Appendix
University-based Accelerator R&D for a Linear Collider
Individual Project Descriptions

In this Appendix, the full project descriptions are given for each of the UCLC projects. The numbering scheme is the same as in the proposal's Project Description.

Contents

2 Beam dynamics calculations and experiments, and accelerator design

2.1 Beam simulation: main beam transport in the linacs and beam delivery systems, beam halo modeling and transport, and implementation as a diagnostic tool for commissioning and operation.

Personnel and Institution(s) requesting funding

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Project Overview

This project will cover simulations of main beam transport in linear colliders, with an emphasis on integrated damping ring to IP simulations; studies of the sources and transport of beam halo from its origin to the IP; implementation of modeling tools as a diagnostic for addressing commissioning and operational issues. Each of these topics is discussed in turn in the following paragraphs. Complete and robust simulation and modeling tools are critical to the evaluation of design and commissioning of NLC and TESLA, and our goal is to develop software with the flexibility to investigate the properties of both machine.

Main beam transport

One of the most essential features of a linear collider is the need for the preservation of a very small vertical emittance during beam transport from the damping ring to the IP. The best estimate of what is required to do this comes from integrated simulations of beam transport from the damping ring to the IP. Elaborate simulation programs have been developed at SLAC, DESY and CERN for the linear collider projects, in which errors can be incorporated, and realistic tuning algorithms can be explored, based on the expected performance of diagnostic systems. The errors are both static and dynamic, and include initial alignment errors, instrumentation resolution, ground motion and mechanical noise. Dynamic stabilization schemes and linac-based and IP feedback can be incorporated.

The worldwide effort in this area could benefit from additional manpower working in collaboration with the existing investigators to refine the simulation tools and develop improved tuning algorithms. We propose to join these ongoing beam simulation efforts, providing additional manpower, as well as fresh perspectives.

We will work closely with our collaborators, who have extensive experience in beam simulation, to identify critical issues which, in the context of the worldwide effort, require attention.

Particular areas of interest to us include the exploration of the tolerance of the baseline emittance preservation schemes to diagnostic faults, realistic modeling of the bunch compressors, and the effects of lattice mismatches. Also, one of our aspirations is to develop the machine model so that it can eventually interact with the control system in such a way that we can use it to diagnose and correct machine errors. Until a real control system exists, we can simulate that as well and begin to understand how the operational problems will become evident and then how they might be addressed.

We would also like to explore the utility of simulations of beam transport from the source to the damping ring.

Our group has considerable experience developing computer models to study the properties of stored and accelerated beams, and for the evaluation of machine performance and diagnosis and correction of guide field errors etc. We have done extensive simulation of single particle dynamics, beam-beam interaction, long range interaction of multiple bunch beams, and of the injection process for both CESR (5.3GeV) and for CESR-c(1.9GeV). We also created a detailed simulation of the positron production process in our linac in order to improve efficiency, and a rudimentary model of a superconducting linac to explore the dependence of single and multi-bunch stability on cavity parameters. We are well equipped to contribute to the effort to model beam transport in a high energy linac.

Beam halo modeling and transport

Understanding and control of beam halo is a crucial issue for linear colliders. The extent of the beam halo impacts the design of the collimation systems and muon spoilers, which in turn determine background conditions at the detector. The collimation systems are also an essential part of the machine protection system, a key issue for machine reliability.

One of the principal open issues in the baseline linear collider designs is the absence of a fully developed pre-linac collimation system. Working with our collaborators, we propose to develop a realistic design for such a system.

Beam halo typically explores regions of the vacuum chamber far from the central axis, where magnetic field nonlinearities, often ignored in main beam transport simulations, may be important. We propose to study the transport of halo particles, represented as longitudinal and transverse beam distribution tails, from the damping ring to where the halo is intercepted, exploring, for example, the effects of nonlinear field errors.

The baseline linear collider collimation systems have been designed to cope with a relatively high level of beam halo, based on previous linear collider experience. This level is typically much larger than simple estimates would indicate. A more basic understanding of the origin of beam halo would allow a better optimization of the collimation system design. We propose to simulate the sources of beam halo (e.g, due to scattering processes in the damping rings, dark current in the linac cavities, etc.) and track these particles from their sources to the collimation systems, where they are removed from the beam. Comparisons will be made to the assumed halo used for the design of the baseline collimation systems for NLC and TESLA, and to the SLC beam halo experience.

Machine commissioning and operation

During machine commissioning, interpretation of measurements of beam position monitors, beam size monitors, cavity higher order modes, etc. will be critical to identification of component failures and implementation of correction algorithms. Typically a simulation is used to compute the effects of the guide field on the beam so that the consequence of various field errors, misalignments, etc. can be anticipated. But during commissioning we must first measure the guide field errors, so that with the help of the models, appropriate corrections can be determined. We plan to develop the modeling tools to extract information about the guide field from the beam instrumentation, so that we can simulate the diagnosis and optimization of machine performance.

Project Activities and Deliverables

The descriptions of year-by-year activities provided below are representative of one possible course of action which seems plausible at this juncture. It should be appreciated that, as we develop a more mature understanding of the issues, and the roles that are most suited for us, and as the needs of the worldwide linear collier effort evolve, it may turn out that the order in which tasks are undertaken is different from what is described below, For example, the beam halo work, described below as being done in the second and third years, could in fact start in the first year, if that turns out to be advantageous. If such a reordering occurs, we expect to produce the same deliverables as specified below, but in different years.

FY2004 Project Activities and Deliverables

During the first year, we will work with our collaborators to assemble, at Cornell, a suite of the existing main beam simulation tools. We will develop expertise in the use of these tools, initially by studying already-solved problems and simple examples. This will allow us to tackle unsolved problems. We will then use the existing codes to address one of the outstanding issues noted above. The exact choice will be determined by the needs and priorities of the worldwide linear collider simulation efforts at that time.

Evidently, a single code, with the capability of modeling damping rings, bunch compressors, linear acceleration, including wake effects, and beam delivery system, does not exist. At present, damping ring to IP simulations are based on mating different codes with emphasis on different physics. We plan to extend the capability of the code that has been developed for modeling CESR and CESR-c dynamics (BMAD) so that we can build a complete end to end simulation, including the beam beam interaction.

To become familiar with the issues involved in the control of beam halo, and to address a known issue in collimation system design, we will undertake a detailed design of pre-linac collimation systems for NLC and TESLA.

The deliverables for the first year will be the capability to use the existing main linac and beam delivery systems simulation routines, and a technical report addressing an outstanding issue in beam simulation. We will also provide improvements to, and/or cross-checking of, some of the existing simulation codes. Finally, we will write a technical report specifying a design for pre-linac collimation systems for NLC and TESLA.

FY2005 Project Activities and Deliverables

In the second year, we will continue to address main beam transport code improvements, and will tackle several other simulation issues which are high priority, and which are suitable for our expertise and interests.

In this year, we will begin to consider what is needed in code development or modification for halo transport. We will build upon existing codes whenever possible. We expect to be able to produce useful results on beam halo transport this year.

We will also develop a strategy for understanding the sources of beam halo.

The deliverables for the second year will be technical reports describing additional code improvements and studies of main beam transport issues. We will also produce codes to do beam halo transport in the main linacs and beam delivery systems. We will write a technical report on the first results from our beam halo transport studies. We will also write a technical report outlining our strategy for understanding and simulating sources of beam halo.

FY2006 Project Activities and Deliverables

In the third year, we expect continue to address outstanding high priority issues in main beam transport.

Based on the halo source strategy developed in the previous year, we will develop codes which simulate the sources of beam halo, and couple these to our halo transport codes. We will compare the results of this work with the assumed halo used for the design of the baseline collimation systems for NLC and TESLA, and to the SLC beam halo experience.

The deliverables for the third year will be additional technical reports describing studies of main beam transport issues. We will produce a technical report documenting our studies of halo sources and halo transport, and the comparisons with linear collider halo design assumptions and SLC experience. Finally, we will write a technical report documenting the diagnostic capability of our codes, including, for example, evaluation and correction of orbit, optical and coupling errors based on beam position monitor data.

Budget justification

This work will be carried out primarily by the personnel noted above from Cornell, with help from our collaborators. We have requested support for one graduate student in the first year of the activity, growing to 1.5 and then 2 in the subsequent years (not included in this budget). Computing equipment support for the student(s), and a small travel allowance for meetings with our collaborators and conference attendance is included.

Indirect costs are calculated at Cornell's 58% rate on modified total direct costs.

Three-year budget, in then-year K$

Institution: Cornell University

Item	FY2004	FY2005	FY2006	Total
Other Professionals	0	0	0	0
Undergraduate Students	5	5	5	15
Total Salaries and Wages	5	5	5	15
Fringe Benefits	0	0	0	0
Total Salaries, Wages and Fringe Benefits	5	5	5	15
Equipment	5	10	20	35
Travel	2	2	3	7
Materials and Supplies	0	0	0	0
Other direct costs	0	0	0	0
Total direct costs	12	17	28	57
Indirect costs	4.06	4.06	4.64	12.76
Total direct and indirect costs	16.06	21.06	32.64	69.76

2.2 Damping ring studies for the LC

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Project Overview

The goals for the beam emittances of the proposed Linear Collider (LC) are far smaller than those achieved at existing accelerators. Thus, the obstacles to be encountered will be substantial, although hopefully not insurmountable. A major limitation on the performance of the LC will be the damping rings and the emittances achieved there. Experiments have been performed, or are planned, at a number of facilities, including the ATF at KEK and CESR at Cornell. We propose to travel to the ATF for a two-week period and to CESR for a two-week period per year for the next three years to assist in gaining a theoretical understanding of the results of their experiments.

The NLC/JLC design normalized horizontal emittance coming out of the damping rings is 3 mm-mrad, with the normalized vertical emittance being two orders of magnitude smaller. The beam charge is about 10^{10} particles per bunch. The most important limitation on achieving the design emittances in the damping rings is that of intrabeam scattering (IBS). Thus, it will be important to understand more fully the challenges that intrabeam scattering will present. With James Bjorken, we developed the theory of IBS for strong focusing accelerators and spent a number of years at Fermilab analyzing beam emittance growth rates from IBS in the Antiproton Source's Accumulator Ring. Also, we worked with David Finley and Alvin Tollestrup in analyzing IBS growth rates for the Tevatron upgrade. In this project, we will revisit IBS within the context of the LC damping rings. The results will be important for the TESLA design as well.

FY2004 Project Activities and Deliverables

Intrabeam scattering involves multiple small-angle Coulomb scatterings of particles within a bunch. The theory in Reference [2] does not specify the precise minimum scattering angle of the particles and only estimates it. Some work on this effect is contained in Reference [3]. During the first year, we propose to work more on this issue. Also, we will begin our studies of the data from prototype damping ring experiments at ATF, CESR, and the Advanced Light Source. Our results will be written in a detailed report and published.

FY2005 Project Activities and Deliverables

The vertical emittance in a damping ring is largely determined by vertical dispersion and horizontal-vertical coupling; thus, one wants to minimize these effects in the accelerator lattice design. Even so, the operating regime of the ATF demands a better understanding of the coupling among the three degrees of freedom and its effects on intrabeam scattering. An excellent start in this direction is contained in Reference [3], where they extended the theory contained in Reference [2]. During the second year, we propose to analyze this effect further and compare with the data from the prototype experiments. Our results will be written in a detailed report and published.

FY2006 Project Activities and Deliverables

Armed with a better understanding of the predictions of intrabeam scattering, during the third year, we will concentrate on the wealth of data that should have been collected by that time and fine tune our understanding of the ability to achieve the small design emittances of the various linear collider designs. Others are studying various other effects that could compromise the damping rings' performance. These include such effects as electron cloud build-up, residual gas ionization, the injection efficiency of the damping rings, the interaction of the beam with radiation, and the influence of newly injected pulse trains on ones previously stored. During the third year of this project, we plan to use the results from those other studies to achieve a quantitative understanding of how to unravel those other effects from that of intrabeam scattering. Our results will be written in a detailed report and published.

Budget Justification

The entire project will consist mainly of theoretical and computational calculations. The first year's budget will mainly support one graduate student and travel for the Principal Investigator (PI) to spend two weeks at the ATF in Japan and two weeks at CESR at Cornell University. Computational equipment will be purchased for the graduate student.

During the second year, we include the same funds as requested the first year, increased mostly for inflation. Also, computational equipment will be purchased for the PI.

During the third year, we include the same funds as requested the second year, increased mostly for inflation. Also, additional computational equipment will be purchased for the PI.

Indirect costs are calculated at North Carolina A&T's 40% rate on modified total direct costs, which excludes tuition.

