Proposal to the University Consortium for a Linear Collider

August 31, 2002

Proposal Name

Experimental, simulation, and design studies for linear collider damping rings

Classification (accelerator/detector: subsystem)

Accelerator: damping rings

Personnel and Institutions requesting funding

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Project Overview

Studies of wiggler-related dynamic aperture limitations. Two classes of circular accelerators will generate damping almost entirely in wiggler magnets: linear collider damping rings and some low-energy e^+e^- factories, such as CESR-c. Wigglers are unlike typical accelerator magnets in that they have longitudinal magnetic fields which are comparable to their transverse fields. Also, the design orbit has an angle and a displacement relative to the wiggler axis. The combination of the longitudinal field and the angle through the wiggler produces an effective field error, as does the combination of the field roll-off near the wiggler edge and the displacement from the wiggler axis. The effective field nonlinearity is quite strong, severely limits dynamic aperture in linear collider designs, and may decrease the damping rate for large-amplitude particles. We intend to develop and test a design algorithm for wigglers and lattices which preserves the dynamic aperture, and test this algorithm with beam measurements in CESR-c. We will apply the same techniques to the various linear collider damping ring designs to demonstrate that they have adequate dynamic aperture and amplitude-dependent damping rate (or optimize those designs until they do).

Studies of beam-based alignment and emittance correction algorithms. The linear collider damping rings designs have an unprecedented low vertical emittance. Coupling and vertical dispersion must be very well corrected. It is likely that beam-based alignment (BBA) will be needed to reference the beam position monitors to the magnets with high precision. We plan to model BBA and correction algorithms in the ATF damping ring at KEK and in CESR-c with the simulation code BMAD (see below), with special attention to the role of systematic errors in BBA. We will compare the simulation results with observations at ATF and at CESR-c. The goal is to produce improved BBA and emittance correction algorithms.

Studies of intrabeam scattering. At the high particle densities of the linear collider damping rings, intrabeam scattering (IBS) will cause an increase of the emittance of the beams. In the NLC main damping ring the achievable emittance may be limited by IBS. Several theoretical models [1], [2], [3] have been used to calculate IBS emittance growth rates. These models agree well with each other, but disagree with experiments at the ATF in which the emittance growth may be higher than calculated by a factor of 1.5 to 2. We plan to use CESR-c in a low-emittance mode to measure the IBS emittance growth, evaluate the theoretical models, and to compare with the ATF data.

Studies of space charge effects. The large density of particles in the linear collider damping rings creates a significant space charge tune shift. The tune shift is not the same for all particles, and the area of the tune "footprint" is significant. If this tune footprint overlaps strong resonance lines, particles may be lost, or the emittance may grow. We want to determine if it is possible to operate a storage ring with the large space charge tune shift of the linear collider damping rings without excessive losses or emittance growth. To do this, we will operate CESR-c in a low emittance mode and scan the tune plane while monitoring beam lifetime, radiation, and beam size. These observations will be compared to particle-tracking simulations including space charge.

Investigation of collective effects relevant for damping rings. Several beam stability issues are of particular importance for the damping rings of future linear colliders. Each will be investigated by machine studies in CESR-c. These are: the instability threshold for the electron-cloud effect in a low emittance, wiggler dominated ring; the instability threshold for the fast-ion instability in a low-emittance ring; and impedance-driven instabilities at the short bunch lengths of the linear collider damping rings. We will also investigate strategies for electron emission suppression (*e.g.*, by the use of coatings such as TiN).

High-quality beam diagnostics are required for the measurement of small beam sizes and short bunch lengths. We plan to improve the following existing CESR diagnostic systems: high-resolution beam size diagnostics (interferometric technique); and streak camera bunch length and shape monitoring.

Development of simulation and modeling tools. We plan to develop, at Cornell and at Minnesota, simulation and modeling tools to support the measurements in CESR-c and the analysis of ATF data. The modeling code will be based on an existing object-oriented particle-tracking library, BMAD [4], that has been extensively tested against an operating machine, CESR. We plan to develop an Intel architecture, Linux operating system computing farm at Minnesota (10% share, with the remaining 90% for the CLEO program) and to port the simulation tools from Tru64 to Linux. To understand the significance of measurements in CESR-c, we will make detailed comparisons of the simulated properties of the linear collider damping rings with CESR-c, including dynamic aperture with wiggler nonlinearities, intrabeam scattering, space charge, and other collective effects. We will also use the models to explore coupling and dispersion correction schemes that can then be tested in CESR-c. Our study will include an independent evaluation of the characteristics of the NLC and TESLA damping rings.

