ILC Damping Rings R&D Plan

Summary of Work Packages, Resource Requirements and Deliverables

Revision 8: 28 May 2007

The R&D Objectives identified as "Very High Priority" are contained within the following Work Packages:

S3 WBS	Work Package	S3 WP Coordinator(s)
2.1.1	Lattice Design	Mike Zisman
2.1.4	Low-Emittance Tuning	Andy Wolski
2.2.1	Impedance-Driven Single-Bunch Instabilities	Marco Venturini
2.2.3	Electron Cloud	Mauro Pivi
2.2.4	Ion Effects	Mauro Pivi & Marco Venturini
3.5.1	Fast Injection/Extraction Kickers	Tom Mattison

Staff Effort (FTE; excludes operational support for Facilities)

S3 WBS	2007	2008	2009	2010
2.1.1	3.0	3.0	1.5	1.0
2.1.4	7.5	7.5		
2.2.1	4.5	4.5		
2.2.3	8.5	9.0		
2.2.4	6.0	4.0	4.0	
3.5.1	8.0?	8.0?		

M&S (US$k; excludes operating costs for Facilities)

S3 WBS	2007	2008	2009	2010
2.1.1	0	0	0	0
2.1.4	350	350	100	100
2.2.1	0	0		
2.2.3	762	782		
2.2.4	200?	200?		
3.5.1	1,000?	1,000?	1,000?	

Travel (US$k)

Travel costs are estimated at the rate of US$10k per FTE-year.

S3 WBS	2007	2008	2009	2010
2.1.1	30	30	15	10
2.1.4	75	75		
2.2.1	45	45		
2.2.3	85	90		
2.2.4	60	40	40	
3.5.1	80	80		

Facilities

S3 WBS	
2.1.1	None required
2.1.4	CesrTA, ATF, ALS, APS
2.2.1	None required
2.2.3	CesrTA, PEP-II, KEKB, DAΦNE, (LHC)
2.2.4	CesrTA, ATF
3.5.1	ATF, FNAL-A0, DAΦNE, (CesrTA)

Key Deliverables (of Very High Priority Objectives)

Objective 2.1.1.1: Lattice design for baseline positron damping ring

- Baseline lattice design with acceptable properties.
- Lattice description including geometrical layout, magnet parameters and specifications, aperture requirements, lattice parameters (e.g., momentum compaction, damping times, natural emittance, natural energy spread), estimate of dynamic aperture, and injection and extraction system specifications.
- Lattice documentation (including MAD input and output files).

Objective 2.1.1.2: Lattice design for baseline electron damping ring

- Baseline lattice design with acceptable properties.
- Lattice description including geometrical layout, magnet parameters and specifications, aperture requirements, lattice parameters (e.g., momentum compaction, damping times, natural emittance, natural energy spread), estimate of dynamic aperture, and injection and extraction system specifications.
- Lattice documentation (including MAD input and output files).

Objective 2.1.4.3: Demonstrate < 2 pm vertical emittance

- Demonstration that the vertical emittance goal of 2 pm in the damping rings is achievable.
- A range of essential information and data for improving the completeness of low-emittance tuning simulations, for optimising low-emittance tuning techniques (Objective 2.1.4.1), and for specifying design requirements for the lattice, coupling correction schemes (2.1.4.5), instrumentation and diagnostics performance, and survey and alignment accuracy (Objective 2.1.4.2).

Objective 2.2.1.2: Characterization of single-bunch impedance-driven instabilities

- Estimates of the instability thresholds.
- Characterization of the beam dynamics associated with the instability.
- Feedback and guidance on the specifications and technical designs for the lattice and vacuum chamber components.

Objective 2.2.3.1: Characterize electron-cloud build-up

- Detailed and reliable description of electron cloud density in various sections (wiggler, bends, quadrupoles, field-free) of the positron damping ring, under a variety of possible conditions. The conditions will include ranges of beam parameters, and specifications for the vacuum system, and for the wiggler and other magnets.

Objective 2.2.3.2: Develop electron-cloud suppression techniques

- Technical specifications for techniques to be used to suppress build-up of electron cloud in the positron damping ring, consistent with aperture and impedance requirements.
- Guidance for the design of the vacuum chamber material and geometry (Objective 3.1.1.1), and for the technical designs for principal vacuum chamber components (Objective 3.1.1.2).

Objective 2.2.3.3: Develop modeling tools for electron-cloud instabilities

- Support for the determination of electron-cloud instability thresholds (Objective 2.2.3.4) for the positron damping ring.
- Guidance for the specification of the secondary electron yield as input for the characterization of an electron-cloud build-up (Objective 2.2.3.1).

Objective 2.2.3.4: Determine electron-cloud instability thresholds

- Prediction of the electron cloud driven single-bunch instability threshold for the positron damping ring.
- Specification of the maximum permissible cloud density in the positron damping ring, as a target for the development of mitigation techniques (Objective 2.2.3.2).

Objective 2.2.4.1: Characterize ion effects
and Objective 2.2.4.2: Specify techniques for suppressing ion effects

- Experimental validation of theoretical models and simulation tools for the fast ion instability.
- Indication of machine design parameters (including bunch filling patterns, lattice optics, feedback and vacuum specifications) capable of delivering a beam with the required quality and stability without limitations from ion effects.
- Guidance for optimization of design of vacuum and feedback systems, and optimization of the optics design, to avoid limitations from ion effects.

Objective 3.5.1.1: Develop a fast high-power pulser for injection/extraction kickers

- *Deliverables to be defined.*

Work Package 2.1.1
Lattice Design

Work Package Coordinator: Michael Zisman

Potential Investigators

ANL
Louis Emery
Aimin Xiao

Cockcroft Institute
James Jones
Andy Wolski

Cornell
Mark Palmer
David Rubin

IHEP
Jie Gao
Yi-peng Sun

LBNL
Gregg Penn
Ina Reichel
Weishi Wan
Mike Zisman

SLAC
Yunhai Cai

Summary of Required Resources

Objectives

S3 WBS	Objective	Priority
2.1.1.1	Lattice design for baseline positron ring	Very High
2.1.1.2	Lattice design for baseline electron ring	Very High

Staff Effort (FTE; excludes operational support for Facilities)

S3 WBS	2007	2008	2009	2010
2.1.1.1	2.0	2.0	1.0	0.5
2.1.1.2	1.0	1.0	0.5	0.5

M&S (US$k; excludes operating costs for Facilities)

S3 WBS	2007	2008	2009	2010
2.1.1.1	0	0	0	0
2.1.1.2	0	0	0	0

Travel (US$k)

Travel costs are estimated at the rate of US$10k per FTE-year.

S3 WBS	2007	2008	2009	2010
2.1.1.1	20	20	10	5
2.1.1.2	10	10	5	5

Facilities

None required.

Objectives

Objective 2.1.1.1: Lattice design for baseline positron damping ring

High Priority

The lattice for the positron ring must meet many functional requirements. In particular, the lattice must provide:

- circumference compatible with all beam scenarios proposed for the ILC linacs;
- damping time of ≈ 25 ms;
- acceptance adequate to accommodate undamped positron beam;
- geometry compatible with conventional facilities requirements (e.g. the central injector complex);
- momentum compaction factor compatible with instability threshold requirements, and other dynamical and technical considerations (e.g. RF voltage requirements);
- acceptable values for emittance ($\gamma\varepsilon_x < 8$ nm) and energy spread ($\approx 1 \times 10^{-3}$);
- acceptable sensitivity to magnet misalignments and vibrations;
- space to accommodate components for injection, extraction, wigglers, diagnostics;
- adjustability of momentum compaction, emittance, circumference as needed to meet the above requirements.

Because the performance of the damping rings complex, as well as the specifications of much its hardware, depend on the lattice, it is important to complete and "freeze" the lattice design as soon as possible. Moreover, the criticality of this design means that an alternative design must also be explored to permit a choice of approach to be made before finalizing the design.

A number of updates to the present working lattice and the alternative design are needed before the lattice configuration can be frozen:

- incorporate RF configuration reflecting RDR changes;
- provide for circumference adjustability;
- provide for flexibility in the momentum compaction factor;
- provide location for abort dump;
- include the ability to provide a phase trombone;
- lumped injection and extraction kickers;
- separated injection and extraction straight sections;
- specify possible locations for dipole and skew quadrupole correctors to permit low-emittance tuning studies;
- specify bpm locations;
- define nomenclature for ring elements;
- specify beam-stay-clear apertures;
- demonstrate adequate dynamic aperture using realistic error tolerances.

Principal Investigators on these tasks will be:

Yunhai Cai
Louis Emery
Jie Gao
Mark Palmer
Gregg Penn
Ina Reichel
David Rubin
Yi-peng Sun
Weishi Wan
Andy Wolski
Aimin Xiao
Mike Zisman

Objective 2.1.1.2: Lattice design for baseline electron damping ring

High Priority

The lattice for the electron ring must meet many functional requirements. In particular, the lattice must provide:

- circumference compatible with all beam scenarios proposed for the ILC linacs;
- damping time of ≈ 25 ms;
- acceptance adequate to accommodate undamped positron beam;
- geometry compatible with conventional facilities requirements (e.g. the central injector complex);
- momentum compaction factor compatible with instability threshold requirements, and other dynamical and technical considerations (e.g. RF voltage requirements);
- acceptable values for emittance ($\gamma\varepsilon_x < 8$ nm) and energy spread ($\approx 1 \times 10^{-3}$);
- acceptable sensitivity to magnet misalignments and vibrations;
- space to accommodate components for injection, extraction, wigglers, diagnostics;
- adjustability of momentum compaction, emittance, circumference as needed to meet the above requirements.

Because the performance of the damping rings complex, as well as the specifications of much its hardware, depend on the lattice, it is important to complete and "freeze" the lattice design as soon as possible. Moreover, the criticality of this design means that an alternative design must also be explored to permit a choice of approach to be made before finalizing the design.

