Comments from S3 Task Force on CesrTA Proposal

19 March, 2007

A proposal has been developed for a program of experimental studies at CESR, in support of the research and development necessary for the ILC damping rings. The proposed program addresses topics already identified as Very High Priority by the S3 Task Force, namely:

- Electron cloud effects;
- Ion effects;
- Ultra-low emittance tuning and operation.

Detailed plans have been drawn up for studies in FY08-FY10; it is envisaged that the program would continue beyond that period, depending on the results of studies in the first years of operation. The timescale on which CesrTA would deliver results is well-matched to the overall timescale for the ILC, in particular the completion of an Engineering Design Report by 2010.

Over the course of each year, CesrTA operations would account for roughly 1/3 of the time, CHESS (light source) operations would account for a further 1/3 of the time, with the remaining 1/3 of a year being down-time for maintenance and installation of equipment. Regarding resources, the present situation is that funding is available to cover the bulk of operational and R&D expenses in FY08, but there is some shortfall that must be covered if the CesrTA proposal is to proceed. Every effort has already been made to address the FY08 shortfall by reducing the cost of the proposed CesrTA program, or by reducing regular operational expenditure. The funding for FY09 and beyond is much less certain.

The S3 Task Force has discussed the CesrTA proposal in the context of the prioritized research and development program. We have considered in particular:

- The necessity for the proposed studies in addressing areas of known technical risk;
- The potential impact on the design and cost of the ILC;
- The possibility of pursuing at other facilities the studies proposed for CesrTA;
- Possible modifications to the CesrTA program to reduce costs.

This document summarizes our conclusions and recommendations.

We acknowledge that funding for the CesrTA program could impact other areas of ILC research, although we would request that the funding agencies make the necessary additional funds available, so as to avoid any adverse effects. There are examples of ILC R&D projects that are resourced internationally, but it is not felt realistic to put such a model in place for CesrTA in the time available.

It is important to note that the studies proposed for CesrTA were included in the damping rings R&D plans before the shortfall in funds for FY08 became apparent. Therefore, although it was known that the CesrTA program would address very high priority R&D

items, the available funds for damping rings R&D in the US for FY08 have already been fully allocated to support other, equally high priority, R&D activities.

It is important to recall that for the ILC to achieve its luminosity goals (and hence its physics goals), the damping rings have to meet their performance specifications for producing very stable, high intensity, ultra-low emittance beams on a routine basis. The beam quality required goes beyond what has been demonstrated in existing facilities, even after years of concerted effort. The present configuration has been developed with reduction in technical risk a key consideration. However, while the beam quality specifications are believed to be achievable, the need to keep construction costs to an acceptably low level has required some design decisions that can only be justified by a continuing experimental R&D program. This R&D program has to produce results on the timescale of the EDR, if machine construction is to be approved. CesrTA is needed to allow significant activities within this R&D program to take place on the required timescale.

Electron Cloud Effects

Electron cloud was a performance limitation in the B-factories, which was overcome by wrapping solenoids around the beam pipe, to trap the electrons close to the vacuum chamber walls. In the ILC positron damping ring, there are significant sections of the ring, namely the bending magnet and wiggler sections, where solenoid fields will not be an effective countermeasure against electron cloud, because of the strong dipole fields. The original configuration for the ILC damping rings specified two positron damping rings, to halve the beam current in each ring and thereby mitigate the build-up of electron cloud. To reduce costs, the configuration was changed during studies for the Reference Design Report to eliminate one positron ring; this decision assumed continued R&D into electron cloud mitigation techniques as a very high priority for ILC. The risk for the ILC, based on present understanding of electron cloud effects, is that build-up of electrons in the vacuum chamber of the positron damping ring could significantly limit beam quality and intensity; and that modifications to fix any problem could be expensive (if long sections of vacuum chamber need to be replaced, for example) and time-consuming.

Several techniques appear promising, including coatings with low secondary-electron yield, grooved chambers, and the use of clearing electrodes. However, the configuration choice for a single positron damping ring can only be validated by experimental demonstration of the effectiveness of one or more of these techniques, and the wiggler section is of particular importance. Experimental tests of electron-cloud suppression methods are in progress in PEP-II, but these will not address regions with strong wiggler fields. Studies of electron cloud are also possible at KEK-B, but tests in the appropriate regime of strong wiggler fields and low beam emittance will not be possible without significant effort to install new equipment; and the operational schedule for KEK-B means that the results necessary to validate the present ILC configuration would not be available on the timescale of the EDR.

