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1. FY03 PROGRESS FOR PEP-II by John Seeman

Construction and installation of PEP-II was completed within budget in early July 1998. First collisions were observed in late July that was two months ahead of the final PEP-II DOE construction milestone. The BaBar detector was installed in May 1999. PEP-II has been delivering luminosity to BaBar nearly continuously over the past 52 months. PEP-II exceeded its design luminosity in October 2000 by achieving 3.30 x 10^{33} cm^{-2} s^{-1}.

Progress in FY2003:

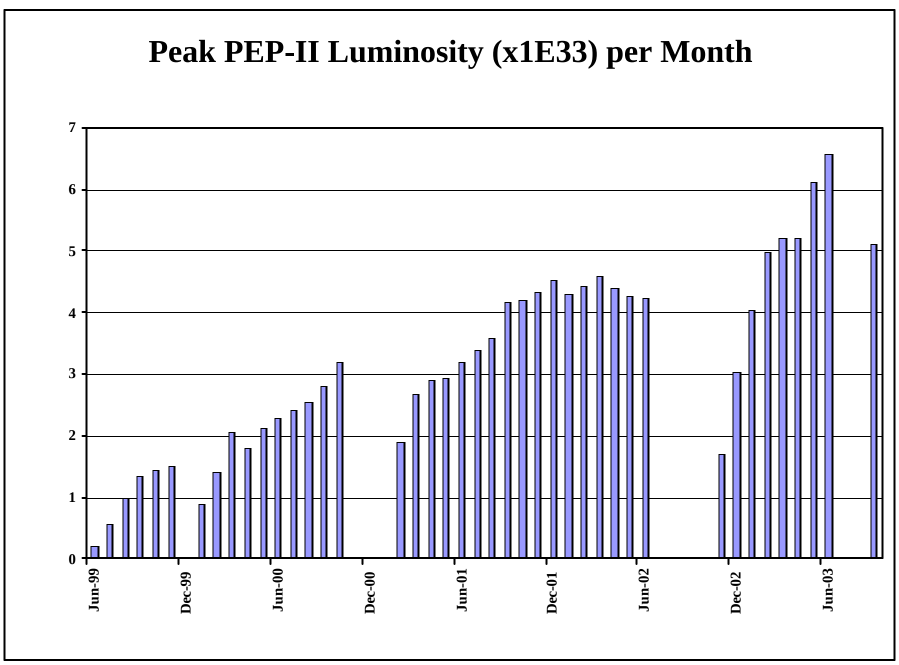
In FY2003 several milestones for the PEP-II program were achieved. PEP-II exceeded twice its design luminosity this year (May 2003) by achieving 6.58 x 10^{33} cm^{-2} s^{-1}. This very high luminosity was reached using 1034 bunches with 1550 mA of positrons and 1175 mA of electrons. The vertical and horizontal beam sizes at the interaction region were about 4.6 by 114 microns, respectively. Furthermore, PEP-II delivered 395 pb^{-1} in one day to BaBar in June 2003. This rate is three times the design delivered luminosity per day of 130 pb^{-1}/day. Thus, the luminosity delivery efficiency is excellent. Overall, from May 1999 to October 2003, PEP-II has delivered 141.6 fb^{-1} to BaBar.

There have been maintenance downtimes every year to install PEP-II upgrades and make repairs. There were two this fiscal year: one in the fall and one in the summer. Early in the fiscal year, the summer 2002 shutdown ended November 15. During that down, an HER RF station was installed and the interaction region support tube was removed and improved. A bellows on the beryllium vacuum chamber inside the support tube was over heating from Higher Order Mode (HOM) heating from the beam. During the fall shutdown significant additional cooling was added to cure this problem. In addition, the BaBar detector took the opportunity to make minor repairs to their silicon tracker that is also inside the support tube.

After November 15, 2002, both rings stored beams within 24 hours of turn-on. The PEP-II accelerator has been in continuous operation from November 15 through the end of June 2003 except for a ten-day end-of-year holiday break. About 5% of the time was spent on accelerator development directed towards luminosity improvements. There have been many advances. The interaction region cooling upgrade from the summer has been perfect. The heating issues from last run are gone and it appears that this bellows chamber will be safe to about four times an increase in the luminosity. The new abort kickers with a shorter pulse time had teething problems but these problems were solved quickly. The abort systems are now working very well. Due to improved backgrounds in the detector, the number of beam aborts has been reduced. In a typical week the accelerator uptime fraction is 92-98 %. A new computer program called Global Orbit Feedback (GOF) was made to work and corrects the beam orbit in both rings many times each hour. The unwanted orbit excursions in both rings needed to be reduced to improve magnetic lattice stability. The accelerator physics computer code “MIA”(Model Independent Analysis) has been commissioned to fix beta-beats and coupling errors. MIA has fixed global beta beats and coupling in the LER but so far has had trouble fixing local IR parameters. MIA improvements are under way. Nevertheless, this program will now being put to work on the HER also. Computer knobs have been developed to locally reduce βy^* in both rings. These beta knobs will be put to use as soon as the global beta beats are fixed using MIA.

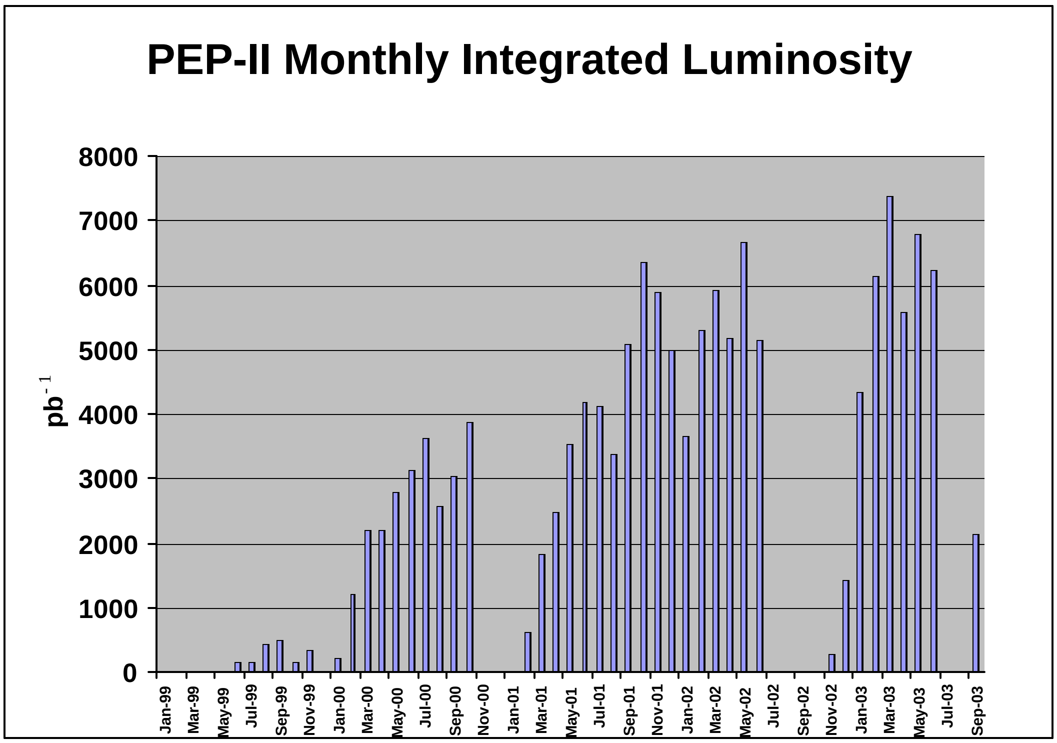
It was found empirically that local orbit bumps that adjust dispersion and coupling around the rings can increase the luminosity by fixing subtle interaction region beam parameters. For example, an x-bump of 4 mm in the early part of the IR6 chicane in LER increased the luminosity by 5%. Additional bumps gave smaller improvements. The three RF stations in LER work well and shorten the LER bunch length, as expected. However, shorter bunches increase the heating in many of the LER bellows and feedback feed throughs. Both components were worked on in the summer of FY2003 to improve cooling. On a different front, initial studies to bring the LER and HER horizontal tunes to just above the half integer resonance have started with considerable success. The luminosity as a result increased by about 30%. A further move in the horizontal tune toward the half integer is expected in the fall. The technique of slow-continuous injection (trickle charging) to keep the luminosity nearly constant has been tried and has made significant progress. BaBar has taken several shifts worth of data with trickle charging but more work needs to be done before extended-time use is tried. Overall, the electron beam current has been raised from 1.0 A to 1.15 A. The positron current has been increased from 1.8 A to 2.4 A in tests. These higher currents will be soon used to increase the luminosity.