A number of updates to the present working lattice and the alternative design are needed before the lattice configuration can be frozen:

- incorporate RF configuration reflecting RDR changes;
- provide for circumference adjustability;
- provide for flexibility in the momentum compaction factor;

- provide location for abort dump;
- include the ability to provide a phase trombone;
- lumped injection and extraction kickers;
- separated injection and extraction straight sections;
- specify possible locations for dipole and skew quadrupole correctors to permit low-emittance tuning studies;
- specify bpm locations;
- define nomenclature for ring elements;
- specify beam-stay-clear apertures;
- demonstrate adequate dynamic aperture using realistic error tolerances.

Principal Investigators on these tasks will be:

Yunhai Cai
Louis Emery
Jie Gao
Mark Palmer
Gregg Penn
Ina Reichel
David Rubin
Yi-peng Sun
Weishi Wan
Andy Wolski
Aimin Xiao
Mike Zisman

Work Package 2.1.4
Low Emittance Tuning

Work Package Coordinator: Andy Wolski

Potential Investigators

ANL
Louis Emery
Vadim Sajaev
Aimin Xiao

Cockcroft Institute
James Jones
Kosmas Panagiotidis
Andy Wolski

Cornell
Scott Chapman
Don Hartill
Richard Helms
Mark Palmer
David Rubin
Maury Tigner

KEK
Kiyoshi Kubo
Junji Urakawa

LBNL
Gregg Penn
Ina Reichel
Marco Venturini
Mike Zisman

Oxford University
Armin Reichold
David Urner

SLAC
Yunhai Cai

Summary of Required Resources

Objectives

S3 WBS	Objective	Priority
2.1.4.1	Develop strategies for low-emittance tuning	High
2.1.4.2	Specify requirements for survey, alignment and stabilization	High
2.1.4.3	Demonstrate < 2 pm vertical emittance	Very High
2.1.4.4	Specify support schemes for damping rings magnets	High
2.1.4.5	Specify orbit and coupling correction scheme	High

Staff Effort (FTE; excludes operational support for Facilities)

S3 WBS	2007	2008	2009	2010
2.1.4.1	2.0	2.0		
2.1.4.2	0.5	0.5		
2.1.4.3	2.0	2.0		
2.1.4.4	2.0	2.0		
2.1.4.5	1.0	1.0		

M&S (US$k; excludes operating costs for Facilities)

S3 WBS	2007	2008	2009	2010
2.1.4.1	0	0		
2.1.4.2	0	0		
2.1.4.3	350	350		
2.1.4.4	0	0	100	100
2.1.4.5	0	0		

Travel (US$k)

Travel costs are estimated at the rate of US$10k per FTE-year.

S3 WBS	2007	2008	2009	2010
2.1.4.1	20	20		
2.1.4.2	5	5		
2.1.4.3	20	20		
2.1.4.4	20	20		
2.1.4.5	10	10		

Facilities

Experimental studies at CesrTA, ATF, ALS and APS are required to complete Objectives 2.1.4.1, 2.1.4.2 and 2.1.4.3. Results from these studies are also required for Objectives 2.1.4.4 and 2.1.4.5.

Objectives

Objective 2.1.4.1: Develop strategies for low-emittance tuning

High Priority

The baseline parameters for the ILC specify an extracted normalized vertical emittance of 20 nm from the damping rings; this corresponds to a geometric emittance of 2 pm at the damping rings' energy of 5 GeV. Although there is a budget of 10 nm normalized emittance growth between the damping rings and the interaction point, any increase in the vertical emittance extracted from the damping rings will have a direct adverse impact on the ILC luminosity.

There are several effects that contribute to vertical beam emittance in storage rings, but the dominant ones in electron rings (as will be the case for the ILC damping rings) are related to misalignments of the quadrupole and sextupole magnets. Achieving a vertical emittance of the order of a few picometers will depend on three factors:

- appropriate design of the lattice to minimize sensitivity of the vertical emittance to magnet alignment errors;
- precise initial alignment of the magnets (to within tens of microns);
- rigorous and systematic compensation of the residual alignment errors using beam-based techniques.

The lowest vertical emittance achieved in any existing storage ring is 4.5 pm in the KEK-ATF [1]. Some other storage rings, for example the Advanced Light Source at LBNL, have approached this value [2]. The principle difficulty in low-emittance tuning lies in determining the coupling sources with sufficient precision to allow an effective correction to be applied: in the picometer emittance regime, magnet misalignments of a few microns are significant. A further difficulty is that with such low emittances, the beam size is generally just a few microns, and the instrumentation required to make precise beam size measurements in this regime is still under development. This means it is not possible to apply coupling corrections based on simple direct measurements of beam size; instead, more sophisticated approaches are required.

Generally, the first step in minimizing the vertical emittance involves correcting the orbit and dispersion using steering magnets. The second step requires optimum settings to be determined for the corrector magnets, such as skew quadrupoles, used to compensate residual alignment errors. This can be done in a variety of ways: one method that has been applied with some success at the ATF is to minimize the orbit response in one plane (horizontal or vertical) to deflections applied with a small number of carefully selected steering magnets in the other plane (respectively, vertical or horizontal) [3]. Alternative methods include use of orbit response matrix analysis [4], model independent analysis [5] and phase advance analysis [6]. For some of these techniques, efforts to apply them to tuning for vertical emittance in the picometer regime have only recently begun.

Despite considerable effort over several years, the target emittance of the damping rings has not been achieved in any existing facility, and a thorough study of low-emittance tuning techniques is therefore necessary. Such a study should include optimization and comparison of existing techniques, as well as the development of new approaches. The work should be undertaken over the timescale of the

Engineering Design Report, since the results are likely to have some impact on a number of aspects of the damping rings design and specifications, including:

- Lattice design. It is often necessary to make compromises in the design between competing requirements. For example, a particular working point in tune space might be optimum from point of view of dynamic aperture, but poor in terms of the sensitivity of the lattice to alignment errors.
- Alignment specifications. The specifications on the survey alignment of the magnets are presently based on studies that are not completely rigorous, and are known to be demanding, particularly for the baseline configuration in which both damping rings are located in a single tunnel. Improving the effectiveness of coupling correction methods could ease the requirements on the survey alignment.
- Instrumentation and diagnostics. Experience at the ATF has emphasized the critical role of the performance of the instrumentation (particularly the beam position monitors, and beam size diagnostics) in achieving low vertical emittance. The specifications for the instrumentation will depend on the techniques proposed for low emittance tuning. Different techniques have different requirements in terms of functionality (e.g. for turn-by-turn measurements from the BPMs) and performance.

We also note that existing techniques often require considerable time to be spent in data collection and analysis; for example, orbit response matrix analysis at the ATF takes several hours. If frequent tuning of the damping rings is required (as may be expected, given the sensitivity to magnet alignment at the level of a few microns), it will be necessary to develop a technique that can be applied quickly, or, ideally, continuously.

Achieving the objective of developing techniques for low-emittance tuning will involve the following tasks:

1. Evaluate sensitivity of present baseline and alternative lattice designs to a variety of magnet misalignments, and compare the results with the lattices of existing facilities. This will be an ongoing task as new lattice designs are developed.
2. Perform a rigorous comparison of existing low-emittance tuning techniques, to understand how the effectiveness of the various techniques depends on the lattice design, initial survey alignment, and functionality and performance of instrumentation.
3. Develop alternative low-emittance tuning techniques based on, for example, model independent analysis or phase advance analysis, and compare the effectiveness of these techniques with existing methods.

Potential Investigators on these tasks will be:

Richard Helms
Mark Palmer
Kosmas Panagiotidis
Gregg Penn
Ina Reichel
David Rubin
Marco Venturini

Andy Wolski
Mike Zisman

A total effort of 2 FTE per year for two years will be required. Work will include mostly simulation and theoretical studies, though tests of tuning strategies on operating facilities (e.g. ATF, ALS, APS, CesrTA) would be valuable (see Objective 2.1.4.3).

No M&S budget is required.

Work on these tasks is ongoing. The goal is to complete all tasks by the end of 2008 as input for the Engineering Design Report (EDR).

The required input includes:

- Latest damping rings lattice designs; and lattices for existing storage rings to be used for benchmarking and tests.
- Data from previous studies of low-emittance tuning.
- Estimates of anticipated survey alignment precision and diagnostics performance (BPMs, beam size monitors etc.)

The main deliverables will be:

- Guidance on requirements for the damping rings lattice design to ease sensitivity to magnet alignment errors.
- Guidance on the requirements for survey, alignment and stabilization of magnets (Objective 2.1.4.2), and the configuration of the orbit and coupling correction scheme (specification and layout of the diagnostics, and orbit and coupling correction magnets – Objective 2.1.4.5).
- Optimized tuning methods that can be applied to demonstrate vertical emittance of less than 2 pm in existing facilities (Objective 2.1.4.3).

If the objective is not achieved, then achieving and maintaining the specified vertical emittance in the damping rings will be at risk. There could be significant impact on the luminosity of the ILC.

Objective 2.1.4.2: Specify requirements for survey, alignment and stabilization

High Priority

As described for Objective 2.1.4.1, achievement of the specified vertical emittance of 2 pm in the damping rings will depend on accurate survey and alignment of the magnets, particularly the quadrupoles and sextupoles. Current estimates suggest that the required accuracy will be demanding, particularly given two damping rings in a single tunnel. Developments with the lattice design, low emittance tuning techniques (Objective 2.1.4.1) and experimental experience (Objective 2.1.4.3) could all impact the required accuracy of the magnet alignment. It is important that careful studies of the alignment accuracy are carried out, taking account of developments in the lattice design, tuning techniques etc., so that the specifications remain realistic.

Achieving this objective will involve the following task:

1. Use the results of studies of low-emittance tuning techniques (taking account of lattice design developments, instrumentation specifications etc.) to

determine appropriate, realistic specifications on the alignment for the various magnets in the damping rings.