Three-year budget, in then-year K$

Institution: North Carolina A&T State University

Item	FY2004	FY2005	FY2006	Total
Graduate Student (RA)	12	13	14	39
Undergraduate Students	0	0	0	0
Total Salaries and Wages	12	13	14	39
Fringe Benefits	0	0	0	0
Total Salaries, Wages and Fringe Benefits	12	13	14	39
Equipment	3	3	3	9
Travel	8	9	10	27
Materials and Supplies	1	2	3	6
Other direct costs (Tuition)	12.24	13.27	14.3	39.81
Total direct costs	36.24	40.27	44.3	120.81
Indirect costs	9.6	10.8	12.0	32.4
Total direct and indirect costs	45.84	51.07	56.3	153.21

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2.3 BACKGAMMON: A Scheme for Compton backscattered photoproduction at the Linear Collider

Personnel and Institution(s) requesting funding

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Collaborators

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Project Overview

We propose to investigate the possibility of Compton backscattering low energy laser pulses off the spent electron and positron beams at the Linear Collider. The hot backscattered photons would then scatter off fixed targets for a rich variety of physics studies in a scheme dubbed BACKGAMMON, for BACKscattered GAMMas On Nucleons. The first objective would be to operate a heavy quark factory, since the cross sections for charm and bottom quark production would be favorable for producing large numbers of these flavors. Secondly, if the incident laser pulses are circularly polarized, the backscattered photons would be circularly polarized as well, allowing the possibility of producing polarized τ pairs on fixed targets. Also, BACKGAMMON's polarized hot photons could scatter off polarized targets and play an important role in elucidating the spin structure of nucleons. Finally, there is the possibility of studying the photon structure function in spent electron beam scattering on laser photons.

The original idea for using the Linear Collider for producing Compton backscattered photon beams for operation of a heavy quark factory is described in [1]. There it is shown that, if one had an electron beam of hundreds of GeV energy, then one could produce greater than the 10^9 B meson pairs per year that the theorists said were needed to elucidate CP violation in the B meson system. That was before the advent of the current generation of B factories using electron-positron colliders. Soon after the description of BACKGAMMON for heavy quark production, it became clear that this scheme could be used to operate a polarized τ factory as well. This and subsequent ideas are contained in References [2, 3, 4, 5, 6].

Milburn [7] and independently Arutyunian and collaborators proposed the original idea of using Compton backscattering in accelerators [8, 9, 10]. The detailed theory of Compton backscattering, incorporating the accelerator lattice functions of the initial electron beam, was derived in Reference [1]. The first practical application of Compton backscattering in a physics experiment was the measurement by Ballam *et al.* of γp hadronic cross sections in a bubble chamber at SLAC [11]. Since that initial experiment, there have been a number of studies using Compton backscattered photons, including the Brookhaven National Laboratory's Laser Electron Gamma Source (LEGS) Facility [12, 13] and applications of Compton backscattered photon beams to measure the polarization of electron beams [14, 15, 16, 17, 18, 19]. Thus, Compton backscattering has enjoyed a rich history.

BACKGAMMON would be unobtrusive to the baseline Linear Collider design. It should be viewed as an add-on experiment to the Linear Collider that is worthy of further study. It would involve the following fixed target experiments:

BACKGAMMON I
Unpolarized laser pulses would be incident on the spent electron beam to produce unpolarized hot photons for the photoproduction of heavy quark flavors to study a variety of phenomena, including CP violation in the neutral B meson system, high precision studies of bottom and charm decays, searching for rare and forbidden bottom and charm decays, QCD studies using heavy quark pair events, heavy quark spectroscopy, heavy quark baryons, and other checks on the Standard Model.

BACKGAMMON II
While BACKGAMMON I is using the spent electron beam, circularly polarized laser pulses would be incident on the spent positron beam to produce circularly polarized hot photons for the photoproduction of polarized t pairs, to study a variety of phenomena, including improving the τ neutrino mass limits from such decays as $\tau \rightarrow K^- K^+ \pi^- \nu_\tau$, searching for CP violation in the lepton sector of the Standard Model, searching for rare and forbidden τ decays, studying the Lorentz structure of τ decays, and other checks of the Standard Model.

BACKGAMMON III
At the conclusion of BACKGAMMON II, the polarized hot backscattered photons would be incident on polarized nucleon targets to measure the gluon contribution to the nucleon spin. An excellent discussion of this point is contained in [20]. The spin content of the nucleon still is not understood.

Laser Requirements

In Reference [5], the laser requirements of BACKGAMMON are briefly discussed. There, it is emphasized that the laser requirements in this scheme are less stringent than those for a $\gamma-\gamma$ collider. For the $\gamma - \gamma$ collider, the aim is to convert each electron in the collider bunch into a hot photon, leading to the requirement of 1 Joule per laser flash with a 1 kHz repetition rate. In BACKGAMMON, for 10^9 electrons per bunch, only 1 mJ per laser pulse at 1kHz will produce the 10^9 B pairs per year; while for 10^{10} electrons per bunch, as called for in the LC designs, 10^{10} B pairs per year would be produced. Moreover, if one could push the laser rep rate up to the 10 kHz called for in the LC designs, then one could produce up to 10^{11} B pairs per year. These B meson pairs would be produced in a much cleaner background than that of the hadron machines, such as the 10^{11} B pairs per year proposed for the BTeV experiment at Fermilab.

A specific laser design and implementation at BACKGAMMON could lay the groundwork for the $\gamma-\gamma$ collider laser system, with the main difference being the lower power requirements for BACKGAMMON. For the $\gamma - \gamma$ collider, it has been suggested that a diode pumped semiconductor laser is plausible [21]. However, for the high repetition rates needed in both these schemes, it may be necessary to time-multiplex a set of lasers. More R&D is needed to settle this issue.

FY2004 Project Activities and Deliverables

During FY 2004, we will study the feasibility of using the disrupted beams after the electron-positron interaction point for Compton backscattering laser pulses. Initial discussions with TESLA accelerator physicists make the idea sound promising. We will study the backgrounds from the electron-positron interaction point to insure that they are manageable and design beamlines to bring the best quality electron and positron spent beams to the two interaction points with the lasers. Also, we will ascertain whether BACKGAMMON leads to high statistics physics data inaccessible by other means.

On the theoretical side, we will understand the details of the angular dependences of the polarizations of the photoproduced τ pairs, and we will perform theoretical studies of the physics issues as outlined above. This would involve both analytic approaches and simulations of the phenomenology. The results of our FY 2004 activities will be written in a detailed report, with specific attention given to the question of whether the laser optics and beamlines and the gamma extraction beamlines are compatible with realistic linear collider extraction lines.

Future Activities

If the FY 2004 investigations show that BACKGAMMON is indeed feasible and has important advantages over other experimental methods, we will seek supplementary funding from UCLC for FY 2005 and FY 2006 to carry out detailed design studies for BACKGAMMON, focusing on the detector system and simulations of the fixed target photoproduction experiments enumerated above.

Finally, we will begin to investigate the possibility of using the doubly spent electron beam (after both e^+e^- and e–laser interaction points) to scatter off a second low energy laser pulse and study the photon structure function. For a review, see [22].

Budget justification

The project will consist mainly of computational and theoretical calculations. The single-year budget mainly will support one graduate student and travel for the Principal Investigator (PI) and one collaborator to visit each other's university for the purpose of working on the project. Computational equipment will be purchased for the graduate student.

Indirect costs are calculated at North Carolina A&T's 40% rate on modified total direct costs, which excludes tuition.

One-year budget, in then-year K$

Institution: North Carolina A&T State University

Item	FY2004
Graduate Student (RA)	12
Undergraduate Students	0
Total Salaries and Wages	12
Fringe Benefits	0
Total Salaries, Wages and Fringe Benefits	12
Equipment	3
Travel	3
Materials and Supplies	1
Other direct costs (Tuition)	12.19
Total direct costs	31.19
Indirect costs	7.6
Total direct and indirect costs	38.79

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2.4 Experimental, simulation, and design studies for linear collider 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 may be in disagreement with experiments at the ATF. 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 have begun the development, at Cornell and at Minnesota, of simulation and modeling tools to support the measurements in CESR-c and the analysis of ATF data. The modeling code is based on an existing object-oriented particle-tracking library, BMAD [4], that has been extensively tested against an operating machine, CESR. We are constructing an Intel architecture, Linux operating system computing farm at Minnesota, approximately 10% of which will be dedicated to linear collider accelerator work, with the remaining 90% for the CLEO-c program. Funding for this facility has been obtained from the Department of Energy and the University of Minnesota. Ten 2-GHz processors are currently installed, with acquisition of 60 faster processors planned for late summer 2003. An additional 60 processors are planned for acquisition by summer 2004. The porting of the simulation tools from Tru64 (Compaq Alpha Unix) to Linux should be completed by fall, and preliminary testing is already under way of the management system for running tracking computations in a multiprocessor environment.

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.

FY2004 Project Activities and Deliverables

During the first year we plan to:

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

2. 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);

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

4. Complete development of an Intel architecture, Linux operating system computing farm at Minnesota with a 10% share for linear collider research.

5. Complete the port of the Cornell accelerator simulation tools from Tru64 to Linux and implement parallel processing on the Minnesota computing farm.

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

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

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

The first year deliverables are the publicly available simulation codes of item 3 above and four technical reports on items 1, 2, 7, and 8.

FY2005 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.

FY2006 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 58% rate on modified total direct costs.

Three-year budget, in then-year K$

Institution: Cornell University

Item	FY2004	FY2005	FY2006	Total
Other Professionals	0	21.0	0	21.0
Graduate Students	0	0	0	0
Undergraduate Students	0	0	0	0
Total Salaries and Wages	0	21.0	0	21.0
Fringe Benefits	0	6.51	0	6.51
Total Salaries, Wages and Fringe Benefits	0	27.5	0	27.51
Equipment	0	0	0	0
Travel	3.0	3.0	3.0	9.0
Materials and Supplies	30.0	30.0	0	60.0
Other direct costs	0	0	0	0
Minnesota subcontract	14.617	31.888	32.682	79.187
Total direct costs	47.617	92.398	35.682	175.697
Indirect costs(1)	22.94	37.795	1.74	62.475
Total direct and indirect costs	70.557	130.193	37.422	238.172

(1) Includes 26% of first $25K subcontract costs

Budget justification: University of Minnesota

The budget for the Minnesota component of the project assumes that scientific personnel (Poling, Smith), who receive base support from the Department of Energy, 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. This will provide an accelerator-physics option as part of the training of HEP students, a model that could help to address workforce needs both within our field and in other areas where accelerator science has application. For the first year of the project, while the group continues its ramp-up and development of expertise, support is requested for one student only for the summer of 2004. 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. Currently Benjamin Rancourt, a senior physics major, is participating in the project. The first-year travel budget covers two to three trips each for Poling and Smith to linear collider meetings and to work with collaborators. The second and third years include additional funds to support one trip each for the graduate and undergraduate students.

Indirect costs are computed using the University of Minnesota's rate for on-campus research (48.5%). Graduate student fringe benefits 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. Annual salary increases of 3% have been assumed.

Three-year budget, in then-year K$

Institution: University of Minnesota

Item	FY2004	FY2005	FY2006	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	1.4	5.9	6.1	13.4
Total Salaries, Wages and Fringe Benefits	6.3	18.4	19.0	43.7
Equipment	0	0	0	0
Travel	4	5	5	14
Materials and Supplies	0	0	0	0
Other direct costs	0	0	0	0
Total direct costs	10.3	23.4	24.0	57.7
Indirect costs	4.317	8.488	8.682	21.487
Total direct and indirect costs	14.617	31.888	32.682	79.187

References

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

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[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).

2.5 Investigation and prototyping of fast kicker options for the TESLA damping rings

Personnel and Institution(s) requesting funding

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Collaborators

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Project Overview

The large number of bunches (2820) and the relatively large inter-bunch spacing (337 ns) in the TESLA linear collider design give 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.

In the TESLA baseline, the rise and fall time of the damping ring injection and extraction kickers determine the circumference of the ring. There is considerable leverage in developing faster kickers, as this translates directly into a smaller circumference ring. The baseline system for 500 GeV (cm) parameters has a 20 ns specification for the kicker pulse width; this becomes about 12 ns for the 800 GeV (cm) parameters. Designs and prototype results exist [1] for conventional kickers with widths of 7 ns, and design have been developed for more novel ultrafast schemes [2] using electron beams.

We propose to further explore the feasibility of the kicker designs described in the references cited above, particularly the very fast stripline kicker[1]. We will also develop new ideas for fast kickers. For example, we will explore the possibility of the use of the ponderomotive force from a high-intensity laser pulse to provide a very short kick to the beam. We will work closely with our collaborators from the University of Illinois and Fermilab in exploring their novel fast kicker concept.

In the TESLA baseline design, both the injection and extraction kickers must be fast. The injection kicker is considerably more difficult than the extraction kicker, because of the larger beam size at injection. We will investigate the possibility of single-turn injection of beam into the damping rings, which would eliminate the need for a fast injection kicker.

It should be noted that, in addition to the small pulse width (of order ns) required for the kicker, extremely good pulse-to-pulse reproducibility is required in order to avoid beam jitter at the collision point. The fast intra-train feedback at TESLA cannot compensate for pulse–to-pulse jitter introduced by the extraction kicker. Part of the evaluation of the feasibility of any new kicker scheme must include an evaluation of the expected pulse-to-pulse jitter.