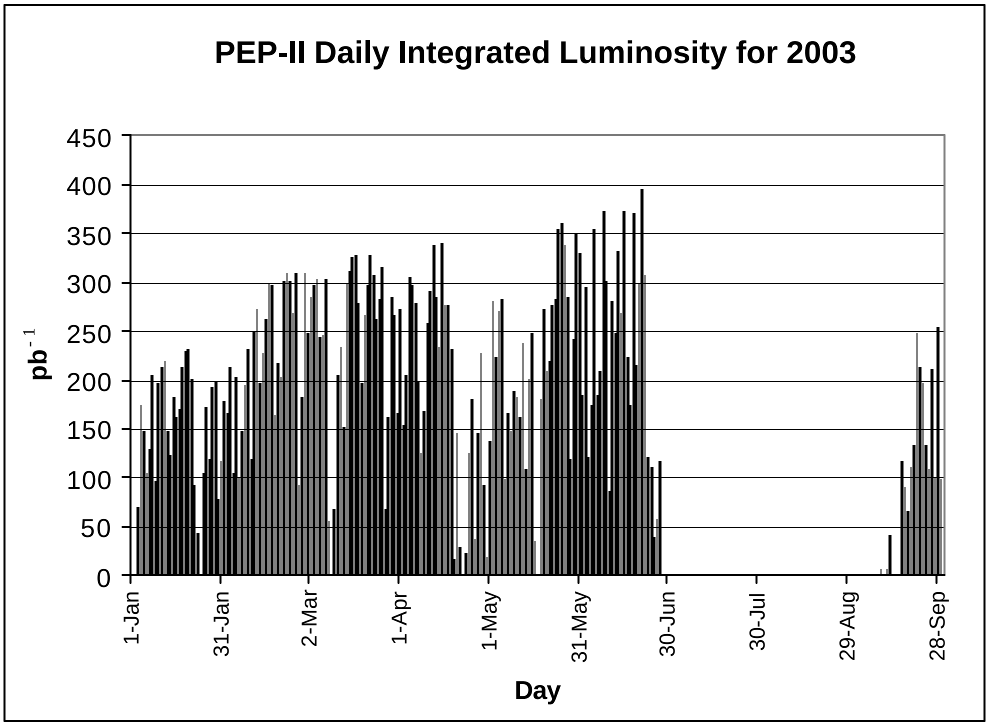
Included below are plots of the peak luminosity in each month, the integrated luminosity per month and day, and the total integrated over PEP-II's history. The FY2003 run has clearly been the best ever.



Many accelerator upgrades were installed during the two-month Summer 2003 shut down in July and August to allow increased luminosity and reduce backgrounds in BaBar in the fall run. A new HER RF station was installed and commissioned to increase the current from 1.4 to 1.6 amperes this coming year. A HER collimator was installed to reduce the backgrounds to BaBar from HER injection and collisions. All the position monitors near the interaction region were converted to full x-y operation to improve steering. Additional solenoids were wound on the straight section vacuum chambers in the LER to handle the electron cloud instability in the By-3 and By-2 bunch patterns. Additional cooling fans were added to all the LER bellows around the ring due to Higher Order Mode (HOM) power. Additional shielding will be added near the collimators in the LER near the BaBar detector. A design study for moving the interaction region quadrupoles closer to the collision point has started and will take several months. All these improvements were carried out to improve colliding beam conditions at the IR and to allow higher beam currents and a lower βy^*.

The fall FY2003 run started on September 2. The turn-on was very rapid and by the end of the month a peak luminosity of 5.2 x 10^{33} $cm^{-2}s^{-1}$ was achieved which is 80% of the old peak in June. Furthermore, an integrated luminosity of about 2.2 fb^{-1} was delivered bringing the total delivered to BaBar to 141.6 fb^{-1} since the start of collisions in May 1999. The intention is to collide for BaBar until the end of July 2004 and then have a two-month summer down in August and September.




PEP-II Daily Integrated Luminosity for 2003
450
400
350
300
250
200
150
100
50
0
pb -1
1-Jan
31-Jan
2-Mar
1-Apr
1-May
31-May
30-Jun
30-Jul
29-Aug
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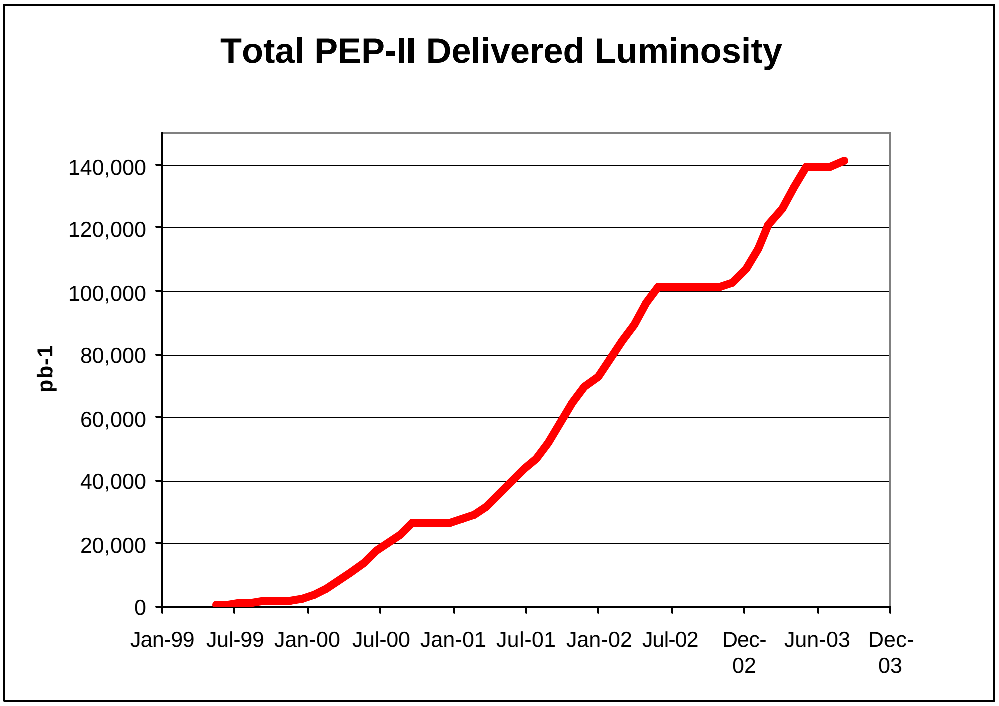
Day



2. FY03 PROGRESS IN BABAR AT PEP-II by Marcello Giorgi and Bill Wisniewski

BABAR Experiment

The past year has been one of progress and discovery for the *BABAR* experiment, with many new results on CP asymmetries, *B* decays, and charm physics. The detector continues to perform extremely well, with an operational efficiency of 97%. Since the start of running in October 1999, *BABAR* has accumulated an integrated luminosity of 113 fb^{-1} on the Υ(4S) resonance, corresponding to 123 M *B*-meson pairs, and an additional 12 fb^{-1} taken 40 MeV below the resonance. The analysis of the data has led to a broad range of results and over 50 publications. An additional 50 papers are nearing completion.

