# THE CONVERSION AND OPERATION OF THE CORNELL ELECTRON STORAGE RING AS A TEST ACCELERATOR (CESRTA) FOR DAMPING RINGS RESEARCH AND DEVELOPMENT*

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*Abstract*

In March of 2008, the Cornell Electron Storage Ring (CESR) concluded twenty eight years of colliding beam operations for the CLEO high energy physics experiment. We have reconfigured CESR as an ultra low emittance damping ring for use as a test accelerator (CesrTA) for International Linear Collider (ILC) damping ring R&D. The primary goals of the CesrTA program are to achieve a beam emittance approaching that of the ILC Damping Rings with a positron beam, to investigate the interaction of the electron cloud with both low emittance positron and electron beams, to explore methods to suppress the electron cloud, and to develop suitable advanced instrumentation required for these experimental studies (in particular a fast x-ray beam size monitor capable of single pass measurements of individual bunches). We report on progress with the CESR conversion activities, the status and schedule for the experimental program, and the first experimental results that have been obtained.

## INTRODUCTION

One of the leading R&D issues for the positron damping ring of a future linear collider is to ensure that the density of electron cloud (EC) build-up in the vacuum chambers can be kept below the levels at which beam instabilities and incoherent emittance growth will occur. In the present ILC damping rings (ILCDR) design, the presence of the EC in the positron ring limits the maximum current that can be stored and hence the minimum circumference of the ring that can be employed. As such, it is a significant cost driver for this accelerator system as well as being a major source of concern for whether the design can reach its performance goals. The ILCDR design targets a geometric vertical emittance of 2pm at the design energy of 5GeV [1]. No positron storage ring has operated in this parameter regime. Estimates of the instability thresholds for the baseline 6.5 km circumference indicate that secondary electron yield (SEY) values for the vacuum chambers must be less than 1.2 for stable operation. The regions of greatest concern for EC build-up have been identified as the wiggler and dipole vacuum chambers [1]. In order to validate these estimates for the ILCDR and to support continued R&D on EC mitigation measures, a program of EC research was approved to begin at CESR at the conclusion of CLEO-c colliding beam operations in early 2008.

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## CESR AS A TEST ACCELERATOR

There are two principal goals of the CesrTA program. The first is to characterize the impact of the EC on ultra low emittance beams. By benchmarking EC simulations in a parameter regime approaching that of the ILCDR, we can significantly improve our confidence in the ILCDR performance estimates and determine whether further updates to the design are required. The second goal is to continue the ILC R&D program into mitigation measures that can reduce the EC build-up to levels which will maximize the safety margin for stable positron damping ring operation. Results from these studies will be incorporated into the ILCDR design by mid-2010.

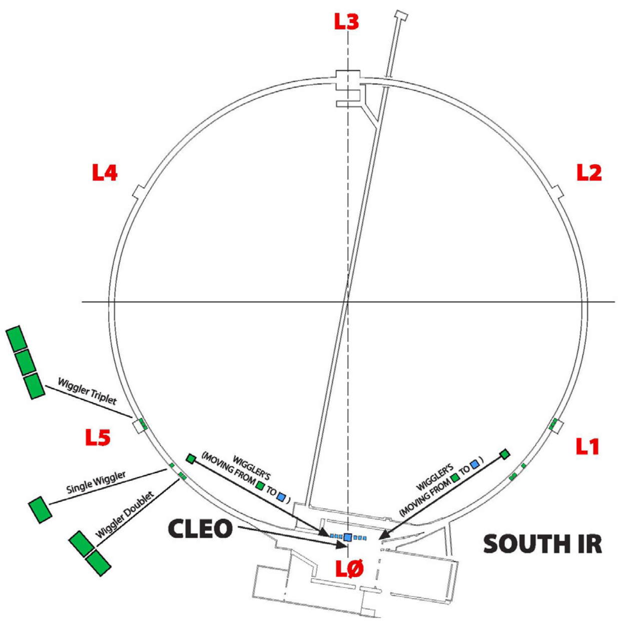


Figure 1: Layout of the Cornell Electron Storage Ring. For the CesrTA reconfiguration, 6 superconducting wigglers from the machine arcs must move to the L0 straight, formerly occupied by the CLEO detector, which can be configured for zero dispersion.