If a new fast kicker scheme is found to be technically feasible on paper, we propose to do an engineering design of a prototype, build the device, and test it using a high energy electron beam.

If the development of a fast kicker is successful and the ring size can be reduced, the average current will go up and at some point multibunch beam stability becomes the limiting factor to a further reduction in the ring size. This has been explored for two specific cases in prior work [3], for an earlier set of TESLA beam parameters. We propose to update and expand on these considerations, including our current understanding of critical stability issues such as the electron cloud, and to determine the minimum ring size permitted by beam dynamics considerations.

FY2004 Project Activities and Deliverables

During the first year, we will review fast kicker schemes which have been proposed in the past, and explore the feasibility of new kicker schemes. We will investigate the possibility of single-turn injection of beam into the damping rings. We will determine the minimum ring size permitted by beam dynamics considerations. This work will be done by one of the scientific staff members, together with a graduate student.

The first year deliverables will be 3 technical reports: on the feasibility of fast kicker schemes, the feasibility of single-turn injection for the TESLA damping rings, and on the minimum allowable ring size as set by the beam dynamics.

FY2005 Project Activities and Deliverables

Assuming that we have found a feasible design for a fast kicker scheme, in the second year we will execute an engineering design for a prototype kicker, and build the prototype. Although it may not be a full scale device, we will include in the prototype all the features needed to address the principal technical challenges of the device. The work will be done by scientific and engineering staff members, and the graduate student.

The second year deliverable will be the prototype kicker.

FY2006 Project Activities and Deliverables

In the third year, we will test the performance of the kicker. This will involve electrical measurements such as peak current, rise and fall time, and pulse-to-pulse reproducibility. We will also test the kicker in a high energy electron beam, either at CESR or a similar facility with an available beam. The work will be done by scientific and engineering staff members, and the graduate student.

The third year deliverable will be a technical report describing the results of the kicker prototype tests.

Budget justification

The first year's activities are limited to design studies, which will involve staff members and one graduate student (not included in the budget shown here). Travel funds are included to cover trips for consultations with collaborators and to DESY.

During the second year, the design and construction of the prototype will be supported by 1/2 FTE of engineering and technician manpower. The graduate student support will continue.

During the third year, the testing of the prototype will be supported by 1/4 FTE of technician manpower, together with a graduate student.

Indirect costs are calculated at Cornell's 58% rate on modified total direct costs.

Three-year budget, in then-year K$

Institution: Cornell University

Item	FY2004	FY2005	FY2006	Total
Other Professionals	0	41	21	62
Graduate Students	0	0	0	0
Undergraduate Students	0	0	0	0
Total Salaries and Wages	0	41	21	62
Fringe Benefits	0	12.71	6.51	19.22
Total Salaries, Wages and Fringe Benefits	0	53.71	27.510	81.22
Equipment	0	0	0	0
Travel	5	5	10	9
Materials and Supplies	0	50	25	75
Other direct costs	0	0	0	0
Total direct costs	5	108.71	62.510	176.220
Indirect costs	2.9	63.052	36.256	102.208
Total direct and indirect costs	7.9	171.762	98.766	278.428

References

[1] B. I Grishanov et. al., Very Fast Kicker for Accelerator Applications, TESLA note 96-11 (1996)

[2] V. Shiltsev, Beam-beam Kicker for Superfast Bunch Handling, NIM A374, p. 137 (1996)

[3] V. Shiltsev, TESLA Damping Ring Impedances: Preliminary Design Consideration, TESLA note 96-02 (1996)

3 Beam diagnostic monitors and electron sources

3.1 Improved simulation codes and diagnostics for high-brightness electron beams.

Personnel and Institution(s) requesting funding

C. Bohn, Department of Physics, Northern Illinois University.

Collaborators

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S. Voronov, University of Rochester and Northern Illinois University
U. Happek, University of Georgia
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Project Leader

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Project Overview

The first component of this proposal is the development of improved simulation codes for high-brightness photoinjectors. The ultimate goal is to have a fast, accurate simulation code that (1) couples the longitudinal and transverse dynamics, (2) accounts for rapid evolutionary time scales, and (3) quantifies details in the beam structure, such as beam halo. The Fermilab/NICADD Photoinjector Laboratory [FNPL; NICADD denotes the Northern Illinois Center for Accelerator and Detector Development headquartered at the Department of Physics, Northern Illinois University (NIU)], of which H. Edwards is the Facility Manager, is an electron injector like that used at the TESLA Test Facility; it provides an excellent basis for testing new codes against laboratory experiments. The second component of the proposal is development of interferometric and electro-optic diagnostics for measuring bunch lengths and density profiles. The diagnostics will be tested and improved at FNPL, and they will be used in conjunction with bunch-compression experiments.

Linear colliders call for an injected electron beam with high bunch charge, low normalized transverse emittance, and short bunch length. A generic desire is to optimize the beam brightness to minimize the need for beam "cooling" like that done with a damping ring. This is the underlying motivation for the flat-beam experiment that is being conducted at FNPL [1]. Ideally, the injected beam would have bunch charge well exceeding 1 nC, a normalized emittance of order 1 μm, and a bunch length of a few mm (which gets compressed by an order of magnitude at higher energies). These parameters push the beam-brightness frontier. Accordingly, to understand the underlying beam dynamics likewise pushes the frontier of injector-simulation tools. For example, one must account more accurately for intricacies of space charge and wakefield effects. As a matter of principle this can be done with an N-body code, but N would need to be large and the computational time correspondingly long. To explore the parameter space in developing first designs of injectors, fast codes are needed, and to be used with confidence, these codes must comprise sufficiently accurate models of the beam physics. This is the context of the simulation effort discussed herein.

We propose to explore the possibility of developing a new code based on wavelets. The use of wavelets in the context of N-body simulations that involve long-range $1/r^2$ Coulomb interactions between particles is new. There is apparently only one related paper, and it was just published in June 2003 [2]. This paper demonstrates that wavelet denoising in the context of N-body simulations of two-dimensional disk galaxies results in a hundred-fold improvement in performance. The early stages of evolution in Coulomb systems are driven by long-range collective interactions as opposed to short-range collisional encounters; whether the two-body forces are attractive or repulsive should be relatively unimportant. Because the gravitational and electrostatic forces have identical long-range scaling, the findings of Ref. [2] should carry over to charged-particle beams. Our idea, conceived prior to the appearance of this paper, is to apply wavelet decomposition/denoising to three-dimensional beams with space charge. The basic advantage is that wavelets provide a multiscale "image" of the beam. Because noise arising from the use of macroparticles is present on all scales, the use of wavelets removes most of the noise without altering the beam's inherent structure. In developing new code, C. Bohn will generally do the underlying theoretical work, and I. Sideris (a postdoctoral computational physicist) will generally do the programming. A NIU physics graduate student (who possesses a doctorate in mathematics) has begun to explore this topic as the basis for his Ph.D. dissertation in physics. We request funding to support this graduate student.

Preserving a hierarchy of scales in the time-dependent space-charge potential is dynamically important. Our recent research has revealed that nonlinear, time-dependent forces commonly establish large populations of globally chaotic orbits in beams that are out of equilibrium, and such orbits can even be present in thermal-equilibrium beams [3,4]. When present, these chaotic orbits mix exponentially throughout their accessible phase space with a time scale of only a few orbital periods, i.e., very much faster than collisional relaxation. We have also found that the presence of colored noise due to space-charge fluctuations and/or machine imperfections can, when combined with parametric resonance associated with low-order oscillatory modes, generate much larger halos than would be inferred from parametric resonance alone [5]. Thus, all scales are potentially important to the dynamics. The use of wavelets will generate potential-density pairs that preserve these scales, thereby enabling accurate computations that apply well beyond predictions of conventional root-mean-square beam properties. The new wavelet-based algorithm would apply anywhere collisionless processes are important. For example, as concerns linear colliders, it would apply not only to injectors, but also toward a better understanding of the dynamics in the TESLA damping rings.

The length of an electron bunch is an important parameter for high-energy linear colliders. Wakefields depend on the bunch shape and are a limiting performance factor. Plus, the luminosity at the interaction point depends on the phase spaces of the colliding beams. One approach for measuring the longitudinal density profile of the bunch is to measure and analyze the coherent radiation produced either by transition, diffraction, or synchrotron radiation. A generic instrument for doing so is an interferometer [6]. In addition, monitoring and controlling nonlinear influences on a beam, such as wakefield effects, requires excellent time resolution. Linear-collider applications call for a time resolution of about one-tenth the root-mean-square bunch length, which for the NLC works out to be $\sim$10 μm. Moreover, single-shot capability is required for monitoring bunch-to-bunch fluctuations. Conventional techniques, such as streak-camera measurements, have much coarser time resolution, typically $\sim$1 ps, i.e., $\sim$300 μm. The same comment applies to existing interferometers, in that they typically operate in the wavelength region above $\sim$200 μm, which means accessing bunch lengths shorter than $\sim$500 fs has not been possible. Accordingly, these interferometers are also limited in their ability to distinguish fine structure in the longitudinal density profile.

Prof. Uwe Happek and his group at the University of Georgia have designed a number of Michelson interferometers; they are in operation at Cornell, Vanderbilt, UCLA, Argonne, and Jefferson Laboratory. Interferometric diagnostics are high-bandwidth far-infrared (FIR) devices. Their implementation is generically "flexible" in that they can be used to measure, e.g., transition radiation emitted as the beam passes through a thin foil (an invasive measurement), or diffraction radiation emitted as the beam passes through a hole in the foil (a noninvasive measurement), or synchrotron radiation emitted during bunch compression (also a noninvasive measurement). NICADD recently procured from Happek a new Michelson interferometer that is designed to push down the lower limit of the accessible bunch length by an order of magnitude, i.e., to about 20 μm. D. Mihalcea (a postdoctoral experimental physicist) developed the control software and has been testing the new instrument. However, it averages over many bunches; it is not single-shot.

A next-generation single-shot interferometer that combines a multichannel detector with a Fresnel mirror to measure electron-beam-induced coherent radiation will be developed in connection with this proposal. The Fresnel mirror is used to divide the wavefront of the incoming coherent radiation; an interferogram forms in the focal plane due to the different path lengths of the resulting wavefronts. The Fresnel mirror eliminates the moving parts inherent to the Michelson design and results in a rugged instrument. This is an important advantage, particularly for a UHV instrument wherein the moving parts would require special bearings or vacuum feedthroughs.

Development of the single-shot instrument relies on the availability of a suitable multichannel detector. We propose to consider two options: a room-temperature array of mirage detectors and a cryogenically cooled array of superconducting transition-edge detectors. Either option could be used for a conventional interferometer with a single-element detector; the cryogenic detector is attractive in that it offers the possibility to design a windowless, ultrahigh-vacuum (UHV) device.

The mirage detector is based on the use of a thin metal film as a spectrally flat absorber. The film heats the air above its surface, and a diode-laser beam probes the heated air. Changes in the refractive index deflect the laser beam, and a position-sensitive photodetector monitors the beam's location. The device's sensitivity is accordingly limited by thermal fluctuations, similar to a Golay cell. Multichannel detection is achieved by focusing the laser beam with a cylindrical mirror to a line above the absorbing surface, with subsequent detection of the beam deflection by an optical multichannel detector (CCD, photodiode array, or position-sensitive detector array). A room-temperature mirage detector has the additional advantage of being compatible with the use of fiber-optic cable for remote detection, eliminating the ubiquitous electrical noise associated with linear accelerators. Disadvantages are its slow response time, limited sensitivity due to thermal fluctuations, and for an UHV device, the need for a vacuum window that would inherently limit the transmitted coherent radiation spectrum.

To monitor bunch-to-bunch beam dynamics for electron bunches emitted at a high repetition rate, we will develop a multichannel detector based on superconducting transition-edge bolometers. While the operation of these detectors is complicated by the need for cryogenics, they are both fast and sensitive. Moreover, the transition-edge detector array can be used in a UHV-compatible instrument connected directly to the beamline, thereby circumventing the need for a vacuum window.

To summarize, the plan is to develop a multichannel interferometer that will permit studies of single bunches, as opposed to properties averaged over many bunches. Existing multichannel FIR detectors are very large and cumbersome, making their use in accelerator beam lines impractical. By contrast, a single-shot interferometer based on the Fresnel mirror design (or equivalent approaches such as a Lloyd's mirror) combined with a multichannel detector would enable compact devices, of roughly the size of the new Michelson interferometer (30 cm x 15 cm x 15 cm) recently procured from Happek. A portion of the funding for materials and supplies will likely be used in developing mirage detectors for interferometric applications. Prof. Happek will do most of the hardware development for the single-shot instrument; commissioning and testing will take place at FNPL.

Electro-optic (EO) sampling is a noninvasive technique offering picosecond time resolution of the electric field at the EO material [7]. It is based on the Pockels effect. When an electric field is applied to a certain class of crystals the refractive-index ellipsoid is modified, and as a result retardation (phase shift) is introduced between two orthogonally polarized components of a pulse of light traversing the crystal. This retardation can be detected by observing the change in the polarization of laser light transiting through the crystal. By using short laser pulses and varying the delay between the "probe" pulse and the pulse that produced the electron bunch, the "pump" pulse, one can sample the time dependence of the electric field.