The *BABAR* physics program uses the enormous data sample to pursue three main goals: (1) perform a comprehensive set of measurements of CP-violating asymmetries in *B* meson decays; (2) systematically map out rare decay processes; (3) perform detailed studies to elucidate the dynamics of processes involving heavy quarks. The first two goals focus on testing the Standard Model, measuring its parameters, and searching for the effects of new physics, while the third goal is designed to build a solid foundation by elucidating the interplay between electroweak and strong interactions in heavy-quark processes.

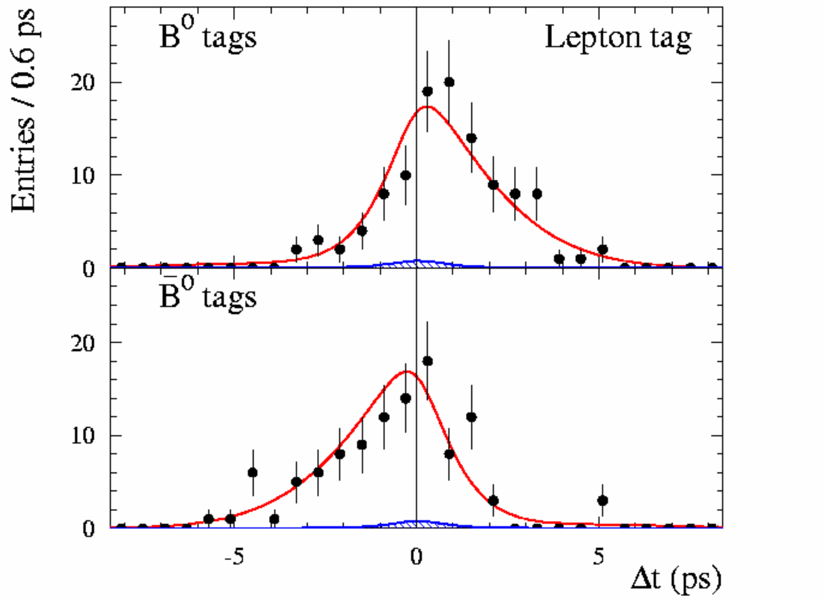


Fig.1. sin2β $B^0 \rightarrow J/\psi K_S$ and $B^0 \rightarrow J/\psi K_L$ analysis: Flavor tagged *?t* distribution for the lepton tag category with the fit likelihood superimposed. The shaded portion represents the background contribution.

During the past year, we have made substantial progress in all three areas. We published the measurement of the CP violating parameter sin2β=0.741±0.067±0.034 using the benchmark decays $B^0 \rightarrow J/\psi K_S$ and $B^0 \rightarrow J/\psi K_L$ (and similar processes involving other charmonium states). This result established that the pattern of CP violating effects and quark transitions predicted by the Standard Model plays a strong role in *B* decays. The analysis also established that the observed CP asymmetry is the result of interference between amplitudes for *B* decay and *B* mixing, as expected. This mechanism produces a CP asymmetry with a very simple, sinusoidal time dependence. The angle β is now by far the most precisely measured angle of the Cabibbo-Kobayashi-Masakawa (CKM) unitarity triangle, whose three internal angles α, β, and γ characterize CP asymmetries in different processes. The remarkable predictive power of the Standard Model arises from the fact that both the angles and sides of the unitarity triangle govern various quark transitions in a highly interrelated manner.

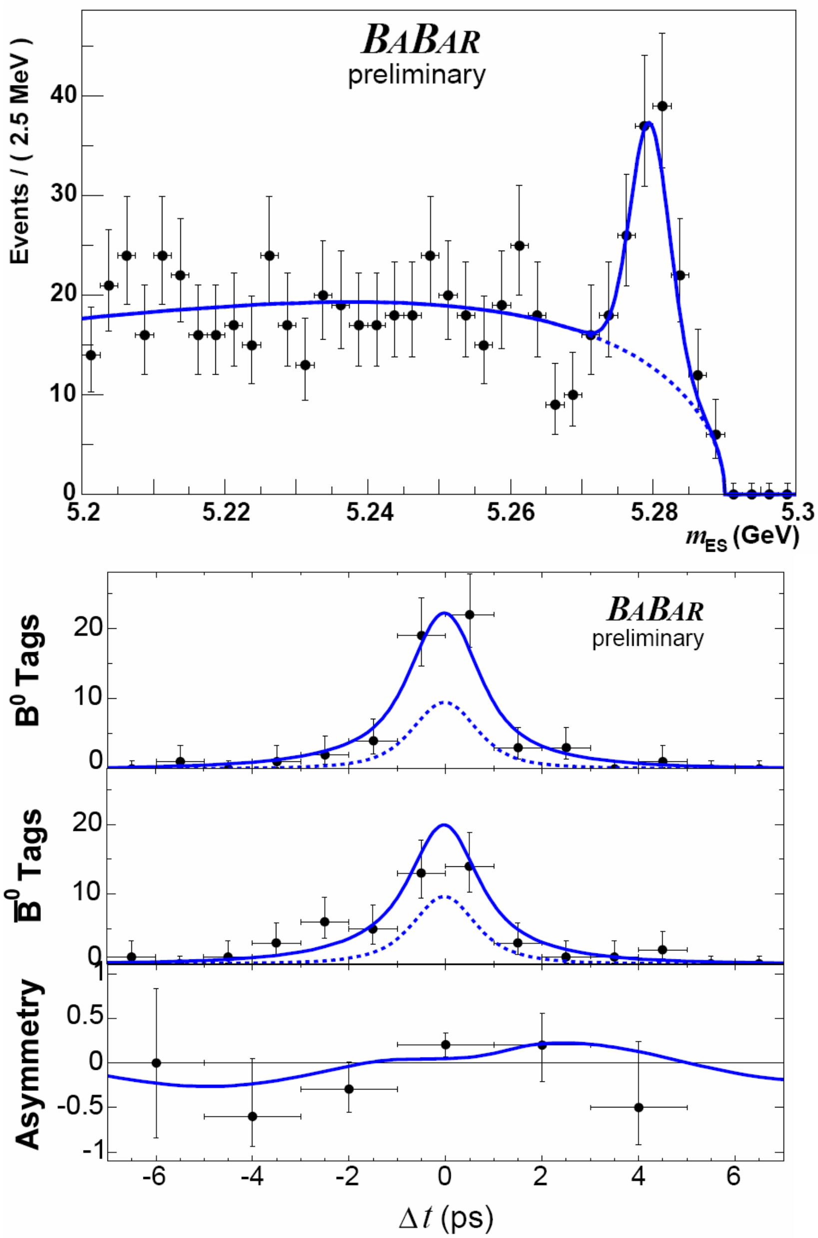


Fig.2. sin2β ϕK_S analysis: Signal in m_{ES} ; ?*t* distributions for ϕK_S events where solid lines represent all events and dashed lines background; raw asymmetry.