The first step in achieving these goals is to reconfigure CESR as a damping ring. During the CESR-c/CLEO-c high energy physics program, twelve superconducting damping wigglers were installed in the CESR arcs [2]. For 2GeV operation, these wigglers provide 90% of the radiation damping in CESR and, in their original arc locations, could be used for emittance control of the colliding beams. For ultra low emittance operation, all twelve wigglers must be located in regions with zero dispersion. The CesrTA lattice provides for zero dispersion locations in the L0, L1 and L5 straight sections which are shown in Fig. 1 [3]. Six of the CESR-c wigglers must be relocated to the CESR L0 straight, in place of the CLEO detector. The remaining six wigglers, located in the L1 and L5 straights, can remain in place. Table 1 provides CesrTA lattice parameters for operation at 2GeV with twelve wigglers and at 5GeV with six wigglers. Fig. 2 shows the 2.085GeV ultra low emittance lattice functions. We are targeting a vertical emittance of 10-20pm range after full machine correction in the 2GeV lattice.

In addition to the layout modifications for low emittance operation, support for EC experimental areas and instrumentation upgrades to aid in beam dynamics studies and low emittance tuning are central components of the CesrTA program. These modifications include:

- Deployment of local EC diagnostics, in particular retarding field analyzers (RFAs), in vacuum chambers in each of the representative magnetic field regions in CESR. This includes the instrumentation of the vacuum chambers in drift regions as well as in dipole, wiggler and quadrupole magnets [4,5,6].
- Installation of flexible EC experimental regions where vacuum chambers incorporating various EC mitigations can be tested. Mitigation tests will explore ways to control the EC build-up in dipole and wiggler vacuum chambers, the regions of greatest concern for the ILCDR.
- Addition of instrumentation for achieving, tuning and characterizing ultra low emittance beams. This includes upgrades to the CESR beam position monitor system and deployment of x-ray beam size monitors (xBSM) capable of bunch-by-bunch measurements of beam sizes of several microns [7].
- Upgrading the CESR feedback system to support operation with bunch spacings as short as 4ns.

Table 1: CesrTA 2GeV and 5GeV Lattice Parameters

| | | |
|---|---|---|
| Energy [GeV] | 2.085 | 5.0 |
| No. Wigglers | 12 | 6 |
| Wiggler Field [T] | 1.9 | 1.9 |
| $Q_x$ | 14.57 | |
| $Q_y$ | 9.6 | |
| $Q_z$ | 0.075 | 0.043 |
| $V_{RF}$[MV] | 8.1 | 8 |
| $\varepsilon_x$ [nm-rad] | 2.6 | 35 |
| $\tau_{x,y}$ [ms] | 57 | 20 |
| $\alpha_p$ | $6.76\times10^{-3}$ | $6.23\times10^{-3}$ |
| $\sigma_l$ [mm] | 9.2 | 15.6 |
| $\sigma_E/E$ [%] | 0.81 | 0.93 |
| $t_b$ [ns] | ≥4, steps of 2 | |

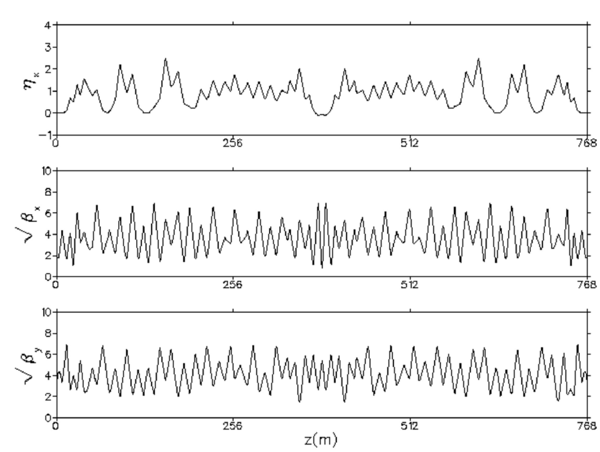


Figure 2: Lattice functions for the CesrTA 2.085GeV baseline lattice.

