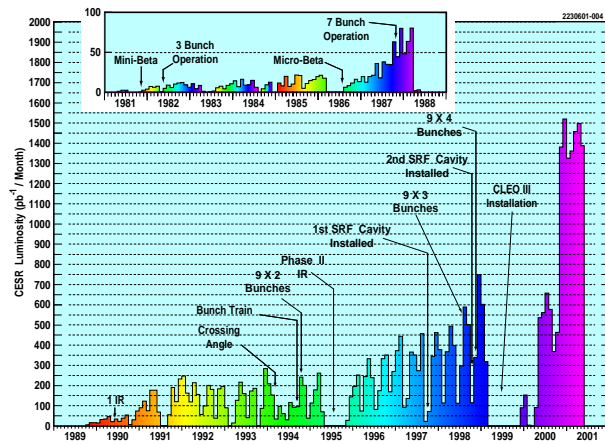


Figure 6: CESR luminosity history.

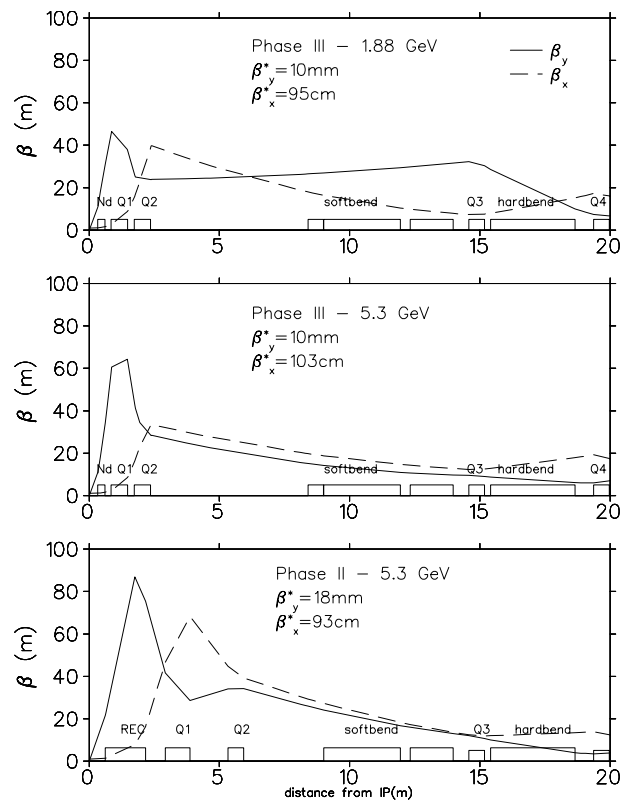


Figure 7: Existing IR with 1.5m permanent magnet quad at bottom. Superconducting IR quad layout and optical functions for 5.3GeV and 1.88GeV are above.

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