In principle, the EO technique permits direct time-domain measurements of both beam-induced wakefields and the electric field from a single bunch itself. The technique was recently applied at FNPL in the former connection, specifically, to measure the beam-induced wakefield of a six-way cross [8]. The direct field of the bunch itself could not be resolved; the prevailing conjecture is that it was concealed by the arrival of the early-time wakefield at the crystal. The conjecture makes sense from simple time-of-arrival considerations pertaining to the geometry of the cross and the location of the crystal within the cross.

The design of the vacuum chamber housing the EO crystal is key to measuring the direct field of the beam. One possibility is to use a tapered vacuum chamber for low wakefields. We propose to design, build, and (in collaboration with Fermilab personnel) implement such a chamber, and thereby access the beam field. Part of the program will be to cross-correlate the density profile extracted from the EO-measured field against that from the interferometer and the projected longitudinal density obtained by use of a deflecting-mode cavity (once it is installed). These cross-correlations should go far toward validating the interferometric and electro-optic techniques. C. Bohn will do the theoretical work to design the vacuum chamber for the EO diagnostic. S. Voronov, a newly hired postdoctoral laser and optics expert will be key in commissioning and operating the new diagnostics. We request funds to purchase components for the interferometric and electro-optical diagnostics and to support a graduate student in commissioning the devices. In addition, we will collaborate with Dr. Bill Gabella of Vanderbilt University toward improving the time-resolution of the electro-optic diagnostic. In particular, Dr. Gabella will be working to develop an improved short-pulse probe laser.

Plans at FNPL are to install a third-harmonic deflecting-mode cavity to enable direct measurement of the beam's longitudinal phase space. Once this diagnostic is available, we will use it as a cross-check of the interferometric and electro-optic diagnostics. Measurements with the full diagnostic suite at FNPL will be applied toward benchmarking the new simulation code.

FY2004 Project Activities and Deliverables

Activities: Develop theory for wavelet-based space-charge algorithm. Design the single-shot interferometer based on tests of multichannel detectors. Design low-impedance vacuum chamber for the electro-optic diagnostic and begin its fabrication.

Deliverables: Technical papers on space-charge physics and associated computational techniques. Design of the single-shot interferometer. Design of the low-impedance vacuum chamber.

FY2005 Project Activities and Deliverables

Activities: Develop and demonstrate the wavelet-based space-charge algorithm. Construct the single-shot interferometer and begin testing it at FNPL. Finish the low-impedance chamber and install it in FNPL; configure electro-optic diagnostic and begin testing.

Deliverables: Initial wavelet-based simulation code, single-shot interferometer, low-impedance vacuum chamber.

FY2006 Project Activities and Deliverables

Activities: Benchmark the wavelet-based simulation code against FNPL experiments. Characterize beam with the interferometric and electro-optic diagnostics and cross-correlate their results. Improve the temporal resolution of the electro-optic diagnostic pending the successful development at Vanderbilt of a short-pulse probe laser.

Deliverables: Benchmarked simulation code. Papers on experiments involving the interferometric and electro-optic beam diagnostics.

Budget Justification

Successful completion of this proposal requires dedicated participants, both professional staff (not budgeted here) and two graduate students. It also requires modest hardware investments for the interferometric and electro-optic diagnostics, mostly toward the former. Most of the hardware costs appear in the first year (for the interferometric multichannel detectors and the electro-optic vacuum chamber). Modest funds for design modifications are requested for the second and third year as part of bringing the diagnostics to maturity.

Three-year budget, in then-year k$

Institution: Northern Illinois University

Item	FY2004	FY2005	FY2006	Total
Other Professionals	0	0	0	0
Graduate Students	37.080	38.192	39.330	114.602
Undergraduate Students	0	0	0	0
Total Salaries and Wages	37.080	38.192	39.330	114.602
Fringe Benefits	0	0	0	0
Total Salaries, Wages and Fringe Benefits	37.080	38.192	39.330	114.602
Equipment	0	0	0	0
Travel	0	0	0	0
Materials and Supplies	15	7.5	7.5	30
Other direct costs	0	0	0	0
Total direct costs	52.080	45.692	46.830	144.602
Indirect costs	13.541	11.880	12.176	37.597
Total direct and indirect costs	65.621	57.572	59.006	182.199

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3.2 Non-intercepting electron beam size diagnostics using diffraction radiation from a slit

Personnel and Institution(s) requesting funding

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Collaborators

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Project Leader

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Project Overview

The Linear Collider presents new challenges for beam instrumentation. Some of the beam dimensions are of the order of a few nm (at the i.p.), and to be able to reach these small sizes, the beams have to be tightly controlled and understood from their very inception onward. A number of different techniques are available in the arsenal of beam size and beam emittance measurements (e.g. transition radiation, metal wire, laser wire, laser interferometry, cavity BPM). Experiments of electron bunch profile measurements have been conducted using coherent synchrotron radiation (CSR), coherent transition radiation (CTR), as well as coherent diffraction radiation (CDR) [1-3]. Because the CDR perturbs the electron beam less than CTR and CSR, it is a better choice for monitoring the electron beam bunch shape. The use of diffraction radiation (DR) for measuring the transverse beam dimension is a new non-invasive technique, only partially investigated at the present time [4-5]; for example transverse beam size and emittance measurements have not been performed even though it is apparently possible to make precision measurements of bunch length, emittance at low energies, and the transverse size. This collaborative effort involving physicists and facilities from Cornell and Vanderbilt is aimed toward a comprehensive investigation of the potential use of DR over the broad spectrum of energies to be found at the Linear Collider.

Diffraction radiation is emitted from relativistic electron bunches passing through an aperture in a metal screen. The simplest aperture is a circular hole or a slit. The DR, like the transition radiation, is in the forward direction along the electron path, and in the backward direction along the direction of specular reflection from the the metal screen. The DR intensity is proportional to the square of γ, and it is distributed in angle as 1/γ, where γ is the electron energy factor ($E_{beam}/m_e c^2$); thus, both the intensity and the angular distribution can be used to deduce the beam energy[6]. The DR technique can be developed as a low cost, compact, and non-intercepting monitor which can be very useful for each element of the Linear Collider, starting with the injection linac, the damping rings and the main linac. DR has the potential capability to diagnose multiple beam parameters such as longitudinal and transverse beam sizes, energy, position, divergence and emittance. The DR technique also can be developed as a single shot measurement. As the DR technique measures the spectrum and angular distribution in the frequency domain, it has very high spatial and time resolution, and it is easy to satisfy the requirements of the Linear Collider facility. The goal in spatial resolution in this proposal is less than 1 μm in the longitudinal and transverse beam size measurement. From the analysis of measured data, the error on bunch length is estimated to be of the order of about 20%. One limitation that is apparent is due to the shrinking angular distribution with increasing γ, potentially limiting transverse beam size measurements to energy below 5 GeV(depending on background); however other properties such as bunch length measurement improve with increasing beam energy making this technique very viable at the Linear Collider.

The coherent properties are included in the DR spectrum in which the radiation wavelength is nearly equal to the beam bunch length. In the case of the LC, 100 μm bunch lengths would produce radiation in the 0.1 mm wavelength region. The CDR has a fixed phase relative to the electron bunches, and the measurement of the coherent radiation gives the longitudinal bunch form factor f(ω) and hence provides information about the longitudinal bunch distribution function S(z). Therefore, the electron distribution in a bunch can be obtained from the inverse Fourier transformation of the form factor. In addition, the angular distribution of the DR from an electron passing through a slit in a metal foil has polarization properties because of the interference effects between the two half-planes of the radiator. The polarization shows different properties with the electric field parallel and normal to the plane of slit plane. The electron beam transverse dimension can be measured through the analysis of the angular distribution of the diffraction radiation [4-5].

We propose the measurement of the coherent DR spectrum from a slit in a metal foil. The longitudinal profile will be evaluated from the fast Fourier transform of the autocorrelation function and the use of the minimal phase approximation. The results will be compared to that of intercepting CTR (Coherent Transition Radiation) and non-intercepting electro-optic measurement experiments conducted in the same environment.

In addition, we propose measure the electron beam transverse dimension through the analysis of the angular distribution of DR. A simple CCD camera can measure the angular polarization of DR. The total intensity of normal angular distribution has a minimum value when the beam passes through the center of slit. In practice, this property can be used to center the electron beam in the slit, and it may be a useful tool with which a cavity BPM can be centered on the beam.

It should be noted that much more accurate angular information of DR can be obtained by placing two slits. We also propose to measure interference from the forward radiation off one slit as it interferes coherently with the backward radiation from the other. Analyzing the whole angular distribution in the normal plane and fitting it to the theoretical prediction allows us to determine the transverse dimension of electron beams, beam energy and emittance.

The bulk of the design and construction of the apparatus will be done at the Vanderbilt FEL Center, where there are available experienced scientists, mechanical and design engineers and where, importantly, a minimum of eight hours of beam time per week will be made available to this project. Bibo Feng, who is the accelerator physicist at the Vanderbilt FEL, has performed CDR experiments at the Tohoku University Linac in Japan, and has experience measuring e-beam emittance, beam current as well as transverse and longitudinal beam profiles. Steve Csorna, a physics faculty member, who is a particle physicist, has worked with Don Hartill at Cornell in the measurement of the CESR beam's transverse size from the two slit interference of synchrotron radiation. Bill Gabella, the associate director of the Vanderbilt FEL Center, is an accelerator physicist who has experience in measuring bunch length using coherent transition radiation.

FY2004 Project Activities and Deliverables

In the first year, we will conduct the simulation work of DR which applies to the fundamental description of the bunch length experiment and the beam transverse size experiments. The calculation of CDR and incoherent DR under different conditions will help to understand the principles and to direct the design work of the experimental devices. We will write the calculation codes as well as the data processing programs.

We will design and build a Martin-Puplett type interferometer which will be used for the CDR spectral experiments. Two Golay cell FIR detectors and some optical components are needed for this purpose. We will design and build a radiator as well as its housing chamber for the experiments. The two pieces of thin metal foils or aluminum coated silicon plates can be used as the radiator. The slit of the radiator should be moved to intercept the electron beam by an actuator. The slit width will be adjusted by moving the two half foils in the same plane. It emits transition radiation when the slit is closed, thereby allowing us to directly compare the results from DR and TR techniques.

The first year deliverables will be a Martin-Puplett type interferometer, the DR radiator, and a technical report for DR experiments.

FY2005 Project Activities and Deliverables

In the second year, the CDR measurement devices will be built and commissioned at the Vanderbilt linear accelerator. The linear accelerator at Vanderbilt is a Mark III type linac, which produces electron energy from 25 MeV to 45 MeV with average beam current 200 mA. By measuring the coherent radiation spectrum intensity we will be able to derive the beam bunch length and longitudinal intensity profiles.

We will also measure the DR angular distribution from the radiator to yield the beam transverse dimension according to the angular distribution theoretical calculation. We will measure the interference image from two DR screens with slits to obtain more detail information of the angular distribution of DR, and derive the electron beam properties such as beam transverse size, beam energy and beam angular spread.

The second year deliverables will be a technical report describing the coherent DR and incoherent DR experimental results at Vanderbilt.

FY2006 Project Activities and Deliverables

During in the third year, we will carry out the beam property experiments using coherent DR and incoherent DR at the Cornell accelerator facility with higher electron beam energy. The device for measuring the angular distribution will be designed and built for accommodating different wavelengths and radiation bandwidths corresponding to different beam energy and slit width of the radiator.

The third year deliverables will be a technical report describing the coherent DR and incoherent DR experimental results at Cornell accelerator facility.

Budget justification

The first years activities are limited to design and build an interferometer and a DR radiator, which will involve staff members (not included in the budget shown here). A minimal amount of travel funds is included to cover collaboration meetings.

We expect that the second and third year will be primarily devoted to studying the properties of the DR under varying beam conditions at Cornell and Vanderbilt. Low energy running (50 MeV) can be efficiently performed at Vanderbilt, high energy running will be at Cornell (CESR). The postdoc will have the primary responsibility for scheduling runs, acquiring data and doing a significant portion of the data analysis.

We expect that on the basis of what we learn during the first year, we will need to buy additional specialized equipment and electronics.

Three-year budget, in then-year K$

Institution: Vanderbilt University (Fringe benefits are calculated at 26.6% rate on total salaries, and indirect costs are calculated at 51% rate on total salaries, fringe benefits and travel)

Item	FY2004	FY2005	FY2006	Total
Other Professionals	0	30	35	65
Graduate Students	0	0	0	0
Undergraduate Students	0	0	0	0
Total Salaries and Wages	0	30	35	65
Fringe Benefits	0	7.98	9.31	17.29
Total Salaries, Wages and Fringe Benefits	0	37.98	44.31	82.29
Golay cell detector	10			
high-vacuum chamber	15			
calibration source	4			
radiator and mount		10		
CCD camera,data acquiring system			10	
Equipment	29	10	10	49
Travel	5	5	8	18
Materials and Supplies	0	0	0	0
Other direct costs	0	0	0	0
Total direct costs	34	52.98	62.31	149.29
Indirect costs	2.55	21.92	26.678	51.148
Total direct and indirect costs	36.55	74.9	88.988	200.438

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3.3 Single-shot, electro-optic measurement of a picosecond electron bunch length.

