PROJECT DESCRIPTION

Design Studies for Converting CESR to a Damping Ring Test Facility

Personnel and Institution(s) requesting funding

J. Alexander, R. Ehrlich, L. Gibbons, D. Hartill, R. Helms, M. Palmer, D. Rubin, D. Sagan, L. Schachter [1], M. Tigner, Cornell University

Collaborators

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

Project Leader

D. Rubin
dlr10@cornell.edu
(607)255-3765

Project Overview

We propose to reconfigure the Cornell Electron Storage Ring (CESR) as a dedicated test facility, CesrTF, to investigate beam physics and instrumentation critical to the design and operation of the international linear collider (ILC) damping rings. The CesrTF facility would serve as a complement to the Advanced 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 two 6 km rings for the positrons. The choice of two rings for positrons is driven by concerns about the electron cloud instability as determined from detailed simulations. We intend to use CesrTF 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.

[1] Visiting for the 2006-2007 academic year from Technion – Israel Institute of Technology, Haifa, Israel.

CesrTF 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 less than 3 nm. Attaining a vertical emittance comparable to the ILC design specification then requires very good vertical dispersion and transverse coupling corrections.

CesrTF 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 366 bunches spaced every 6 and 8 ns.

At 5 GeV beam energy, CESR's single beam current limit is in excess of 400 mA, and at 1.9 GeV, with 12 wigglers operating at peak field of 1.2 T, the instability threshold is greater than 180 mA with 45 bunches. The current limit in a low emittance configuration is presumably dominated by the same dynamics that will be at play in the ILC damping ring, providing an ideal opportunity to explore that limit.

A range of damping ring phenomena and technologies can be investigated in a dedicated test facility. The CESR operations group has developed sophisticated tools for correcting orbit, focusing, coupling, and dispersion errors using beam based measurements. We would like to apply existing techniques to the task of achieving the few picometer vertical emittance specified for the ILC design, so that we can understand the limitations and to implement new algorithms as required. The effort to reduce vertical emittance will necessarily be coupled with tests of new instrumentation designed to measure the very small beam size. The flexibility to store closely spaced bunches will permit tests of fast extraction kickers and pulsers. The CESR injector can deliver electron beams as well as positron beams, allowing for the possibility of measuring effects peculiar to electrons (as well as positrons), like the fast ion instability, and to distinguish species dependent from species independent effects.

Unique features that CesrTF offers are:

- Operation with positrons (not available at other facilities) or electrons
- Wiggler-dominated operation
  - CESR-c wigglers match or exceed all damping ring requirements
- Low emittance operation
  - Few nm horizontal emittance
  - Potential vertical emittance in the few to several pm range
- Large energy range accessible
  - 1.5 – 5.5 GeV operation
  - Allows detailed characterization of critical dynamics issues
- Large insertion region for testing ILC damping ring hardware
  - Wigglers
  - RF cavities
  - Instrumentation
  - Kickers

Important areas that CesrTF could probe include:

- Electron Cloud Studies
  - Electron cloud buildup
    - Bends
    - Wigglers
  - Diagnostic techniques
    - Diagnostics for wiggler sections
    - Tests of non-invasive diagnostics for a real ring
  - Local amelioration techniques
    - Vacuum chamber design
      - Secondary electron trapping schemes
      - Low SEY chambers
      - Clearing electrodes
  - Dynamics Issues
  - Bunch spacing
  - Energy dependence
  - Instability thresholds
- Fast Ion Instability
  - Wiggler issues
  - Similar in scope to E cloud
- Low Emittance Operation
  - Alignment Issues
  - Emittance Control Algorithms
    - Design
    - Testing
- Damping Ring Hardware Testing
  - Wigglers
  - SRF cavities
  - Kickers/pulsers
  - Low SEY vacuum chambers
  - Instrumentation
  - Feedback system

Our present proposal is for funds to carry out various design studies: to evaluate the CesrTF lattice design in detail; to specify the full range of operating parameters that CesrTF can explore; to evaluate alignment and survey issues as they apply to low emittance operation; to develop software that will be needed to operate and characterize the machine (note that this development will be directly applicable for a final ILC damping ring and can be used for further ILC DR evaluation); to evaluate and design hardware necessary for electron cloud and ion diagnostics and suppression; and to develop and evaluate the engineering plan to convert CESR to a suitable test facility configuration (in particular wiggler configuration, vacuum modifications, instrumentation/feedback requirements, cryogenics modifications, insertion device support, experimental layout, and facility modifications). We envision that prototype work on some key pieces of hardware will begin in the second year.