A total effort of 0.5 FTE per year over two years will be required.

No M&S budget is required.

The goal is to complete the task by 2008, to provide results for the Engineering Design Report.

The required input includes:

- Results from studies of low-emittance tuning techniques (Objective 2.1.4.1) showing the dependence of the final achieved vertical emittance on the initial alignment accuracy.
- Information from survey and alignment experts, for the implications (in time and cost) of specifications for different levels of alignment accuracy.

The deliverables will include:

- Guidance for work on lattice design, instrumentation and diagnostics, low-emittance tuning techniques etc., on whether further work is needed to ease requirements on initial alignment of the damping ring magnets.
- Specifications for the survey and alignment accuracy required for the damping ring magnets.

If this objective is not accomplished, there is a risk that the damping ring design will develop in such a way as to require alignment accuracy for the magnets that is unrealistic (not technically feasible), or can only be achieved at excessive cost.

Objective 2.1.4.3: Demonstrate < 2 pm vertical emittance

Very High Priority

Simulation studies leading to the development of low-emittance tuning techniques should take place as defined by Objective 2.1.4.1. However, experimental verification of any technique is essential for validation of any proposed technique. The performance of any low-emittance tuning technique will be sensitive to details of the machine configuration, performance of the instrumentation and diagnostics, and how the technique is implemented. While many important effects (e.g. systematic dependence of BPM readings on bunch charge, temperature, etc.) can be included in the simulations, real-world experience will be essential for providing realistic conditions for use in the simulations. More importantly, validation of any low-emittance tuning technique will ultimately rely on demonstration of its effectiveness in an operating machine; such a demonstration will also be necessary to validate the specifications associated with the technique, including the lattice design, configuration, functionality and performance of the instrumentation, diagnostics and correction elements, and accuracy of survey alignment of the magnets (Objective 2.1.4.2).

Achieving this Objective will require the following tasks:

1. Evaluation of the availability of facilities (for example, ATF, CesrTA, APS, ALS etc.), and their capability to meet the requirements of low-emittance tuning techniques.

2. Upgrade to diagnostics and instrumentation and orbit and coupling correction systems, where necessary.
3. Implementation of low-emittance tuning techniques, and evaluation of the results (and implications for the damping rings).

A total effort of 2 FTE per year for 2 years will be required.

An M&S budget of $250k per year for 2 years will be needed at the ATF, for upgrades to instrumentation and diagnostics (mostly, the BPM electronics). Some additional M&S funds (estimated at $100k per year for 2 years) may be needed at other facilities.

The goal is to demonstrate 2 pm vertical emittance in an operating storage ring by the end of 2008.

This Objective requires access to appropriate facilities (e.g. ATF, CesrTA, APS, ALS). Results from development of low-emittance tuning techniques (Objective 2.1.4.1) are also required.

The deliverables will include:

- Demonstration that the vertical emittance goal of 2 pm in the damping rings is achievable.
- A range of essential information and data for improving the completeness of low-emittance tuning simulations, for optimising low-emittance tuning techniques (Objective 2.1.4.1), and for specifying design requirements for the lattice, coupling correction schemes (2.1.4.5), instrumentation and diagnostics performance, and survey and alignment accuracy (Objective 2.1.4.2).

If the Objective is not achieved, there will remain doubt as to whether the emittance goal of 2 pm in the damping rings is achievable.

Objective 2.1.4.4: Specify support schemes for damping rings magnets

High Priority

The stability requirements on the damping ring magnets are demanding; the magnet stands must be capable of supporting magnets in the upper and lower damping rings with the necessary stability. Vibrations (at tens or hundreds of hertz) and slow ground motion (over hours, days and weeks) are a concern. Magnets may be placed on individual stands, or grouped on girders; the support scheme that is used will affect the relative alignment accuracy that can be achieved between different magnets, and will have implications for orbit and coupling correction. Specifications are needed for magnet supports that will meet the stability requirements. Technical designs for support stands will be needed for the Engineering Design Report.

The following tasks must be completed:

1. Identify the different options for support schemes. Evaluate the impact of the different options on relative alignment accuracy, and low-emittance tuning.
2. Complete a detailed specification for a particular choice of support scheme for the baseline configuration.

3. Prepare technical designs for the magnet supports, which will allow evaluation of the achievable alignment accuracy, and modeling of the magnet vibration and long-term magnet alignment stability.
4. Construct prototype supports, and evaluate stability performance.

A total effort of 2 FTE per year for 2 years will be required.

An M&S budget of $100k will be required for construction of the prototype supports.

Tasks 1-3 should be completed by 2008, to provide results for the Engineering Design Report. Task 4 can be completed following the EDR.

Results from simulations and experimental studies of low-emittance tuning, and from studies of required alignment accuracies (Objectives 2.1.4.1, 2.1.4.3 and 2.1.4.2) will be required as input for the above tasks.

The deliverables will include:

- Specification of baseline magnets support scheme, consistent with alignment and stability requirements (Objective 2.1.4.2) and low-emittance tuning techniques (Objectives 2.1.4.1 and 2.1.4.3).
- Models of magnet vibration and stability for input to studies of low-emittance tuning (Objective 2.1.4.1) and beam stability.
- Prototype magnet supports, ready for final engineering design.

If this Objective is not achieved, the support scheme and the designs of the supports themselves (critical components for achieving and maintaining low emittance and good stability) will remain incomplete before approval is sought for construction.

Objective 2.1.4.5: Specify orbit and coupling correction scheme

High Priority

Achieving and maintaining ultra-low emittance and good beam stability in the damping rings will depend on, amongst other things, the quantities, locations, functionality and performance of the instrumentation and diagnostics, and the orbit and coupling correction elements. The instrumentation and diagnostics that need to be considered in this context are principally the beam position monitors, and devices for measuring the beam size. The orbit and coupling correction elements will principally consist of steering magnets and skew quadrupoles.

Insufficient quantities, poor performance or inappropriate positioning of the instrumentation will make it difficult or impossible to achieve the specified ultra-low vertical emittance, with resulting adverse impact on the ILC luminosity. However, BPMs are expected to make a significant contribution to the machine impedance, which could affect beam stability; it is therefore undesirable to include more BPMs than necessary. Quantities of orbit and coupling correction elements are principally a question of cost; note that costs are incurred not just in the steering magnets and skew quadrupoles themselves, but also in their power supplies, cables, and in the control system.

An optimized scheme for orbit and coupling correction is necessary for the specifications on beam quality and stability to be achieved, without excessive cost or adverse impact on machine impedance. To achieve the Objective of defining an optimized scheme, the following tasks must be achieved:

1. Identify the options for coupling and correction schemes, including variable numbers and positions of monitors and correctors.
2. Evaluate the performance of the various schemes.
3. Specify the coupling and correction scheme for the baseline configuration, including quantities, functionality, performance and locations of the diagnostics and instrumentation, and the orbit and coupling correction elements.

A total effort of 1 FTE per year for 2 years will be required.

No M&S budget will be required.

All the above tasks should be carried on in parallel with developments in the lattice design, and with studies of low-emittance tuning (Objectives 2.1.4.1, 2.1.4.3) and studies of magnet alignment and stabilization (Objectives 2.1.4.2 and 2.1.4.4). The tasks should be completed by the end of 2008, to provide results for the Engineering Design Report.

The main deliverable will be a detailed description and specification for the orbit and coupling correction scheme to be used in the damping rings.

References

[1] Y. Honda et al, "Achievement of Ultralow Emittance Beam in the Accelerator Test Facility Damping Ring," Phys. Rev. Lett. 92, 054802-1 (2004).

[2] C. Steier, D. Robin, A. Wolski, G. Portmann, J. Safranek, "Coupling Correction and Beam Dynamics at Ultralow Vertical Emittance in the ALS," Proceedings of PAC 2003, Portland, Oregon (2003).

[3] K. Kubo, "Simulation Study of Low Emittance Tuning of the Accelerator Test Facility Damping Ring at KEK," Phys. Rev. STAB **6**, 092801 (2003).

[4] J. Safranek et al, "Matlab-based LOCO," Proceedings of EPAC 2002, Paris, France (2002). A. Wolski, M.D. Woodley, J. Nelson, M.C. Ross, "Analysis of KEK-ATF Optics and Coupling Using LOCO," Proceedings of EPAC 2004, Lucerne, Switzerland (2004).

[5] See, for example, Y. Cai, J. Irwin, M. Sullivan and Y.T. Yan, "Application of Model-Independent Analysis to PEP-II Rings," Proceedings of PAC 2001, Chicago, Illinois (2001).

[6] D. Sagan, R. Meller, R. Littauer, D. Rubin, "Betatron Phase and Coupling Measurements at the Cornell Electron/Positron Storage Ring," Phys. Rev. STAB 3, 092801 (2000).

Work Package 2.2.1
Impedance-Driven Single-Bunch Instabilities

Work Package Coordinator: Marco Venturini

Potential Investigators

ANL
Yong-Chul Chae

Cockcroft Institute
Roger Jones
Oleg Malyshev
Andy Wolski

IHEP
Jie Gao
(Yi-Peng Sun)

LBNL
Marco Venturini

SLAC
Karl Bane
Sam Heifets
Kwok Ko
Zenghai Li
Cho Ng
Gennady Stupakov

Summary of Required Resources

Objectives

S3 WBS	Objective	Priority
2.2.1.1	Development of single-bunch impedance models	High*
2.2.1.2	Characterization of single-bunch impedance-driven instabilities	Very High

*Results from Objective 2.2.1.1 are required input for Objective 2.2.1.2.

Staff Effort (FTE)

S3 WBS	2007	2008	2009	2010
2.2.1.1	3.0	3.0		
2.2.1.2	1.5	1.5		

M&S (US$k)

S3 WBS	2007	2008	2009	2010
2.2.1.1	0	0		
2.2.1.2	0	0		

Travel (US$k)

Travel costs are estimated at the rate of US$10k per FTE-year.

