ADDENDUM

to a

MEMORANDUM OF UNDERSTANDING

between the

INTERNATIONAL LINEAR COLLIDER
GLOBAL DESIGN EFFORT

and

Argonne National Laboratory

for the period

October 1, 2005 to September 30, 2006

1. *Introduction*

This Addendum constitutes the Statement of Work to be performed by Argonne National Laboratory (ANL) in support of the International Linear Collider (ILC) for the period of October 1, 2005 to September 30, 2006. During this time period it is anticipated that the baseline design for the ILC will be derived under the auspices of the GDE and a reference design report and cost estimate will be started. It is conceivable that during the time period of this Addendum more emphasis and thus more resources may be allocated to the R&D efforts described in this Addendum. Alternatively, it is possible that more emphasis will be placed on the reference design report and cost estimate. Such decisions are expected to be made jointly by the GDE and ANL within the context of the international collaborative R&D program.

The activities detailed in this document fall within the scope of the Memorandum of Understanding (MoU) between the GDE and ANL dated dd, 2005. The terms and conditions under which the work will be carried out are found within the MoU and are in force for the duration of time covered by this Addendum.

Work at ANL for the period covered by this Addendum will primarily involve damping ring design, positron sources, and superconducting rf cavity processing. A detailed description of the work to be performed will be developed by ANL and the GDE as one of the first FY06 tasks. This description will include a summary of the manpower and costs assigned to each task. Funds at the level of $300K for ILC R&D will be established at ANL in FY06 by transfer from the DOE as recommended by the GDE-Americas Region Director.

For FY2007 and beyond, ANL proposes to participate in additional topics of the ILC R&D: vacuum, control, survey and alignment, instrumentation, and design gamma-ray undulator. Details of the proposed work and funding requirement for these additional projects are in the next section.

2. *Statements of Work*

This Section contains the Statements of Work to be done at ANL during the period of time covered by this Addendum.

Statements of costs and commitments incurred for each work package will be submitted at the end of each fiscal year quarter to the GDE-Americas Regional Office.

Semiannual technical progress reports for each work package will be submitted at the midpoint and close of the fiscal year to the GDE-Americas Regional Office. These reports will contain descriptions of technical progress, statements of goals for the next reporting period, and indications of long-range plans.

Within two months following the end of the fiscal year, a final technical report for each work package will be submitted, in which the actual work accomplished will be compared with the scope defined in the work package in this MoU.

2.1 ILC-Americas WBS

The ILC-Americas WBS categories are listed below. The work packages defined in the next section are numbered according to this WBS.

WBS	Description	
1	Program direction and administration	
2	Accelerator design, including RDR	
	2.1	Management
	2.2	Global systems
	2.3	Electron sources
	2.4	Positron sources
	2.5	Damping rings
	2.6	Ring to Main Linac
	2.7	Main Linacs: Optics, beam dynamics, instrumentation
	2.8	Main Linacs: RF systems
	2.9	Main Linacs: Cavities and Cryomodules
	2.10	Beam delivery system
	2.11	Conventional facilities
3	Research and development	
	3.1	Management

  - 3.2 Global systems
  - 3.3 Electron sources
  - 3.4 Positron sources
  - 3.5 Damping rings
  - 3.6 Ring to Main Linac
  - 3.7 Main Linacs: Optics, beam dynamics, instrumentation
  - 3.8 Main Linacs: RF systems
  - 3.9 Main Linacs: Cavities and Cryomodules
  - 3.10 Beam delivery system
- 4 Engineering and cost estimation in support of RDR
  - 4.1 Management, technical and engineering services
  - 4.2 Global systems
  - 4.3 Electron sources
  - 4.4 Positron sources
  - 4.5 Damping rings
  - 4.6 Ring to Main Linac
  - 4.7 Main Linacs: Optics, beam dynamics, instrumentation
  - 4.8 Main Linacs: RF systems
  - 4.9 Main Linacs: Cavities and Cryomodules
  - 4.10 Beam delivery system
  - 4.11 Conventional facilities
- 5 Infrastructure and test facilities
  - 5.1 Management
  - 5.2 Global systems
  - 5.3 Electron sources
  - 5.4 Positron sources
  - 5.5 Damping rings
  - 5.6 Ring to Main Linac
  - 5.7 Main Linacs: Optics, beam dynamics, instrumentation
  - 5.8 Main Linacs: RF systems
  - 5.9 Main Linacs: Cavities and Cryomodules
  - 5.10 Beam delivery system
  - 5.11 Conventional facilities
- 6 Reserve

2.2 *Scope of Work*

CATEGORY 2—ACCELERATOR DESIGN, INCLUDING REFERENCE DESIGN REPORT

2.4 POSITRON SOURCES

WBS 2.4.2. End-to-End Simulations of the Undulator-based Positron Sources from the Undulator to the Damping Ring

Description:

During the proposed period, we will perform detailed end-to-end simulations in order to optimize the ILC positron source. The simulated components include: incident-drive electron beam, undulator (photon production), photon collimators, conversion target, positron collection system (mainly the adiabatic matching device, AMD), normal conducting preaccelerator, positron separator and selection optics, and superconducting accelerator-to-damping rings. We will use well-documented and proven accelerator codes (EGS4, GEANT, FLUKA, and PARMELA) to simulate the positron dynamics throughout all the components listed above and provide realistic particle distributions to the damping ring design team. Throughout the simulation, we will provide systematic lists of the positron source parameters to help the GDE team make decisions on the positron design. We will also design a conventional adiabatic matching solenoid that potentially can be operated in a radiation-hard environment; this is a backup scheme for the superconducting solenoid currently being considered. In addition, we will design and simulate the keep-alive conventional positron source, which is essential for availability of ILC operations. Along the way, we will investigate and solve physics problems associated with the positron source design.