Personnel and Institution(s) requesting funding

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Collaborators

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Tesla Test Facility/DESY collaboration under discussion.

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Project Overview

In next linear collider designs, the effort to create and maintain short electron/positron bunches requires a robust technique to measure bunch lengths. Designs have bunch lengths as short as 100 μm, or 330 fs, and a desirable goal is to measure the length to 10% or better. Short bunches have the advantage of avoiding the "bow-tie" degradation of the luminosity from the depth of focus while using strong focusing and small spots at the interaction region. The bunch length also needs to be short compared to the RF wavelength in the linac to avoid nonlinear effects from the accelerating gradient. Control of the bunch length in the magnetic bunch compressor after the damping rings requires accurate measurement of the length. The variation of length with position in the bunch train is also important to create uniform luminosity over the collision time and to correct any "long-range" wakefield or other effects on the bunch train which could lead to worsening of the effective emittance of the train.

Currently measuring electron bunch lengths with coherent transition radiation (or coherent diffraction radiation, or coherent synchrotron radiation), requires scanning a mm-wave interferometer and thus acquires signal over many electron pulses[1]. A technique using the perturbing effects of the passing electron bunch's electric field on a crystal (electro-optic, or EO, effect) measured by a fast Ti:sapphire laser has been demonstrated at the free-electron laser center (FELIX) in the Netherlands[2]-[5]. A non-destructive, single shot measurement of a 1.7 ps long electron beam is performed with an estimated accuracy of 0.37 ps. The wakefields behind the electron beam are also measured with this technique. In Refs.[6, 7], there was difficulty in measuring the direct fields of the electrons because of the strength of the wakefields following the electron bunch; their charge was much greater than in the FELIX experiment. They plan to build a low-impedance structure to house the EO crystal for future measurements.[1]

The goal of this proposal is to perform EO measurements of both (FEL) laser and electron bunch lengths, but make several improvements. One is to use a shorter pulse Ti:sapphire laser, approximately 8 fs instead of 30 fs, and another is to increase the spectrometer resolution. This should yield an error of less than 180 fs on a single-shot measurement of a 1 ps electron beam (assuming a chirped pulse length of about 4 ps for good signal to noise); chirped for a shorter electron pulse of 0.3 ps (assuming a chirp of 1.2 ps) this would result in a resolution of less than 100 fs. Ref. [5] gives the minimum intrinsic resolution as $\Delta t = \sqrt{t_0 t_c}$, where t_0 is the unchirped pulse length and t_c is the chirped pulse

[1] See the UCLC proposal by C. Bohn, Northern Illinois University and Fermilab.

length. Improvements toward the desired 30 fs resolution would come from improving the sensitivity and resolution of the spectrometer, and allowing shorter chirps closer to the actual electron bunch length.

It is important to point out that if timing jitter can be kept smaller than the probe laser pulse length, that length, 8 fs, would be the ultimate resolution in a sampling (many pulse) measurement. This is an important aspect of the research, synchronizing the probe laser to the electron bunch on the sub-100 fs level.

A Ti:sapphire oscillator will be installed at the Vanderbilt Free-electron Laser Center. It will be synchronized with the electron beam (and FEL laser beam). It appears that a laser with an 8 fs pulse length and approximately sub-100 fs synchronization are possible[8, 9]. The first measurements will be the longitudinal profile of the FEL laser pulse which is about 1 ps long. On a bench in the lab, refinements will be made to the spectrometer and pulse picker and resolutions estimated. The EO crystal holder and the laser beamline to our electron beam will be designed and built. The chamber design will be aided by the low-impedance chamber effort at Fermilab's AØ Photoinjector, a part of the UCLC proposal by Court Bohn. Electron bunch length measurements will follow.

For linac physics reasons, it is interesting to measure the evolution/change of the electron bunch through the bunch train. Single-shot EO measurements will be compared to coherent transition radiation measurements of the bunch length, as well as sampling measurements with the EO technique. At the FEL, a geometrically flat beam can be made with about 10:1 aspect ratio and the bunch length measured; the AØ Photoinjector may be available for experiments on truly flat beams with aspect ratios of 50:1, or better. The electron beam at the FEL has a single pulse charge of 50 pC, however the monochromatic xray machine at the Center has single bunch charges of 1-5 nC in 8 ps and is available for experiments.

The current budget below includes approximately 50% of the cost of a synchronized, fast Ti:sapphire laser oscillator. The remaining burden will come from the FEL Center, subsequently the laser will be shared with the Center. Also identified at the Center is a high resolution CCD camera that should be useful for the spectrometer.

The EO measurement is sensitive to all externally applied electric fields, including the wakefield the electrons induce in the structure. This can be a novel way to measure the wakefields. It is important to point out the EO bunch length measurements on FEL's do not seem to suffer from excessive wakefield effects; the bunch charge is typically less than 0.2 nC. While in the Fermilab experiment on the AØ Photoinjector, the currents were 1-12 nC and the direct bunch signal was overwhelmed by the wakefields.

The Vanderbilt FEL Center has the needed expertise for these experiments. The Center routinely runs a 45 MeV electron linac with high average power as a driver for the FEL. The Center also runs a tunable, back-scattered xray source that uses a high-charge, 45 MeV electron bunch and a Ti:sapphire driven glass laser capable of 20 TW in 8 ps. The electrons and the laser are synchronized on the picosecond level. An optical parametric generator system capable of tunable light from UV to mid-IR is also run by Center personnel. That system is based on a Ti:sapphire oscillator and amplifiers driving nonlinear interactions in crystals to generate tunable wavelength light.

FY2004 Project Activities and Deliverables

Activities: Study which of several vendors' fast Ti:sapphire laser oscillators would suit the experiment best in terms of price, speed and especially synchronization. Currently, for budgetary reasons, the laser will be purchased with the option of fast synchronization in its design, but the actual synchronization hardware will be purchased in the following year. Install and begin testing the Ti:sapphire laser system without synchronization. Using a currently available CCD camera, build the spectrometer detector for the system.

Deliverables: Papers describing the studies of electro-optic measurements, for varying geometries of the crystal and the electron beam, for varying impact parameters, and for high resolution.

FY2005 Project Activities and Deliverables

Activities: Finish testing and characterizing the laser, especially the laser pulse length, jitter and stability. Purchase and install the synchronization hardware. Install the pulse picker which selects a single pulse out of the approximately 50 MHz laser repetition rate—needed to decrease measurement background. Build and test the variable pulse stretcher. Using the completed laser system, measure the FEL laser pulse length on a bench using the EO effect. Both single-shot and multi-shot measurements will be performed. Comparisons will be made to auto-correlator pulse length measurements. Design the laser beamline and the low-impedance vacuum chamber for electron EO measurements, use guidance from the Fermilab effort at the AØ Photoinjector.

Deliverables: Completed laser and associated hardware. Paper describing the laser characteristics and ancillary hardware. Design for the laser beamline and the low-impedance vacuum chamber for electron measurements. Description of first measurements of the FEL laser pulse.

FY2006 Project Activities and Deliverables

Activities: Measure the evolution of the FEL laser bunch length during the bunch train. Build and install the laser beamline and the vacuum chamber housing the EO crystal. Perform electron bunch length measurements: single-shot, multi-shot, and evolution during the train. Measure wakefields. Plan similar measurements at the AØ Photoinjector at Fermilab, or DESY, or SLAC, especially to investigate flat beams, shorter beams, and scaling to higher energy.

Deliverables: Papers describing the laser and electron bunch length measurements for a single-bunch and the variation over the bunch train. Paper detailing the wakefield measurements.

Budget justification

The first year of the budget is this proposal's share of the fast Ti:sapphire laser oscillator needed for the experiment. The FEL Center director is very supportive of this line of research and is committed to helping with the purchase of the laser, as well as purchasing or loaning the pump laser that is needed. Current estimates are this should save about half the cost of the final synchronized oscillator, or about \$30K. Also, to spread out the burden of the cost to this proposal, the basic oscillator designed with the possibility of synchronization is purchased in year 1, with the remaining synchronization hardware purchased in year 2. Two vendors have been identified that can supply the fast Ti:sapphire oscillator.

Already available at the FEL Center is a high-resolution CCD camera for building the spectrometer needed for the single-shot measurement.

In year 2, the previously planned/designed synchronization hardware will be purchased and installed. Much of the other needed ancillary laser hardware is either already available or will by purchased by the FEL Center for use in other experiments. The largest budget expense will be the hiring of a post-doctoral researcher or a graduate student whomever is available. This is important as year 2 is the busiest year in this proposal in terms of testing and building experimental components.

In year 3, again the major expense is for a researcher who will be designing and building the laser beamline and EO crystal vacuum chamber for, and then performing, the electron measurements. Plans for further measurements at other facilities will be made.

Three-year budget, in then-year K$

Institution: Vanderbilt University[2]

Item	FY2004	FY2005	FY2006	Total
Post-doctorate or graduate student	0	35	37	72
Total Salaries and Wages	0	35	37	72
Fringe Benefits (26.6%)	0	9.31	9.84	19.15
Total Salaries, Wages and Fringe Benefits	0	44.31	46.84	91.15
Ti:sapph oscillator with synchronization option (50% share)	20			20
synchronization hardware		8		8
improve Pulse picker, 10ns			9	9
high-vacuum chamber, crystal mount			10	10
electro-optic crystals			4	4
Equipment	20	8	23	51
Travel		1	2	3
Materials and Supplies			5	5
Other direct costs		2		2
Total direct costs	20	55.31	76.84	152.15
Indirect costs (51%)		24.128	27.458	51.586
Total direct and indirect costs	20	79.438	104.298	203.736

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3.4 Design for a Fast Synchrotron Radiation Imaging System for Beam Size Monitoring

Personnel and Institution(s) requesting funding

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Project Leaders

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Project Overview

With the high intensity, low emittance beams needed to reach the luminosity goals of the linear collider, beam size monitoring will play an important role in machine operation. In the damping rings, synchrotron radiation emitted by the bunch can provide a means of measuring transverse bunch size and shape [1]. With suitable imaging and high speed detection of the SR, bunch size, shape, and position may be determined with single bunch discrimination and minimal disturbance to the passing beam. A system fast enough to capture such a "snapshot" of a single beam bunch would be a useful addition to the Linear Collider diagnostics package and also be a valuable contribution to general accelerator physics and technology.

We propose to develop imaging and detection techniques that could be used to directly image the synchrotron radiation.

In the NLC(TESLA) designs of the damping ring, the vertical bunch size at the midpoint of the dipole magnets is $\sim 5(7)\mu$m and the horizontal size is $\sim 35(45)\mu$m. Beam energy is $\sim 2(5)$ GeV. The emitted synchrotron radiation is cast forward in a narrow cone of opening angle $1/\gamma$ and has a critical energy of about $3\gamma^3\hbar c/\rho = 8(6)$ keV. An imaging system working in the optical region would be diffraction limited and incapable of resolving the small vertical size of the beam, but wavelengths below 10 nm (i.e., X-rays above ∼0.1keV) will provide sufficient resolution [1]. An optimal choice for the working energy is thus constrained from below by diffraction, from above by critical energy, and must be chosen to permit maximal transmission by the optical components yet maximal absorption by the detector.

Imaging and detecting these photons poses interesting technical challenges. A system suitable for damping ring use requires three principal components:

1. A point-to-point imaging optical system suitable for $\sim 1-10$ keV X-rays. Several technologies exist, including grazing angle mirror systems, diffracting aluminum or beryllium lenses, and Fresnel zone plates. Each has advantages and disadvantages. Grazing angle systems are inherently achromatic, but require high precision control of the surface figure. Diffracting lenses and zone plates are wavelength specific and would require a monochromator upstream, but are mechanically less demanding. (A monochromator has the useful side-effect of reducing flux and therefore reducing thermal load on the dimensionally sensitive optical elements.) Diffracting systems also introduce absorption which must be kept low by suitable choice of material.

2. A low-noise, high speed, high resolution two-dimensional detector with sufficiently fast response to cleanly separate the closely spaced bunches that one will encounter in a Linear Collider damping ring (1.4 ns for NLC, 20 ns for TESLA). Silicon pixel detectors are a plausible detector choice, offering 2-dimensional imaging and high granularity, as well as a low capacitance, low noise source adaptable to the needs of high speed readout. Careful study of the signal transmission characteristics, starting from the absorption processes, through the drift, diffusion, and charge collection in the detector, and the subsequent transport, switching, amplification, and measurement of the signal charge must be undertaken to fully understand the factors that determine achievable bunch resolution time. 1 ns resolution may be achievable in silicon, but subnanosecond resolution likely demands higher mobility materials such as GaAs. The intrinsic spatial resolution of the detector and the magnification of the optical system must be optimized together to achieve best resolution.
3. A high speed data acquisition system to extract signals from the detector, perform signal processing and pass results to accelerator control systems in real time. Appropriate software would be required to render the results in a form easily interpreted by an operator.