With our increasing data samples, we have expanded our time-dependent CP studies to a large number of additional modes, including $B^0 \to \phi K_S$, $B^0 \to \pi^+\pi^-$, $B^0 \to \rho^+\pi^-$, $B^0 \to D^{*+}\pi^-$, and $B^0 \to K_S\pi^0$. In the Standard Model, the decay $B^0 \to \phi K_S$ should yield a value of sin2β equal to that from $B^0 \to J/\psi K_S$. However, this channel is governed by a loop diagram, which makes it sensitive to the effects of new physics. Results so far leave room for such effects, but the statistical uncertainties are still too large for strong conclusions. The other modes listed provide information on the CP violating parameters α and γ. We have observed many new decay modes, including $B^0 \to \rho^+\rho^-$ (which appears very promising for the measurement of α), $B^0 \to \pi^0\pi^0$ (which is surprisingly large), and $B^0 \to K^* l^+ l^-$ (a rare, flavor-changing neutral current process that is sensitive to new physics).

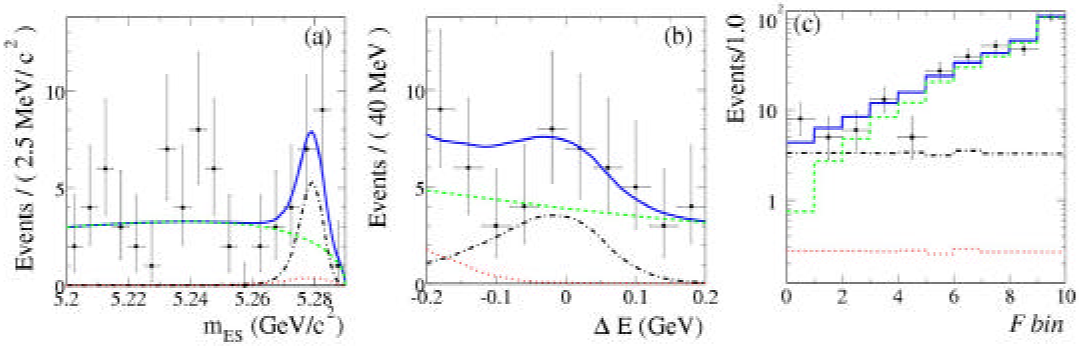


Fig.3. $B^0 \to \pi^0\pi^0$ analysis: $m_{ES,}$? E and F projection plots of the likelihood fit to the data.

We have also measured a host of rare charged and neutral B meson decays that provide a deeper understanding of the role of different "tree" and "penguin" amplitudes in decays to charmless final states. Information from these modes can also be used to constrain the angle γ. The interference between tree and penguin amplitudes can give rise to so-called direct CP violation, which does not involve mixing. We hope to see evidence of direct CP asymmetries in the future.

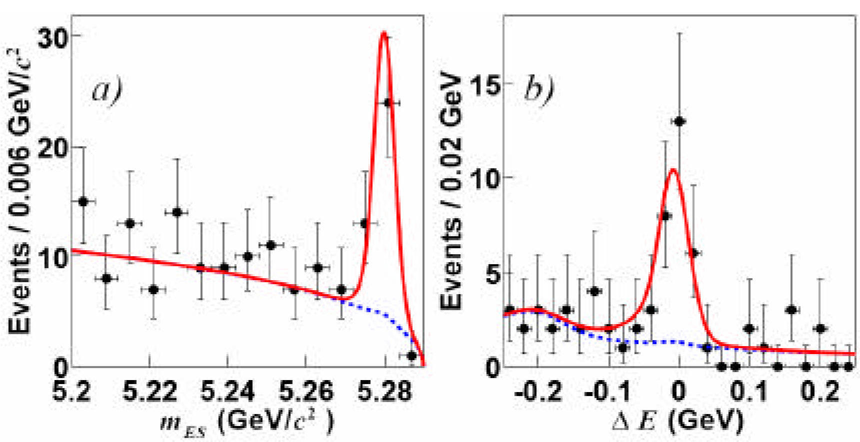


Fig.4. $B^0 \to K l^+ l^-$. Distributions of the fit variables in $K l^+ l^-$ data (points) and projections of the fits (curves). The solid curve is the sum of all fit components including signal; the dashed curve is the sum of all background components.

The sides of the CKM triangle can be related to the rates for certain quark transitions, and such measurements complement the measurements of CP asymmetries, which are related to the angles of the triangle. We have performed new, state-of-the art measurements of the magnitudes of CKM parameters V_{cb} and V_{ub} using semileptonic B decays, and we have studied the detailed dynamical properties of inclusive semileptonic B decays to extract key theoretical parameters describing B decay. The V_{ub} measurement is particularly interesting in that it exploits the large data sample by using events in which one of the two B mesons is fully reconstructed in an hadronic decay mode. In such events, the remaining tracks can be analyzed much more easily, allowing a more inclusive measurement that reduces theoretical model dependence on V_{ub}.

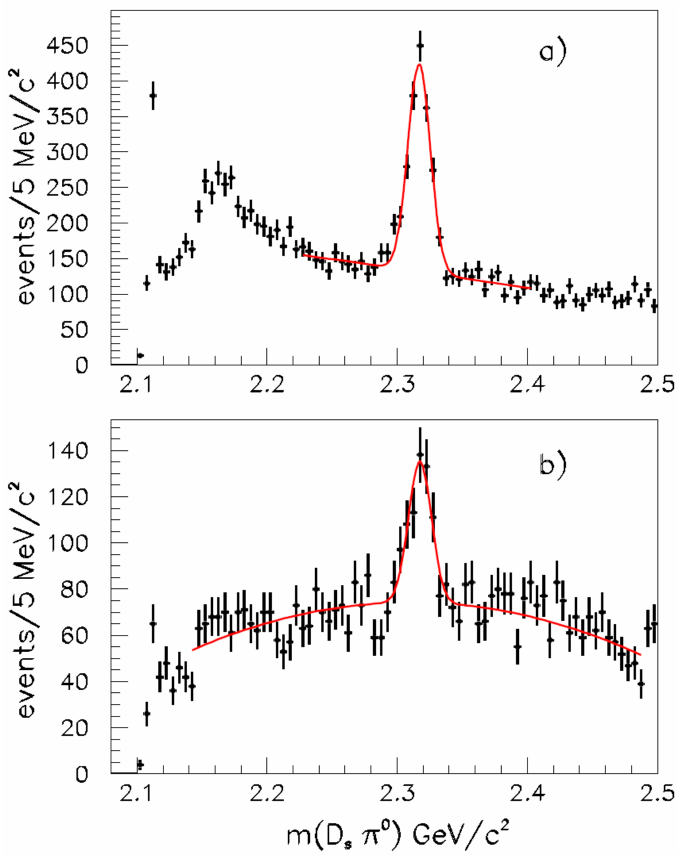


Fig.5. The $D_s^+ p^0$ mass distributions for (a) the decay $D_s^+ \rightarrow K^+ K^- p^+$ and (b) the decay $D_s^+ \rightarrow K^+ K^- p^+ p^0$.

One of the most interesting surprises of the year was our discovery of what appears to be a new *p*-wave charm-strange meson, the $D^*_{sJ}(2.317)$. The mass of the $D^*_{sJ}(2.317)$ is significantly below theoretical predictions. The low mass closes off the normally favored decay channel and results in a large suppression of the decay width. The discovery is a reminder of the significant potential for surprises in the very large data samples available in *BABAR*. The discovery opens up new territory for exploration of meson spectroscopy, and it has already led to many other experimental results, as well as much theoretical interest.