Motivation:

Our work will support the baseline decision and technical design for the ILC positron source. Although the GDE team has selected the undulator-based positron scheme for the ILC, it is critical to perform systematic and detailed end-to-end simulations. Also, a conventional-based keep-alive source is needed for the ILC operation and is yet to be designed.

Collaboration with Other Institutions:

We collaborate closely with the SLAC positron team (John Sheppard and Vinod Bharadwaj), and perform simulations and optimizations as requested by them. We will also work with the DESY positron team on the detailed simulation studies at the intellectual information exchange level.

Milestones and Deliverables:

We will approach the positron source studies on both the numerical simulation and engineering design fronts. To produce the gamma rays, we will follow the TESLA design for the gamma-ray-based positron source, but with the electron beam energy lowered from 250 GeV to 150 GeV. The initial distribution of the charged particles (positron and electron) emerging from the conversion target is simulated using the electromagnetic shower simulation codes EGS4 and GEANT. Next, the generated positrons and electrons go into the positron capture optics, which consists of the adiabatic matching device (AMD) and the preaccelerator. The AMD (a tapered solenoid starting with a high initial field and tapering adiabatically down to the constant end field) is used to match the initially large divergence of the positrons into the preaccelerator, and then the preaccelerator accelerates particles to ~ 250 MeV. Finally, the positrons satisfying the constraint of the damping ring acceptance are captured, passed through a quadrupole focusing system, and continuously accelerated up to 5 GeV before being transported to the damping ring. The beam dynamics, from the conversion target to the entrance of the damping ring, will be performed using the particle tracking code PARMELA.

Proposed Work and Milestones:

During FY2006, the following tasks will be performed:

1. Conduct detailed end-to-end beam dynamic simulations and multivariate optimization from the photon production and collimation at the undulator to the polarized positron production at the target and to the damping ring for different ILC positron designs. Provide the necessary input parameters to the ILC positron source collaboration for baseline considerations and provide particle phase space to the damping ring design teams.
2. Conduct detailed studies on the positron separation and collimation at 250 MeV before injecting into a 5-GeV linac. Detailed magnets requirements and beamline design will be given. We will also investigate phase manipulation schemes that compress and collimate the positron beam for the damping ring input.
3. Perform initial design of the keep-alive positron source. Determine the drive beam energy and intensity based on the requirement from the GDE.
4. Investigate various schemes for the AMD solenoid, such as Bitter magnet, conventional, and superconducting coils. Examine the capturing efficiency as a function of the AMD magnetic field parameters. Produce a final design of the tapered solenoid, and perform a detailed engineering study, including cooling implementation and a power supply.

During FY2007 and beyond we will continue to study the positron beam parameter optimizations as outlined in tasks 1, 2, and 3 for FY2006. In addition, we will perform the following tasks:

1. Construct a prototype AMD solenoid to test cooling and power supply capabilities.
2. Perform radiation background calculations and determine the impact on accelerator components.

In summary, through the work outlined above, we will contribute to the ILC design by making a detailed study of the positron source and its associated issues.

Key Personnel:

Wei Gai, 35%; Wanming Liu, 80%; Haitao Wang, 80%; Kwang-Je Kim, 5%

Cost Summary (06):

Labor (K$)	M&S (K$)	Indirect cost (K$)	Total cost (K$)
143	7		150

Additional support will be provided by ANL internal funding to cover the actual spending.

Expectations for FY07 and Beyond:

The work outlined in FY06 is a multi-year effort and is expected to continue into FY07 and beyond. It is anticipated that more detailed simulation effort is required for the ILC positron source studies to determine detailed hardware components and accelerator designs, e.g., the collimator design for the photon beam; engineering layout for the positron separation region; beamline magnet design for the positron transport; and the keep-alive source target and positron accumulation design.

We will continue to study the positron beam parameter optimizations as outlined in tasks 1, 2, and 3 for FY2006. In addition, we will perform the following tasks:

1. Construct a prototype AMD solenoid to test cooling and power supply capabilities.
2. Perform radiation background calculations and determine the impact on accelerator components.
3. Other tasks as requested by the ILC positron source collaboration.

The expected number of FTEs for FY07 is two, the same as FY06: 1.2 FTE x $215K for ANL staff and 0.8 FTE x $40K for one student; total effort of $296K was rounded to $300K). The total cost expected in FY07 is about $340 K, and the same amount for subsequent years.

Labor (K$)	**M&S (K$)**	**Indirect cost (K$)**	**Total cost (K$)**
300	40		340

2.5 DAMPING RING

WBS 2.5.6 Damping Ring Characterization and Optimization

Description:

First Phase: Further characterize the performance of the seven reference damping ring lattices.

Second Phase: Produce one or more lattice designs for the 6-km baseline positron and electron damping rings. Add features to the accelerator simulation code `elegant`. Further apply principles of multi-objective optimization to damping ring lattice designs.

Motivation:

The first phase supports the Baseline Design Report for the damping ring to be finalized in January 2006. The second phase is required for the Reference Design Report.

Collaboration with Other Institutions:

We collaborate with a worker at FNAL, Bill Ng, who will use tracking code `elegant` for calculating space-charge effects.

Milestones and Deliverables:

First Phase: Provide performance data of the seven proposed optics designs from numerical simulations with the tracking code elegant. Several types of calculations are to be performed, including dynamic aperture boundary with typical magnet errors and determination of particle loss when injecting a beam with realistic initial coordinate distribution.

Second Phase: The lattices designed should meet specifications for damping time, equilibrium emittance, acceptance, etc. and should include all major subsystems, including injection/extraction sections, orbit, optics and coupling correction systems, rf cavities, etc. The circumference should be around 6 km and should allow for a variety of different fill patterns (different numbers of bunches) without changes in circumference or rf frequency.

We will add additional capabilities to `elegant` that are needed for damping ring assessment: i) effect of space charge, which tends to spoil the small vertical beam emittance; ii) various existing coupling formalisms to calculate the equilibrium vertical emittance and coupling angle around the ring lattice; and iii) singular-value-decomposition method for orbit correction.