A well developed literature exists for X-ray optics of the varieties mentioned above [2]. Applications are typically related to focussing X-rays to maximize intensity. Techniques for high speed time-resolved detection of an imaged low emittance beam will require additional development. Further, conventional detection systems use flourescent screens to convert X-rays to optical photons which are then detected by a standard CCD camera, offering no useful time resolution.

A system that would offer 10 ns resolution could usefully image single TESLA bunches, and is within the range of today's technology but not actually available. A system that would offer 1ns resolution could image single NLC bunches, but would require technological development. A system that would offer 10 ps resolution could permit intrabunch resolution, i.e., bunch tomography, but will demand both technological advance and a deep understanding of the physical processes of the detection mechanism.

We propose to investigate a range of existing imaging technologies that could be applied to X-rays in the appropriate energy range. We also propose to study the detector and readout options that could be combined with this optical system to form a high speed bunch imaging device. We expect that the timing requirements on the detector and readout scheme will create significant technical challenges. We will study existing techniques, and where needed develop our own, including the possibility of combining a pixel detector with two amplifiers per channel to allow for a pair of closely spaced "snapshots." For each option, we will explore in detail the fundamental physical processes that determine its ultimate time resolution.

We build on our ten year's experience with silicon detectors and high speed data acquisition technology. We also have ready access to appropriate facilities, including Nanofabrication facilities at both Cornell and SUNY Albany, the X-ray lines at the Cornell High Energy Synchrotron Source (CHESS), and of course the CESR storage ring itself, whose energy and beam size parameters, and bunch spacings are relevant to the existing LC damping ring designs. We also expect to use readily available simulation tools include PISCES (for signal development and transport in solid state detectors), SPICE (for general electronics design), and SHADOW (for X-ray optics design). We will use these, or others as necessary, and will also develop our own Monte Carlo simulation of the entire chain from the point of radiation to the final step of detection. We also have available an extensive stock of small prototype silicon detectors and a well equipped detector development laboratory (including probe station, wire bonder, etc.) which can be used to empirically study general properties of signal development in silicon detectors and cross check the simulations and calculations.

FY2004 Project Activities and Deliverables Review existing techniques for X-ray imaging and use standard software to explore possible optical layouts for the most promising technologies. Evaluate relative merits of each and proceed to design the actual imaging system. Simultaneously, develop software tools and physics basis to simulate signal development in solid state detectors and signal processing electronics to design detector system with optimal response time. Write a technical report on results.

FY2005 Project Activities and Deliverables Pursue most promising design options and confirm essential details of simulations with empirical measurements on existing silicon detectors using available hardware and the CHESS X-ray lines. Write a technical report on results.

FY2006 Project Activities and Deliverables Optimize design details and write final design report.

Budget justification

We request funding for half-coverage of the cost of a large bandwidth oscilloscope (such as the Tektronix TDS 8000B with 80E06 insert) which will enable detailed studies of solid state detector performance at high speed. We also request funding for purchases of computers for the silicon readout systems.

The proposed travel budget covers travel for one of us (JAE) to come to to Ithaca 4 times per year ($2K) and for one of us (JPA) to travel to Albany 4 times per year ($2K).

Three-year budget, in then-year K$

Institution: Cornell University

Item	FY2004	FY2005	FY2006	Total
Other Professionals	0	0	0	0
Graduate Students	0	0	0	0
Undergraduate Students	0	0	0	0
Total Salaries and Wages	0	0	0	0
Fringe Benefits	0	0	0	0
Total Salaries, Wages and Fringe Benefits	0	0	0	0
Equipment	0	20	0	20
Travel	2	2	2	6
Materials and Supplies	2	2	2	6
Other direct costs	0	0	0	0
Albany subcontract	13.491	16.016	13.536	43.043
Total direct costs	17.49	40.016	17.536	75.042
Indirect costs (58%)(1)	5.828	5.312	2.320	13.460
Total direct and indirect costs	23.319	45.328	19.856	88.502

(1) Includes 26% of first $25K subcontract costs

Institution: State University of New York, Albany

Item	FY2004	FY2005	FY2006	Total
Other Professionals	0	0	0	0
Graduate Students	0	0	0	0
Undergraduate Students	0	0	0	0
Total Salaries and Wages	0	0	0	0
Fringe Benefits	0	0	0	0
Total Salaries, Wages and Fringe Benefits	0	0	0	0
Equipment	0	10	0	10
Travel	2	2	2	6
Materials and Supplies	7	2	7	16
Other direct costs	0	0	0	0
Total direct costs	9	14	9	32
Indirect costs (50%)	4.491	2.016	4.536	11.043
Total direct and indirect costs	13.491	16.016	13.536	43.043

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4 RF structure R&D

4.1 RF Breakdown Experiments at 34 GHz

Personnel and Institution(s) requesting funding

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Project Overview

An experimental program is proposed to study rf breakdown in mm-wavelength accelerating structures, with the aim of understanding the basic mechanisms that lead to breakdown. Availability of the recently-commissioned 45-MW, 34-GHz magnicon amplifier at the Yale Beam Physics Laboratory makes these experiments possible. This research is expected to have relevance to fundamental issues in accelerator structure design, as well as to near-term issues for NLC.

Rf breakdown limits the accelerating gradient and thus determines the collider length. One of the most important questions in collider design is the frequency dependence of the maximum achievable accelerating gradient, and studies at frequencies other than 11.4 GHz are expected to help understand limitations faced by NLC. Presently, some experimental breakdown data are contradictory, incomplete, and inconclusive, notably:

(a) Experiments by Loew and Wang [2, 3, 4] demonstrated a square root dependence of maximum surface gradient on frequency in the microsecond pulse length range; independent experiments on single cavities under similar conditions show maximum surface fields of 190 MV/m for S-band and 350-400 MV/m for X-band, in conformity with the square root dependence [8, 13].

(b) For X-band accelerating structures such as those under extensive study in several research groups at SLAC, the maximum surface field is always lower than in a single cavity, and the spread of maximum surface gradient depends on the structure type and parameters. Some recent theoretical investigations at SLAC also indicate that one may expect an increase of the gradient with frequency [5, 6, 7].

(c) CERN experiments [9, 10, 11] do not match the SLAC results, as follows. In cavities designed for 21, 30 and 39 GHz, the maximum surface gradient for a single cavity excited by the beam doesnt appear to depend on cavity size, and equals about 380 MV/m for very short pulse width[12] (At SLAC, the same surface gradient was achieved in a single X-band cavity for pulse width more than 10 times longer). These differences are not understood, but it is suggested that direct comparison may be elusory, since the CERN experiments were done using a train of bunches to shock excite the fields internally, as compared to other experiments performed at SLAC, KEK, and Budker INP, where the fields are externally driven. In further contradiction to the SLAC results, no significant difference was found at CERN between the maximum surface field for single cavities and various accelerating structures.

It is not possible to develop the next generation (multi-TeV) linear collider without careful investigations of the maximum achievable accelerating gradient for higher frequencies. This point has been enunciated repeatedly, within the accelerator community (e.g., Snowmass2001). This knowledge is important for NLC because deeper understanding of the limiting breakdown mechanism and its variations, for examples with different metals and alloys, could enable operation with higher acceleration gradients. Moreover, exact information on the maximum accelerating gradient available and what the optimal operating frequency should be, may allow design of a collider upgrade to a center-of-mass energy which enhanced X-band technology will not allow. In addition, the breakdown investigations under way at SLAC include development of models of this phenomenon, and validation of these models will require experiments over a range of frequencies including frequencies higher than X-band, but carried out under similar conditions. To be able to compare measurement results for S, X and Ka bands and to exclude extraneous effects, these measurements must be done using the same method used at SLAC (in contrast to the method used at CERN): high-power rf amplifier, waveguide system, pulse compressor, variable pulse width, flexibility of conditioning process, etc. The Yale Beam Physics Laboratory's 34-GHz program to establish a Ka-band accelerator test facility satisfies these requirements. The main component of this facility is the 34 GHz, 1 μsec magnicon amplifier with the design power of 45 MW [1]. The tube has already undergone preliminary rf conditioning wherein, after about 60 hours of operation, an output power of about 10.5 MW was achieved in 0.25 μsec pulses. rf conditioning is to continue up towards the rated output level, although the present output is sufficient for providing >500 K pulsed temperature excursions in a dedicated test structure under construction for surface fatigue studies; such studies have direct application to NLC. Furthermore, support from DoE has been secured for a range of Ka-band high-power rf components, including rf windows, needed to transmit and couple the magnicon output power to test structures under evaluation. The first set of these components has been delivered. During the proposed experiments, coordination with SLAC is planned.

In order to achieve the maximum gradient, one should make correct choices for details of the accelerating structure. We propose to develop a test structure with both strong defenses against rf electrical breakdown, and low peak surface magnetic field (in order to minimize pulse heating leading to metal fatigue). The improvements are based on the following innovations:

(a) elliptical irises which reduce the maximum surface electric field: elliptical irises were suggested by the authors [14, 15];

(b) the first cell of the structure [16] will operate in the TM_{020} mode, so as to eliminate an additional overvoltage caused by the input coupler. Also, there is no magnetic field enhancement near the coupling slot.

The structure has a group velocity $v_{gr} = 0.05c$. This turns out to be a reasonable choice in light of experiments with various X-band accelerating structures at SLAC. Details of the current structure design are given in [16].

It is important to emphasize that some of the design features of the test structure can be directly applied to the NLC X-band structure, namely elliptical irises that will reduce surface electric fields and consequently may allow an increase in accelerating gradient of up to 15-20%, and the use of a coupling cell operating in the TM_{020} mode that will allow lowering the risk of breakdown and overheating. It is possible that fabrication of an X-band version of the structure will be undertaken with future funding; data obtained from experimental tests of this structure at the NRL-operated X-band accelerator test facility using the Omega-P/NRL X-band magnicon will also be analyzed in the context of the proposed program.

Successful operation of the aforementioned 34-GHz magnicon, as is already well underway, will allow development to proceed for the 34.272 GHz accelerating structure even before the availability of a full set of high-power Ka-band components such as pulse compressors, mode converters, etc. This is possible because it is proposed to apply the technique commonly used in evaluation of accelerating structures, namely to operate the structure first in a standing-wave mode. In the standing-wave mode, it is expected that surface fields and accelerating gradients of 690 MV/m and 180 MeV/m can be realized using 30 MW of rf drive power fed directly to the structure from the magnicon. At a surface gradient of 690 MV/m in the traveling-wave mode, the accelerating gradient would be more than 340 MeV/m. These experiments will be possible when future funding permits, in which case data obtained from operation of this structure will be analyzed in the context of the proposed program. The major opportunity for analysis of breakdown data will occur when experiments at 34 GHz commence with high power, long pulse excitation of CLIC structures, in a planned collaboration with CERN; this work could begin in late 2003 or 2004, at CERN's discretion.

The research team has decades of rich experience which includes design, building and putting into operation three magnicons in the decimeter and centimeter wavelength domains having up to 10's of MW's of output power; and design, building and operating of electron accelerators based on various structure designs. Individual resumés are available upon request. During all years of the proposed project, student participation is planned, including part-time employment of graduate students and undergraduate participation through senior research projects and contiguous summer employment. During the second and third years, part-time work by a postdoctoral research associate is planned, at a level equivalent to 25% of full-time.

Description of Available Facilities

The Yale Beam Physics Laboratory is well equipped to carry out the proposed research. A cold-test lab for low-power rf tests is equipped to perform scalar analyzer measurements at frequencies from 2 to 50 GHz. High-power tests at 34 GHz will be carried out using a 45-MW magicon amplifier which, during recent commissioning at reduced gun voltage, produced over 10 MW of output power (a record level) after only about 100,000 conditioning pulses. High-power components at 34 GHz, being designed and developed under another program should be available for the tests of CLIC structures; these components include high-power loads, dual directional couplers, mode converters, windows, tapers, power combiners, and pumping sections. Other facilities could become available during the 3-year span of this project, that include a 19-cell high-gradient standing-wave accelerating structure, a resonant ring to obtain $\times 10$ effective peak power enhancement to >400 MW with full 1-μsec pulse width, and a quasi-optical pulse compressor.

Education and Outreach

Education in laboratory-based accelerator physics within the context of the proposed program will take place in the Yale Beam Physics Lab at three levels: undergraduate, graduate, and post-doctoral. It is required for Yale physics majors to carry out an independent senior research project. The budget for the proposed program will allow the academic year senior project (for which there are no earnings) to be enhanced by summer employment between the junior and senior years; in the past, this arrangement has been shown to greatly increase the student's familiarity with research laboratory practice, and to obtain better results by the end of his/her senior year. Graduate students will be given the opportunity, with support under the proposed program, to find summer employment preceding matriculation and between their first and second years. (Normally, Yale graduate students have University fellowships during their first and second years.) This opportunity for summer employment helps students select a long-term area of research towards their Ph.D.'s, and provides important hands-on experience in an accelerator physics research laboratory. Postdoctoral education occurs when young professionals have the opportunity to broaden their skills by working side-by-side on multi-year projects with senior staff associated with the proposed program. Outreach activity that is possible within the context of this program includes a summer visiting appointment for an area high-school physics teacher, field trips for high-school students, and conduct of high-school senior projects (as just completed for the valedictorian of the Hopkins School graduating class in New Haven, who will matriculate as a physics major at MIT in September 2003.) All of these outreach activities have taken place at one time or another in the laboratories of the Principal Investigator during his tenure since 1962 at Yale.

