CESR-C* - A FRONTIER MACHINE FOR QCD AND WEAK DECAY PHYSICS IN THE CHARM REGION

D. Rice†, for the CESR-c Working Group
Cornell University, Ithaca, NY 14853, USA

Abstract

We present a plan for conversion of the Cornell Electron Storage Ring, CESR, to a high luminosity source which will increase the world data set in the range $3<E_{cm}<5$ GeV by factors of 20 to 100 in the next four years. Accelerator physics issues related to high luminosity operation in this energy range have been examined in detail, both in computational and experimental programs. We discuss results from these studies. Beam damping will be enhanced by ~18 m of 2.1 T wigglers. The effect of these wigglers on beam dynamics in a high luminosity storage ring with pretzel orbits is significant. We present calculations and measurements elucidating these effects, many of which are present in proposed linear collider damping rings. We also describe the design of the superferric wigglers and tests on a full size prototype unit.

1 INTRODUCTION

1.1 The Development of CESR

CESR has operated as a 4.7-6 GeV/beam e^+e^- collider at the B meson threshold with peak luminosity well above 10^{33} cm^{-2}-sec^{-1}[1,2]. Forty-five bunches in each beam circulate in a single vacuum chamber and collide at a single interaction point in the middle of the CLEO detector. Super-conducting RF cavities provide the required RF voltage while introducing minimal parasitic mode impedance to the ring. Superconducting IR quadrupoles minimize the chromaticity generated in optics with β^*_V as low as 7 mm.

A full energy injector provides up to 20 bunches (limited by beam loading in the Linac) per injection cycle for top-up of CESR beams in less than 5 minutes.

Continuing the program of innovative upgrades will extend the operating range of CESR to the J/Ψ (E_{beam}=1.55 GeV) through the Υ resonances ($E_{beam}\approx$ 6 Gev). The luminosity performance will provide significant increase in world Charm data sets in a few years of running.

1.2 Charm Physics at CESR/ CLEO

The Charm/Tau regime is excellent ground for studies of weak interaction physics and tests of QCD. [3] A data sample 20-100 times that accumulated to date, combined with the excellent resolution and hermiticity of the CLEO detector will improve by 5-15 the precision of branching ratios and decay constants. Comparison with CLEO data on the Υ resonances will be used in searching for glue-rich states. These measurements will be much cleaner than comparable measurements from the B factories.

* Work supported by US National Science Foundation
† mailto:dhr1@cornell.edu

2 LOW ENERGY ACCELERATOR ISSUES

2.1 Energy Scaling – Bending Magnets Determine Radiation Parameters

When the bunch current, i_b, is limited by the horizontal beam-beam space charge, ξ_x then the luminosity of a collider may be expressed in terms of the energy, E_0 and radiation-influenced parameters:

$$L = 4.55 \times 10^7 (1+r)^2 \frac{k_b E_0^2 \xi_y \xi_x \varepsilon_x}{\beta_y^* C_L} \quad (3)$$

L ((nanobarn-sec)$^{-1}$) is luminosity, r the beam aspect ratio (y/x) at the interaction point, k_b the number of bunches per beam, E_0 (GeV) the beam energy, $\xi_{y,x}$ the beam-beam space charge parameter (vertical, horizontal), β_y^* the vertical focusing function at the i.p., C_L (m) the circumference of the machine and ε_x (m-rad) the horizontal emittance. From this expression we can see that even if all other parameters are constant, luminosity scales as E_0^2. In practice ξ_y, ξ_x and ε_x often vary with energy, producing a steeper scaling law.

2.2 Recovering Radiation Benefits

ξ_y, ξ_x, and particularly ε_x are influenced by synchrotron radiation effects. With careful manipulation of radiation effects, one should achieve a scaling closer to $L \propto E_0^2$.