Following this, we will determine optimization trade-off curves for the most promising designs using existing multiobjective evolutionary algorithms, a promising engineering approach only recently introduced into accelerator design. There are several fundamental parameters in each of the damping ring types that have been proposed; there are also several objectives to minimize or maximize in addition to the basic specifications of damping time, beam emittance, and bunch length. Possible objectives are lattice nonlinearity, beam instabilities, and the total costs. Since the objectives conflict with each other, a special sorting of feasible solutions is presented to the user as points on a surface in a multidimensional objective space (preferably limited to a 2-d or 3-d space). The actual work required is the coding of the objectives and design constraints as a function of decision variables for several or all of the ILC damping ring types.

A higher-level application of this optimization is that of the overall ILC cost relative to a subsystem specification taken as a variable. For example, damping rings have been given a (fixed) specification for the extracted beam bunch length. A change to a shorter bunch can be expensive to implement in a damping ring while making the bunch compressor beamline cheaper. A longer extracted bunch length reverses the respective costs. The global optimum is not known for certain since the costs of the damping ring and the bunch compressor as a function of bunch length have not been modeled as a function of bunch length. What would be useful to calculate is a trade-off curve with the bunch length as a decision variable, and the linear collider performance and global cost as objectives.

Key Personnel:

Aimin Xiao, 100%; Louis Emery, 20%; Yong-Chul Chae, 10%; Vadim Sajaev, 10%

Cost Summary:

Labor (K$)	M&S (K$)	Indirect cost (K$)	Total cost (K$)
130	20		150

Additional support will be provided by ANL internal funding to cover the actual spending.

Expectations for FY07 and Beyond:

Some aspects of the calculations may continue through 2007. As more engineering details are known, simulations will have to be repeated to maintain the integrity of the design.

Specific topics that we want to pursue are:

- Vertical emittance tuning; run APS at lower emittance
- Diagnostics specifications; girder and magnet alignment, magnet stability
- Specify fast orbit correction, optics correction, vertical emittance correction
- Specification for kicker reproducibility (later stage)
- Space-charge effect characterization
- Impedance and instabilities: study single-bunch limits with particle tracking with wakefields modeled from 3D codes
- Specify field uniformity of kicker striplines
- Field quality for damping wigglers
- Specify bunch-by-bunch feedback systems

- Designs for orbit and beam feedback systems
- BPM sensitivity and noise baseline specification
- Specify vacuum system design
- Bunch-by-bunch photon diagnostics
- Injection beam diagnostics specification; rf BPMs, photon diagnostics
- Project coordination

The total FTE requirement will be 2.0, consisting of:
Aimin Xiao, 100%; Yong-Chul Chae, 16%; Om Singh and Glenn Decker, 16%; C-Y Yao and Nick Sereno, 16%; Bingxin Yang, 8%; Vadim Sajaev, 16%; Louis Emery, 25%.

Labor (K$)	**M&S (K$)**	**Indirect cost (K$)**	**Total cost (K$)**
340	30		370

CATEGORY 3—RESEARCH AND DEVELOPMENT

3.2 GLOBAL SYSTEMS

3.2.1 Control Systems

Description:

ANL will participate in R&D for two critical aspects of the ILC global control system, namely implementation of high availability functionality and precision rf/timing distribution.

Successful operation of the ILC demands high availability from its control system, which requires a level of functionality that has not been implemented in accelerator control systems to date. Both hardware and software architecture and design are impacted by the need to implement high availability. New control system software functionality must be developed and demonstrated. Examples of new functionality include self-diagnosis and trouble reporting, and automatic recovery from hardware and software failures.

The control system will also support high availability for the other ILC technical system and accelerator system integration. For example the control system will receive fault and diagnosis information from the various technical systems, using that information to implement automatic system-level failure detection and recovery. Examples include managing the rf system voltage overhead and automatic reconfiguration of beam feedback loops upon failure of a sensor channel. These algorithms and control system functionality must also be developed and demonstrated.

ANL has proposed a first step demonstration of several key software layers to implement high availability. We will lead the development effort and begin evaluating middleware software options such as FT-CORBA. We will then begin the software development and hardware/software integration aspects of this demonstration.

The stability of the low-level rf (LLRF) system is critical to be able to meet the luminosity performance of the ILC. This requires distribution of multiple precision rf phase and timing references throughout the ILC complex to a level that has not been demonstrated. ANL will participate in proof-of-principle demonstration projects.

Motivation:

Our work will support developing and demonstrating two key requirements of the ILC control system, namely high availability and distribution of precision timing/rf phase references.

Collaboration with Other Institutions:

We work closely with controls, instrumentation, and LLRF experts in other institutions world-wide with these development areas. Collaborations already in place include SLAC (Marc Ross, Ray Larsen), Fermilab (Margaret Votava, Patricia McBride, Sergei Nageitsev), DESY (Stefan Simrock), KEK (Shinichiro Michizono), and University of Oxford (Phil Burrows).

Milestones and Deliverables:

During FY06, we will scope out the demonstration projects and establish appropriate work packages with other collaborative laboratories. Specific tasks will include:

1. Begin investigations into the ATCA hardware platform, which will be used as a demonstration platform for the control system software high availability layers. (Both SLAC and ANL have already purchased the same hardware evaluation package to allow collaborative development.)
2. Begin investigation of existing high availability middleware and shelf-management candidates, such as FT-CORBA and ZeroC ICE.
3. Scope out demonstration projects for timing/rf phase distribution, including a trench test of a long fiber run, and distribution in a local sector using copper.

Proposed Work Milestones:

Key Personnel:

John Carwardine (2.5%), Frank Lenkszus (5%), Claude Saunders (10%).

Cost Summary (06):

Labor (K$)	M&S (K$)	Indirect cost (K$)	Total cost (K$)
0	0		0

An ANL internal funding of $45K was provided for this effort.