S3 WBS	2007	2008	2009	2010
2.2.1.1	30	30		
2.2.1.2	15	15		

Facilities

No experimental facilities are required.

Objectives

Objective 2.2.1.1: Development of single-bunch impedance models

High Priority

Although not designated as very high priority, the activities contained in this Objective are instrumental and essential to the achievement of the very high priority Objective 2.2.1.2, as accurate characterization of single-bunch instabilities depends critically on accurate modeling of the machine impedance (or wake fields).

Ideally, the impedance model should be developed in concert with the technical designs for the actual components to be installed in the machine. If limitations in resources do not allow this, a lesser but still satisfactory goal is to demonstrate the acceptability of an impedance model based on the design of components from existing machines, appropriately scaled to meet the basic specifications for the damping rings. This will still provide useful information for the technical design of the damping ring components. Of course, modeling will be extended to the actual machine components if appropriately detailed designs for these become available within the time frame for the present study.

Characterization of the impedance will have to be mostly based on detailed and computationally-intensive numerical calculations starting from the design of realistic machine components, with focus on sources of short-range wake fields. However, simplified models of impedance based on analytical formulas will also be considered for intermediate assessment of the instability thresholds. For some impedance sources, such as the resistive wall or coherent synchrotron radiation in the dipoles and wigglers, modeling based on analytical formulas could be fully satisfactory.

Achieving the goals of this Objective will require the following tasks:

1. Compile a list of all relevant sources of short-range wake fields, and rank the list according to the expected significance of the contribution.
2. Construct or retrieve suitable designs for the relevant machine components. Scale available designs to meet the specifications for the damping rings.
3. Develop analytical models for those impedance sources that do not require detailed numerical description.
4. Develop simplified analytical models for the machine components in order to construct (tentative) preliminary estimates of the total machine impedance, while more detailed numerical models are being constructed.
5. Carry out numerical computations of the wake fields for the relevant machine components.

Potential Investigators on these tasks will be:

Karl Bane
Yong-Chul Chae
Jie Gao
Sam Heifets
Roger Jones
Kwok Ko
Oleg Malyshev
Cho Ng

Gennady Stupakov
Yi-Peng Sun
Marco Venturini
Andy Wolski

To complete all the tasks, including technical design work for the significant vacuum chamber components, will require 3 FTE per year for 2 years. Some additional effort would be useful to permit consideration of alternate designs for some of the machine components to be modelled. No M&S budget is required.

Work on the above tasks has already started and should be completed by the end of 2008.

The required input includes:

- Specifications for the lattice and vacuum chamber components; with detailed technical designs of the vacuum chamber components if possible.
- Designs of relevant machine components (these will be scaled from machines previously studied if the technical designs for the actual components in the damping rings are not available).

The deliverables will include:

- Detailed description of the total short-range wake fields for the damping rings, based on realistic modelling of machine components. This deliverable is required so that an estimate can be made of the current thresholds for single-bunch instabilities (Objective 2.2.1.2).
- Recommendations for optimization of parameters affecting beam stability (in conjunction with Objective 2.2.1.2).
- Feedback and guidance regarding the technical designs of the components in the vacuum chambers of the damping rings (in conjunction with Objective 2.2.1.2).

If the goals of this Objective are not achieved, it will not be possible to make an accurate estimate of the current threshold for single bunch instabilities. A partial achievement of the goals (e.g. if a limited number of machine components can be accurately modelled) could result in unreliable characterization of the instabilities.

The coordinator for this Objective will be Marco Venturini.

Objective 2.2.1.2: Characterization of single-bunch impedance-driven instabilities

Very High Priority

Single-bunch instabilities are particularly insidious as, unlike their multi-bunch counterparts, they cannot be corrected by existing feed-back systems. Careful effort should be devoted to ensuring that single-bunch instabilities can be avoided altogether by a proper design of the machine components and specification of lattice and beam parameters. It is then essential that accurate estimates of the instability thresholds are produced, and feedback regarding design modifications is provided before the technical designs of critical machine components are finalized. Evaluation of instability thresholds can be done using a variety of presently-available methods, which invariably depend on an accurate characterization of all significant sources of short-range wake fields.

Achieving the goals of this Objective will involve the following tasks:

1. Acquire detailed and reliable models of the short-range wake potentials from all relevant machine sources (Objective 2.2.1.1).
2. Use the available models of short-range wake fields to estimate the instability thresholds (using, for example, time-domain simulations and linearized Vlasov equation analysis), and characterize the nature of the instability.
3. Identify the main sources of instability.
4. Determine modifications required (to the lattice design, and technical designs of components) to ensure a reasonable margin of safety between the nominal operating parameters and the instability thresholds.

Potential Investigators for these tasks are:

Karl Bane
Yong-Chul Chae
Jie Gao
Sam Heifets
Gennady Stupakov
Yi-Peng Sun
Marco Venturini

1.5 FTE of effort per year for two years will be required to complete the tasks required for this Objective. No M&S budget is required.

Some work on this task has already been carried out. In addition to the efforts that led to the preliminary estimates contained in [1], work has also been done in benchmarking the existing numerical tools for instability calculations [2]. Present and future activities will have to be conducted in close coordination with those underway in Objective 2.2.1.1. The investigators involved in this Objective should respond as soon as the wake field models for additional machine components become available, and maintain an updated estimate of the instability thresholds. This will allow for early detection of possible problems, and also guarantee a timely delivery of the final assessment of the instability thresholds by the end of 2008.

The required input includes:

- Impedance/wake field models developed in Objective 2.2.1.1.
- Lattice design and beam parameter specifications.

The deliverables will include:

- Estimates of the instability thresholds.
- Characterization of the beam dynamics associated with the instability.
- Feedback and guidance on the specifications and technical designs for the lattice and vacuum chamber components.

In the absence of a reliable estimate of single-bunch instability thresholds there is a risk that the damping rings may not be able to provide a stable beam at full intensity, with the result that the luminosity of the ILC could be seriously compromised.

Remedial measures could require the replacement of substantial sections of the vacuum chamber.

The coordinator for this Objective will be Marco Venturini.

References

[1] A. Wolski, J. Gao, and S. Guiducci, LBNL–59449 (2006).

[2] ILC Damping Rings R&D Workshop, Cornell University, Ithaca, NY, September 26-28 2006, https://wiki.lepp.cornell.edu/ilc/bin/view/Public/DampingRings/ILCDR06/

Work Package 2.2.3
Electron Cloud

Work Package Coordinator: Mauro Pivi

Potential Investigators

CERN
Warner Bruns
Fritz Caspers
Daniel Schulte
Frank Zimmermann

Cockcroft Institute
Oleg Malyshev
Ron Reid
Andy Wolski

Cornell
Jim Crittenden
Mark Palmer

DESY
Rainer Wanzenberg

FNAL
Panagiotis Spentzouris

INFN-LNF
David Alesini
Roberto Cimino
Alberto Clozza
Pantaleo Raimondi
Cristina Vaccarezza

KEK
John Flanagan
Hitoshi Fukuma
Ken-ichi Kanazawa
Kazuhito Ohmi
Kyo Shibata
Yusuke Suetsugu

LANL
Bob Macek

LBNL
John Byrd
Christine Celata
Stefano de Santis
Art Molvik
Gregg Penn
Marco Venturini
Mike Zisman

PAL
Eun-San Kim

Rostock University
Aleksander Markovik
Gisela Poplau
Ursula van Rienen

SLAC
Karl Bane
Bob Kirby
Alexander Krasnykh
Brett Kuekan
Nadine Kurita
Cho Ng
Alexander Novokhatski
Mauro Pivi
Tor Raubenheimer
John Seeman
Lanfa Wang

Summary of Required Resources

Objectives

S3 WBS	Objective	Priority
2.2.3.1	Characterize electron-cloud build-up	Very High
2.2.3.2	Develop electron-cloud suppression techniques	Very High
2.2.3.3	Develop modelling tools for electron-cloud instabilities	Very High
2.2.3.4	Determine electron-cloud instability thresholds	Very High

Staff Effort (FTE; excludes operational support for Facilities)

S3 WBS	2007	2008	2009	2010
2.2.3.1	2.0	2.0		
2.2.3.2	3.0	3.0		
2.2.3.3	2.0	2.0		
2.2.3.4	1.5	2.0		

M&S (US$k; excludes operating costs for Facilities)

S3 WBS	2007	2008	2009	2010
2.2.3.1	35	0		
2.2.3.2	700	755		
2.2.3.3	7	7		
2.2.3.4	20	20		

Travel (US$k)

Travel costs are estimated at the rate of US$10k per FTE-year.

S3 WBS	2007	2008	2009	2010
2.2.3.1	20	20		
2.2.3.2	30	30		
2.2.3.3	20	20		
2.2.3.4	15	20		

Facilities

CesrTA would provide a unique facility for studies of electron cloud under a range of conditions close to those expected in the damping rings. In particular, CesrTA would allow detailed studies of electron cloud build-up in wigglers (Objective 2.2.3.1) and tests of a range of mitigation techniques (Objective 2.2.3.2). Experimental data from several machines (CesrTA, PEP-II, KEKB, DAΦNE, LHC) will be needed for proper completion of all the Objectives. Tests of grooved chambers for suppression of electron cloud are underway in PEP-II. It is possible that the KEKB positron ring could be tuned for low natural emittance (1 nm by reducing the energy from 3.5 GeV to 2.3 GeV), and some time could be available over the next few years for dedicated electron cloud studies.

Overview

To validate the baseline configuration for the ILC damping rings, we need to deliver convincing evidence that the damping rings will be able to provide the required beam emittance and stability in the relevant parameter regime of energy and beam current. Based on studies to date, the electron cloud is considered a particularly significant risk for beam quality in the positron damping ring.

