# PROGRESS REPORT — April 2007

## Design Studies for Converting CESR to a Damping Ring Test Facility

## Applicants/Institution:

J. Alexander, R. Ehrlich, L. Gibbons, D. Hartill, R. Helms, M. Palmer, D. Rubin, D. Sagan,
L. Schachter, M. Tigner

## Principal Investigator:

David Rubin, Laboratory of Elementary Particle Physics, Cornell University

## Collaborators (not requesting support):

N. Kurita, M. Pivi, L. Wang, SLAC
J. Urakawa, KEK
A. Wolski, LBNL and Cockroft Institute
G. Blair, Royal Holloway University of London

## Project Overview

We propose to reconfigure the Cornell Electron Storage Ring (CESR) as a dedicated test accelerator, CesrTA, to investigate beam physics and instrumentation critical to the design and operation of the international linear collider (ILC) damping rings. CesrTA would serve as a complement to the Accelerator Test Facility (ATF), an electron storage ring at KEK. ATF has been successful in achieving, and measuring, the ultra-low emittance required of the ILC damping rings. However, an issue peculiar to the positron damping ring, that is out of reach of the ATF, is the generation of an electron cloud and its effect on the stability and emittance of the beam. The baseline design for the ILC is a single 6 km ring for electrons and a single 6 km ring for the positrons. We intend to use CesrTA to determine how the development of the electron cloud depends on beam parameters, local magnetic fields, and vacuum chamber design. Electron cloud instability thresholds will also be measured. A comparison of the measurements with the simulation results will help to validate the models that are the basis of the ILC damping ring design.

An experimental program to understand the relevant electron cloud physics requires a positron beam, very small vertical emittance, and high field damping wigglers. Flexibility of the bunch structure of the positron beam is essential to explore the dependence of the electron cloud density on bunch spacing and train length. Ideally, the zero current limit of the vertical emittance should be comparable to the specifications of the ILC damping ring so that we will be sensitive to emittance diluting effects of the interaction with the electron cloud. Simulations indicate that the equilibrium electron cloud density will be highest in the damping wigglers and we also propose to test that assertion.

CesrTA will offer flexible operation from energies of 1.5 GeV to 5.5 GeV. At low energy (1.5 GeV-2.5 GeV), superconducting wigglers reduce the radiation damping time by about an order of magnitude. We have created optics that allow us to exploit this capability to achieve a corresponding order of magnitude reduction of the emittance to approximatly 2 nm. Attaining a vertical emittance comparable to the ILC design specification then requires very good vertical dispersion and transverse coupling corrections.

| Parameter | Value |
|---|---|
| No. Wigglers | 12 |
| Wiggler Field | 2.1 T |
| Beam Energy | 2.0 GeV |
| Energy Spread ($\Delta E/E$) | $8.6 \times 10^{-4}$ |
| Horizontal Emittance | 2.25 nm |
| Transverse Damping Time | 47 ms |
| $Q_x$ | 14.53 |
| $Q_y$ | 9.58 |
| $Q_z$ | 0.1 |
| Total RF Voltage | 8.5 MV |
| Bunch Length | 9 mm |
| Momentum Compaction | $7.1 \times 10^{-3}$ |

Table 1: CesrTA Baseline Lattice Parameters.

| Layout | Energy[GeV] | $B_{peak}$[T] | No. Wigglers | Zero current $\epsilon_x$[nm] |
|---|---|---|---|---|
| CesrTA | 2.0 | 2.1 | 12 | 1.8 |
| CESR-c | 2.0 | 2.1 | 6 | 6.5 |
| CesrTA | 2.0 | 1.9 | 12 | 1.9 |
| CesrTA | 2.5 | 2.1 | 12 | 3.2 |
| CesrTA | 1.5 | 1.4 | 12 | 1.3 |
| CesrTA | 5.0 | 2.1 | 6 | 26 |

Table 2: Low emittance optics

CesrTA also offers great flexibility in bunch configuration. The broadband transverse and longitudinal feedback system in CESR can stabilize dipole motion for 183 bunches spaced 14 ns apart, and, with a straightforward upgrade, it can manage trains of bunches with 4 ns spacing.

## Progress Report

### *Lattice development*

We have considered modifications of the machine layout compatible with a very low emittance lattice. This requires that all 12 CESR-c wigglers be located in zero dispersion regions and that the coupling elements associated with our compensation scheme for the CLEO solenoid be removed. 6 of our wigglers are presently located in straights which can already be configured for zero dispersion. The remaining 6 wigglers will need to be relocated to the CLEO interaction region straight. This will be possible in mid-2008 after the end of CESR-c/CLEO-c operations. The resulting parameters for our baseline configuration at 2 GeV beam energy are given in Table 1. In addition to this baseline configuration, we have explored our emittance reach for a number of machine configurations. These studies have varied the number of wigglers, the wiggler fields, the machine energy, and also considered the possibility of low emittance operations in the CESR-c configuration before any machine modifications can be made. Table 2 summarizes several representative configurations. Note that the CESR-c configuration [7] shown will allow us to probe horizontal emittances that are within a factor of 3 of those planned for CesrTA operations.