Expectation for FY07 and Beyond:

During FY07 we will continue providing technical contributions to the demonstration projects on control system high availability and timing/rf phase distribution. Software will be developed to implement the three-tier high availability control system architecture demonstration initiated in FY06. We will continue to lead the demonstration project and make technical contributions to the software development and hardware/software integration.

Timing/rf phase distribution demonstration will continue with the evaluation of various implementation options. The initial goal will be to implement a real-world demonstration of an Active Phase Stabilization fiber system prototype and to evaluate the technical benefits of modulating (chopping) the phase reference. Subsequent work would include prototyping the phase distribution scheme for a complete linac rf sector, with the goal of evaluating phase averaging scheme vs. active phase stabilization vs. phase stable cable.

Labor (K$)	M&S (K$)	Indirect cost (K$)	Total cost (K$)
200	100		300

3.2.2 Instrumentation

3.2.2.1 Development of Time-Resolved Photon Diagnostics for the ILC Multi-GeV Beams

Description:

The next-generation linear accelerators present a number of challenges in the diagnostics of the ultrabright particle beams that are needed to achieve the objectives. In particular, the international linear collider (ILC) designs require effectively very small transverse beam sizes, high peak currents, and a high level of stability at the interaction point [1]. Certain aspects of the ILC beam parameters in the first linac, damping rings, and main linac lend themselves to techniques that already are demonstrated or could be demonstrated at the APS. In the course of developing beam-profiling diagnostics for the APS for beam energies of 50 MeV to 7 GeV in the injector system of APS and the 7-GeV storage ring itself, we have demonstrated the advantages of time-resolved imaging techniques. These techniques are based on the conversion of electron beam distributions to visible, VUV, or x-ray photon distributions and the use of appropriate optics and fast-gated or streak cameras. At the 5- to 7-GeV regime we have performed some of the first optical transition radiation (OTR) and optical diffraction radiation (ODR) experiments in a complementary manner. These are in addition to our optical synchrotron radiation (OSR), x-ray synchrotron radiation (XSR), and undulator radiation (UR) experiments in the rings.

Due to the power density in such beams it is necessary to pursue nonintercepting (NI) diagnostics for beam transverse characterizations. Ideally, the beam transverse size, position, divergence, and angular direction would be measured, but practically speaking, even the monitoring of beam transverse character in the beam generation area, the damping rings, their extraction beamlines, or the high-energy linear accelerator would be useful. One possible technique is based on the generation of optical diffraction radiation (ODR) as a charged-particle beam passes near an edge of a conductor or through an aperture or slit in a conducting plate. Although beam size measurements appeared to be difficult without using double-slit ODR interference phenomena [2], beam divergence, trajectory angle, and position data should be more directly available from a single aperture's ODR. Recently, however, a near-field ODR imaging experiment for a 7-GeV beam passing near the edge of a single metal surface has been done at APS. This demonstrated unambiguously for the first time a relative beam size and position monitor capability that should be relevant to ILC beam issues as well [3].

References:

1. Marc Ross, "Linear Collider Diagnostics," Proceedings of BIW2000, AIP Conference Proceedings 546, p.147 (2000).
2. R.B. Fiorito and D.W. Rule, "Diffraction Radiation Diagnostics for Moderate to High Energy Charged Particle Beams," Nucl. Instrum. Methods B 173, 67 (2001).
3. A.H. Lumpkin et al., "Nonintercepting Electron Beam Diagnostics Based on Optical Diffraction Radiation for X-ray FELs," submitted to the Proceedings of FEL05, Palo Alto, CA, August 21-26, 2005.

Motivation:

The work will support the baseline designs that result in the generation of bright, multi-GeV electron or positron beams. Our time-resolved imaging techniques are based on the conversion of lepton beam distributions to visible, VUV, or x-ray photon distributions and the use of appropriate optics and cameras. Depending on the location in the facility different conversion mechanisms and time scales are relevant. We expect to use OSR or XSR in the damping rings and OTR and ODR in the first linac, the extraction beamlines from the damping rings, and main linac.

In the transport lines the nonintercepting aspect of ODR will be exploited at high charge densities by referencing to OTR images from lower intensity beams.

Collaboration with Other Institutions:

Some feasibility experiments will be done on the SPPS or other high-energy end station at SLAC. Collaboration with D. Rule of NSWC on XTR or ODR analytical modeling is proposed, as funds permit.

Milestones and Deliverables:

Proposed Work Milestones:

We have recently developed an analytical model for near-field ODR imaging that supports the concepts of monitoring beam size and position even in the 10-micron-rms-size regime for several nC of charge at multi-GeV beam energies. If more charge is integrated in the image, the technique may be developed further to perhaps smaller beams. Part of the imaging system may reside in the transport line downstream of the damping ring.

Our initial tasks would be:

1. Evaluate an ODR experiment at 7 GeV on APS.
2. Perform an ODR experiment at 28 GeV on SPPS before it shuts down in FY06 as beam time permits.
3. Perform an OTR/XTR experiment at 28 GeV on SPPS as beam time permits in FY06.

Key Personnel:

Alex Lumpkin (8%)

<u>Cost Summary (06)</u>:

Labor (K$)	M&S (K$)	Indirect cost (K$)	Total cost (K$)
0			0

ANL internal funding of $20K will be provided for this project.

<u>Expectation for FY07 and Beyond</u>:

During FY07 and beyond we would continue to develop the time-resolved techniques adapted to ILC issues that take advantage of our ODR and ring diagnostics experience. Since x-ray imaging is likely to be used for the latter, we anticipate some level of vendor involvement in the prototype development in FY07.