Electron cloud studies in wigglers comprise a key part of the studies proposed for CesrTA. The baseline specifications for the ILC damping wigglers match the parameters of the wigglers already installed in CESR-c; and there is the potential for reproducing beam parameters similar to those specified for ILC. Both of these conditions are essential for tests of electron cloud mitigation techniques to validate the baseline configuration of the ILC positron damping ring, and only CesrTA offers the opportunity for these tests on a timescale matching the EDR.

Ion Effects

Ion effects are a potential limitation on beam quality in the electron damping ring of the ILC. Conventional ion trapping can be avoided by introducing gaps in the fill pattern of bunches in the ring; but ions can still accumulate over the passage of a relatively small number of bunches. Present estimates suggest that for the ILC, an extremely low vacuum pressure must be maintained and a high-performance feedback system implemented to prevent ion effects from limiting beam stability. There are still considerable uncertainties in the estimates of the impact of ion effects, because of the complexity of the interaction with the electron beam and a lack of quantitative experimental data. Although observations have been made at a range of machines, including the ALS, PLS and ATF, it is difficult to achieve and maintain beam quality in the ultra-low emittance regime where fast ion effects become important; and the high-precision instrumentation needed to quantify the effects from ions has been lacking. Further experimental studies are planned at the ATF, but it is unlikely that all issues with ion effects can be resolved before the focus of attention at that facility turns to ATF2.

Reliable estimates of ion effects are essential to validate the design of the ILC damping rings, including the basic parameters for the configuration (such as the circumference and fill patterns) and specifications for the technical subsystems (notably the vacuum system and bunch-by-bunch feedback system). Mitigating ion effects after commissioning, if they prove more severe than expected, could be difficult and expensive. CesrTA provides a valuable opportunity to collect data that will improve our ability to make reliable estimates of the impact of ion effects on the electron damping ring. A detailed understanding of the dynamics of fast ion effects will allow any necessary design modifications and optimization to be made before final engineering design work is undertaken.

Ultra-Low Emittance Operation

The luminosity goal of the ILC depends on achieving 2 pm vertical emittance in the beam extracted from the damping rings. Since, after considerable effort, the lowest achieved emittance in any operating electron storage ring is a factor of two larger than this (at the KEK-ATF), we regard the demonstration of the specified ILC emittance as a very high priority. Work is needed to develop effective techniques for tuning for ultra-low emittance, and for maintaining the emittance over long periods. It is worth noting that with emittances in the range of 2 pm, the beam quality is sensitive to the positions of the magnets at the scale of a few microns. Results from ultra-low emittance tuning studies on the timescale of the EDR will impact the damping rings design by indicating specifications for the lattice design, and the number, locations and required performance of the instrumentation and diagnostics, and coupling correction components. The beam position monitors and advanced instrumentation for fast measurements of micron-scale beams are particularly important in this regard. It is also worth noting that all of the other tests of low emittance tuning are being carried out with electrons. CesrTA is the only facility that offers the possibility of carrying out such tests with positrons. It may well be that a comparison of electron and positron behavior—inside a common vacuum chamber for both beams—will be critical to a full understanding of the mechanisms that could limit reaching ultra-low emittance.

Tuning studies for ultra-low emittance are planned at the ATF and at the Advanced Photon Source (APS). Upgrade of the BPM system at the ATF is in progress, and it is hoped that the improved diagnostics will lead to demonstration of 2 pm vertical emittance. However, given that the difficulty of obtaining the required emittance is dependent on details of the design of the lattice, and the diagnostics and coupling correction systems, experience at a range of storage rings is highly desirable. In the next couple of years, the focus of activities at the ATF will move towards ATF2 and issues to do with the beam delivery system and final focus. This will limit the availability of the ATF storage ring for ILC damping rings studies. The APS is a user facility that again will have limited availability for ILC damping ring studies. There is rarely significant demand from the user community at a light source for regular operation with ultra-low vertical beam emittances; in fact, such operation adversely impacts performance by reducing beam lifetime.

CesrTA offers a valuable opportunity, not simply to demonstrate the ultra-low emittance required for the ILC damping rings, but also:

- to develop techniques that will be required to maintain ultra-low emittance over long periods;
- to gain experience with low-emittance tuning and stabilization techniques that will be invaluable in the design of the lattice, diagnostics and coupling correction scheme for the ILC damping rings;
- to make use of the ultra-low emittance beam in essential tests of a range of beam dynamics issues in the low emittance regime, notably for studies of electron cloud and fast ion instability;
- to facilitate the development of instrumentation capable of making fast beam size measurements with micron resolution.