An experimental program for the electron cloud must deliver, as a minimum, data demonstrating that electron cloud will not prevent the positron damping ring achieving the specified beam emittance and beam stability. Without such a demonstration, serious consideration must be given to adopting an alternative configuration for the positron damping ring that will by itself mitigate the risk from electron cloud.

There are two issues that need to be addressed, if a complete understanding of the impact of electron cloud is to be achieved and effective means to control its effects developed. The first issue is the build-up of the electron cloud; this can be studied in several facilities with the appropriate equipment. However, the damping rings differ from most operating storage rings in having long sections of damping wiggler, where electron cloud could be particularly difficult to control. Simulation studies suggest that even if electron cloud is controlled elsewhere in the machine, there could be sufficient build-up in just the wiggler sections to degrade significantly beam quality and stability. Therefore, it is important that a test facility for studies of electron cloud includes wigglers comparable in design to those proposed for the ILC damping rings, and that the wigglers have appropriate instrumentation to allow detailed measurements of cloud build-up to be made in the presence of various mitigation techniques.

The second issue that needs to be addressed to achieve a proper understanding is related to the dynamics of an ultra-low emittance beam in the presence of electron cloud at various densities. Simulation codes [6] have been useful for characterizing the single-bunch instability driven by electron cloud in proposed storage ring designs. However, there is a need for more extensive benchmarking against experimental data. Also, differences in the results from different codes need to be understood and resolved. In particular, we need to validate models that predict the instability threshold in the parameter regime of the damping rings. Few operating positron storage rings are capable of approaching the very low emittances specified for the ILC damping rings, which limits the options for the facilities at which the necessary studies could be performed; these studies are only realistically possible at the proposed CesrTA and KEKB.

Actions to suppress the electron cloud are required for the positron damping ring. The B-factories have implemented external solenoid fields to mitigate electron cloud in field-free regions, which constitute a large fraction of the PEP-II and KEKB positron rings [1, 2]. Notably, an electron cloud in KEKB remains a major obstacle to shorter bunch spacing and higher luminosity, even with solenoid windings [3]. In the ILC damping rings, beam instability can occur even if electron cloud is present only in the wigglers and dipoles, where external solenoid fields are not effective in preventing build-up of the cloud. Therefore, R&D is required into techniques that can be applied in regions of strong magnetic fields to prevent build-up of electron cloud.

Examples of alternative configurations that would reduce the risk from electron cloud include the use of one or more mitigation techniques in the vacuum chamber (surface coatings with low secondary electron yield, clearing electrodes, grooved or slotted surfaces, and the use of an antechamber to reduce the seed electrons) and ultimately the construction of a second positron damping ring.

Recently, the first measurements of sample materials installed directly in the PEP-II and KEKB beam lines have reported very encouraging results. Samples have been exposed to synchrotron radiation and to the impact of electrons. After a conditioning period, the measured secondary emission yield is close to or lower than unity for various materials. A secondary yield close to unity considerably reduces the formation of an electron cloud. Although very promising, these results are preliminary and should be repeated in vacuum chamber conditions closer to those expected in the ILC damping ring.

After conditioning, the effect of surface recontamination by residual gases may enhance the wall secondary electron yield. This effect has been observed in laboratory experiments following conditioning by electron bombardment and subsequent exposure to base vacuum pressure for several days. The effect of surface recontamination should be investigated in an accelerator environment.

Furthermore, preliminary studies (mostly based on simulations, but supported by some laboratory measurements) suggest that techniques such as clearing electrodes, triangular grooves or slots in the wall of the vacuum chamber, could be effective at suppressing the electron cloud in regions of strong wiggler or dipole fields [4, 5]. The use of clearing electrodes is particularly effective at suppressing the formation of the cloud in the vicinity of the beam. The use of other mitigation techniques may reduce the cloud density to acceptable levels rather than suppressing it.

On the basis of the simulation studies, a single 6 km positron damping ring has been adopted in the baseline configuration for the ILC. However, a demonstration of the effectiveness of possible suppression techniques is required to validate this choice; an (expensive) alternative is to use two positron damping rings to reduce the beam current. Any technique used to mitigate build-up of electron cloud must be consistent with stringent requirements for large aperture and low impedance in the damping rings.

There are still significant questions regarding the implementation of the proposed mitigation techniques, so it cannot simply be assumed that use of all the available techniques will solve the problem. An important part of the proposed R&D at a test facility will be to address technical issues with the mitigation techniques: e.g. how best to apply a coating that will achieve low secondary electron yield and that will be sufficiently robust to withstand the high radiation environment in the damping rings; and how to optimise the designs of clearing electrodes to provide maximum suppression of electron cloud, while minimizing the impact on the ring in other respects.

Furthermore, an electron cloud is observed in several existing proton and positron storage rings even after several years of beam operation. The conditioning effect may depend on the presence of synchrotron radiation and on the vacuum chamber materials. The R&D effort should also be directed to understanding the formation of an electron cloud in existing machines, by investigating the conditioning for different materials and in different regions of an accelerator.

Key Tasks

Achieving the stated Objectives will involve completing a number of tasks, including the following key items:

Objective 2.2.3.1: Characterize electron-cloud build-up

1. Characterize the electron cloud build-up by simulations and measurements in existing accelerators, including:
   a) measurements in PEP-II (by transmission of RF signals), KEKB, CesrTA, HCX (LBNL);
   b) measurements and simulations in dipoles, wigglers and quadrupoles.

Objective 2.2.3.4: Determine electron-cloud instability thresholds

2. Characterize the electron cloud instability by measurements in existing facilities, including (for example) CesrTA or KEKB operating with ultra-low emittances.
7. Obtain (by simulation) detailed and reliable characterization of single-bunch electron cloud instability for the positron damping ring.
8. Evaluate the need for mitigation techniques such as antechambers, clearing electrodes, grooves and slots in addition to coatings for the ILC damping ring baseline configuration and for alternate configurations.

Objective 2.2.3.2: Develop electron-cloud suppression techniques

1. Test coating techniques and determine conditioning effectiveness in PEP-II, KEKB, LHC, DAΦNE, CesrTA:
   a) Characterize the conditioning effect of thin-film coatings, stainless steel, aluminum, and copper installed in accelerator beam lines and exposed either to high levels or low levels of synchrotron radiation. Evaluate the efficiency of conditioning of NEG coating with respect to TiN.
   b) Characterize the surface recontamination rate.
   c) Characterize the durability of thin-film coatings after long term exposure in an operating accelerator beam line, PEP-II.

If additional mitigation techniques are required (based on the outcome of Objectives 2.2.3.1 and 2.2.3.4):

2. Test clearing electrodes in magnetic field regions including wigglers at KEKB and CesrTA and dipoles at PEP-II. Characterize the impedance seen by the beam, the generation of higher order modes (HOMs), and the power deposited in the electrodes.
3. Test triangular grooves or slots in existing machines, including bend and wiggler sections in CesrTA and PEP-II. Characterize the impedance and HOMs.

Objectives

Objective 2.2.3.1: Characterize electron-cloud build-up

Very High Priority

Coupling between an electron cloud and the circulating beam can cause a single-bunch (head-tail) instability and incoherent tune spreads that may lead to increased emittance, beam blow-up and ultimately to beam losses directly affecting the collider luminosity. Many of the electron cloud effects have been evaluated by simulations.

There has been significant progress in characterizing the build-up in most areas of the damping rings, and the simulations have been benchmarked and are believed to be reliable. However, there are still uncertainties in the wiggler sections where the electron cloud could have a significant impact. Further studies are also needed of electron cloud trapping in quadrupoles.

Achieving the objective of characterizing the electron cloud build-up will involve the following tasks:

1. Characterize the electron cloud build-up by simulations and measurements in existing accelerators, including:
   a) measurements in PEP-II (by transmission of RF signals), KEKB, CesrTA, HCX (LBNL);
   b) measurements and simulations in dipoles, wigglers and quadrupoles.
2. Perform simulations of electron cloud build up in different sections of the ILC damping rings with different fill pattern configurations as possible mitigation.
3. Compile the electron cloud density obtained by simulations over the machine lattice of the ILC damping rings.

Potential Investigators on these tasks will be:

Warner Bruns
John Byrd
Christine Celata
Jim Crittenden
Stefano De Santis
Mark Palmer
Mauro Pivi
Marco Venturini
Lanfa Wang
Frank Zimmermann

A total effort of 2 FTE per year for two years will be required. Work will include simulation and experimental studies.

An M&S budget of around US$35k is required in 2007.

Work on these tasks is ongoing. The goal is to complete all five tasks by the end of 2008 as input for the Engineering Design Report (EDR).

The required input includes:

- Experimental data from various machines, including CesrTA, PEP-II, KEKB, LHC, and DAΦNE.
- Lattice design and initial specifications for vacuum system, wigglers and general magnets for the damping rings (including a variety of alternative design specifications).
- Beam parameters and possible fill patterns (bunch charge, bunch spacing) for the damping rings.

The main deliverable will be:

- Detailed and reliable description of electron cloud density in various sections (wiggler, bends, quadrupoles, field-free) of the positron damping ring, under a variety of possible conditions. The conditions will include ranges of beam parameters, and specifications for the vacuum system, and for the wiggler and other magnets.

The detailed description of the electron cloud density is required as input for studies of electron cloud instability (Objectives 2.2.3.3 and 2.2.3.4); to support design work on the vacuum system (Objectives 3.1.1.1 and 3.1.1.2); and to guide the selection of possible fill patterns for the damping rings.

If the objective is not achieved, there will remain considerable uncertainty regarding the impact of electron cloud on the ability of the positron damping ring to deliver the specified beam quality and stability. There is a potentially significant impact on ILC luminosity. Remedial measures following commissioning could be difficult and expensive.