We will perform the following tasks:

Year 1:

1. Design, procure, and install the OTR/ODR test station (or modify an existing flag station)
2. Perform initial ODR feasibility experiments at 7 GeV with slit geometry.
3. Develop with a consultant the capability to model the ODR patterns observed at 7 GeV and determine sensitivities. Scale to 5 GeV and 250 GeV as feasible.
4. Identify appropriate techniques and locations of the imaging device for the damping ring
    - Identify photon field: visible light, fast x-ray imaging, or other techniques
    - Identify appropriate photon source: bend magnet, undulator, or wiggler
    - Identify location of the imaging device on the damping ring lattice
    - Procure x-ray optics for prototype

<u>Key personnel</u>:

Alex Lumpkin (10%), Bingxin Yang (5%), Don Rule (10%) (NSWC)

<u>Cost Summary</u>:

Significant portion of M&S will be used for purchasing prototype x-ray optics. We anticipate no single M&S item of $75 K or more will be required to undertake this effort.

	Labor (K$)	M&S (K$)	Indirect cost (K$)	Total cost (K$)
FY2007	30	55		85

Year 2:

1. Perform more extensive ODR experiments with polarizers and bandpass filters to improve sensitivity to beam parameters. Evaluate impact parameter, slit dimension, and beam offset effects. Utilize intensified camera as needed.
2. Continue to develop with a consultant the capability to model the ODR patterns observed at 7 GeV and 28 GeV to determine sensitivities.
3. Develop specifications of the imaging optics for the damping ring task.
   - Conceptual design of the imaging optics and procure x-ray optics
   - Identify items requiring R&D
   - Test critical items at 7 GeV at APS Sector 35 or other surrogate facility

Key personnel:

Alex Lumpkin (10%), Bingxin Yang (5%), Don Rule (10%) (NSWC)

Cost Summary:

	Labor (K$)	M&S (K$)	Indirect cost (K$)	Total cost (K$)
FY2008	30	55		85

Year 3:

1. Based on the results in the first two years, an ODR experiment would be designed for tests at SLAC at 14 GeV in LCLS or 30 GeV in the end station with a higher duty factor beam as deemed appropriate. Alternatively, the APS booster might be run with a lower emittance lattice or a different energy and the beam-dump line might be modified for smaller beam sizes for further tests of ODR.
2. Continue studying ODR scaling issues analytically.
3. Continue time-resolved tests with OSR and XSR at S35 or other source using fast cameras.

Key personnel:

Alex Lumpkin (10%), Bingxin Yang (5%), Don Rule (10%) (NSWC)

Cost Summary:

	Labor (K$)	M&S (K$)	Indirect cost (K$)	Total cost (K$)
FY2009	30	55		85

3.2.4 Survey and Alignment

3.2.4.1 Implementation of a New X-ray Alignment Technology for the ILC Main Linacs

Description:

Both the ILC main linacs and the 200-m-long-undulator section for the positron production require high precision alignment of the beam-guiding multipoles placed along the cryogenic accelerating structures or between undulator sections. A viable alignment technology defining a straight line with required accuracy will have important implications for the overall layout and construction of the ILC.

We propose a novel alignment technique utilizing the x-ray beam of an undulator in conjunction with pinholes and position-sensitive detectors for positioning ILC beamline components. Two retractable pinholes at each end of the beamline define a stable and reproducible x-ray beam axis (XBA). Pinhole or zone plate targets are precisely positioned on the XBA using a pinhole camera technique. Position-sensitive detectors responding to both x-ray and electron beams enable direct transfer of the position setting from the XBA to the electron beam. This system has the potential to deliver superior alignment accuracy on the order of micrometers for target pinholes/zone-plates in the transverse directions.

Details of this new technique are outlined in a Light Source Note (LS-310) at the Advanced Photon Source, Argonne National Laboratory. The 200-m-long undulator of the ILC positron source is similar in length and aperture size as the LCLS undulator discussed in the Note. We propose to expand the system described in the Note to adapt to the 10-km length scale of the linacs. The ILC is based on superconducting technology so the integration issues, such as on-axis versus off-axis techniques, proper mounting and actuation of alignment targets in low temperature environment, need further consideration. In addition the designs of several zone plates are required to maintain the focusing condition at different locations in the linacs.

Motivation:

Whether the main linacs will be straight or following the time-varying equipotential surface on earth is of primary importance for the ILC design. Limitations on alignment and position monitoring technology will be a major factor in this decision, along with the technical challenges associated with beam based alignment on a curve.

We propose to develop an x-ray optics-based alignment and monitoring technique that will provide 10- to 25-μm transverse position accuracy over the entire length of the ILC main linacs.

Collaboration with Other Institutions:

Close collaboration with SLAC alignment personnel will be needed to interface with the conventional alignment which provides the foundation for the x-ray alignment system.

We will also work with the ILC main linac machine physicists at SLAC to integrate the x-ray alignment procedure with the beam-based alignment technique.

For the hardware development, we envision outside vendor support through SBIR contracts.

Milestones and Deliverables:

We will perform simulations of the alignment optics from the undulator source, through pin-hole or x-ray zone plates, to the detector end of the beamline, with ILC parameters. The simulations will be used optimize the optics design for best attainable resolution and accuracy. In FY2006, we will provide a written report and assess the applicability of the x-ray alignment technique for the ILC.

Proposed Work Milestones:

Key Personnel:

Horst Friedsam, 25% FTE; Bingxin Yang, 10% FTE.

Cost Summary (06):

FY06 work will be supported by ANL internal funding.

Expectation for FY07 and Beyond:

Assuming the success of the pre-design simulation work in FY06, we propose to develop the engineering specifications though simulations in FY07-08. Due to the unusual properties of the x-ray zone plate design and development, we anticipate significant vendor involvement in the hardware development, such as through SBIR contracts. No hardware development at this stage is planned at ANL. The cost of the development program and the detailed work break-down structure is shown below.