The *BABAR* Detector is now beginning its fourth data run. The first run began with turn-on in 1999 and ended in summer 2000 with about 25fb^{-1} recorded. During the second run, which stretched from late fall 2000 to summer 2002, about 71fb^{-1} were recorded. A shorter third run, which began in late fall 2002 and ended in summer 2003, resulted in the further accumulation of about 35fb^{-1} of data. Close collaboration between PEP-II and BABAR has been a major component of the success of the luminosity improvement program, including the development of a capability for continuous injection in the LER while accumulating data. The detector subsystems, aside from the Resistive Plate Chambers (RPCs) of the Instrumented Flux Return (IFR), have met the design goals and continued to perform well.

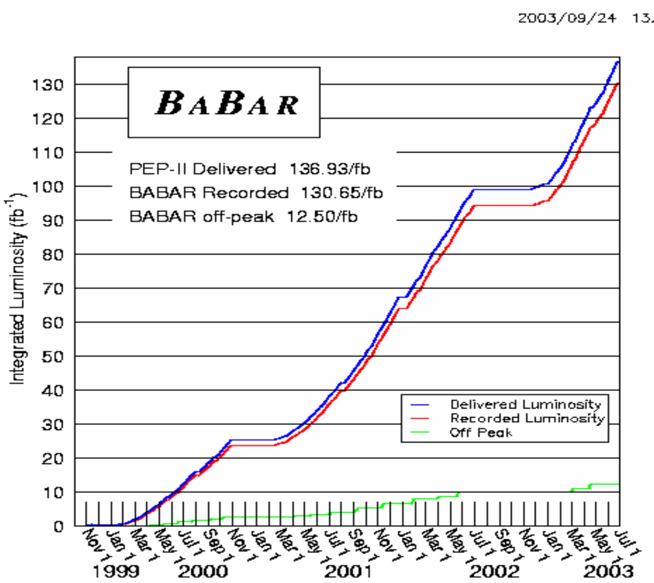


Fig.6. Integrated luminosity since the beginning of data taking in 1999 through Run 3.

One area that has received considerable attention over the past few years is the IFR. After encountering unexpectedly early decline in the performance of the RPCs, at least in part due to inadequate quality control and operation at elevated temperatures, the collaboration has undertaken a major effort to address the serious losses in muon identification efficiency that have resulted. Unfortunately all attempts to remediate the performance of the existing chambers through 2002 have failed. Therefore, new RPCs were produced in FY2002 for the forward endcap, with significantly improved quality control. These devices were rigorously tested before installation during an extended shutdown in the summer and fall of 2002. At the same time, additional absorber was added to the forward endcap in order to increase the muon identification efficiency and reduce pion contamination. Five one-inch layers of brass replaced RPC layers inside the door. Four inches of additional steel between two double layers of RPCs were installed on the outside of the forward doors. In addition, a belt of two layers of RPCs was added to better cover the interface between the barrel and endcap. The new RPCs performed efficiently during the third data run. Additional steel will be added this year to reduce negative effects of beam-related backgrounds on the longevity of the endcap RPCs.

In fall 2002 the experiment turned to the upgrade of the barrel IFR, consistent with a realization that the physics program of the experiment should extend to the end of the decade. By this time, considerable operational experience had been gained with well-constructed RPCs. Also, extensive laboratory work done during the attempts at remediation established a better understanding of the detector physics issues for RPCs. With the goal of developing a reliable system, the collaboration undertook to consider alternative technologies for the replacement, ultimately leading to the adoption of Limited Streamer Tubes (LSTs) as the technology. The plan is to replace two barrel sextants in a standard summer shutdown in 2004, with the balance to be replaced during the longer shutdown planned for accelerator upgrades in 2005. Production of the LSTs is about to begin. In order to enhance muon identification and pion rejection, six layers of sensors in the barrel will be replaced with 7/8" brass.

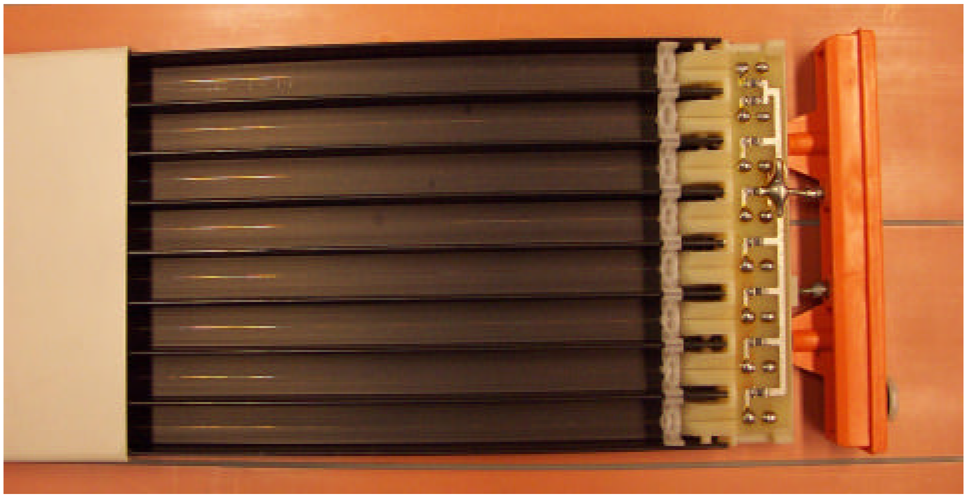


Fig.7. LST tubes with cover drawn back to expose wires, carbon paint and end plugs.

The support tube, which is threaded through the drift chamber and contains the Silicon Vertex Tracker (SVT), final focus beam-line elements, as well as the beam pipe, was removed in summer 2002 in order to add cooling to the bellows located at the ends of the beryllium section of the beam pipe. At this time, the SVT was extensively tested and many of the small number of dead-sections were restored to operation. During the removal operation, the Drift Chamber (DCH) inner beryllium wall was damaged. This was repaired, and the support tube was reinstalled without incident.

Measurements of radiation effects for the SVT modules are in progress; initial results have been that the silicon strips and the readout chips are likely to last to 5 Mrad. However, there are indications that the performance of the readout chips may be degraded at lower doses under certain circumstances. Spares amounting to 30% of the modules have been built to replace damaged modules and those suffering from radiation damage. The natural time for replacement of these modules from the standpoint of radiation damage and the upgrade of the accelerator interaction region is 2005.

The DIRC, which uses Cerenkov light to identify particle species, was upgraded during the 2002 shutdown. At higher background rates that will accompany higher luminosity, the DIRC electronics was expected to generate significant dead-time. This would lower the efficiency for recording events produced by the accelerator. By replacing one ASIC chip on each board, this performance limitation was removed.

During the past year there have been indications that the DCH electronics may also limit data-taking at higher luminosity. The need for, and nature of, a fix for this problem is now under investigation, with the expectation that an upgrade of the electronics will be needed before the 2005 shutdown.

The trigger is in the middle of being upgraded to handle higher luminosity. Additional information from the DCH will be used to ensure that events originate close to the interaction point along the beam-line. All the electronics has been produced. The new system is presently being commissioned in parallel with the current tracking trigger system. The data acquisition computer system has also been upgraded to handle higher luminosity.