In the CesrTA configuration, CESR offers an experimental program with a wiggler-dominated ring where the CESR-c superconducting wigglers are the technology choice for the ILCDR baseline design. Measurements in CESR can be carried out with both electron and positron beams to carefully elucidate species-dependent effects. The ability to operate over a wide range of energies, bunch spacings and bunch intensities enables systematic probes of both the primary photoelectron and secondary electron contributions to the cloud build-up. Through the course of the program, roughly 240 experimental days are scheduled which will enable a thorough set of measurements to be performed.

## UPGRADE STATUS

Two major upgrade downs have now been completed for the CesrTA program. The first took place during the summer of 2008 while the second took place in February 2009. During these downs, the principal modifications to the CESR layout for low emittance operation were completed. Six superconducting wigglers were removed from the CESR arcs and installed in the L0 straight. In order to accommodate the new L0 beam line, the inner detectors were removed from CLEO and a new magnet support structure was installed. Fig. 3 shows the new L0 layout. Two of the L0 wigglers had their original vacuum chambers removed and replaced with new vacuum chambers with EC diagnostics [6]. Each of these instrumented chambers contains three RFAs, one located longitudinally in the center of a main pole, one at the boundary between two poles, and one in the region near the edge of pole where the field begins to roll off. Fig. 4 shows the RFA placement with respect to the wiggler poles along with a picture of one of the RFAs during assembly. One vacuum chamber has an untreated Cu surface while the second was coated with TiN for comparison. At least two additional diagnostic wiggler chambers are planned for installation in 2009, one with a grooved surface and one with a clearing electrode for EC mitigation. In addition to the wiggler chambers, RFAs were also installed in the adjacent drift sections in the L0 straight. Finally a photon beam stop in the downstream direction of the positron beam was installed which will permit 5GeV operation of the L0 wigglers.

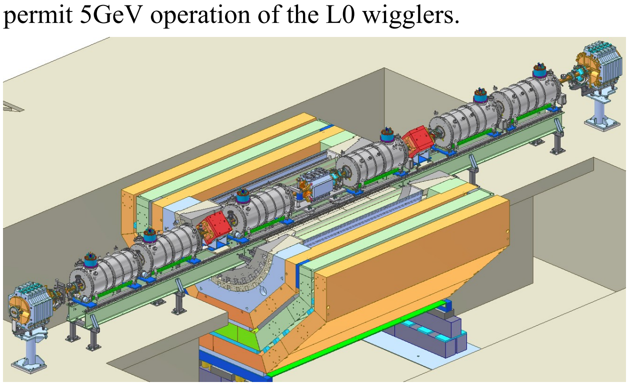

Figure 3: Isometric cutaway view of wiggler string installed in the former CLEO interaction region (L0). The CLEO tracking detectors were removed in order to accommodate the beam line in this region.

Other ring modifications during these downs included:

- The upgrade of an existing Cornell High Energy Synchrotron Source (CHESS) beam line for x-ray imaging of the positron beam size [7] and preparations for similar modifications for an electron beam size monitor.
- Deployment of dipole and drift chambers, instrumented with RFAs, in the CESR arcs.
- Installation of two experimental regions in the CESR arcs where test chambers with EC mitigations can be deployed and tested.
- Modification of the L3 straight as an EC experimental region including removal of the vertical electrostatic separators in CESR which were needed for colliding beam operations and were one of the principal sources of impedance in the ring. Changes also included installation of the diagnostic chicane from SLAC for which studies were incomplete at the end of PEP-II operations in 2008 [8].
- Installation of the supporting infrastructure for the CesrTA instrumentation upgrades.