	Labor (K$)	**M&S (K$)**	**Indirect cost (K$)**	**Total cost (K$)**
FY2007	70	20		90
FY2008	70	20		90

3.2.4.x Implementation of a new X-ray alignment technology for the ILC main linacs

3.2.4.x.1 Conceptual layout considerations for implementing this technology

3.2.4.x.2 Integration issues (compatibility with the cryogenic environment, on-axis vs. off-axis considerations)

3.2.4.x.3 Zone plate development

3.2.4.x.3.1 X-ray zone plate calculation for the ILC main linac

3.2.4.x.3.2 Alignment zone plate specification

3.2.4.x.3.3 Conceptual design of zone plate mountings in the main linac's cryostats

3.2.4.x.4 X-ray source R & D

3.2.4.x.4.1 Undulator calculation and specification

3.2.4.x.4.2 Source pinhole R&D and specification

3.2.4.x.5 Detector R & D (to be specified later)

3.4 Positron Sources

3.4.1 Gamma-ray Undulator

Description:

APS has been working towards developing a superconducting undulator for use on the APS storage ring. Several-period test pieces, some with a 14.5-cm period and some with a 15-cm period, have been wound using NbTi superconductor. The measured quench current of the wound test pieces matched what was expected from quench measurements of short wire samples. The superconductivity was stable even when a heater was turned on to simulate thermal load from the electron beam. This scheme for building a 14.5- or 15-cm-period undulator for APS that would deliver photons ranging from 20 to 25 keV in the first harmonic looks feasible, but with little or no margin.

A proposal was made by collaborators at the National High Magnetic Field Lab (NHMFL) in Florida to use Nb_3Sn conductor instead of NbTi. Nb_3Sn conductor has a higher critical current and would allow a higher undulator field to be reached. An undulator could be designed to have a separately cooled beam tube at 77 K. This would allow much of the beam heat load to be removed at 77 K without it reaching the 4-K superconductor. A quench of the superconductor would not affect the temperature of the beam liner nor result in a pressure burst seen by the stored beam. Such a design would be very attractive for a high-reliability storage ring, so this option is being pursued.

In collaboration with NHMFL, short sections of undulator, with enough pieces of the cryostat to demonstrate the feasibility of the overall concept, are being built. Two different schemes for assembling the windings are being tested, one involving a single monolithic mandrel that is wound as a single piece, and one that is modular with coils that are individually wound and stacked alternately with pole pieces. Tests of a device are expected to take place in the summer of 2006. Measurements of the magnetic field quality will also be part of the collaboration. APS has already assembled an initial vertical measurement system; a horizontal measurement system that can map the field of a completed device is being designed.

One challenge with using the Nb_3Sn superconductor is flux jumping, which results in the coil quenching at currents well below what was expected from quench measurements of short samples of wire. In initial tests at APS using Nb_3Sn conductor, flux jumping limited the achievable current. A cure for flux jumping is to make the strands of superconductor thinner. As the superconductor becomes thinner, however, the fraction of the coil that is taken up by insulation grows. In a further collaboration with researchers at Lawrence Berkeley National Laboratory, the possibility of using a ceramic insulation in place of the common but very bulky fiberglass is being tested. Also at LBNL, the Nb_3Sn reaction process is being investigated. Although it has a shorter reaction time that results in an incomplete reaction and a lower quench current on a short sample, it also reduces the migration of Sn into the Cu superconductor matrix. This contamination of the Cu worsens its conductivity. A high-conductivity Cu matrix contributes to the stability of the completed superconducting coil and can reduce instability due to flux jumping. The tradeoff in determining the optimal reaction time is being investigated.

All of this work is presently being supported by APS.

Motivation:

The positron source relies on having an intense source of gamma rays, to be provided by a long undulator. Based on research at Cornell, Daresbury, and Rutherford Labs, it has been decided to pursue a superconducting design. The present concept is for a helical undulator, in contrast to the planar undulator that is the immediate goal of the APS work. It is also for a shorter period (~1 cm) than the 1.4- to 1.5-cm period of the APS device. Nonetheless, there is much in the APS effort that would be immediately applicable to an ILC undulator. Beam heating from the 150-GeV electron beam that goes through the ILC undulator would be expected to be higher than the few-watts-per-meter length that is expected for APS. Thus a liquid-nitrogen-temperature beam liner could be even more valuable for ILC. The need for good measurements of the magnetic field quality of the undulator is shared. The assembly techniques being developed and tested for the APS undulator could be applied to an ILC undulator as well, and improvements in conductor insulation would also be applicable to both.

Once design tests for the APS undulator are completed in 2006, the application of those designs to a helical undulator would require specific support. Adaptation of the measurement system to the measurement of a helical field geometry would also require additional support. If the extent of the superconducting project at APS were to expand to encompass an ILC helical undulator, it would make sense to refurbish an existing liquid He liquefier and install it at APS.

Collaboration with Other Institutions:

The APS is presently collaborating with the National High Magnetic Field Lab in Florida and Lawrence Berkeley National Laboratory, as described above.

Participation in the superconducting undulator part of the ILC project would entail good communication and probably collaboration with the existing efforts at Cornell, Daresbury, and Rutherford Labs.

Milestones and Deliverables:

An assessment of the challenges, a conceptual design for a helical undulator, and a definition of interfaces for facilities, diagnostics, utilities, beam parameters, etc. would be goals for 2007.

Proposed Work Milestones:

Key Personnel:

E. Gluskin, S.H. Kim, R.L. Kustom, E. Moog at APS; H. Weijers, J. Miller at NHMFL; R. Schlueter, S. Prestemon, D. Dietderich, and S. Marks at LBNL.

Cost Summary (06):

The cost of adapting APS designs to a helical undulator will be better estimated once we know what the final APS designs are. The present feasibility project with NHMFL is expected to cost $300K. Adaptation of the design and a similar feasibility test for a helical design will probably entail similar cost.

The total cost of refurbishing and installing the He liquefier is expected to be $400K.