Wiggler magnets can provide controllable radiation without large effects on beam orbits. When the wigglers dominate radiation in a ring, the following scaling applies:

Damping time: $\tau \propto \frac{1}{L_W B_W^2}$

Horizontal Emittance: $\varepsilon_X \propto B_W H_W$

Energy spread: $\frac{\sigma_E}{E_0} \propto \sqrt{B_W}$

New variables are L_W, the length of wigglers; B_W, the peak magnetic field in the wigglers; H_W, the square of the normalized dispersion at the wiggler, and σ_E the beam's R.M.S. energy spread. The peak field of the wiggler is limited by the maximum acceptable energy spread, and the desired damping time determines the length of wigglers needed. The horizontal emittance may then be set by controlling H_W. Table 1 shows CESR-c parameters parameters at several energies. All configurations use 45 bunches/beam in 9 trains of 5 bunches and a horizontal crossing angle at the interaction point of ±2.5-3.3 mr. Measured data at 5.3 GeV are given for reference.

. Table 1: Parameters with and without wigglers (1.9 GeV)

Parameter	**No Wigglers**	**18m 2.1T wigglers**
ε_X	30	220 nm-rad
Damping time	570	55 ms
σ_E/E_0	2 x10^{-4}	8x10^{-4}

Table 2: CESR-c Parameters

E_0 [GeV]	**1.55**	**1.88**	**2.5**	**5.3**
Luminosity [$\div 10^{30}$cm^{-2}-sec^{-1}]	150	300	500	1250
i_b [mA/bunch]	2.8	4.0	5.1	8.2
I_{beam} [mA/beam]	130	180	230	360
ξ_y	0.035	0.04	0.04	.06
ξ_x	0.028	0.036	0.034	.028
σ_E/E_0 [x10^3]	0.75	0.81	0.79	0.67
$\tau_{x,y}$ [ms]	69	55	52	22
B_W [Tesla]	2.1	2.1	1.75	0
β_y^* [cm]	1.0	1.0	1.0	1.8
ε_x [nm-rad]	230	220	215	205

3 CESR-c Hardware

CESR is well posed for effective operation at low energies. Superconducting IR quadrupoles [4] enable operation with β^*_V as low as 7 mm. Integral skew quadrupoles provide effective adjustment of coupling compensation of the experiment solenoid field. Four single-cell superconducting RF cavities [5] give a peak field over 9 MV while minimizing coupling impedance for higher modes, and keep the bunch length comparable with the design β^*_V of 1 cm. Wideband feedback systems [6] in all 3 dimensions control coupled bunch instabilities. The only major new hardware needs are wiggler magnets.

3.1 Wiggler Magnets

The CESR-c wiggler design [7] is based on superferric technology. Figure 1 shows the coils and iron of a wiggler. The magnets will be built in standard units, each with 1.3 m active length and a wiggler period of 40 cm. The cryostats will have a warm bore, water cooled vacuum chamber and have a flange-to-flange length of 1.7 m including a NEG vacuum pump port..

Fourteen wigglers will be placed in one third of the ring circumference close to utilities for convenience of optics and utilities. The cryogens will be provided through transfer lines extended from the present s.c. RF system. There will be 100 watt additional load from the wiggler cryostats and transfer lines.

Beam Dynamics: The "pretzel" orbit used to separate beams at parasitic crossing points and the large emittances in a collider place stringent demands on beam transport properties of the wigglers.

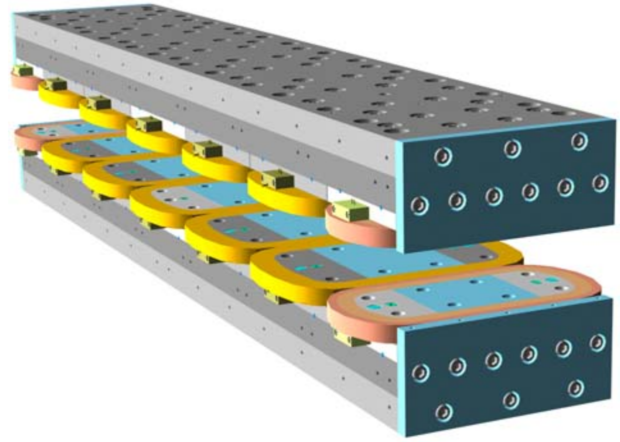


Figure 1: 7 pole superferric wiggler cold mass

Even an ideal wiggler (infinite pole width) exhibits focusing is in the *vertical plane only* [8] and has a linear part that is independent of the wiggler field period, λ_W, an octupole like component that increases as λ_W^{-2}, and higher order terms. The linear focusing term causes a tune shift of 0.1 integer for each wiggler in CESR-c and must be designed into the optics.