During 2002 it was recognized that the computing model for the experiment, which uses an Objectivity Database, would not scale well to larger data samples. The prescription to cure this problem was a new data storage model. Intense development of the new model has occurred during this year, with deployment already underway. The benefits of this remarkable effort are already apparent in the rapid turnaround of data taken at the start of Run 4. We have high expectations that the new computing model will allow faster and more ready access to the rapidly expanding *BABAR* data sample. It should also enhance our ability to make use of collaboration wide computing resources.

The goal of Run 4 is to accumulate an additional 100 fb^{-1} as part of a longer-term plan to accumulate a full sample of 500 fb^{-1} by the end of 2006. The collaboration and the laboratory are in the process of exploring the physics case for extending this rich *B* physics program until the end of the decade or beyond. We have already demonstrated that there is a strong physics case for few ab^{-1} samples, which have the potential of reaching new thresholds in our ability to obtain a complete picture of CP violation in *B* decays. Beyond this, there is a vigorous effort underway to define the physics case for a new facility, capable of luminosities ranging upward toward 10^{36} $cm^{-2}s^{-1}$.

3. FY03 PROGRESS IN PARTICLE ASTROPHYSICS PROGRAM by Steve Kahn

With the arrival of Roger Blandford (from Caltech) and Steven Kahn (from Columbia) the newly inaugurated Kavli Institute for Particle Astrophysics and Cosmology (KIPAC) began "operations" in July of this year. KIPAC will eventually be housed in a new building on the SLAC site, funded partially by a generous gift from Fred Kavli and the Kavli Foundation. Designs for the building are nearly complete, with groundbreaking expected for Spring 2004, leading to initial occupancy in August 2005. It will be a 25,000 square foot facility housing 90 people, including faculty, staff, students, and visitors. The building will include a 150-seat auditorium and an information center including video conferencing facilities, advanced computer imaging facilities and an interaction space.

Eight postdoctoral scholars were recruited to KIPAC at the beginning of the calendar year, and took up residence this September. They are: Drs. Edward Baltz, Andrei Frolov, Ming Feng Gu, Win Ho, Philip Marshall, John Peterson, Masao Sako, and Anatoly Spitkovsky. Sako and Spitkovsky are Chandra Fellows, and Ho is a Hubble Fellow. Together, they bring a wealth of activity in a rich variety of fields ranging from quantum cosmology to X-ray spectroscopy of astrophysical sources. In addition, a number of distinguished visitors will spend part of the 2003-04 academic year at the Institute.

Under the auspices of KIPAC, initial discussions have been held to facilitate significant SLAC involvement in two major upcoming projects in experimental cosmology: The Supernova Acceleration Probe (SNAP), and the Large Survey Synoptic Telescope (LSST). SNAP is a wide-field telescope in space designed to provide sensitive constraints on the nature of dark energy in the Universe, primarily through measurements of the redshift-distance relation using Type Ia supernovae as calibrate-able standard candles. As presently envisaged, SLAC will play a major role in the design and development of the Observatory Control Unit for the mission, and will spearhead a corollary scientific program using SNAP measurements of strong gravitational lensing systems for cosmology. LSST is a large aperture, wide-field ground-based telescope designed to survey the entire visible sky every few days. SLAC will lead the development of a 2.2 Gpixel camera for this facility and of the associated data acquisition system, which must be designed to handle a data rate approaching 18 Tbytes per night. A by-product of the LSST survey will be sensitive map of the dark matter distribution in the $z < 1$ Universe, derived from weak gravitational lensing of background galaxies. The power spectrum of the mass distribution in dark matter as a function of redshift is also a sensitive probe of dark energy. Thus these two projects will provide complementary tests of our current standard cosmological model.

Two new faculty positions associated with KIPAC were recently posted, one in theoretical and/or computational astrophysics and the other in experimental and/or observational astrophysics. Both positions are intended for beginning assistant professors and will be joint between the SLAC HEP faculty and the Physics Department on the Stanford campus.

GLAST

The Gamma-ray Large Area Space Telescope, GLAST, is a satellite-based experiment under construction to measure the cosmic gamma-ray flux in the energy range 20 MeV to >300 GeV, with supporting measurements for gamma-ray burst transients in the energy range 10 keV-25 MeV. With a sensitivity that is more than a factor 30 greater than that of the EGRET detector on GRO, GLAST will open a new and important window on a wide variety of high energy phenomena, including supermassive black holes and active galactic nuclei, gamma-ray bursts, supernova remnants and cosmic ray acceleration, and searches for new phenomena such as supersymmetric dark matter annihilations, Lorentz invariance violations, and big bang particle relics. The launch is scheduled for early 2007.

The Large Area Telescope (LAT) is the high-energy instrument on GLAST. The LAT collaboration is a novel teaming of particle physicists and high energy astrophysicists. The LAT PI and Spokesperson is Professor Peter Michelson (Stanford and SLAC). The LAT is being developed in a partnership between NASA and the DOE, with substantial contributions from Italy, Japan, France, and Sweden. The LAT project is managed at SLAC.

The LAT collaboration consists of approximately 125 scientists, including 40 post-docs graduate students. There were two full collaboration meetings in FY03, at Goddard Space Flight Center in October and in Rome, Italy in September. Accompanying both meetings were full-day science symposia devoted to specific topics (multi-wavelength observations in October and diffuse emissions in September), providing additional interactions with the broader science community. The next full collaboration meeting will take place at SLAC. In addition, the Senior Scientist Advisory Committee (SSAC) meets regularly, approximately every six weeks, by teleconference and in person. Science preparation has been proceeding within the context of parallel topical groups which have been meeting with varying frequency, and an update to that organization is under discussion. The first data challenge will commence in late 2003, providing the first end-to-end of the instrument simulation, reconstruction, and science analysis tools. A full day of data will be simulated, including all backgrounds and a few physics surprises.

Project

The project made important progress in all major areas in 2003. A significant milestone was the CD-3/CDR review May 12-16, 2003, and the subsequent achievement of CD-3 status. Just prior to the CD-3/CDR review, the French space agency, CNES, announced their decision to withdraw funding for LAT, along with many other programs, due to very large internal budget shortfalls. The CNES hardware participation was primarily in the calorimeter, preparing the crystal detector elements (CDEs). LAT project management identified this as a risk area in the year prior to this event, and it initiated a second source qualification program in the U.S. This helped to mitigate the technical impact, but the CNES pullout was nevertheless a major blow to the project at a critical time. In spite of this setback, the project successfully completed the review. The CNES pullout, along with a limited list of other issues and the recognized need to maintain schedule float and cost contingency, resulted in a re-baselining process, involving both DOE and NASA, that included a three month schedule extension.

In addition to the CD-3/CDR review, other reviews involving the LAT project in 2003 included the following: quarterly and mini-Lehman reviews November 12-13 2002, January 30, 2003, and July 31, 2003; a sequence of detailed subsystem peer reviews prior to CD-3/CDR; the SLAC Director's Assessment May 20-21; and the NASA Mission NAR in June 2003.

Communication within the LAT team was improved through a revised suite of meetings, including a monthly face-to-face management meeting with all the subsystem managers, starting in June. There are several teleconferences daily for the subsystems and other integrated projects, along with a weekly Engineering Meeting teleconference.

The LAT Project added key personnel in the areas of mechanical engineering, TKR interfaces, electronics, flight software, and system engineering.

An *ad hoc* group developed more detailed plans for the LAT Instrument Operations Center (LIOC), which will be responsible for the instrument command and control generation, health and safety monitoring and analysis, data pipeline processing, and interfaces to the science analysis. A second *ad hoc* group is reassessing the plans for the end-to-end tests of the data acquisition system, now that the design is complete, with results ready in early 2004.

