CBN 06-4
June, 2006

Operational Status of CESR-c *

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Abstract

We summarize recent running experience at the Cornell Electron Storage Ring (CESR) operating as a high-statistics production-threshold factory for mesons containing charm quarks. Since beginning operation at beam energies near 2 GeV in late 2003, CESR has accumulated world-record samples of D and D_s meson decays and has also operated in an energy-scanning mode, making unique contributions to the presently very active field of charm spectroscopy. CESR lattice design is characterized by the versatility provided by the variety of beam-line components applied to the challenges imposed by the beam-beam interactions at the parasitic crossing points in the pretzel orbits and the necessity of powerful superconducting wiggler magnets used to tune damping and emittance. We describe the observed tune-plane, beam-current and luminosity limits, our understanding of their sources and near-term plans for operational improvements.

INTRODUCTION

CESR-c [1] is presently operating at a beam energy of 2.085 GeV with 3 bunches 4.2 m apart in each of 8 trains separated by 75.6 m or 79.8 m. During luminosity operation, the current is limited to about 2.7 mA/bunch, i.e. 130 mA total current in both beams. While this is about a factor of four less than the value estimated in the 2001 design report, the machine performance has nearly reached the level required for completion of the physics program scheduled to end in 2008. A number of improvements have been carried out since the report at PAC'05[2]. The present report summarizes that activity, identifies the limits on present performance, and describes plans for further improvement in the near-term.

PROGRESS SINCE PAC 2005

The operational history of CESR-c since its first run at 1.88 GeV is shown in Fig. 1. The first production run following PAC 2005 was an energy scan from August to September with fine center-of-mass energy steps of 20 MeV to optimize D_s production. Our ability to provide stable running was initially adversely affected by the need to redesign the linear optics for each energy step. The vertical focusing of the wiggler magnets is substantial (Q_Y=0.1 per wiggler) and since the accurate modeling of the wiggler non-linearities is based on Taylor maps at a fixed field value [3], we initially redesigned the linear optics from scratch for each energy step, resulting in substantial empirical tuning to reëstablish high-luminosity running conditions. Investigations showed that a linear approximation to the wiggler fields which preserved their vertical focusing strength at the various beam energies sufficed to allow incremental changes in the operating optics, resulting in much-reduced turn-around times between energy steps.

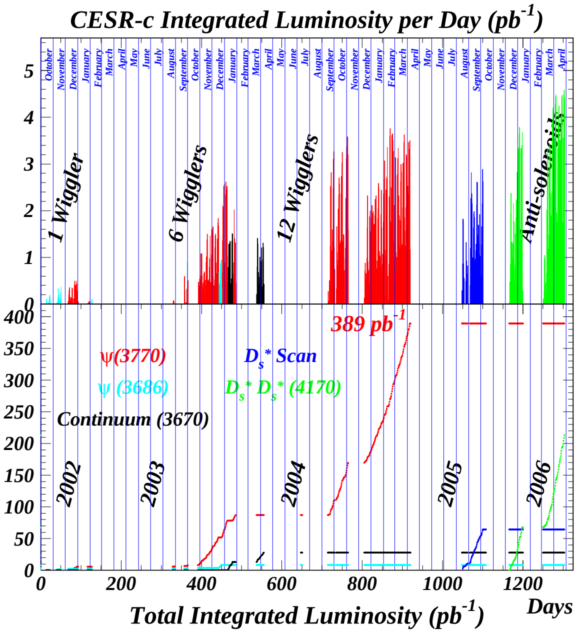

Figure 1: CESR-c daily integrated luminosity history and accumulated data samples since 2002

Following the production run with the full complement of twelve superconducting wiggler magnets at the $\psi(3770)$ resonance which ended in the spring of 2005, an extensive program of modeling the luminosity operation was undertaken. This study succeeded in excluding both the wiggler non-linearities and the localized radiation pattern due to the wigglers as primary sources of limitation on the specific luminosity. On the other hand, important degradation was found to arise from optics distortions resulting from the beam-beam interaction (BBI) and from energy-dependent coupling errors in the interaction region (IR) associated with the skew-squad-based compensation method together with the larger energy spread associated with the wiggler-based damping. Consequentially, two 36-inch long 2 T "anti-solenoid" magnets were designed, built and installed on either side of the CLEO detector in January, 2006.

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* Work supported by the National Science Foundation
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Figure 2 shows the effect of the redesigned optics on the dependence of luminosity on beam current. The new compensation scheme is shown to recover much of the luminosity degradation caused by the energy error of the compensation of the CLEO solenoid. The recent history of CESR-c peak luminosity (Fig. 3) shows an improvement of more than 15%, commensurate with expectations derived from the model.