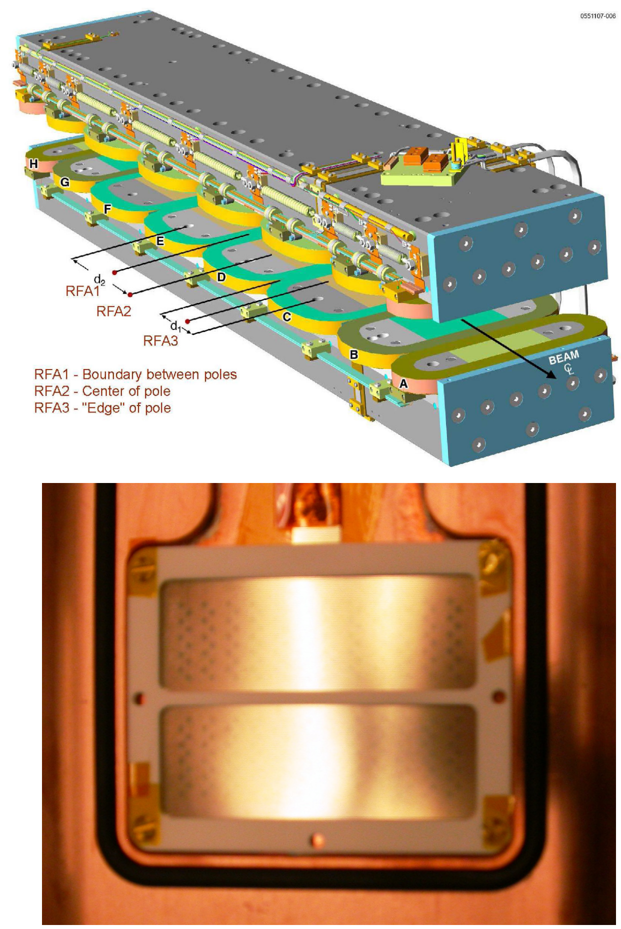


Figure 4: Isometric view of wiggler magnet (top) showing the locations of the three RFAs installed in each vacuum chamber. RFA #1 is located at the boundary between two of the main poles, RFA #2 is located at the center of a pole, and RFA #3 is located near the edge of a pole where the vertical magnetic field begins to roll off longitudinally. RFA structure during assembly (bottom).

## FIRST RESULTS

Detailed optics correction of the CesrTA 2.085GeV lattice took place during the January 2009 running period [9]. At that point, studies of the resulting vertical emittance were carried out. Fig. 5 shows xBSM measurements made at three points during a coupling knob scan in the fully corrected low emittance lattice. During the course of low emittance tune-up the smallest observed source size was ~15µm corresponding to ~37pm vertical emittance [10]. Measurements using coded aperture optics yielded similar results [11]. The emittance was also characterized by means of Touschek lifetime measurements. The lifetime of a uniform train of bunches can be written as:

$$\frac{di}{dt} = -\frac{i}{c} - \frac{i^2}{b}$$

where $i$ is the bunch current, $b$ is the Touschek parameter, and c is a constant. The parameter $b$ depends in detail on the dynamic energy acceptance, the RF voltage and the vertical emittance. Fig. 6 shows Touschek parameter data and simulation for a range of conditions. The simulation curve which best matches the data corresponds to a vertical emittance of approximately 32pm. Thus, the two characterizations of our achieved vertical emittance appear consistent and indicate that we are within a factor of two of our target vertical emittance of 20pm.

A number of electron cloud measurements were made during the January 2009 experimental run. This included RFA and TE wave measurements to characterize the electron cloud build-up around the CESR ring. Fig. 7 shows RFA energy scans of the EC build-up for the two instrumented wigglers after extensive beam processing. Comparisons between measurement methods and with simulation are ongoing [12,13].