The dynamic aperture for the various sets of optics has been evaluated for fractional energy offsets

| Element | Alignment |
|---|---|
| quad, bend, and wiggler offset | 150$\mu$m |
| sextupole offset | 300$\mu$m |
| quad,bend,wiggler, and sextupole roll | 100$\mu$rad |

Table 3: Nominal magnet misalignment resolution in CESR

of 0.5% and 1%. Tracking is based on symplectic integration. The same wiggler map is used for the dynamic aperture tracking as for CESR-c calculations [1]. The results indicate that the dynamic aperture is adequate to capture the large amplitudes characteristic of the injection process[6].

### *Low emittance correction/tuning*

The vertical emittance that can be obtained in CesrTA will be sensitive to alignment errors around the ring and to the emittance coupling that can be obtained. Magnet misalignments in CESR create vertical dispersion and couple horizontal and vertical emittance. In order to achieve the target vertical emittance, the sensitivity to misalignments has been characterized and algorithms for correcting misalignments have been evaluated. Table 3 shows the nominal alignment resolution that we can achieve with existing survey techniques.

Simulations have been performed incorporating the random misalignment of elements using multiple seeds. These simulations assume that, with sufficient effort, we can achieve alignment accuracies around the ring which are consistent with our alignment resolutions. With the alignment errors at the nominal level of our alignment resolution the resulting uncorrected vertical emittance in CesrTA optics would be approximately 140$\mu$m. The principle source of vertical emittance is the vertical dispersion generated by offsets of CESR quadrupoles. Simulations indicate that the vertical dispersion can be measured and effectively compensated with the dipole correctors that are adjacent to every quadrupole in the storage ring. The simulations include BPM resolution and results for 200 random seeds yield an average vertical emittance of 3.9pm. 95% of the seeds can be corrected to better than 8.2pm. Measurements of the amplitude of quadrupole vibrations are underway.

### *X-ray beam size monitor*

We are developing a fast x-ray camera for high resolution ($\sim 1\mu$m) bunch by bunch beam size measurements and emittance tuning. We plan to build two cameras and install two x-ray lines so that we can measure both electron and positron beams. We have preliminary designs for the layout and optics of the beam lines.

### *Touschek/IBS studies*

Intrabeam scattering (IBS) will play a significant role in the emittance that can be attained in CesrTA with a bunch charge corresponding to the ILC bunch charge. We have incorporated IBS physics in the BMAD library of accelerator software tools so that its impact can be evaluated for the various configurations without approximations. For our baseline 2.0 GeV lattice with $\epsilon_x$ =2.25nm, a 9mm bunch length, and assuming that the machine has been corrected to achieve a 5pm vertical emittance in the zero current limit, we find that the horizontal emittance grows by a factor of $\sim 2$ as we move from zero to $10^{10}$ particles in a bunch. As shown in Figure 1, the effect of intrabeam scattering also depends on the source of vertical emittance (coupling or dispersion), and the zero current vertical emittance. For an ILC bunch with $2 \times 10^{10}$ particles, the horizontal emittance is

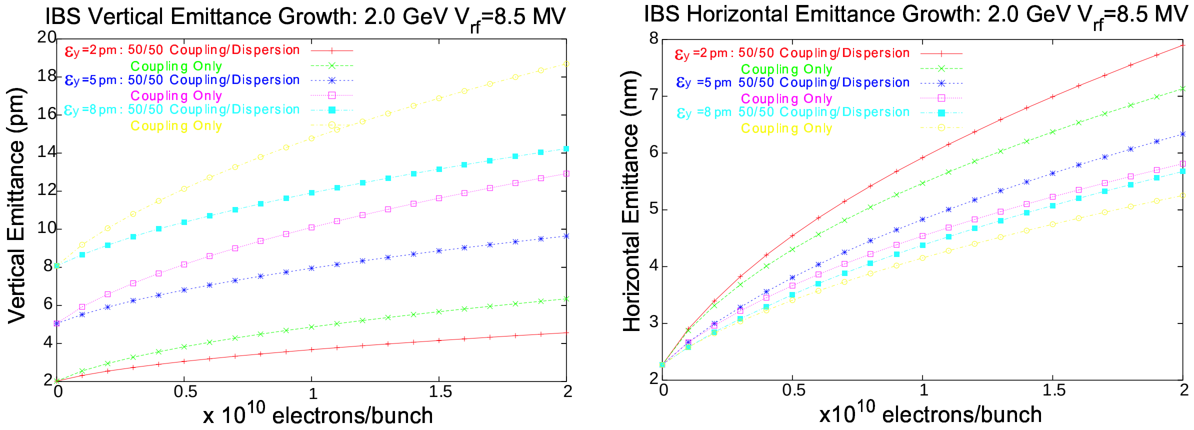

Figure 1: The effect of IBS depends on bunch charge, zero current vertical emittance, and the source of the vertical emittance (coupling and/or dispersion).