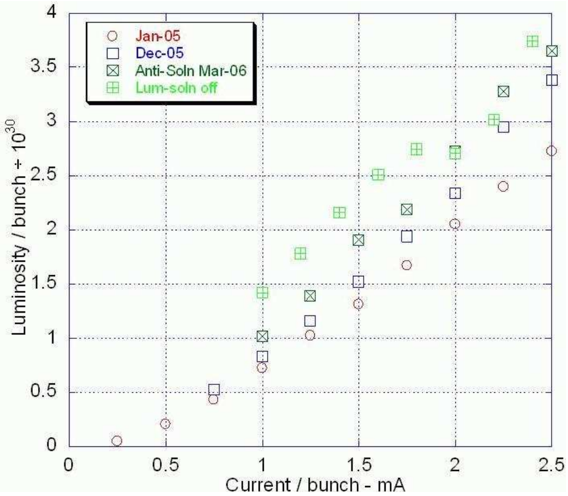

Figure 2: CESR-c luminosity as a function of bunch current. The improvement in operation between January and December 2005 is compared to the result of using solenoid magnets on either side of the CLEO detector solenoid to compensate the effect of its field on the IR optics. Also shown is a model calculation of the luminosity with the CLEO solenoid turned off ("Lum-soln off").

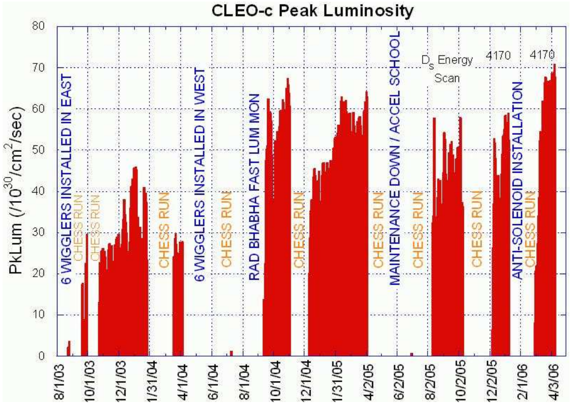

Figure 3: History of CESR-c peak luminosity since 2003

PRESENT OPERATIONAL LIMITS

We are presently limited to a bunch current of about 2.5 mA during high-energy physics operation. At this current level, optical distortions resulting from the BBI prevent further injection. Table 1 compares our present operating parameters to the design parameters and to the operating values in the Spring of 2005. We have measured that a single electron bunch with current as high as 8 mA can be injected into a full load of positrons. We also know that higher bunch currents can be stored if the beams are not in collision. As a result, much effort has been put into modeling the beam-beam interaction both at the interaction point (IP) and at the parasitic crossings.

	2001 Design	4/2005	4/2006
L (10^{30} cm^{-2}s^{-1})	300	65	70
$I_{\rm beam}$ (mA)	180	75	65
Nr bunches	45	40	24
$\epsilon_{\rm H}$ (nm-rad)	220	135	120
$\xi_{\rm V}$	0.04	0.024	0.029
$\beta^*_{\rm V}$ (cm)	1.0	1.2	1.2
$\sigma_E/E(10^{-4})$	0.81	0.85	0.81
$\tau_{\rm H,V}$ (ms)	55	50	55

Table 1: Recent CESR operating parameters compared to the design values and to those of the production running prior to PAC 2005

Some improvement has been obtained by including simulation of the long-range BBI in the lattice design algorithm. Nonetheless, the distortion of the beta function is substantial, even when the tunes are held constant during filling [4]. Further improvements to the lattice design procedure since the Spring of 2005 include constraining the difference between the electron and positron linear optics, and reducing the energy dependence of the beta functions.

Operational improvement has been obtained by establishing similar optics for luminosity running and for electron injection, thus permitting a top-off mode for refilling the beams. The ability to avoid dumping the electron beam results in less thermal cycling of beam-line elements and increased reproducibility of operating conditions fill-to-fill. Since the beam currents are now stable at the 20% level, the beam-beam interaction strength is also stable, eliminating the need for complicated compensatory tuning of its focusing/defocusing effect with each fill and also avoiding hysteresis effects in the quadrupoles, obviating the need for frequent de-hysterizing cycles. The typical turn-around time has decreased from four minutes to less than two minutes. Figure 4 compares operating currents and luminosity over a 24-hour period on April 8, 2006 to those of March 26, 2005.

Since we are presently limited by the current levels we can achieve during injection, the vertical beam-beam parameter is not yet saturated, resulting in an advantage in running at higher bunch currents with fewer bunches. Combined with careful empirical tuning, this has allowed us to lower the pretzel orbit amplitude by 15%, reducing sensitivity to nonlinear off-axis guide field errors and lowering radiation backgrounds in the CLEO detector.