APS in-house effort could add up to $250K because a new person would need to be hired. A potential candidate has been identified who has expertise in superconducting undulators. He will reach the mandatory retirement age at his present (European) institution in summer 2006 and is interested in continuing to work on superconducting undulators at the APS.

Expectation for FY07 and Beyond:

The development of a superconducting helical undulator for ILC will be a multi-year project.

Labor (K$)	M&S (K$)	Indirect cost (K$)	Total cost (K$)
250	500		750

3.5 DAMPING RING

3.5.1 Development of Time-Resolved Photon Diagnostics for the ILC Damping Ring

Description:

The positron/electron damping rings of the ILC present a number of challenges in the diagnostics of the ultrabright particle beams: very small transverse beam sizes, high peak currents, and a high level of stability at extraction. Certain aspects of the ILC damping ring beam parameters lend themselves to techniques that are already demonstrated or could be demonstrated at the APS. In the course of developing beam-profiling diagnostics for the APS for beam energies of 50 MeV to 7 GeV in the injector system of APS and the 7-GeV storage ring itself, we have demonstrated the advantages of time-resolved imaging techniques. These techniques are based on the conversion of electron beam distributions to visible, VUV, or x-ray photon distributions and the use of appropriate optics and fast-gated or streak cameras. At the 5- to 7-GeV regime we have effectively used optical synchrotron radiation (OSR), x-ray synchrotron radiation (XSR), and undulator radiation (UR) to characterize the electron beam properties and study beam dynamic instabilities.

The proposed work covers the following tasks, which are also listed in the document "ILC Damping Rings R&D, Design and Engineering Tasks List" as 3.8.3.2, 3.8.3.3, and 3.8.3.4.

1. Develop instrumentation for monitoring emittance damping
   Develop instrumentation for monitoring the damping of the beam emittance. In the positron ring, the maximum beam sizes range from 20 mm × 20 mm (H × V) at the injection to 50 μm × 5 μm at the extraction. Hence the image tool needs to have a fine spatial resolution and a large field of view, as well as a wide dynamic range.

2. Develop instrumentation for injection imaging (first turn diagnostics)
   Develop instrumentation for imaging the injected beam in the first several turns to aid tuning of injection process.

3. Develop a precision bunch-by-bunch beam size monitor
   Develop a precision monitor, e.g., an OSR or XSR monitor that can be used to measure the beam size and tilt on a bunch-by-bunch basis; this will be important for diagnosing collective effects.

Motivation:

The work will support the baseline designs for the ILC damping ring. Our time-resolved imaging techniques are based on the conversion of lepton beam distributions to visible, VUV, or x-ray photon distributions and the use of appropriate optics and cameras. In the damping ring, time-resolved features will be critical since the lepton beam in the ILC damping rings will attain very high charge density before extraction. A number of instabilities may occur during the damping process, especially in the final stage. While design efforts are made to suppress these instabilities, adequate time-resolved diagnostics tools are required to verify that the design goals have been achieved and characterize the instabilities when they do occur.

Collaboration with Other Institutions:

Milestones and Deliverables:

Proposed Work Milestones:

In FY06, imaging techniques using OSR and XSR will be evaluated with the ILC damping ring beam parameters. A multi-tool package appears to be needed, with OSR and XSR used for different parts of the beam parameter space and time scale.

Key Personnel:

Bingxin Yang, Alex Lumpkin

Cost Summary (06):

Work in FY06 will be supported by ANL's internal funding.

Expectation for FY07 and Beyond:

During FY07 and beyond we will develop the time-resolved techniques based on the ILC damping ring beam properties. The high spatial resolution required to measure the damping ring beam requires the use of x-ray imaging tools, where the main issue is the perfection of the optical element. A major part of the development is to reach an optics design practical for the current manufacturing capability.

We will perform the following tasks:

FY2007: Identify appropriate techniques and locations of the imaging device for the damping ring

- Identify photon field: visible light, fast x-ray imaging, or other techniques
- Identify appropriate photon source: bend magnet, undulator, or wiggler
- Identify location of the imaging device on the damping ring lattice
- Design x-ray optics prototype and order the prototype optics

Key personnel:

Bingxin Yang (10%), Alex Lumpkin (10%)

Cost Summary:

Significant portion of M&S will be used for purchasing prototype x-ray optics. We anticipate no single M&S item of $75 K or more will be required to undertake this effort.

	Labor (K$)	**M&S (K$)**	**Indirect cost (K$)**	**Total cost (K$)**
FY2007	40	150		190

FY2008: Develop specifications of the imaging optics for the damping ring task
- Conceptual design of the imaging optics for fast imaging
- Design test stand for prototype x-ray optics
- Procure test stand in the APS diagnostics beamline

Key personnel:

Bingxin Yang (10%), Alex Lumpkin (10%)

Cost Summary:

	Labor (K$)	**M&S (K$)**	**Indirect cost (K$)**	**Total cost (K$)**
FY2008	40	150		190

FY2009: Test prototype optics with OSR and XSR at the APS
- Install test stand in the APS diagnostics beamline
- Test x-ray optics at the APS diagnostics beamline

Key personnel:

Bingxin Yang (10%), Alex Lumpkin (10%)

Cost Summary:

	Labor (K$)	**M&S (K$)**	**Indirect cost (K$)**	**Total cost (K$)**
FY2009	40	20		60

3.7 Main Linacs, including RF Systems

3.7.1 Electropolishing System for the ILC at the ANL-FNAL Joint Facility

Description:

ANL proposes in FY06 to establish a capability for electropolishing (EP) 9-cell elliptical cavities for the ILC. The proposed facility is intended to complement existing EP R&D activities and to be a pre-production facility focused on development of an industrialized production capability for the ILC. It is recognized that this is the first attempt to start a production plan and that any future large-scale EP facility or industrial facility, or industrialization effort will have to evolve in concert with participation from the world community.