There is significant expertise and experience among the accelerator physics group with optics characterization and tuning in CESR. The goal for CesrTA is to operate routinely with emittances in the range 5 – 10 pm (at low bunch charge), which would be an interesting regime for a number of beam dynamics studies, including electron cloud and ion effects. Coupling correction simulations suggest that it may be possible to achieve emittances below 5 pm at CesrTA. At higher bunch charges, intrabeam scattering is likely to increase the vertical emittance by a factor of two or more above the value in the limit of low charge.

Achieving emittances of a few picometers at CesrTA is a demanding goal that is likely to require an upgrade of some diagnostics, such as the beam position monitors. While restricting the scope of such an upgrade could save costs, it increases the risk that the target emittance might not be achieved, with consequent limitation on the beam dynamics studies and further instrumentation development. For this reason, we feel that the proposed upgrade of the diagnostics system should be supported as an important component of the program.

Ultra-Low Emittance Diagnostics

A significant obstacle to successful tuning for 2 pm emittance in existing storage rings has been the lack of a fast emittance diagnostic with the necessary resolution. Laser wires presently provide the most advanced capability for ultra-low emittance measurements. However, a precision beam-size measurement with the laser wire in the KEK-ATF, for example, takes several hours, which makes it impractical to optimize the coupling correction on beam-size measurements directly. Instead, indirect measurements (such as orbit response matrices) have to be relied upon to determine the coupling correction, and such procedures are themselves inefficient and prone to inaccuracy. Development of a picometer-emittance diagnostic with, ideally, bunch-by-bunch and turn-by-turn measurement capability will be essential for the ILC damping rings, and the absence of such a device could severely limit commissioning and operation with noticeable impact on ILC luminosity. As well as potentially making a significant contribution to the achievement of vertical emittances in the range of a few picometers at CesrTA, and hence enabling a range of studies of beam dynamics in the regime of ultra-low emittance, knowledge of the design and experience with the operation of a fast, ultra-low emittance diagnostic could have some impact on the EDR specification and design of the damping rings. For example, specifications of alignment tolerances, coupling correction schemes and tuning schedules will be dependent on estimates of the ease of achieving and maintaining vertical beam emittances of a few picometers, which in turn depend on the available instrumentation and diagnostics.

Development of a fast, ultra-low emittance diagnostic is a highly appropriate project for CesrTA, since it fits extremely well with the proposed program of beam dynamics studies at ultra-low emittance. The CesrTA proposal includes development of an X-ray beam size monitor potentially capable of bunch-by-bunch and turn-by-turn measurements of transverse beam profiles in the few-picometer emittance regime. Studies for fast, ultra-low emittance beam instrumentation have also been proposed (to DOE) by ANL, but have not been funded. It was expected that development of the required instrumentation would be performed at Cornell, as part of the CesrTA proposal. Proper development of fast, ultra-low emittance instrumentation requires ready access to a storage ring operating in the appropriate regime; few, if any, such facilities currently exist, but one would be provided by the CesrTA proposal.

General Issues and Comments

We note that significant effort has been made to reduce the costs of the proposal while maintaining a meaningful and coherent program. For example; the original proposal specified a bunch length in CesrTA of 6 mm, but since a change in the baseline specification for the ILC damping rings in favor of a 9 mm bunch length, a corresponding change has been made in the specification for CesrTA. This has resulted in the elimination of some RF cavities and power supplies. Some reduction in scope of the upgrade of the BPM system, and reduction in power available for longitudinal feedback have also been considered. However, these changes to the proposal are undesirable because of the limitations that could result in beam quality (emittance) and intensity, respectively.

As mentioned previously, providing substantial resources for CesrTA on an international model has also been discussed, but is not considered realistic on the timescale set for the EDR. On the other hand, a number of international groups have expressed an intention to collaborate on the CesrTA program; examples include a group from Oxford University working on automated systems for precision alignment, and the ATF group from KEK, who are interested in a range of instrumentation and beam dynamics studies.

Conclusions

To reduce construction costs for the ILC damping rings, decisions for the baseline configuration have been made that require validation for the EDR. CesrTA would provide a unique opportunity to validate key decisions on the timescale of the EDR; for example, demonstration of control of electron cloud in the wigglers is necessary to validate the choice for a single positron damping ring. The proposal describes a coherent program that directly addresses critical issues of beam quality and stability in the ILC damping rings, as well as potentially providing a facility for development and tests of critical components, such as the injection/extraction kickers. We recommend that every effort be made to fund the CesrTA proposal, consistent with maintaining continued progress in the other key areas of damping ring R&D.