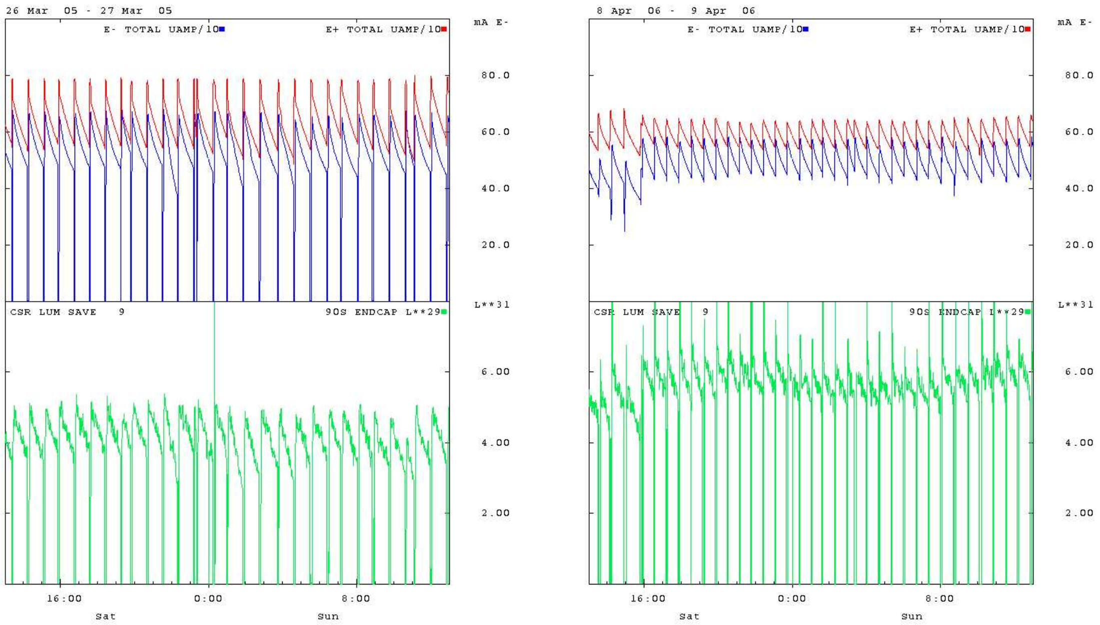

Figure 4: 24-hour time-scans CESR currents and luminosity comparing the conditions of 4/8/2006 to those of 3/26/2005

A number of recent instrumental improvements have proved useful [5]. One such diagnostic tool which has undergone substantial development is the use of near-IP beam-position-monitor data on a turn-by-turn basis to measure and compare the coupling of the electron and positron beams at the IP. Another is the recently commissioned bunch-by-bunch data-acquisition systems which have made possible measurements of betatron tunes and vertical beam sizes bunch-by-bunch. Preliminary results indicate some electron cloud build-up, evinced by an increase in vertical tune of more than a kHz for positrons along a train of 20 bunches spaced 4.2 m apart. These investigations will continue during the coming summer.

NEAR-TERM IMPROVEMENT PLANS

A variety of measures are planned for the near-term operation of CESR-c, including tune-plane exploration with sextupole tuning, injector tuning and maintenance, improvements in magnet monitoring, and improving the e^+/e^- coupling match using skew sextupoles. In addition, the recent progress in IR optics using the new solenoid compensation, opening up the tune plane, and duty-cycle improvement reëmphasize the need for mitigating the effects of the beam-beam interaction. Until now, operational compensation of the BBI effects has consisted of global tune corrections, which necessarily result in distortions of the beam functions near the parasitic crossings. We have developed an optics correction algorithm based on locally closed beta bumps using eight quadrupole magnets around each set of crossings. Initial results from machine studies in April, including compensation of the effects of the beam-beam interaction at the IP, are encouraging [4].

CONCLUSION

The CESR-c project has now matured to the point of entering production mode. During the past year, detailed modeling of machine performance has resulted in the implementation of new IR optics based on small superconducting solenoid magnets. Bunch-by-bunch and turn-by-turn diagnostic monitoring tools have been developed. Empirical tuning has improved our understanding of limitations on performance. The lattice design procedure has been modified to include consideration of the beam-beam interaction, and compensation algorithms have been modeled and tested. A level of performance has been achieved which yields confidence that the foreseen physics program will be completed. This program envisions doubling the present sample of ψ(3770) decays, quadrupling the $\mathrm{D_s}$ sample, and recording 30 million ψ(3686) decays, each of which exceed the sum of existing world samples.

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