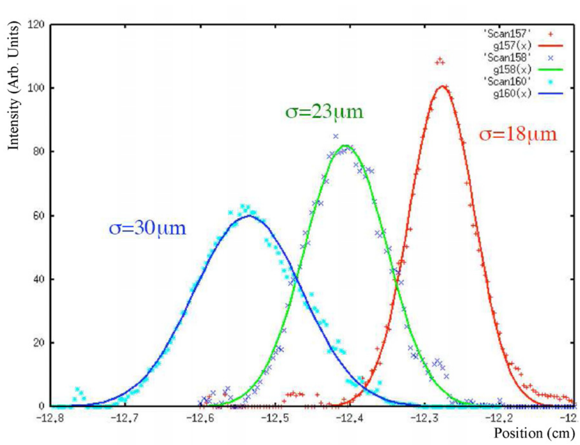


Figure 5: xBSM measurements using Fresnel zone plate imaging. The data are from a scan of a coupling knob after the first complete round of lattice correction in the CesrTA 2.085 GeV low emittance conditions.

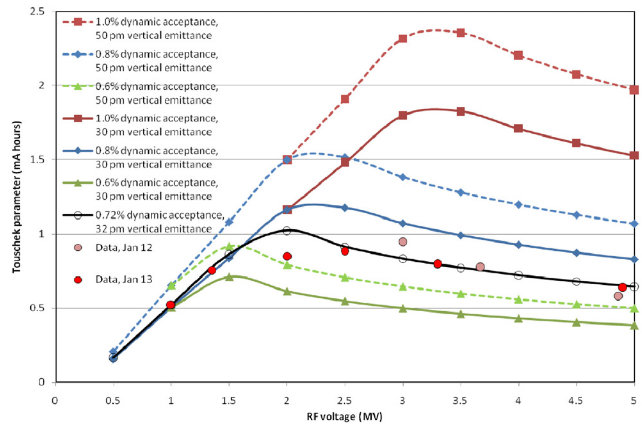


Figure 6: Data and simulation results for Touschek lifetime measurements in the CesrTA low emittance lattice at 2.085 GeV. The best match between the simulation and experimental data is the curve corresponding to 32 pm vertical emittance with a dynamic acceptance of 0.72%. The measured acceptance was 0.8%.

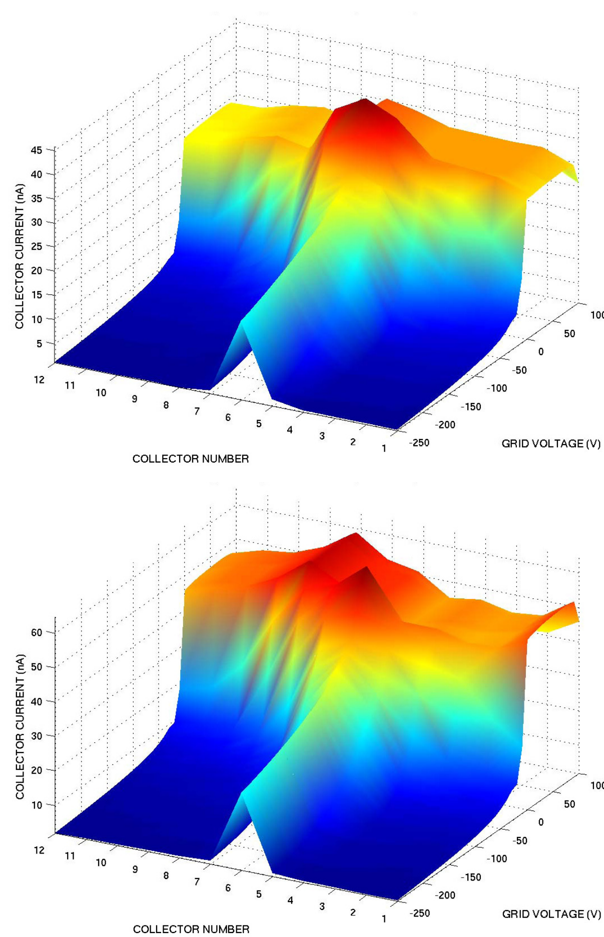


Figure 7: RFA energy scan data for detectors located in the center of the wiggler poles for the Cu vacuum chamber (top) and TiN-coated vacuum chamber (bottom). Data acquired for a single positron train of 45 bunches with $2.2\times10^{10}$ particles/bunch.