Objective 2.2.3.2: Develop electron-cloud suppression techniques

Very High Priority

Actions to suppress the electron cloud are required for the positron damping ring. The B-factories have implemented external solenoid fields to mitigate electron cloud in field-free regions, which constitute a large fraction of the PEP-II and KEKB positron rings [1, 2]. Notably, the electron cloud effect in KEKB remains a major obstacle to shorter bunch spacing and higher luminosity, even with solenoid windings [3]. In the ILC damping rings, beam instability can occur even if electron cloud is present only in the wigglers and dipoles, where external solenoid fields are not effective in preventing build-up of the cloud. Therefore, R&D is required into techniques that can be applied in regions of strong magnetic fields to prevent build-up of electron cloud.

Preliminary studies (mostly based on simulations, but supported by some laboratory measurements) suggest that techniques such as grooves in the wall of the vacuum chamber, or the use of clearing electrodes, could be effective at suppressing the electron cloud in regions of strong wiggler or dipole fields [4, 5]. On the basis of these studies, a single 6 km positron damping ring has now been adopted in the baseline configuration for the ILC. However, a demonstration of the effectiveness of possible suppression techniques is required to validate this choice; an (expensive) alternative is to use two positron damping rings to reduce the beam current. Any technique used to mitigate build-up of electron cloud must be consistent with stringent requirements for large aperture and low impedance in the damping rings.

Achieving the objective of developing suppression techniques for the electron cloud will involve the following tasks:

1. Test coating techniques and determine conditioning effectiveness in PEP-II, KEKB, LHC, DAΦNE, CesrTA:

    a) Characterize the conditioning effect of thin-film coatings, stainless steel, aluminum, and copper installed in accelerator beam lines and exposed either to high levels or low levels of synchrotron radiation. Evaluate the efficiency of conditioning of NEG coating with respect to TiN.

    b) Characterize the surface recontamination rate.

    c) Characterize the durability of thin-film coatings after long term exposure in an operating accelerator beam line, PEP-II.

If additional mitigation techniques are required (based on the outcome of Objectives 2.2.3.1 and 2.2.3.4):

2. Test clearing electrodes in magnetic field regions including wigglers at KEKB and CesrTA and dipoles at PEP-II. Characterize the impedance seen by the beam, the generation of higher order modes (HOMs), and the power deposited in the electrodes.

3. Test triangular grooves or slots in existing machines, including bend and wiggler sections in CesrTA and PEP-II. Characterize the impedance and HOMs.

Note that the goal of using clearing electrodes would be to eliminate almost completely electron cloud from the centre of the vacuum chamber, while other techniques (such as coating the chamber surface, or using a grooved chamber surface) would aim to reduce the electron cloud density to acceptable levels.

Potential Investigators on these tasks will be:

David Alesini
Fritz Caspers
Alexander Krasnykh
Bob Macek
Art Molvik
Cho Ng
Mark Palmer
Mauro Pivi
Yusuke Suetsugu
Lanfa Wang

A total effort of 3 FTE per year for two years will be required. Work includes mainly experimental studies with support of simulations.

An M&S budget of US$700k in 2007 and US$755k in 2008 is required to support the following activities:

Activity Code	Title	Contact	M&S US$k	
			2007	2008
2.2.3.F	Electron cloud lab measurements and PEP-II studies	Mauro Pivi, SLAC	67	80
2.2.3.G	Studies of clearing electrodes for suppressing electron cloud build-up	Mauro Pivi, SLAC	337	350
2.2.3.K	Studies of grooved vacuum chamber surfaces for electron cloud suppression	Mauro Pivi, SLAC	288	320
2.2.3.L	Experiments on suppression of electron cloud	Yusuke Suetsugu, KEK	5	5

Work on the necessary tasks should start now. The goal – to determine an effective method to reduce electron cloud density to acceptable levels – should be achieved by the end of 2008 as input for the Engineering Design Report (EDR).

The required input includes:

- Experimental data from machines including CesrTA, PEP-II, KEKB, LHC. Data should include detailed comparison of electron cloud density with beam in sections with mitigation techniques implemented (grooved and/or coated surfaces, clearing electrodes, etc.) compared with the electron cloud density in sections without mitigating techniques.

The deliverables will include:

- Recommendation of mitigation techniques to prevent the electron cloud from limiting the performance of the ILC positron damping ring. (This deliverable will be a key contribution to the Engineering Design Report, by early 2009).
- Technical specifications for techniques to be used to suppress build-up of electron cloud in the positron damping ring, consistent with aperture and impedance requirements.
- Guidance for the design of the vacuum chamber material and geometry (Objective 3.1.1.1), and for the technical designs for principal vacuum chamber components (Objective 3.1.1.2).

If electron cloud mitigation techniques are not developed and demonstrated to be sufficiently effective for the proposed baseline positron 6 km ring, then two 6 km rings or a single ring of much larger circumference are possible alternatives. If the electron cloud density is not reduced below the threshold level for beam instabilities, then the positron damping ring will be unable to provide a beam meeting the specifications for quality, stability and intensity; this will have a potentially significant impact on the luminosity of the ILC.

Objective 2.2.3.3: Develop modeling tools for electron-cloud instabilities

Very High Priority

Simulation codes [6] have been useful for characterizing the single-bunch instability driven by electron cloud in proposed storage ring designs. However, there is a need for more extensive benchmarking against experimental data. Also, differences in the results from different codes need to be understood and resolved. Finally, the simulation codes need to be applied to the damping rings to determine the impact of electron cloud on beam stability, given the results of the studies of cloud build-up under various conditions (Objective 2.2.3.1).

Because of the long computing time required to model accurately the complex interaction between the beam and the electron cloud, simulation codes typically "lump" the interaction at a finite number of "interaction points" (IPs) around the ring. The number of IPs is limited by the available computer power. Benchmarking of simulation codes shows that better agreement between different codes can be achieved by increasing the number of IPs, but differences are still an order of magnitude.

Although qualitative comparisons between simulation codes and experimental observations (for example, of the effects of chromaticity, or the signals present in the tune spectra) are leading to increased confidence in the results of the simulation codes, further benchmarking is needed to refine the models before the results can be considered sufficiently reliable that a machine design can be based upon them.

Achieving the objective of developing modeling tools for electron-cloud instabilities will involve the following tasks:

1. Implement existing quasi-static simulation codes, and demonstrate agreement for existing designs for the damping rings.
2. Develop 3D simulation codes that include accurate models of wiggler fields.
3. Develop combined build-up and instability codes into a single, self-consistent modeling tool.
4. Track the beam in a lattice with a distributed electron cloud at each ring element.

Potential Investigators on these tasks will be:

Kazuhito Ohmi
Frank Zimmermann
Panagiotis Spentzouris
Christine Celata
Eun-San Kim
Mauro Pivi

A total effort of 2 FTE per year for two years will be required. Work involves mostly simulations.

A small M&S budget of roughly US$7k per year for software and computing equipment is needed.

Work on these tasks is ongoing. The goal is to complete all four tasks by the end of 2008 as input for the Engineering Design Report (EDR).

The required input includes:

- Experimental data from machines including CesrTA, PEP-II, KEKB, and LHC.

The deliverables will include:

- Support for the determination of electron-cloud instability thresholds (Objective 2.2.3.4) for the positron damping ring.
- Guidance for the specification of the secondary electron yield as input for the characterization of an electron-cloud build-up (Objective 2.2.3.1).

If modeling tools for electron-cloud instabilities are not successfully developed, the risk is to underestimate the effect and make more likely to be hampered by difficulties in generating the specified emittance in the 6 km damping ring. On the opposite side, a possible risk would be to overestimate the instability threshold and consequently apply solutions that raise the ring impedance and increase costs. Finally, if electron cloud suppression techniques are found to be effective (Objective 2.2.3.2) the developing of modeling tools for electron-cloud instabilities (this Objective 2.2.3.3) and determining electron-cloud instability thresholds (Objective 2.2.3.4) would decrease in priority.

Objective 2.2.3.4: Determine electron-cloud instability thresholds

Very High Priority

Simulations for the baseline 6 km damping ring lattice indicate a threshold for single-bunch instability at an averaged cloud density of around 1.4×10^{11} electrons/m^3, but there is still considerable uncertainty in the results. The instability appears as an incoherent emittance growth [7, 8], which would limit the beam quality in the damping rings at full intensity, and adversely impact the luminosity. If mitigation techniques are not used and electron cloud is allowed to develop, the threshold density is reached after few bunch passes. A more accurate determination of the electron-cloud instability thresholds is important when considering what level of mitigation is needed. Furthermore, there is a need to compare the actual simulation results for the ILC damping ring with different codes [9].

Achieving the objective of determining the electron-cloud instability thresholds will involve the following tasks:

1. Resolve discrepancies in predictions for the ILC damping ring from different codes.
2. Characterize the electron cloud instability by measurements in existing facilities, including (for example) CesrTA or KEKB operating with ultra-low emittances.
3. Benchmark the simulation codes against experimental data from existing machines.
4. Perform simulations which include various magnetic field configurations (field-free regions, dipoles, quadrupoles) and a range of realistic electron cloud distributions (from Objective 2.2.3.1).
5. Perform 3D simulations including wiggler sections.
6. Perform self-consistent build-up and instability simulations.
7. Obtain (by simulation) detailed and reliable characterization of single-bunch electron cloud instability for the positron damping ring.

8. Evaluate the need for mitigation techniques such as antechambers, clearing electrodes, grooves and slots in addition to coatings for the ILC damping ring baseline configuration and for alternate configurations.

Investigators on these tasks will be:

Kazuhito Ohmi
Frank Zimmermann
Panagiotis Spentzouris
Christine Celata
Eun-San Kim
Mauro Pivi

A total effort of 1.5 FTE in 2007 and 2.0 FTE in 2008 will be required. Work involves mainly simulations, with support of experimental data.