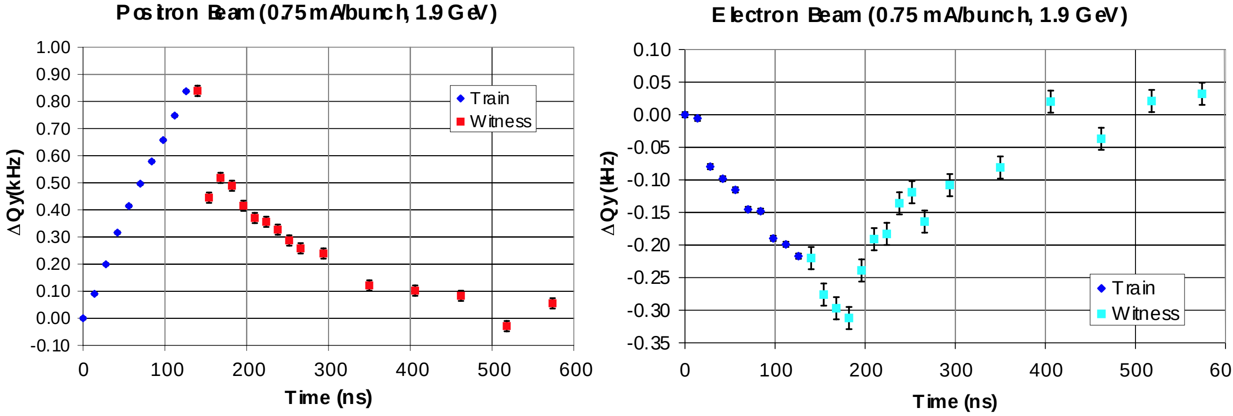

Figure 2: The blue points (labeled train) indicate the bunch by bunch tune shift of the 10 bunch train with 14ns spacing. The red points (labeled witness) indicate the tune of a witness bunch that trails the end of the train at 14ns intervals.

2.7 times larger than the zero current value. In the limit that the vertical emittance is dominated by coupling, these same growth factors will apply. Since the IBS growth rates scale as $\gamma^{-4}$, the emittance blowup can be reduced further by lengthening the bunch, or at the expense of slightly larger zero current emittance, moving to higher energy.

### *Electron cloud simulation and measurements*

Measurements of bunch by bunch tune shift and beam size indicate the presence of an electron cloud. In one set of measurements we store a ten bunch train of positrons with 14ns spacing. We then inject a witness bunch at integral 14ns intervals beyond the end of the train. The bunch by bunch tune shift is shown in the left plot of Figure 2. The development of the cloud is evident from the increasing tune shift along the 10 bunch train. The decay distance of the cloud is extracted from the tune shift of the witness bunches. Measurements of a similarly configured electron beam suggests the presence of an electron cloud as well, but with a somewhat lower density. We are beginning to use the Ecloud[8] program to simulate growth of electron cloud in the CESR guide field so that we can make comparisons with the measurements. We have also designed and built a set of retarding field analyzers (RFA) for installation in May 2007. We will use the RFAs to study the local evolution and lifetime of the electron cloud.

*4ns transverse feedback*

CESR operates in a colliding beam mode with a bunch spacing of 14ns and with bunch by bunch digital feedback for electrons and positrons in horizontal, vertical and longitudinal planes. The 500MHz RF system can accomodate bunch spacing of 4ns. We have developed an analog system, that utilizes the same amplifier and kicker as the digital system, but with the capability of damping trains of bunches with 4 ns spacing. In recent tests, we have stored a 21 bunch train, with bunch charge of $2 \times 10^{10}$ particles, (1.4mA/bunch) with 4ns spacing. Longitudinal self excitation is evident at total beam current of about 20mA, but it is self limiting and does not cause particle loss. Nevertheless, we plan to extend the capability of our digital longitudinal system to 4ns spacing.

## Activities planned for the second year of this proposal

During the second year, while design and engineering studies continue, funds will be needed for prototyping instrumentation and hardware. We intend to design the vacuum chambers and diagnostics required to characterize electron cloud growth in wigglers, dipoles, quadrupoles and drifts. We will prepare vacuum designs to support operating some portion of the wiggler complement at 5.0 GeV beam energy. We will also complete our plans to upgrade the CESR instrumentation for ultra low emittance correction and tuning. Finally we will develop the full facilities plan for modifying the CESR ring.

## References

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