FY2004 Project Activities and Deliverables

During the first year, we will begin to develop a design of the test stand, which besides the accelerating structure will include a 34-GHz high power feeding system and diagnostics. The test stand will be configured to accommodate CLIC structures that will be fabricated at CERN specifically for testing at 34.3 GHz, rather than at the CLIC frequency of 30 GHz. An annual report will be presented and engineering drawings of the accelerating structure will be completed.

FY2005 Project Activities and Deliverables

During the second year, the manufacturing of the CLIC test structure is to be completed, and fabrication and cold test of the structure can be anticipated. Tests of CLIC structures will continue, and data analysis will begin—with the aim of deepening understanding of the underlying breakdown mechanisms. An annual report will be presented. The accelerating structure will be completed and delivered.

FY2006 Project Activities and Deliverables

During the third year, analysis of data from CLIC structures will continue, and the accelerating structure will be assembled and connected to the magnicon, provided its fabrication was completed during FY2005. Then, the structure conditioning and experiments will be started. The components of the test stand will be assembled together with the accelerating structure. Using data accumulated from tests at Yale on CLIC structures, from the 34-GHz-accelerating structure described above as tested at Yale, and from an X-band version of the latter tested at NRL, attempts will be made to develop a model for helping to understand the basic mechanisms that govern rf breakdown in accelerating structures. The final report will be presented.

Budget justification

The first year's activities are limited to design studies which involve staff members with the aim of configuring the experimental facilities to accommodate CLIC structures and (possibly) the 34-GHz accelerating structure. This activity will be partially supported with funds for undergraduate and graduate student participation. During the second year, breakdown tests on CLIC structures will be performed and fabrication and cold test of the 34-GHz accelerating structure could be carried out using base program funding. This activity will be partially supported with funds for undergraduate and graduate student participation, and for support of 25% of an Associate Research Scientist. During the third year, breakdown tests will continue, and data will be analyzed. This activity will be partially supported with funds for undergraduate and graduate student participation, and for support of 25% of an Associate Research Scientist. Indirect costs are 63.5% MTDC (normally excluded categories include equipment over $2000, graduate student tuition, subcontracts over $25,000). Fringe benefits are 10.0%, 11.0% and 12.0% on undergraduate wages in BY-1, BY-2, and BY-3, respectively; are zero on graduate student wages; and are 40.0%, and 42.0% on Associate Research Scientist salary in BY-2 and BY-3, respectively.

Three-year budget, in then-year K$

Institution: Yale University

Item	FY2004	FY2005	FY2006	Total
Post Doctoral Associate (0%, 25%, 25%)	0	11.000	11.550	22.550
Graduate Students	5.625	5.906	6.202	17.733
Undergraduate Students	1.403	1.472	1.545	4.420
Total Salaries and Wages	7.028	18.378	19.297	44.703
Fringe Benefits	0.140	4.562	5.036	9.738
Total Salaries, Wages and Fringe Benefits	7.168	22.940	24.333	54.441
Equipment	0	0	0	0
Travel	0	0	0	0
Materials and Supplies	2.007	1.525	0.132	3.664
Other direct costs	0	0	0	0
Total direct costs	9.175	24.465	24.465	58.105
Indirect costs	5.826	15.535	15.535	36.896
Total direct and indirect costs	15.001	40.000	40.000	95.001

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4.2 Research in Superconducting Radiofrequency Systems

Personnel and Institution(s) requesting funding

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Project Overview

Rapid advances in superconducting cavity performance have made RF superconductivity an important technology for a variety of accelerators, fulfilling the needs for high energy physics, nuclear physics, radioactive beams for nuclear astrophysics, intense proton accelerators for neutron spallation sources, muon acceleration for future neutrino factories and muon colliders, storage ring light sources, free electron lasers, fourth generation x-ray free electron lasers, and energy recovery linacs. Improved understanding of gradient-limiting mechanisms, together with technology advances, are responsible for the steady increases in performance [1]. Gradients of 25 MV/m at Q values of 10^{10} are now regularly achieved in one-meter long superconducting structures suitable for TESLA (TeV Energy Superconducting Linear Accelerator). To reach such gradients, high-purity, high thermal-conductivity niobium is used to prevent thermal breakdown of superconductivity, while high pressure rinsing and clean room assembly techniques are used to reduce field emission and voltage breakdown. LEPP research has played a major role in pushing cavity performance to these levels [2].

The goal of our future R&D program will be to push gradients towards the theoretical limit (50 MV/m), which is another factor of two higher than achieved levels. Advances in understanding gradient and quality factor (Q) limitations, together with progress in gradients will benefit the goals of TESLA and its upgrades to higher energies and luminosities.We also plan to explore improved cavity designs that lower surface fields thereby raising the maximum possible accelerating gradient. Preliminary explorations suggest designs that offer a 20% improvement, raising the theoretical accelerating field limit for superconducting structures to 60 MV/m.

We are also developing new techniques for cavity fabrication and treatment to lower production costs for 20,000 cavities needed for a 500 GeV CM linear collider. If such procedures are successful with smaller cavities, we aim to combine the less expensive fabrication and processing techniques with the improved designed and build multi-cell structures. Here we will need the help of industry.

The sophisticated techniques associated with fabricating, treating and testing superconducting niobium cavities now resides primarily in European industries. Having a US industry learn these high tech procedures would greatly improve the choices for US contributions to the linear collider. During the third year of the proposal we will transfer the high level of technology associated with fabrication, surface preparation and cryogenic testing of superconducting structures to one or more US firms while fabricating, treating and testing full scale structures with improved design and methods.

We assume that the on-going R&D under our regular NSF contract will continue to be funded at the levels we have requested in our five-year NSF proposal, 020278, also referred to as the Blue Book, CESRP 01-1. Much of the work described in the first two years will be carried out by graduate students doing doctoral work. Funds are requested for equipment, materials, supplies and surface analysis work. Support for graduate students is paid for by our regular NSF contract.

Basic studies of the sources of high field Q-slope and quench field in Nb cavities

Two mechanism operate to reduce the Q of a superconducting cavity at accelerating fields above 20 MV/m. One is field emitted electrons from particulate contaminants in the high electric field regions of the cavity. This phenomenon is quite well understood and methods to control emission are in hand. High pressure water rinsing (at 100 bar) eliminates field emission by eliminating micron and sub-micron particles. The high power available for the beam can also be used to burn up any residual emitters that accidentally enter structures during the final stages of assembly. The other important field limitation is a phenomenon called the "high field Q-slope" [3]. In very clean cavities that show little or no field emission, there persists a steady decline in Q_0 above 20 MV/m, followed by a quench between 20 and 30 MV/m. Absence of x-rays corroborates absence of field emission. Temperature maps reveal that power dissipation occurs over high magnetic field regions of the cavity. Yet the losses are not uniform. Collaborative work at several laboratories shows that electropolishing, instead of the standard chemical etching procedure, substantially reduces the Q-slope and increases the quench field. Another cavity treatment (baking at 100^oC for 48 hours) further improves the high field Q-slope of electropolished cavities, and raises the quench field substantially. Baking also has a slight beneficial effect on the Q-slope of chemically etched cavities, but no significant effect on the quench field. As a result of these new procedures accelerating fields of 35 MV/m are now realized in TESLA 9-cell structures as needed for the 800 GeV to one TeV upgrade.

An understanding of the Q-slope mechanism will point the way to treatments that can lead to even higher performance. There has been some recent theoretical progress as well as new models proposed for explaining why electropolishing and baking help to reduce the Q-slope. One mechanism is magnetic field enhancement at grain boundaries[4]. Surfaces prepared by buffered chemical etching tend to develop grain boundary steps and sharp grain boundary edges due to differential etch rates for different grains. Electropolishing eliminates steps due to higher etch rates at sharp features. A model for the benefits of baking involves the redistribution of oxygen in the rf layer[5].

Much experimental and simulation work remains to validate these explanations or to eliminate them. We plan to use our state-of-the-art thermometry system to identify hot regions responsible for the Q-slope, and premature quenches [6]. These studies will be carried on single cell cavities with surfaces prepared by a variety of methods, such as chemical etching, electropolishing, baking, and anodizing (electrolytic oxidation). After identifying lossy regions we will dissect the cavity and study the spots with surface sensitive techniques such as Auger, SIMS (secondary ion mass spectrometry), and XPS (x-ray photoelectron spectroscopy). Auger and SIMS will give surface sensitive elemental information, while XPS will help sort out differences in surface oxides. Use of other surface techniques may be warranted.

Graduate students will carry these studies. Students will also prepare niobium samples by the same techniques and carry out parallel measurements with surface analytic instruments.

Improved Geometries, Fabrication and Preparation Another way to tackle the high field Q-slope is to modify the cavity design to reduce the ratio of the peak magnetic field to the accelerating field. Although field emission is present in some cases, it does not present a brick wall limit because techniques exist to control it. This means that the peak surface electric field is less important than the peak surface magnetic field.

Preliminary studies using cavity design codes show that introducing re-entrant shapes offers the possibility of lowering the surface magnetic field by at least 10%, if we allow the surface electric field to rise by 20%. Since the cell-to-cell coupling factor of the re-entrant geometry is also higher, it is possible to reduce the aperture to make further reduction in the surface magnetic field. We expect to continue such optimization studies during the first year to determine the best cell length, aperture and higher order mode propagation properties.

The re-entrant shape leads to some technological complications for cavity fabrication, surface preparation and cleaning, which we intend to address at the single cell level during the second year.

Today, 9-cell TESLA cavities which are purified with Titanium at 1350^{o}C and electropolished reach accelerating fields of 35 MV/m. High temperature treatment for purification of 9-cell structures calls for large and expensive UHV furnaces. Heat treatment is also a lengthy process, since the furnace cycle takes three days. Diffusion of titanium into the bulk demands removal of more than 100 μm of the surface, another time-consuming operation.

To reduce large scale production costs, we aim to explore heat treatment at the half-cell stage. Stacking cups interleaved with titanium foils can improve the packing fraction in a furnace by at least a factor of two, thereby reducing the investment in infrastructure and processing time. Preliminary tests show that optimization of the time/temperature cycle during heat treatment can also lower the diffusion length of the titanium from 100 μm to about 20 μm, yielding a substantial reduction in chemical processing time.

The present method of electropolishing involves a large and expensive facility that must rotate a cavity full of acids and carefully exhaust the hydrogen produced at the counter electrode. Hydrogen dissolved in the bulk niobium precipitates as normal conducting islands of niobium-hydride on cool down. If so contaminated, an electropolished cavity must be heated at 750^{o}C for several hours to drive out the dissolved gas. Half-cell electropolishing is simpler, more open and poses less danger of hydrogen contamination.

In order for these proposed economical methods to succeed it is necessary to devise an electron beam welding procedure that produces an excellent final weld which requires very little post etching. The final weld operation must not contaminate the cavity surface. Preliminary welding studies show that both these conditions can be met.

During the first and second years, we plan to make several single cell cavities with the improved (re-entrant) shapes and prove out novel half-cell purification, electropolishing and final welding procedures.

Transferring superconducting rf technology to US industries During the 3rd year, the Cornell SRF group will work closely with US industries to build several multi-cell niobium structures of the advanced geometry with the more economical production and preparation methods. This will be an essential step for industry to develop large scale industrial process for 20,000 cavities. Cornell Research Associates, technicians and graduate students will collaborate with industrial personnel using Cornell facilities described below. As a result, industries will learn the special techniques involved in deep drawing, half-cell purification, half-cell electropolishing, electron beam welding, and final chemical etching. We plan to take the industries through the special procedures of high pressure rinsing and cold testing 9-cell cavities to TESLA gradients of 25 MV/m and above. By using Cornell infra-structure, industries would not have to make the large up-front investment in facilities. Manpower support for Cornell personnel will be paid for out of our regular NSF contract. We anticipate that industrial firms would expect Cornell to cover part of the costs of training time for industrial personnel as contracts.