The pre-production facility will provide critical hands-on experience with the EP of ILC cavities, which is required to provide credible technical guidance and support for the longer-term industrialization process. Such experience should be launched as early as possible to fit with the evolving large-scale plan. The proposed effort will parallel the process R&D that is being performed elsewhere (DESY, JLab, and KEK).

Essential requirements of the pre-production facility are:

1. to incorporate what is known from ongoing operations at Cornell, DESY, JLab, and KEK/Nomura;
2. to be modular and flexible in order to permit evolution as the EP process is developed (worldwide) to meet ILC requirements;
3. to have a throughput capability, maintainability, and availability suitable for processing at least 50 cavities per year by 2009; and
4. to support and enable the design and establishment of a production EP facility that can be updated to achieve an evolving state-of-the-art.

In FY06, a complete electropolishing system for polishing ILC 9-cell elliptical cavities will be designed, installed, and qualified.

All of the major infrastructure, including a large chemical room and fume scrubber, a deionized water system, electropolishing power supplies, and other acid-handling equipment, is already present and will be available for this effort. Likewise, important logistics issues such as safety, acid procurement, handling, storage, and disposal have already been addressed at ANL.

This proposal requires that fabricated cavities be provided to ANL for electropolishing and that a cold test facility be available elsewhere to test the cavities after electropolishing.

Motivation:

A U.S.-based expertise in fabrication, processing, and operation of 9-cell elliptical cavities will be required for the proposed International Linear Collider. This expertise will be required if the U.S. is to successfully host the ILC, or if built elsewhere, if the U.S. is to make meaningful contributions to the main linac system. In addition, the pre-production facility would help meet the anticipated cavity processing needs in the U.S. of 100 cavities by 2010, 60-100 cavities in 2009, 20-25 cavities in 2008, and up to 12 cavities in 2007, and would help establish a credible industrialization plan for presentation to the U.S. Department of Energy by 2010. The work proposed will be carried out in support of the goal of building U.S. expertise and will be performed in collaboration with the ILC-Americas.

Recently the international SCRF community, in drafting the ILC baseline configuration document, has adopted electropolishing as the chemical procedure for cavity surface preparation despite many outstanding technical questions on the optimum techniques needed for 9-cell cavities and a relatively small base of worldwide expertise.

The ANL Physics Division has used electropolishing to produce state-of-the-art performance in low- and medium-velocity superconducting (SC) accelerating structures for more than 150 niobium cavities. Recently achieved peak magnetic fields in ANL cavities (having 2x the surface area of the ILC cavity) are comparable to those in ILC cavities running at accelerating gradients of 30 MV/m. With the completion of a new $2M cavity processing facility at ANL (done in collaboration with FNAL), an opportunity has been created to leverage ANL expertise and facilities for the development of high-gradient SC cavities for ILC. This R&D proposal directly addresses the need for additional work on EP directed toward industrialization of this critical production step for ILC.

Electropolishing is the best available chemical processing technique for niobium cavities today. Establishing a production capability for electropolishing in the U.S. in a relatively short time frame, which we propose to facilitate, is critical to U.S. participation in cavity production for the ILC linac.

<u>Collaboration with Other Institutions</u>:

The proposal to perform electropolishing at ANL for the ILC would build upon ongoing collaborations with FNAL in which chemical polishing of 3.9-GHz elliptical cavities and electropolishing for proton driver cavities is already planned or underway at ANL. This new proposal for the FY06 ILC effort would involve collaboration among personnel from ANL, FNAL, and LANL. The proposed work would also require ongoing design consultation and review with other technical experts from both the U.S. (Cornell, JLAB) and abroad (DESY, KEK).

<u>Milestones and Deliverables</u>:

1. In consultation with the ILC technical community and with potential U.S. vendors, design a horizontal, closed-loop electropolishing (EP) apparatus to be housed within the ANL portion of the joint processing facility.
2. In addition to consultation during the design process, have the design reviewed by technical experts from laboratories and institutions within the U.S. and abroad in order to maximize the potential benefits to ILC derived from the new system.
3. Fabricate, test, and commission the electropolishing system.
4. Develop and document techniques and train personnel in electropolishing in such a way that key hardware and expertise may be easily transferable to other U.S. institutions or industry.

Proposed Work Milestones:

Key Personnel:

Michael Kelly (ANL) and Tsuyoshi Tajima (LANL) consulting for FNAL will coordinate the technical design. The effort required of these personnel would be 0.75 FTE total. Ken Shepard (ANL) and Mark Kedzie (ANL) will provide technical expertise for tasks including performing a preliminary design, conducting a technical design review, and overseeing procurement and construction of the electropolishing system. Total additional effort in addition to Kelly and Tajima would be 0.75 FTE in FY06.

Cost Summary (06):

Labor (K$)	M&S (K$)	Indirect cost (K$)	Total cost (K$)
300	100		400

We expect that no single M&S item of $75 K or more will be required to undertake this effort. The above budget assumes support from ANL internal funding at the level of $125 K for this project in FY06.

Expectations for FY07 and Beyond:

In FY07 and beyond, activities would include EP of prototype cavities, training of technicians and engineers from industry and/or national laboratories, and testing of hardware concepts and techniques as required to support development of large-scale production facilities. Funding levels for FY07 would be at least at the level of FY06, and very possibly increased as required to support the evolving schedule and scope of preparation for ILC production.

Labor (K$)	M&S (K$)	Indirect cost (K$)	Total cost (K$)
400	100		500

3. Execution

3.1 Effective Date

This Addendum to the Linear Collider MOU shall become effective upon the latter date of signature of the Parties. It shall remain in effect until superseded or October 1, 2006 whichever should come first.

3.2 *Approval*

The following concur in the contents of this Addendum:

___________________________	___________________________
Gerry Dugan, Regional Director, GDE-Americas	Kwang-Je Kim, ANL ILC Program Leader
___________________________	___________________________
Date	Date