Measurements in support of the simulations are proposed at KEK. An M&S budget of US$20k is needed in each of 2007 and 2008 to support these measurements.

Work on these tasks is undergoing. The goal is to complete all tasks by early 2009 as input for the Engineering Design Report.

The required input includes:

- Experimental data from machines including CesrTA, PEP-II, KEKB, and LHC.

The deliverables will include:

- Prediction of the electron cloud driven single-bunch instability threshold for the positron damping ring.
- Specification of the maximum permissible cloud density in the positron damping ring, as a target for the development of mitigation techniques (Objective 2.2.3.2).

Knowledge of the electron-cloud instability thresholds is essential when considering what level of mitigation of the electron cloud will be required. If instability occurs at a density that is lower than predicted, the mitigation techniques may be insufficient to ensure the required beam quality. Conversely, if it is thought necessary to reduce the cloud density to a much lower level than absolutely required, there is a risk that the mitigation techniques selected will raise the ring impedance and increase costs.

References

[1] H. Fukuma in *Proceedings of ECLOUD04*, Napa, California (2004) and CERN-2005-001.
[2] A. Kulikov, A. Novokhatski and J. Seeman in the *Proceedings of ECLOUD04*, Napa (2004) and CERN-2005-001.
[3] KEKB 2005 Annual Report, p.2, http://www-kekb.kek.jp:16080/pukiwiki/index.php?Documents
[4] L. Wang, G. Stupakov, T. Raubenheimer, in *Proceedings of EPAC06*, Edinburgh (2006).
[5] L. Wang, H. Fukuma, S. Kurokawa, M. Pivi, and G. Xia, in *Proceedings of EPAC06*, Edinburgh (2006).

[6] F. Ruggiero, F. Zimmermann, Simulation Codes Web Repository http://care-hhh.web.cern.ch/care-hhh/simulation_codes_catalogue_and_repository.htm
[7] A. Wolski, J. Gao, and S. Guiducci, LBNL–59449 (2006).
[8] M. Pivi, T. O. Raubenheimer, L. Wang, K. Ohmi, R. Wanzenberg, A. Wolski, Frank Zimmermann, in *Proceedings of EPAC06*, Edinburgh (2006) and submitted for publication in Phys. Rev. ST AB.
[9] K. Ohmi, in *Proceedings of ECLOUD04*, Napa, California, (2004).

Work Package 2.2.4
Ion Effects

Work Package Coordinators: Mauro Pivi and Marco Venturini

Potential Investigators

CERN
Warner Bruns
Daniel Schulte
Frank Zimmermann

Cornell
Jim Crittenden
Mark Palmer

DESY
Eckhard Elsen
Guoxing Xia

KEK
Takashi Naito
Nobuhiro Terenuma
Junji Urakawa

LBNL
John Byrd
Christine Celata
Stefano de Santis
Marco Venturini

SLAC
Mauro Pivi
Lanfa Wang

Summary of Required Resources

Objectives

S3 WBS	Objective	Priority
2.2.4.1	Characterize ion effects	Very High
2.2.3.2	Specify techniques for suppressing ion effects	Very High

Staff Effort (FTE; excludes operational support for Facilities)

S3 WBS	2007	2008	2009	2010
2.2.4.1 and 2.2.4.1	6.0	4.0	4.0	

M&S (US$k; excludes operating costs for Facilities)

S3 WBS	2007	2008	2009	2010
2.2.4.1 and 2.2.4.2	200?	200?		

Travel (US$k)

Travel costs are estimated at the rate of US$10k per FTE-year.

S3 WBS	2007	2008	2009	2010
2.2.4.1 and 2.2.4.1	60	40	40	

Facilities

Experimental data from several machines (including CesrTA, KEK-ATF) will be needed for proper completion of all the Objectives.

Objectives

Objective 2.2.4.1: Characterize ion effects

Very High Priority

and Objective 2.2.4.2: Specify techniques for suppressing ion effects

Very High Priority

This Work Package consists of two Objectives, the first to “Characterize Ion Effects” (Objective 2.2.4.1) and the second to “Specify Techniques for Suppressing Ion Effects” (Objective 2.2.4.2). Both of these objectives are ranked as “Very High Priority”. The two objectives are considered together in the description of this Work Package.

Ion effects have long been recognized as possible sources of current limitation in storage rings for negatively charged particles. Limitations in machines operating under normal conditions have so far been the result of “conventional” effects, in which ions are trapped in the potential well of the circulating beam over multiple turns. Effective cures have been developed and include beam-shaking, electrodes, and use of clearing gaps between bunch trains.

More recently it was discovered that even if conventional ion trapping was suppressed, a “fast ion instability” (FII) [1] could develop under the more extreme machine parameters in damping rings for future linear colliders. Important parameters include the bunch size and beam current. Ions can be created during the passage of a single long bunch train, and cause emittance degradation before being cleared by a gap in the fill pattern. Simulations indicate that this effect is potentially very serious for the ILC electron damping ring. Fortunately, these simulations also suggest that splitting the bunch train into a number of shorter trains will be a viable solution for suppression of the fast ion instability. There is a pressing need to demonstrate that, by proper design for the machine, the instability growth rates can be brought within reach of feasible feedback systems.

While the qualitative aspect of the simulation results is not in question, there are still doubts about their accuracy. Fast ion instabilities have been detected in existing machines during experiments carried out under rather unconventional conditions, but these experiments have mostly provided proof of the existence of the effect, rather than a reliable benchmark of existing theory. For this reason, a significant portion of the required effort will be concerned with the design of experiments suited to accurate validation of present simulation models and computational tools. Further refinement of present simulation models may also be needed.

The ultimate goal is to ensure that the design (including specification of feedback system, vacuum levels, and bunch train patterns) is such that the damping rings will be capable of delivering a beam with the required quality.

Achieving the Objectives will involve the following tasks:

1. Validate existing theoretical models and simulation tools for the fast ion instability by carrying out suitable measurements in available storage rings.
2. Refine existing simulation tools beyond their current state or develop new tools if necessary to achieve acceptable agreement with the experiments.

3. Demonstrate the existence of viable machine designs capable of meeting the specifications for beam quality and stability, and show experimental feasibility of these designs using existing machines if possible.
4. Explore the effectiveness of a variety of mitigation techniques (such as clearing electrodes), if necessary.

Work on the above tasks will build on the experience accrued during the investigations for the baseline configuration choice [2] and subsequent studies. Potential Investigators on these tasks will be:

Warner Bruns
John Byrd
Christine Celata
Jim Crittenden
Stefano de Santis
Eckhard Elsen
Takashi Naito
Mark Palmer
Mauro Pivi
Daniel Schulte
Nobuhiro Terenuma
Junji Urakawa
Marco Venturini
Lanfa Wang
Guoxing Xia
Frank Zimmermann

An effort of 4 FTE in 2007, followed by 2 FTE per year in 2008 and 2009, will be required for experimental studies. Simulation and modelling work will require a further 2 FTE per year for 2007, 2008 and 2009.

An M&S budget of roughly $200k per year will be needed to support the experimental studies.

Access to key facilities, including CesrTA and KEK-ATF will be required.

The required input includes:

- Designs for the lattice and for the vacuum system, and specifications for the feedback system.

The main deliverables will be:

- Experimental validation of theoretical models and simulation tools for the fast ion instability.
- Indication of machine design parameters (including bunch filling patterns, lattice optics, feedback and vacuum specifications) capable of delivering a beam with the required quality and stability without limitations from ion effects.
- Guidance for optimization of design of vacuum and feedback systems, and optimization of the optics design, to avoid limitations from ion effects.

If the Objectives are not met, the ability to deliver the required beam specifications at extraction could be compromised, resulting in reduced luminosity.

References

[1] T. Raubenheimer and F. Zimmerman, Phys. Rev. E, 52, 5487 (1995).
[2] A. Wolski, J. Gao, and S. Guiducci, LBNL–59449 (2006).

Work Package 3.5.1
Fast Injection/Extraction Kickers

Work Package Coordinator: Thomas Mattison

Potential Investigators

Cornell
Gerry Dugan
Robert Meller
Mark Palmer
David Rubin

FID-GmbH
Vladimir Efanov

FNAL
Marc Ross

KEK
Takashi Natio
Junji Urakawa

LBNL
Stefano de Santis

LLNL
Craig Brooksby
Ed Cook

LNF
David Alesini
Fabio Marcellini

SLAC
Craig Burkhart
Richard Cassel
Anatoly Krasnykh
Ray Larsen

UBC
Tom Mattison

UIUC
George Gollin

Summary of Required Resources

Objectives

S3 WBS	Objective	Priority
3.5.1.1	Develop a fast high-power pulser for injection/extraction kickers	Very High
3.5.1.2	Develop physics designs for kicker striplines	High

Staff Effort (FTE; excludes operational support for Facilities)

S3 WBS	2007	2008	2009	2010
3.5.1.1	6.0?	6.0?	6.0?	
3.5.1.2	2.0?	2.0?	2.0?	

M&S (US$k; excludes operating costs for Facilities)

S3 WBS	2007	2008	2009	2010
3.5.1.1	800	800?	800?	
3.5.1.2	200	200?	200?	

Travel (US$k)

Travel costs are estimated at the rate of US$10k per FTE-year.

S3 WBS	2007	2008	2009	2010
3.5.1.1	60	60	60	
3.5.1.2	20	20	20	

Facilities

Experimental studies at the ATF have played a vital role in the recent development of kicker technology for the ILC damping rings; work at the ATF will continue to be of great importance as the focus of activities shifts to ATF2 (for studies of issues related to the beam delivery system). Other facilities, such as DAΦNE, and the A0 beamline at FNAL, will also play an important role in development of fast kicker technology.