Broader Impact

Most issues that are being investigated as part of this proposal have implications for operating accelerators. We expect that this research will contribute to the fundamental understanding of issues relevant for current electron and positron circular accelerators. Furthermore, the software and hardware developed for this application will be directly applicable to other machines such as synchrotron light sources.

This proposal will further the teaching mission of Cornell University by supporting undergraduate and graduate students in accelerator physics. In addition, we expect to expose undergraduates to the field of accelerator physics by making relevant research projects available as part of the LEPP Research Experience for Undergraduates Program which is specifically targeted at students from institutions that do not support large research programs. In general, the training of new accelerator physicists is expected to have a significant impact on a range of fields which presently depend on particle accelerators for their research — this includes the materials sciences, medicine, solid state physics, and biophysics as well as nuclear and high energy physics.

Results of Prior Research

Present status of CesrTF design studies

We have conducted preliminary studies to verify the validity of the CesrTF design concept. Our first step was to evaluate the machine layout for modifications suitable for test facility operation. A key point is that CESR-c's damping wigglers need to be placed at zero dispersion locations to obtain the smallest possible beam emittance. CESR is presently configured with two interaction regions, each approximately 18 m in extent, which can be configured for zero dispersion. The south region is the present home of the CLEO detector while the north region is the former location of the CUSB detector. After the end of CESR-c/CLEO-c operations in mid-2008, we plan to remove the CLEO detector, thus making both regions available. Our present CesrTF layout envisions moving 6 of the 12 CESR-c wigglers to the north interaction region, along with suitable cryogenics support. Simulations indicate that we can leave the remaining 6 CESR-c wigglers in their present locations in the CESR arcs, a triplet in the west and a triplet in the east, where the lattice can be designed to provide two additional zero dispersion sections. This will leave the south interaction region available for insertion devices such as specialized beam instrumentation, prototype damping ring hardware, etc. It also allows for the possibility of installing an extraction line at that location.

Figure 1 shows the optics functions for our present lattice design. Key machine parameters for this configuration are given in Table 1. The integer horizontal tune in this design has been chosen to minimize emittance. Touschek estimates in these optics yield lifetimes of order minutes for vertical emittances in the several picometer range.

The dynamic aperture of these optics has been evaluated for fractional energy offsets of 0.5% and 1% and is shown in Figure 2. Tracking is based on symplectic integration using the same wiggler map as is used for CESR-c calculations [1]. Particles are considered lost when their amplitude significantly exceeds the real physical aperture. The horizontal emittance of the injected beam is assumed to be 1000 nm. The beam is also taken to be fully coupled so that the vertical emittance is half the horizontal (500 nm). These results indicate a very acceptable dynamic aperture.

As has already been noted, the equilibrium horizontal emittance obtained for this configuration is 3 nm. It is dominated by intrinsic emittance generation in the wigglers themselves.