SRF Infrastructure. Newman Laboratory at Cornell has extensive infrastructure for research and development in RF superconductivity as well as for production, preparation, and testing of superconducting cavities. These facilities have been used to build the prototype SRF cavities for CEBAF and TESLA, as well as all the cavities that power the present storage ring at Wilson Laboratory (CESR). Cavity production facilities include a 100 ton press for deep drawing niobium cavity cells, digital control milling machines for precise die machining, an electron beam welder large enough for TESLA scale cavities, and a large UHV furnace to purify cavity half cells at 1300 C. Cleaning facilities include open and closed cavity etching systems that can handle TESLA type cavities, high purity water rinsing systems, and high pressure (100 atmospheres) water rinsing. There is a new 1100 sq ft Class 100 clean room for cavity assembly and a smaller Class 100 area for preparing smaller test cavities. There are several portable clean room set ups for critical assembly. Test setups include three radiation shielded pits, two of which can accommodate 1300 MHz cavities. We have several cryostats, and cryostat inserts to test cavities from 200 MHz to 3000 MHz, several 200 Watt CW power sources and a 1.5 MW pulsed klystron for high pulsed power processing 1300 MHz cavities. High power testing capabilities exist for windows at 500 MHz and HOM loads at 2450 MHz. Research facilities include a rapid thermometry system for studying single cell 1500 MHz cavities, field emission apparatus, and dedicated scanning electron microscope with energy dispersive analysis for element identification installed in a class 1000 clean room. An Auger System with SIMS Analysis capabilities augments our surface analysis capabilities.

FY2004 Project Activities and Deliverables

Studies of the sources of high field Q-slope and quench field in Nb cavities: This work will span the entire three year proposal period. As gradients in superconducting cavities continue to rise toward the theoretical upper limit, we expect new loss mechanisms to arise that will need investigation.

Improved Geometries, Fabrication and Preparation: The first year's deliverables will be progress reports and papers to conferences and journals on studies to optimize the shape of cavities.

FY2004 Project Activities and Deliverables

Studies of the sources of high field Q-slope and quench field in Nb cavities: This work will continue in the second year. The second year's deliverables will be progress reports and papers.

Improved Geometries, Fabrication and Preparation: The second year's deliverables will be single cell cavities with improved shapes and test results, as well as progress reports and papers.

FY2006 Project Activities and Deliverables

Studies of the sources of high field Q-slope and quench field in Nb cavities: This work will continue in the third year. There will be a final report.

Improved Geometries, Fabrication and Preparation: Through the technology transfer program to US industry, we will fabricate two to three multi-cell niobium structures and test these structures at 2K. There will be a final progress report.

Budget justification and three-year budget, in then-year K$

Institution: Cornell University

Item	FY2004	FY2005	FY2006	Total
Equipment	5	5	10	20
Materials and Supplies	3	6	106	15
Other direct costs: Surface Analysis Contracts	0	5	10	15
Other direct costs: Industrial Personnel	0	0	50	50
Total direct costs	8	16	176	200
Indirect costs	1.74	6.38	96.280	104.40
Total direct and indirect costs	9.740	22.380	272.280	304.40

Equipment: Computers for thermometry data acquisition RF for cavity testing
Materials & Supplies: helium, nitrogen, niobium, acids, In the third year, funds are provided for niobium cavity fabrication.
Surface Analysis: Hourly rate to Evans East for SIMS, XPS
Industrial personnel for technology transfer program in third year

References

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5 Accelerator Control

5.1 Investigation of GAN Techniques in the Development and Operation of the TTF Data Acquisition System

Personnel and Institution(s) requesting funding

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Project Overview

It is generally agreed that a future Linear Collider can only be built and operated as a truly international project. The Global Accelerator Network was conceived as an idea to facilitate sharing of world-wide competence and resources. While the GAN idea is applicable to many aspects of the Linear Collider project we will concentrate on accelerator control and remote operation which are central to the GAN concept. At the first International Workshop on Global Accelerator Network concepts held earlier this year at Cornell University [1] it became clear that remote operation and control can be carried out with today's technology — given enough resources. The challenge is to do this with existing resources so that these scarce resources, not necessarily all available at the same geographic location, can be used as efficiently as possible.

Parts of a technical solution that will allow the remote control and operation of a distant accelerator have been demonstrated at DESY, Cornell and elsewhere but a complete control system design using the GAN approach has not been carried out. We propose to evaluate existing collaborative tools required to carry out the system design and develop new ones where needed. To test these concepts, an upgrade program for the data acquisition system (DAQ) for the Tesla Test Facility (TTF) will be carried out so that remote access of TTF data is possible. With reliable remote access to the data, remote operation of the TTF to carry out significant machine studies by accelerator physicists located at remote sites can be effectively and safely conducted. With the upgraded data acquisition system in place, our goal is to carry out beam emittance measurements on the TTF from Cornell.

In addition to the proposed activities at the TTF, we are exploring possible possible collaboration with scientists at both the NLC Test Accelerator facility SLAC and at the Accelerator Test Facility at KEK in Japan. We hope to be able to contribute to the data acquisition and analysis systems at these two test facilities in much the same way as we plan with the TTF.

Tools that allow shared code development as well as documentation are critical for the success of these activities. Affordable video conferencing tools that work reliably in many different countries to exchange ideas across these geographical boundaries are also key to the success of such a collaboration. The effectiveness of these video conferencing tools will be evaluated as part of this project.

TESLA Test Facility

In 1992 the TESLA collaboration began construction of a test facility for a future linear collider. The TESLA Test Facility (TTF) [3] is located at the Deutsches Elektronen-Synchrotron (DESY) in Hamburg and has been in operation with prototype superconducting accelerator sections since 1998. In its current configuration, the TTF is a 300 m long linear accelerator with several cryostats equipped with 9 cell superconducting modules that routinely operate with accelerating gradients of up to 25 MV/m. A laser driven RF gun is the source of electrons. The facility can also be configured as a free electron laser.

The control system of the TTF is based on the Distributed Object–Oriented Control System DOOCS [4] developed at DESY in the early 90's. This control system fulfills many of the requirements for a future linear collider control system. Its object–oriented design from the device server level up to the operator console makes it modular and flexible. The design uses the standard Ethernet communication protocol based on remote procedure calls (RPCs) that allows for remote operation of the TTF control system. The multi–protocol architecture for device servers permits the incorporation of any equipment contribution from an international collaborator without changing the interface to the control system. Remote operation of the TESLA test facility has been carried out from two collaborating sites demonstrating the GAN capabilities of this control system.

Not only will operation and control of the machine move from one institution to another in a GAN–enabled world but each remote site will require the ability to access and analyze the data collected during the operation of the TTF. Institutions that contribute essential hardware to the accelerator system will need to study the hardware behavior during operation and analyze the collected information. This is invaluable for detecting potential problems with the design and also for monitoring the long–term behavior in a real environment. For this, a data acquisition system similar to those in HEP experiments can provide an ideal solution. HEP experiments generate large amounts of data as well as high data rates which will be the case for the TTF and a future linear collider.

TTF Data Acquisition System

To meet these needs for the TTF, an accelerator data acquisition project was started in 1997 and began operating last year. It was considered as a proof–of–principle system with a final system to follow.

This prototype system uses the well-known ROOT framework [5] from HEP experiments on top of DOOCS. ROOT has become, since its initial development in 1995, a full–fledged analysis tool. It is well suited for handling large amounts of data and the large file sizes that are expected for the LHC experiments. With full diagnostics and control the TTF data acquisition system will generate similar data streams. ROOT has very good histogramming and visualization capabilities with a large number of statistical functions. If these are not sufficient, the built–in C++ interpreter permits running any standard C++ code. Since it is used widely in HEP, support from other groups and laboratories is excellent. The current analysis tools in the prototype system, based on MatLab, will be complemented by tools based on ROOT.

The current TTF DAQ does not fit well into a GAN world since it is locally installed and is not easily used from remote sites. A better data storage concept is needed which supports remote access and remote usage of ROOT specific tools. We propose to take this existing system as a starting point and then develop and build GAN–enabled data acquisition parts into it. With the new data acquisition system in place, we plan to carry out beam emittance measurements on the TTF from Cornell.

Collaborative Tools

Central to the success of this project is the incorporation and evaluation of collaborative tools to accomplish both the distributed development and the remote operation of the the TTF DAQ system. We will explore the sociological and technical issues in this effort, keeping in mind the broader context of further linear collider research, development and operation.

Video conferencing will be the primary means of minimizing the effects of distance, to as great a degree as possible, between geographically distributed participants. We plan to use VRVS as an affordable video conferencing system at the core of our collaborative tool set. We will provide point–to–point and multi–point capability (i.e. a reflector) so that all members of the effort can be in optimal communication regardless of where they are working.

Besides video conferencing, we plan to evaluate several tools including whiteboards, documentation systems, code development environments and repositories. All these systems have to fulfill GAN specific requirements: easy accessibility from all collaboration sites, support for multiple platforms and languages, shared and restricted access levels, safe storage, and the capability of working on low-bandwidth connections (not withstanding the higher bandwidth requirements of video conferencing).

Considerations of security will be important in the deployment of these tools. The ability to function through firewalls without opening up holes that might introduce vulnerability to the networks involved will be essential.

As the development and deployment of the TTF DAQ progresses, we will evaluate the effectiveness of these distributed collaborative techniques. We will be looking at sociological factors, the impact of latency inherent in the network, and other aspects of working over geographical distances.

FY2004 Project Activities and Deliverables

The first year will be dedicated to the evaluation of possible extensions to the existing prototype of the TTF data acquisition system. The main focus will be on global accelerator network specific enhancements. Data storage concepts which will allow for easy access to the recorded data by off–site collaborators will be developed. A first concept design will be carried out and a prototype system will be developed. Collaboration with scientists at the NLC TA and the ATF at KEK will be actively pursued to provide assistance on similar problems that these facilities face.

In addition, the first stage of collaborative tools will be deployed including video conferencing tools as well as code design and development environments.

Deliverables for the first year will be the prototype of a database and management system and a report on the effectiveness of using collaborative tools in an early project design and development stage.

FY2005 Project Activities and Deliverables

The main focus for this year will be further development of the database and developing tools needed for retrieving the data in a GAN environment. In addition, the first prototypes of visualization and analysis programs will be developed. Active collaboration with the NLC TA and/or the KEK ATF groups should be underway.

Deployment of collaborative tools especially for code management and documentation will be necessary for this part of the project. The documentation of the existing data acquisition and the added database will be carried out using these tools.

Deliverable items will be a usable database for the TTF DAQ as well as the first parts of a documentation system covering database and data retrieval. Remote operation of the TTF to carry beam emittance measurements will be attempted from Cornell.

FY2006 Project Activities and Deliverables

In the third year we will focus on the development of visualization and analysis tools. We will investigate if the standard HEP software package ROOT is suitable for this purpose and if it can be used in parallel or even replace the commercial product MatLab. Collaboration with the NLC TA and/or the KEK ATF groups will continue.

A technical report on the use and exploration of collaborative tools during the three years of developing and implementing the software will be provided.

Budget justification

We have used current information and/or actual experience plus inflation rates of 5% for salaries and 3% for other expenses as appropriate. We have assumed a start date of October 1, 2003 in calculating indirect costs and fringe benefits. We have requested funds for a half time graduate student in the last year of the proposal at Ohio State University. We have requested funds for part time undergraduate students for the second and third years of the proposal at Ohio State University.

The computer related items are required to carry out the collaborative development program and consist primarily of desktop video conferencing tools. Required database software, and software management tools for the collaborative development of the data acquisition software are also included.

Travel funds for Ohio State University are requested to cover the cost of attending needed meetings among the collaborators to carry out the proposed program.

Three–year budget, in then–year K$

Institution: Cornell University

Item	FY2004	FY2005	FY2006	Total
Other Professionals	0	0	0	0
Graduate Students	0	0	0	0
Undergraduate Students	0	0	0	0
Total Salaries and Wages	0	0	0	0
Fringe Benefits	0	0	0	0
Total Salaries, Wages and Fringe Benefits	0	0	0	0
Equipment	0	0	0	0
Desktop VRVS Systems	2	6	6	14
Control Room VRVS System	0	3	0	3
VRVS Reflector	4	0	0	3
Whiteboard	0	4	0	4
Network Equipment	1	2	3	6
Router	0	0	0	0
Web/Database Server	0	3	2	5
Database software	3	3	3	9
Collaborative Software	5	10	15	30
Travel	0	0	0	0
Materials and Supplies	0	0	0	0
Other direct costs	0	0	0	0
Ohio State subcontract	5.233	11.213	31.844	48.290
Total direct costs	20.233	42.213	60.844	123.290
Indirect costs(1)	10.061	20.895	19.044	50.000
Total direct and indirect costs	30.294	63.108	79.888	173.290

(1) Includes 26% of first $25K subcontract costs

Institution: Ohio State University

Item	FY2004	FY2005	FY2006	Total
Other Professionals	0	0	0	0
Graduate Students	0	0	10	10
Undergraduate Students	2	4	4	10
Total Salaries and Wages	2	4	14	20
Fringe Benefits	0	0	0.3	0.3
Total Salaries, Wages and Fringe Benefits	2	4	14.3	28.3
Equipment	0	0	0	0
Travel	1.5	1.5	4	7
Materials and Supplies	0	2	3	5
Other direct costs	0	0	0	0
Total direct costs	3.5	7.5	21.3	32.3
Indirect costs (49.5 %)	1.733	3.713	10.544	15.99
Total direct and indirect costs	5.233	11.213	31.844	48.29

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