The focus of the hardware efforts in 2003 has been the engineering model development. The engineering model program was designed to test the manufacturing processes in each subsystem and to provide a component of the qualification program. In addition, the individual subsystem engineering models were integrated together at SLAC as testbed in the year prior to flight instrument integration. That effort provided an excellent test of LAT assembly procedures, system-level functionality, test procedures, and data acquisition and analysis software. Some of the engineering model hardware, along with a cosmic ray event, is shown in Figure GLAST-1.

Other hardware highlights included:

- Completed fabrication of all LAT silicon strip detectors by Hamamatsu. This is a major accomplishment, since silicon detector availability was identified as an important risk area early in the project. The detectors have excellent characteristics, performing well beyond the requirements with high yield. Ladder production in Italy was also started, with excellent yields.
- The calorimeter engineering model passed its full suite of environmental qualification tests.
- All ACD flight PMTs were received and tested, with excellent yields. All electronics parts were ordered, along with other major components.
- Final versions of ACD, CAL and DAQ ASICs were delivered in September and are now undergoing testing.
- Remaining mechanical/thermal design issues at CD-3/CDR have since been resolved and reviewed.
- The LAT assembly facility and clean room in building 33 has been put into operation. All integrated engineering model activities are taking place there.

In 2004, the qualification testing of the subsystems will be complete, flight hardware will be in production, and integration of the instrument will begin.

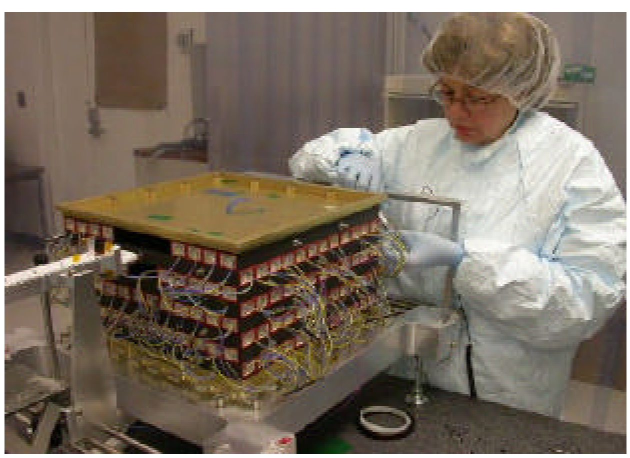


Figure a CAL engineering model assembly

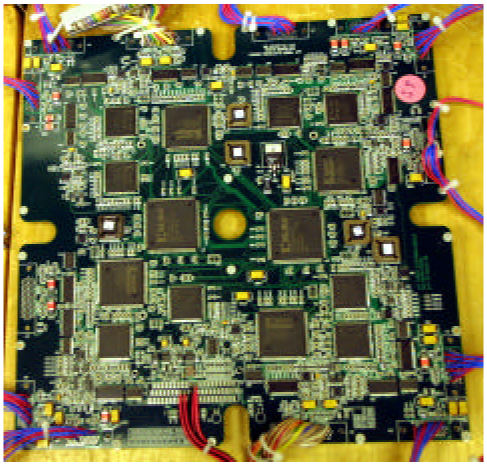


Figure a Tower Electronics Module (TEM) prototype.

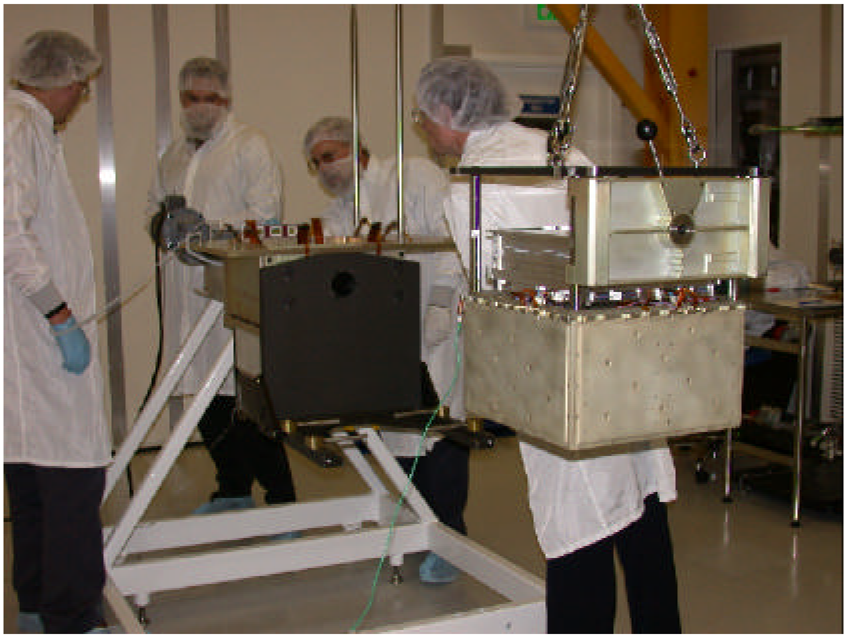


Figure b Engineering model integration. The tracker mini-tower is on top of the calorimeter.

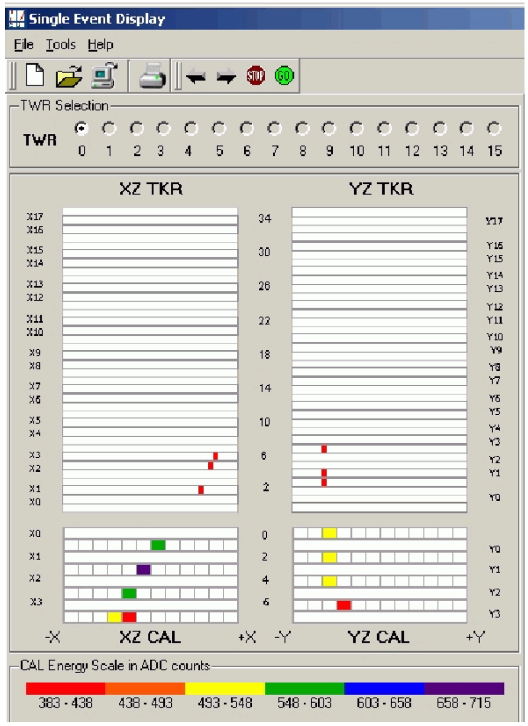


Figure c Online event display of a cosmic ray muon event in the engineering model.

GLAST New Physics Working Group.

Work has continued this year in expanding our understanding of the possible sources of dark matter for which GLAST can set significant limits. There is also interest in how GLAST can be used to set limits on the size of large extra dimensions. Very good limits have been obtained by theorists using EGRET data.

Unconventional Stellar Aspect (USA) Experiment

Work has continued this year on analyzing the observations from the USA X-ray telescope. USA (Unconventional Stellar Aspect) experiment is a satellite x-ray timing telescope designed to measure the energy distribution and time structure from months to micro seconds of the x-ray flux from the 30-40 brightest x-ray sources in our galaxy and nearby galaxies. The observing program yielded well over seven mega seconds of observational data on about 90 sources being brought from space to NRL and then to SLAC for analysis by SLAC personnel.

This year two refereed journal papers and two Stanford Physics Ph.D.s. have resulted from this work. The topics of these papers centers on X-ray time series analysis of observations from black hole and neutron stars fed by normal stars via an accretion disk. Through this work, we gain insight into the regions of very strong gravity, the nature of black holes, and the extreme electromagnetic fields near the surface of the neutron stars and the horizon of the black hole.

At this writing 8 refereed journal papers have been published, and 4 are in preparation. The USA effort has produced 7 Stanford Ph.D. theses, and there is one more Stanford Ph.D student working on the data at this time.