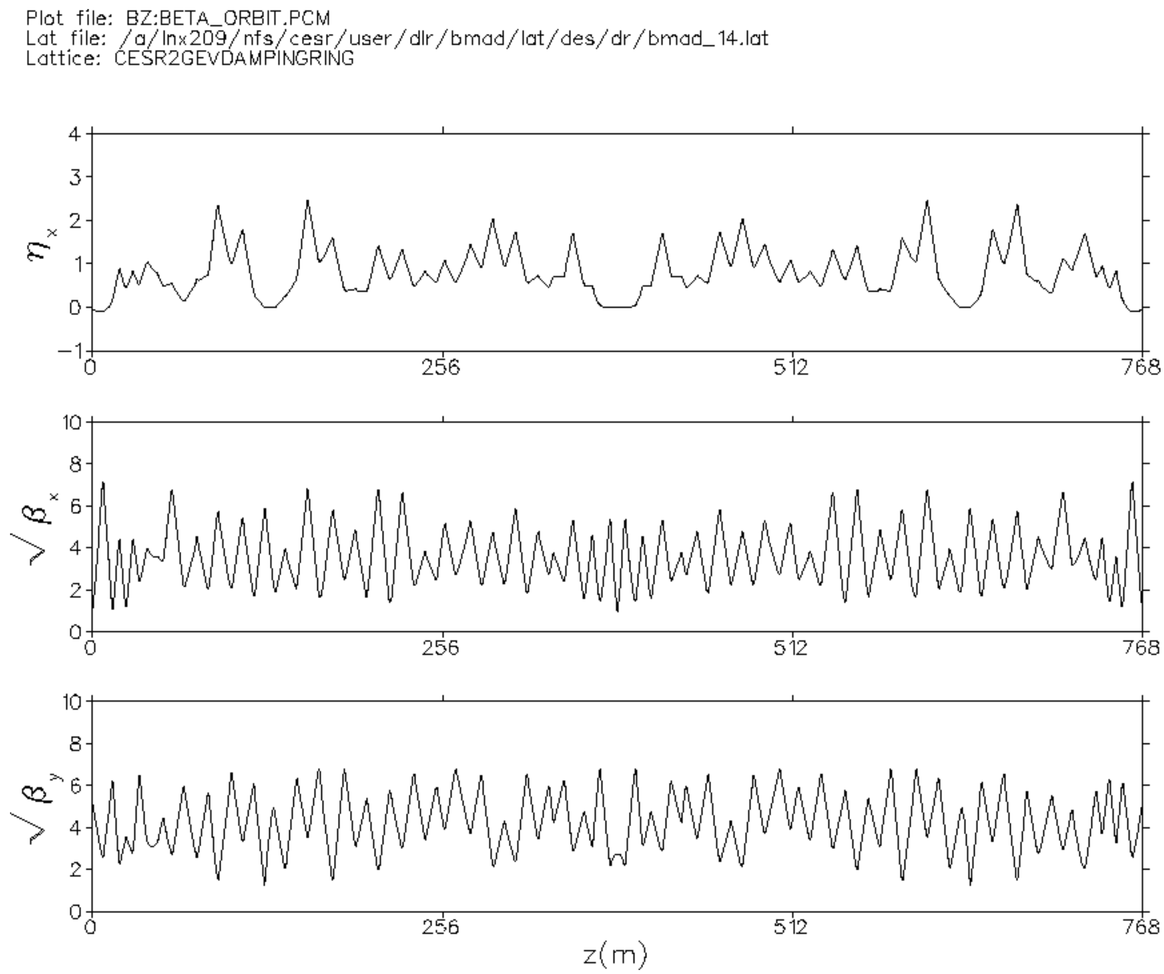

Figure 1: CesrTF Lattice Parameters

Emittance generated in the wigglers scales proportionally with the value of the horizontal beta function in the wiggler and inversely with the cube of the wiggler bending radius. Thus further optimization of the lattice and wiggler fields offers the possibility of further reduction of the horizontal emittance below the present value.

The vertical emittance that can be obtained in CesrTF will be sensitive to alignment errors around the ring and to the emittance coupling that can be obtained. A low current beam-beam scan in our present CESR-c high energy physics optics indicates that emittance coupling in tuned up luminosity conditions has reached the 0.5% level. This measurement was made in the presence of the CLEO solenoid, which has to be compensated, and with CESR's electrostatic "pretzel" turned on to separate the beams. We would expect to do at least this well, if not significantly better, when running with a single, on-axis beam in the CesrTF configuration. Taking the 0.5% coupling value and a 3 nm horizontal emittance gives a vertical emittance of approximately 15 pm which is at an interesting level for damping ring studies. If the emittance coupling could be reduced to 0.2%, the resulting 6 pm would be comparable to the best vertical emittance achieved to date in ATF. Alignment errors can increase the vertical emittance significantly. Without correction, the quadrupole misalignments that CESR presently operates with would make contributions to the vertical emittance that are several

Parameter	Value
No. Wigglers	12
Wiggler Field	2.1 T
Beam Energy	2.0 GeV
Energy Spread ($\Delta E/E$)	8.6×10^{-4}
Horizontal Emittance	3 nm
Transverse Damping Time	47 ms
Q_x	14.53
Q_y	9.58
Q_z	0.1
Total RF Voltage	14.4 MV
Bunch Length	6.9 mm
Momentum Compaction	7.1×10^{-3}

Table 1: CesrTF Parameters. Note that an RF accelerating voltage of 3.7 MV/cavity gives the above synchrotron tune and bunch length. It may be difficult to realize such a high voltage.

times greater than the above levels. Work is presently beginning to evaluate what combination of improved survey and alignment techniques as well as beam-based measurement and correction techniques will be required to obtain the desired vertical emittance.