Review of TESLA damping ring design and optics. The large number of bunches (2820) and the relatively large inter-bunch spacing (337 ns) in the TESLA design gives a bunch train which is more than 200 km long. A damping ring of this size would be very costly, and so the bunch train is damped in a compressed form, with a bunch spacing of 20 ns, leading to a damping ring with a circumference of 17 km. This ring is still quite large, and, apart from the cost issue, has some technical disadvantages (such as large space charge effects) related to its large size. We will investigate other technical solutions (such as vertically stacked rings) for the damping rings, and compare the advantages and disadvantages relative to the baseline design. Many of the constraints on the ring design are determined by fast kicker technology. We propose investigating and prototyping a fast kicker in another section of this proposal.

Investigation of the superferric option for NLC and TESLA damping ring wigglers. The baseline design of wigglers for NLC and TESLA is based on permanent magnet technology. Superconducting wigglers were also considered in both cases but not chosen. At LEPP, we have experience both with permanent magnet systems, and, in connection with CESR-c, have developed expertise in the design and fabrication of superferric wigglers. We will re-examine the possibility of superferric wigglers for the linear collider damping rings. We will re-evaluate the technical and cost advantages and disadvantages of each technology choice.

FY2003 Project Activities and Deliverables

During the first year we plan to:

1. Complete inclusion of wiggler tracking into the particle tracking code;

2. Complete the development of a design algorithm which maximizes the dynamic aperture of a wiggler-dominated ring;

3. Calculate the intrabeam scattering growth rate for the ATF, NLC, and TESLA damping rings and a low-emittance configuration of CESR-c using multiple theoretical models [1], [2], [3] (including development of codes when not currently available);

4. Develop a space charge element for particle tracking simulations;

5. Develop an Intel architecture, Linux operating system computing farm at Minnesota (10% share)

6. Port the Cornell accelerator simulation tools from Tru64 to Linux for use on the Minnesota computing farm.

7. Start upgrades of the streak camera bunch length and shape monitor and the interferometric beam size monitor, including integration into the CESR control system;

8. Perform an independent evaluation of the robustness of the NLC and TESLA damping ring lattices; and

9. Investigate and report on alternative damping ring solutions for TESLA.

The first year deliverables are the publicly available simulation codes of items 1, 3, and 4 above and four technical reports on items 2, 3, 8, and 9.

FY2004 Project Activities and Deliverables

In the second year we plan to:

1. Benchmark the design algorithm and particle-tracking code for a wiggler-dominated ring by measuring the dynamic aperture, orbit-dependent tune shifts, decoherence, phase space distortion, and amplitude-dependent damping rate in CESR-c;

2. Measure the intrabeam scattering growth rate in a low-emittance configuration of CESR-c and document the implications of this measurement for analysis of the ATF data and for the linear collider damping rings;

3. Perform a complete simulation (tune plane scan) of the NLC and TESLA damping rings and CESR-c, including wiggler nonlinearities, intrabeam scattering and space charge, to determine the optimum operating points and particle loss rates;

4. Complete upgrades of the streak camera bunch length and shape monitor and the interferometric beam size monitor, including integration into the CESR control system;

5. Develop well-optimized correction algorithms for BBA and vertical dispersion and coupling correction that can be applied to the NLC and TESLA damping rings and to tests in CESR-c and possibly ATF;

6. Perform an analysis of the ATF BBA and emittance correction data; and

7. Perform an evaluation of the technical and cost advantages of permanent magnet and superferric wigglers for the NLC and TESLA damping rings.

The second year deliverables are six technical reports on items 1, 2, 3, 5, 6 and 7 above and the upgraded instrumentation of item 4.

FY2005 Project Activities and Deliverables

In the third year we will complete this program. We plan to:

1. Apply the design algorithm for optimizing the dynamic aperture in a wiggler-dominated ring to the NLC and TESLA designs and optimize the NLC and/or TESLA designs if their safety margin is found to be inadequate;

2. Perform an experimental tune-plane scan in a low-emittance mode of CESR-c while monitoring beam lifetime, particle loss, and beam size to benchmark the particle-tracking code;

3. Implement and test the algorithms for BBA and vertical dispersion and coupling correction in a low-emittance configuration of CESR-c;

4. Measure the instability threshold for the electron-cloud effect, the fast-ion instability, and impedance-driven single-bunch instabilities at short bunch length in a low-emittance configuration of CESR-c.