Bunch-by-bunch tune shift measurements are a key probe of the overall EC build-up around CESR. A standard technique is to use a leading train and then place witness bunches at various delays behind the train to study the development and the decay of the EC. Fig. 8 shows witness bunch tune shift data obtained with both positron and electron beams along with simulation results of the expected horizontal and vertical tune shifts obtained using POSINST. The data and simulations are in reasonable, albeit not perfect, agreement for both species. We have obtained considerable data at various energies (thus dramatically changing the photon flux distribution around the ring) and with various bunch patterns, spacings, and intensities. Detailed parameter scans are presently underway to determine the best model parameters for describing the EC build-up around CESR [14,15]. These parameters will then serve as inputs to our upcoming studies of EC induced instabilities and incoherent emittance growth at ultra low emittance.

## CONCLUSION

The CesrTA conversion is now approaching completion. Modifications to the ring layout are in place

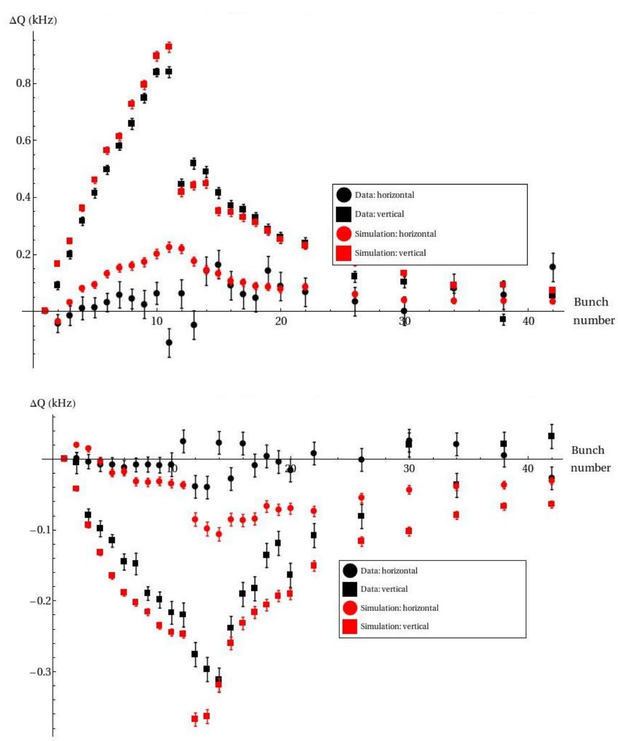


Figure 8: Plots showing vertical and horizontal tune shift data obtained in CESR using the witness bunch technique. For these studies, a witness bunch of $1.2\times10^{10}$ particles is placed at various delays behind a leading train of 10 bunches of the same charge with 14ns spacing. The data shown was obtained for a beam energy of 1.89GeV while CESR was still in the CESR-c layout. The top plot is for a positron beam and the bottom plot is for an electron beam. POSINST simulation results are in reasonable agreement with the data for both species.

and the remaining upgrade effort is focused primarily on our diagnostics and beam instrumentation improvements. An experimental program for electron cloud and low emittance tuning studies with >150 operating days is planned for the period from now until mid-2010 at which point the results of these studies will be incorporated into the ILCDR design.

For a program of this size, there are many people to thank. In particular, we would like to express our appreciation to the Wilson Laboratory technical staff who have enabled this effort. We also thank our colleagues in the ILC damping rings group and the electron cloud R&D community who have provided their support as well as many useful discussions and suggestions.

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