Closely related research

Ongoing linear collider research at Cornell is supported under the grant NSF PHY-0355182, entitled “University-based Accelerator R&D for a Linear Collider”. The most closely allied work to the current proposal is work that is continuing under the grant entitled “Experimental, Simulation, and Design Studies for Linear Collider Damping Rings” which was funded in the amount $32,870 (Cornell-only portion) covering the period 9/1/04–8/31/06. As part of this research a range of simulation studies [2, 3] and instrumentation development [4] pertinent to damping design and operation has been carried out. An evaluation of dynamic aperture issues in damping rings and a review of wiggler technologies conducted as part of this grant were incorporated into the ILC damping ring baseline decision [5]. Research under this grant has also contributed to the training of 2 graduate and 1 undergraduate students.

Facilities, Equipment and Other Resources

The facilities of the Cornell Laboratory for Elementary-Particle Physics (LEPP) include: an accelerator complex (linac, synchrotron, storage ring, and insertion devices) along with the CLEO detector; computer facilities and staff within the laboratory; additional large-scale (up to several hundred nodes per cluster) parallel computing facilities at the Cornell Theory Center; an electronics shop and staff to support hardware design, fabrication and testing; a drafting shop and support staff with up-to-date design tools; and, a well-equipped machine shop.

First year Project Activities and Deliverables

Deliverables for the first year include:

1. A detailed layout and lattice for the test facility configuration.
2. Software tools for lattice correction and low emittance tuning.

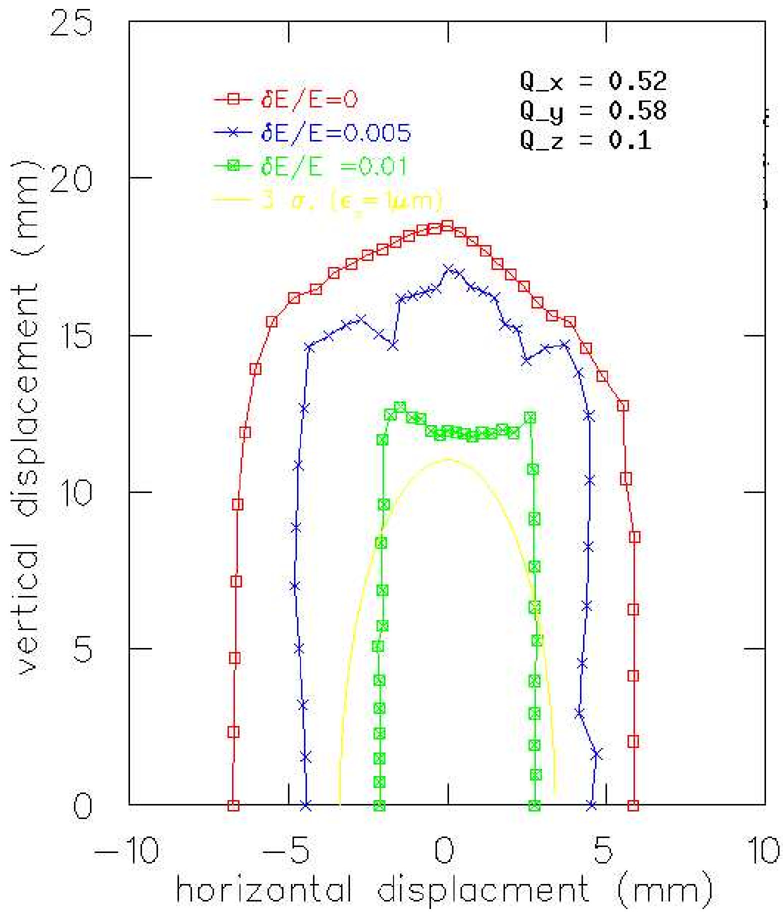

Figure 2: CesrTF dynamic aperture for 0.5% and 1% energy offsets. The smooth yellow curve corresponds to 3σ of the the rms size of the injected beam.

3. Results from beam simulations: this will include a full evaluation of alignment sensitivities, modeling of the ring dynamics (including the impact of electron cloud effects for positron operation and the fast ion instability for electron operation), and detailed projections of the operating parameters which can be obtained.
4. Detailed simulations of electron cloud build-up in the CesrTF configuration and an evaluation of the diagnostics needed to validate the models.
5. A review of instrumentation and feedback requirements for CesrTF operations: in particular this will include evaluations of the requirements for low emittance beam measurement as well as the requirements for operations with bunch configurations (ie, suitable bunch spacing and bunch train length) necessary for electron cloud and fast ion instability studies.