The third year deliverables are four technical reports on items 1 through 4 above.

Budget justification: Cornell University

Each year's activities will require the involvement of Cornell LEPP staff members and one graduate student (who are not included in the budget shown here).

The first year's activities at Cornell will require travel funds for consultation with collaborators at DESY, SLAC, KEK, and LBNL. Construction of the upgraded instrumentation will require funding for materials and supplies.

The second year's activities at Cornell will require travel funds for consultation with collaborators. Construction and installation of the upgraded instrumentation will require funding for materials and supplies and 1/4 FTE technician manpower.

The third year's activities at Cornell will require travel funds for consultation with collaborators.

Indirect costs are calculated at Cornell's 57% rate on modified total direct costs.

Three-year budget, in then-year K$

Institution: Cornell University

Item	FY2003	FY2004	FY2005	Total
Other Professionals	0	21	0	21
Graduate Students	0	0	0	0
Undergraduate Students	0	0	0	0
Total Salaries and Wages	0	21	0	21
Fringe Benefits	0	7	0	7
Total Salaries, Wages and Fringe Benefits	0	28	0	28
Equipment	0	0	0	0
Travel	3	3	3	9
Materials and Supplies	30	30	0	60
Other direct costs	0	0	0	0
Total direct costs	33	61	3	97
Indirect costs	14	14	2	30
Total direct and indirect costs	47	75	5	127

Budget justification: University of Minnesota

The budget for the Minnesota component of the project assumes that scientific personnel (Poling, Smith) will be partially redirected from other activities to linear collider research. High energy physics graduate students who have not yet embarked on a thesis project will be recruited to participate in this effort for roughly one year each. For the first year of the project, while the group is ramping up and developing expertise, support is requested for one student only for the summer of 2003. In the second and third years full support is requested for one student during the summer and half-time support is requested for one student during the academic year. It is expected that one undergraduate student at a time will also be involved in this research, with support from University of Minnesota undergraduate research programs. The first-year travel budget covers two to three trips each for Poling and Smith to linear collider meetings and to work with collaborators at Cornell. The second and third years include additional funds to support one trip each for the graduate and undergraduate students.

The equipment item in the first year represents a 10% share of a $\sim$100-CPU computing farm (Intel architecture, Linux) that is under development at Minnesota. This farm, which will replace a currently operating 25-node (Compaq Alpha) farm, is primarily for simulations associated with our CLEO program. The proposed 10% share can provide fast turn-around linear-collider simulations as needed by Minnesota personnel and collaborators. The total budget for the farm is $100,000, with a planned university contribution of one half of this total.

Indirect costs are computed using the University of Minnesota's rate for on-campus research (48.5%). Graduate student fringe benefits and equipment are exempt from indirect costs. The fringe rates for graduate students include health benefits and tuition during the academic year, and health insurance and FICA during the summer. Inflation of 3% has been assumed in computing the personnel costs for the second and third years.

Three-year budget, in then-year K$

Institution: University of Minnesota

Item	FY2003	FY2004	FY2005	Total
Other Professionals	0	0	0	0
Graduate Students	4.9	12.5	12.9	30.3
Undergraduate Students	0	0	0	0
Total Salaries and Wages	4.9	12.5	12.9	30.3
Fringe Benefits	1.1	5.7	5.8	12.6
Total Salaries, Wages and Fringe Benefits	5.9	18.2	18.7	42.8
Equipment	5	0	0	5
Travel	4	5	5	14
Materials and Supplies	0	0	0	0
Other direct costs	0	0	0	0
Total direct costs	14.9	23.2	23.7	61.8
Indirect costs	4.3	8.5	8.7	21.5
Total direct and indirect costs	19.2	31.7	35.2	83.3

References

[1] A. Piwinski, in Handbook of Accelerator Physics and Engineering, A. Chao and M. Tigner, eds., p. 125 (1999).

[2] J. Bjorken and S. Mtingwa, Particle Accelerators **13**, p. 115 (1983).

[3] T. Raubenheimer, Ph.D. thesis, SLAC-387, Sec. 2.3.1 (1991).

[4] D.L. Rubin and D. Sagan, "CESR Lattice Design", Proc. 2001 Particle Accelerator Conference, Chicago, paper RPPH121 (2001).