A realistic wiggler field has a finite roll off across the pole face ($\Delta B_y(x)$) and, combined with the beam's systematic displacement in the horizontal plane, creates an effective vertical field integral [9] These nonlinearities resemble conventional multipoles and increase as λ_W^2. Thus the choice of wiggler period is a compromise between these two nonlinear effects.

Incorporating many strong wigglers in the ring while maintaining good dynamic aperture requires careful design, optimizing λ_W and field uniformity. A tracking code [10] has been used to model the wiggler nonlinearities.

3.2 Wiggler Development

A full size prototype wiggler has been designed and built at CESR. The magnet has been tested to 25% above operating field in a vertical dewar and will be installed in CESR in July, 2002.

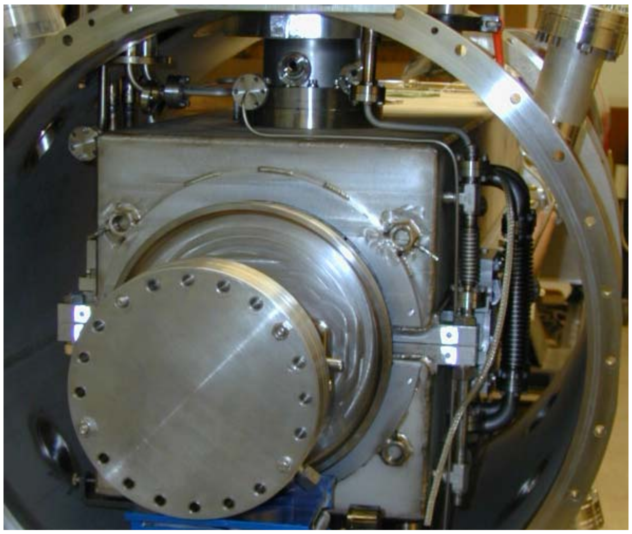
Coils: A NbTi wire with 1.35:1 Cu:superconductor ratio is used in the coils. The diameter is 0.795 mm including 23 micron formvar insulation. A relatively large filament (~50 μ) is used since field ramping is not needed.

The wire is wound on individual iron poles, which are then assembled on a 3" thick iron yoke or backing plate. The coil packages are preloaded with 40 MPa pressure to control coil motion from magnetic forces at 4.2K. The coil ends are left free, constrained by hoop forces.

LHe Enclosure & Cryostat: Each half wiggler cold mass is enclosed a stainless steel shell, the two halves connected by tubes for LHe and wiring (Figure 2). The cold mass is suspended in a 24" diameter cryostat shell by epoxy-fiber straps such that motion during cooldown is minimized. 80K heat shields are placed between cold mass and all room temperature surfaces.

Testing: Several model magnets have been tested, including two smaller 3-pole models and a full size prototype. All have operated well above the design field. Magnetic field quality measurements have been in good (<0.1%) agreement with calculations. After a high precision, detailed field map of the full size prototype, it will be installed in the storage ring in July, 2002 for measurements of beam dynamics effects and colliding beam operation in the Charm regime.

Figure 2: Cold mass in cryostat. 80K shield and support straps are not yet installed.



4 MEASUREMENTS

The CHESS synchrotron radiation facility provides high brightness beams to the users from two permanent magnet wigglers. At 1.8 GeV these wigglers exhibit non-linearities comparable to the CESR-c wigglers and thus provide the means to test beam dynamics calculations.

Vertical focusing in wigglers: Both linear and cubic focusing effects have been measured. The linear term causes a tune shift in vertical plane only, which has been measured for both wigglers and found to be in good agreement with expectations. The cubic term was measured by observing vertical tune shift aa a function of vertical displacement in the wigglers. Agreement with calculation is quite good as shown in Figure 3.