Second year Project Activities and Deliverables

Deliverables for the second year include:

1. A plan for vacuum chamber modifications required to support the wigglers
   - Vacuum chambers and beamstops for operation between 1.5 and 5.5 GeV for some portion of the wiggler complement

- Vacuum chamber designs and prototype hardware that support all necessary electron cloud and fast ion instrumentation requirements

2. A plan for upgrading the CESR cryogenics system to support installation of the existing wigglers in low dispersion regions of the ring.
3. A plan for upgrading the CESR instrumentation and feedback systems for test facility operation.
4. A plan for supporting (including vacuum issues) a range of prototype insertion devices in the south experimental region.
5. An overall facility modification plan.
6. Diagnostic vacuum chambers for electron cloud studies and some beam instrumentation prototypes.

Budget justification:

Activities for the first year are conceptual and design oriented. These activities will require the involvement of Cornell LEPP research and professional staff members (salaries not included in the present budget), one graduate student and one undergraduate student. Additionally, travel funds will be required in order to consult with our collaborators in the US, Europe, and Asia. The travel funds for both years include $5000 for two trips to KEK, $3000 for two trips to the west coast, and $4000 for two trips to Europe.

During the second year, while design and engineering studies continue, we will also need to expend funds for prototyping instrumentation and hardware that will be needed for CesrTF operations. The table below summarizes the expected costs to prototype upgraded beam position monitor hardware suitable for turn-by-turn acquisition of multibunch data at the bunch spacings that we will explore in the damping ring configuration. Also summarized are the cost estimates for preparing the first instrumented vacuum chambers for installation into CESR that will allow detailed studies of electron cloud generation and suppression.

2nd Year Hardware Items	Estimated Cost
Multibunch, Turn-by-turn BPM Electronics Module:	
Prototype Front-End Analog Boards (4 per module)	$4000
Timing Interface Board	$700
I/O Board	$600
Digital Signal Processor Board	$1600
Power Supply	$1000
CESR Timing Pickoff Unit	$350
Cables, Connectors, Enclosure, and Misc.	$650
Cost of complete unit	$8900
Cost for 3 prototype units:	**$26,700**
Instrumented Vacuum Chambers for Electron Cloud Studies:	
Wiggler Vacuum Chamber	$2500
Bend Vacuum Chamber	$3000
Electron Cloud Instrumentation	$8000
Readout Electronics	$5000
Vacuum Pumps	$8000
HV Power Supply	$2000
Total cost of chambers/diagnostics:	**$28,500**
Total:	**$55,200**

Two-year budget, in then-year K$

Item	First year	Second year	Total
Other Professionals	0	0	0
Graduate Students	24.407	36.068	60.474
Undergraduate Students	8.5	8.5	17.0
Total Salaries and Wages	32.907	44.568	77.474
Fringe Benefits	0	0	0
Total Salaries, Wages and Fringe Benefits	32.907	44.568	77.474
Equipment	0	55.2	55.2
Travel	12.0	12.0	24.0
Materials and Supplies	0	0	0
Other direct costs	17.909	18.874	36.783
Total direct costs	62.816	130.642	193.457
Indirect costs	26.121	33.375	59.495
Total direct and indirect costs	88.936	164.016	252.952

Indirect costs are calculated using Cornell's 58% rate on modified total direct costs. The entries in the "other direct costs" category are for graduate student tuition and health benefits.

References

[1] D. Sagan, J. Crittenden and D. Rubin, "A Magnetic Field Model for Wigglers and Undulators", Proc. 2003 Particle Accelerator Conference, Portland, Oregon (2003), p. 1023.

[2] R. W. Helms and D. L. Rubin, "A Compact Damping Ring Using RF Deflectors for the International Linear Collider," Proc. 2005 Particle Accelerator Conference, Knoxville, Tennessee (2005).

[3] J. Urban and G. Dugan, "CESR-c Wiggler Studies in the Context of the International Linear Collider Damping Rings," Proc. 2005 Particle Accelerator Conference, Knoxville, Tennessee (2005).

[4] M.A. Palmer, *etal.*, "A Bunch-by-Bunch and Turn-by-Turn Instrumentation Hardware Upgrade for CESR-c", Proc. 2005 Particle Accelerator Conference, Knoxville, Tennessee (2005).

[5] ILC Baseline Configuration Document, http://www.linearcollider.org/wiki/doku.php?id=bcd:bcd_home.