Objectives

Objective 3.5.1.1: Develop a fast high-power pulser for injection/extraction kickers

Very High Priority

The extraction kicker must extract single bunches from the train without disturbing other bunches yet to be extracted, and the injection kicker must inject single bunches into the train without disturbing bunches yet to be extracted. Ideally, the sum of the electrical pulse width, stripline electrical propagation time, and stripline beam propagation time, should be less than twice the bunch spacing. This allows operation with no extra gaps in the bunch train or kicker rise or fall. For 6 ns bunch spacing, and 3 MHz kicker burst rate, performance close to this has been demonstrated with 30 cm striplines and FID GmbH pulsers. For alternative parameters with 3 ns bunch spacing and 6 MHz burst rate, there is not yet a demonstration of a satisfactory pulser. Even with 6 ns bunch spacing, there are concerns about the baseline noise between pulses, and the cost and single-source issues with FID GmbH pulsers.

The worst-case consequence of failing to develop an adequate damping ring kicker pulser is a damping ring that cannot function. More realistically, it might be necessary to increase the bunch spacing beyond 6 ns in the damping rings, presumably with proportionate reduction in luminosity. The 3 ns bunch spacing parameters imply that some effect has limited the feasible bunch charge, and it is desired to increase the number of bunches to compensate the loss of luminosity. If the kicker pulsers cannot support 3 ns bunch spacing, that luminosity loss would not be compensated, although operation with low bunch charge and increased bunch spacing would still be possible.

The R&D tasks involved ideally include:

1. Bench test fast pulser driving a resistive load to verify parameters (rise and fall times, amplitude, jitter, burst mode).
2. Bench test fast pulser driving mismatched loads (open, short) to verify robustness.
3. Bench test fast pulser driving stripline structures instrumented for kick field measurements, including cables and loads.
4. Beam test fast pulser and stripline unit with instrumentation to allow precision measurements of beam deflection as a function of the timing separation between bunch passage and kicker pulse.
5. Beam test fast pulser and stipline unit with sufficient circulating current to detect any adverse effect of beam-image currents on the pulser.
6. Perform long-term (operation over many months) reliability and stability tests.
7. Perform cost-engineering study.

As is appropriate for such a critical issue, there are several complementary pulser R&D efforts. Because pulser R&D work to date has been funded largely by laboratory initiative rather than GDE direction, the program has some overlaps and gaps. Improved coordination mechanisms are being put in place.

FID GmbH Pulsers

One thrust of effort is to use commercial pulsers from FID GmbH, and this has produced the best results to date. This small company makes a variety of very fast pulsers and is willing to develop customized systems. Many (although not all) of their devices use Fast Ionization Dynister (FID) switches. FIDs can switch far higher power levels than FETs, but have a maximum rep rate lower than the desired burst rate, so burst mode requires multiple devices and a non-trivial power-combiner. Their devices also typically have a Delayed Step Recovery Diode (DSRD) circuit as the final stage. A consequence of this appears to be that the "off" state of the pulser can have undesirable large currents (of order 1% of the peak current), extending for hundreds of nanoseconds before and after the pulse. Whether this can be controlled, or whether the machine can tolerate it, is an important issue.

Pulsers from FID have been purchased or borrowed for testing with beam at the A0 line at Fermilab (Cornell, UIUC), ATF at KEK, and in the near future with DAΦNE at LNF. While these programs address some of the above tasks, they are either (useful) demonstrations rather than real development, or are part of another laboratory program that happens to have relevance to ILC.

A proposal has been made by FID GmbH to develop a next-generation pulser capable of higher voltage and higher burst rate. A partner institution should be found to pursue this, and negotiate the technical goals, and a funding model for the cost of several hundred thousand dollars should be developed. The partner institution should have an experienced fast-pulse engineer, and ideally experience with high technology sole-source arrangements.

Inductive Adder FET Pulsers

FET switches are a more mature technology than dynistor switches, and have the advantages of on-off control at high repetition rate and absence of significant off-state current. The disadvantages of FET switches are a lower product of hold-off voltage and forward current, and slower rise and fall times in high-power applications. To achieve the required power levels for the ILC kickers, many FETs must be used in a series-parallel combination. The inductive adder technology developed by LLNL has many circuit boards operated near ground potential and distributed around a center conductor such that their output voltages add together. This approach has been used successfully in a number of accelerator applications. LLNL is collaborating with SLAC to develop a version for the ILC damping rings, with an emphasis to date on high availability and system engineering. Beam testing at the ATF and ATF2 facilities is envisioned.

The switching speed of the FETs and the pulse propagation delays in the inductive adder structure need to be improved substantially before even 6 ns bunch spacing could be supported. This will likely be challenging but not necessarily impossible in a pure FET approach (Behlke GmbH in Germany produces FET-bank switches with faster rise and fall times). Another possibility is to develop a hybrid between FET switches and a faster auxiliary component like a DSRD (as in some devices from FID GmbH) or a saturating-ferrite element.

Delayed Step Recovery Diode (DSRD) Pulsers

There has been collaboration between a small group at SLAC and industrial partners supported by DOE SBIR funding to fabricate DSRD components in the US and utilize them in fast pulser circuits targeted for ILC kickers. The pulser circuit being developed at SLAC is similar to some FET-DSRD hybrids made by FID GmbH. The results from bench testing of development components are promising, but the program is not yet producing complete pulser units, and substantial increases in the funding and staffing would be required to do so. Even at the current level of effort, the industrial partner aspect is developing a second source of DSRD components, and the circuit work at SLAC is producing technical knowledge that would be needed to negotiate specifications and price in a large purchase of commercial pulsers using DSRDs, e.g., from FID GmbH. Collaboration between the SLAC-LLNL FET-switch effort and the SLAC DSRD-switch effort on a hybrid pulser should be encouraged.

Other Pulser Technologies

Another possible fast switching element is saturating ferrite, which can produce fast rise times at very high power levels from slower-rising pulses. Saturating ferrite pulse-sharpening transmission lines were used to improve the rise time of the thyratron pulser for the SLC electron damping ring extraction kicker. There are instances of impressive agreement between numerical simulation and experiment in the literature, down to sub-nanosecond rise times. The geometry and biasing of the ferrite structure are important parameters. A concern is that the trailing edge of the pulse may be degraded by the recovery from saturation.

It may also be possible to use saturating ferrite as a non-linear amplitude filter, to block the long-duration low-amplitude currents between pulses that are common with DSRDs. In this application, the saturation current level could be much less than the full pulse amplitude, so degradation of the pulse fall time would be much less of a concern.

The University of British Columbia group plans to investigate the possible application of saturating ferrite technology for ILC damping ring kicker pulsers, probably in collaboration with the TRIUMF laboratory. FET-based pulsers (e.g., commercial pulsers from Belkhe GmbH, or pulsers designed at TRIUMF) will be used to drive ferrite transmission line structures at appropriate voltage and current levels to study the pulse delivered to a resistive load. Numerical simulations will be developed to help design the structures and to understand the measurements. Both the rise time improvement and amplitude filter operation modes will be studied.

Objective 3.5.1.2: Develop physics designs for kicker striplines

High Priority

The kicker structure must convert the pulse energy into the magnetic and electric fields that deflect the beam. A stripline structure in the vacuum chamber is the anticipated solution. The two strips are driven with equal and opposite currents propagating against the beam direction, and the currents continue into resistive loads. The geometry of the strips and the surrounding vacuum chamber determines the electrical impedance, and the uniformity of the electric and magnetic fields. Good impedance matching is desired to avoid energy being reflected back to the pulser, and to prevent energy being trapped inside the structure and thereby degrading the fall time. Good uniformity is especially important for the positron injection kicker, where the beam essentially fills the aperture, and all particles within the beam should receive the same deflection angle to avoid losses. A non-uniform field is likely to cause vertical deflections as well as horizontal deflections.

Bunches within the beam also induce current pulses in the striplines. If the induced currents persist between bunches, they will disturb the following bunches. The electrical connections from the striplines to the pulsers and loads could in principle couple the pulses out, but maintaining good matching to the very high frequencies of the short current pulses is a challenge, especially in the end transitions. The beam excites the TEM mode with the same sign currents in both strips, while the pulsers excite the TEM mode with the opposite sign currents, and novel geometries are required to obtain impedance matching for both modes even away from the end transitions. Even if the pulses are coupled out, they can still be reflected back in from mismatches in the cables and connectors. In principle, the load should absorb the pulses propagating toward it, but matching to high frequencies is a concern. The pulser is not a matched resistive load, so current pulses from the beam are likely to be reflected from it, and may also disturb its operation.

A kicker structure not properly matched to the pulser and load would degrade the fall time, which would require increased bunch spacing, and in extreme cases, cause reflections that would disturb other bunches. A structure with poor field uniformity could cause loss of positrons at injection, resulting in radiation damage to damping ring components. Strong collimation before injection might reduce the losses and thus limit the radiation damage, but at the cost of a reduction in positron intensity. A kicker structure with poor beam-impedance properties could cause beam instabilities that would limit the maximum damping ring current with good emittance. Poor beam impedance properties could also lead to kicker structure heating that could limit total current or bunch charge.

The kicker structure R&D effort to date is substantial but somewhat fragmented. Researchers at the University of Illinois and at Fermilab have collaborated in building and operating a stripline structure for single-pass pulser tests in the A0 beamline at Fermilab, which has also been used by a group at Cornell. Another structure has been built and operated in the ATF ring at KEK for pulser tests with circulating beam, and more structures will be built in the near future to extract the beam for the ATF2 program using fast pulsers from FID GmbH. A group at LBNL is collaborating on the AFT2 kicker structure, focusing on numerical modeling and design. A group at Frascati National Laboratory will build new kicker structures for injection into the DAΦNE ring in the near future. The new structures will be driven by very high voltage pulsers supplied by FID GmbH, and will have many similarities to the kind of kicker structures required for ILC. There is also effort at SLAC on TDR measurements of kicker structures, and on numerical simulations.

Placeholder for engineering.