Large amplitude non-linear motion: The trajectory of large amplitude particles was found to be stable for normal betatron tunes. We found that beam losses when tuning across the 2/3 integer resonance were strongly dependent on the vertical closed orbit in the wigglers, as expected. Turn-by-turn position data were plotted after exciting a coherent betatron oscillation with a single turn vertical kick. Motion was found to be quite linear except near 2/3 and ¾ integer resonances. Phase space plots of the latter, comparing measured and tracking data , are shown in Figure 4.

Bunch length and lifetime: Measurements of bunch length vs. current and Touschek are both in good agreement with calculations. [11]

Figure 3 – Measured wiggler cubic terms

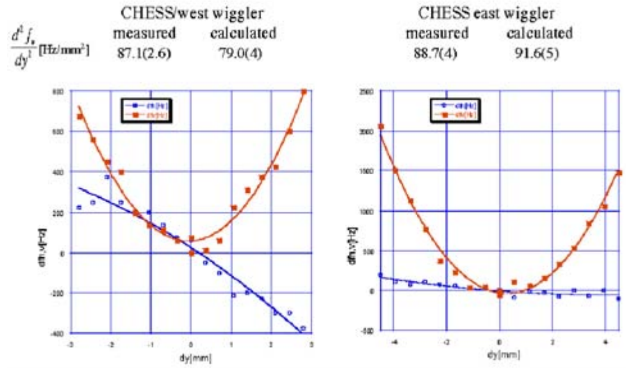
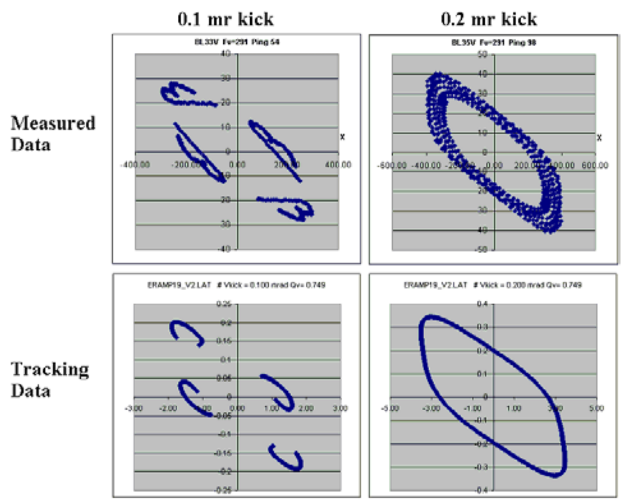


Figure 4 – Large amplitude non-linear beam motion



5 CONCLUSION

The conversion of CESR to extend high luminosity operation to 1.5 GeV is well underway and on schedule. The strong wigglers combined with very large aperture requirements pose challenges to maintain acceptable dynamic aperture. Measurements of magnetic fields and in CESR suggest that these are under control.

By March, 2003 we will have 6 wigglers installed in CESR and begin low energy operation at a significant fraction of CESR-c specifications. Full operation with all wigglers will begin before the end of 2003.

Much credit goes to the many people who have contributed to the design, development, and analysis of CESR-c components.

6 REFERENCES

[1] D.L. Rubin et al., *Proc. 2001 PAC*, p. 3520
[2] D. Sagan , D. Rubin, *Proc. 2001 PAC*, p.3517
[3] K. Benslama et al., *hep-ex 0205003* (2002)
[4] J. Welch, et al. *Proc. 2001 PAC*, p. 3472
[5] S. Belomestnykh et al., *Proc. 2000 EPAC*, p.2025
[6] M. Billing et al., *Proc. 2001 PAC*, p.1243
[7] A. Mikhailichenko, *Proc. 2001 PAC*, p.3648.
[8] J. Corbett, Y Nosochkov, *Proc. 1999 PAC,* p. 2358
[9] J. Safranek et al., *Proc. EPAC 2000*, p. 295,
[10]D. Sagan, "BMAD" dcs@cesr10.lns.cornell.edu
[11]S. Nikitin, *Proc. 2001 PAC*, p. 2845