Other PAP Topics

Work has continued on various topics using archival and guest observer data. New proposals have been accepted for the Integral and the XMM missions. In addition, a number of papers were submitted for publication. Some topics under consideration and their progress at this time are:

- X-ray spectroscopy of the iron K line in a Seyfert galaxy
- Spectral study of galactic winds in nearby active galaxies
- Transmission spectroscopy of gas in galaxies located in the line of sight to quasars: paper in press
- Modeling of gamma ray emission in blazars, paper in press:
- Analysis of long-term variability data of Seyfert galaxy NGC 4151
- Study of the nature of variability of accreting white dwarfs
- Study of mergers in cluster of galaxies; paper submitted: "Complex Structure of Galaxy Cluster Abell 1689: Evidence for a Merger from X-ray Data?"
- Study of variability of active galaxies with known black hole mass
- Study of non-thermal processes in clusters of galaxies
- Analysis of the Integral observations of AGN NGC 4151 and IC 4329a
- X-ray spectroscopy of blazars using the XMM satellite

Other activities

- AstroE2 is now scheduled for launch in January-February of 2005. The AstroE2 mission will allow observations of GLAST-LAT objects in X-ray to hard X-ray bands and carry out simultaneous observations of many interesting transient phenomena
- Active participation in organization of three conferences at SLAC/Stanford; "KIPAC Inaugural symposium" (Oct. 18, 2003), "Polarization in X-ray and gamma-ray sources"(Feb. 9-11, 2004), and Texas at Stanford Symposium (December 2004).
- Work on Constellation X (ConX). ConX is a major new X-ray telescope being developed as a NASA mission.
- R/D work to develop a hard X-ray polarimeter to be flown on a balloon with an instrument capable of decisively choosing a correct model of Crab Pulsar in one balloon flight.
- Semiconductor Compton Telescope R&D with collaborators in Japan and Princeton.
- R/D for NeXT X-ray/hard X-ray mission for possible participation in Japanese X-ray/hard X-ray mission.

4. FY03 PROGRESS IN Experiment E158: A Precision Measurement of the Weak Mixing Angle in Møller Scattering by Krishna Kumar

Over the last decade, high-energy collider experiments have tested the electroweak theory with great precision, probing at the TeV scale for new physics beyond the standard model. On the other hand, tests of the electroweak interaction at low Q^2 are typically less sensitive by an order of magnitude. In September 2003, the final data collection of SLAC experiment E158[1] was completed, which seeks to determine the weak neutral current coupling of electrons to high precision at low Q^2. This is achieved by measuring the left-right parity violating asymmetry in the Møller scattering of 48.3 GeV longitudinally polarized electrons from the atomic electrons in a liquid hydrogen target. When all the data are analyzed the world's most precise determination of the electroweak mixing angle $\sin^2\theta_W$ at low Q^2 will be obtained.

E158 Overview

Target electrons, in a 1.5 m long cell of liquid hydrogen (10.5 gm/cm^2), are bombarded by a 48 GeV electron beam, the longitudinal polarization direction of which is changed pseudo-randomly keeping all other beam parameters unchanged. Møller electrons, *i.e.*, beam electrons scattering from target electrons, are isolated by a forward magnetic spectrometer consisting of 3 dipole "chicane" and four quadrupole magnets, oriented with their magnetic axes along the primary electron beam direction. Møller electrons of interest in the full range of the azimuth (spanning the polar angular range 4.5 mrad < θ_{lab} < 9 mrad) traverse through the bores of the quadrupoles and are brought to focus in a ring on a calorimeter located 60 m downstream of the target.

The experimental asymmetry is measured by averaging the fractional difference in the cross section over many complementary pairs of beam pulses of opposite helicity. In order to achieve the desired statistical error of order 10 parts per billion (ppb) in a reasonable length of time, the integrated signal of more than 20 million electrons must be detected each beam pulse.

The E158 experiment successfully carried out the final commissioning and took a 5 week production run at design current between January and May, 2002. The machine delivered stable beam at a repetition rate of 120 Hz, with a peak charge of 5.5×10^{11} at 45 GeV and 3.5×10^{11} at 48 GeV. The high luminosity beam was delivered at an efficiency exceeding 60% against the clock, running the long pulse beam to E158 interleaved with beam delivery to PEP-II, with low jitter in all the beam parameters and the high beam polarization. E158 profited greatly from the development of a new polarized photocathode by the SLAC Polarized Source Group through their research and development efforts for the Next Linear Collider. Figure 1 summarizes the machine parameters and compares them with those of the Linear Collider.

[1] SLAC E158 proposal, K. Kumar spokesman and contact person, (1997) (www.slac.stanford.edu/exp/e158/documents/proposal.ps.gz)

Parameter	E158	NLC-500
Charge/Train	6 x 10^{11}	14.3 x 10^{11}
Train Length	270ns	260ns
Bunch spacing	0.3ns	1.4ns
Rep Rate	120Hz	120Hz
Beam Energy	45 GeV	250 GeV
e^- Polarization	80%	80%

Figure 4: Beam parameters for the E158 experiment compared to those for the Next Linear Collider

The second run of 6 weeks took place from October 1 to November 26, 2002. In preparation for this run, improvements were made to further reduce backgrounds. The most beneficial change was the introduction of large removable collimator to intercept electrons originating from elastic and inelastic electron-proton scattering in the target. During the first physics run we found that these events—mainly inelastic *ep* scattering—gave rise to an asymmetry of 1.5 ppm in the outer calorimeter. In principle, spill-over from this large asymmetry had the potential to corrupt the order-of-magnitude smaller asymmetry expected from electroweak Møller scattering into the inner calorimeter.

Preliminary Physics Result

In parallel, work continued on the analysis of Run I. In April 2003, the collaboration deemed itself ready to "unblind" the raw asymmetry result, since a first pass at all statistical and systematic errors had been made. The result, which was released by Kumar at a SLAC seminar on April 3, 2003, was found to be A_{PV}(Moller at Q^2 = 0.03 GeV^2) = -151.9 ± 29.0 (stat) ± 32.5 (syst) parts per billion.

The statistical significance is 3.6σ from zero, proving for the first time ever that parity is violated in the Moller scattering process. From this asymmetry measurement, a preliminary value for the electroweak mixing angle $\sin^2\theta_W$ can be extracted at Q^2 = 0.027 GeV^2: 0.2371 ± 0.0025 (stat) ± 0.0027 (syst).

2003 Physics Run (Run III)

The final data taking phase of the E158 experiment took place from June 15 to September 10, 2003. The experiment began commissioning for this final phase on June 15. The physics run began on July 10, 2003 and terminated on September 10, 2003. For this run, SLAC installed a new polarized source photocathode based on recent research by the NLC group that yielded between 85% and 90% beam polarization with the full peak charge required for the E158 physics run. The efficiency of the accelerator and the apparatus was typically around 70%. It is anticipated statistical error on the raw asymmetry from run III alone is 15 ppb, which would make the measurement by far the most precise electroweak asymmetry ever measured.

E158 Outlook

The E158 data collection phase has now been completed, an outstanding achievement both for the accelerator and the E158 collaboration. The history of the luminosity of the three runs is shown in figure X. The statistical error on $\sin^2\theta_W$ is expected to be 0.0011. Our target is to produce the final result for the experiment next summer. Assuming that the systematic error is smaller than the statistical error, the final result will be the most precise low Q^2 measurement of $\sin^2\theta_W$. These results are expected to be final in 2004.

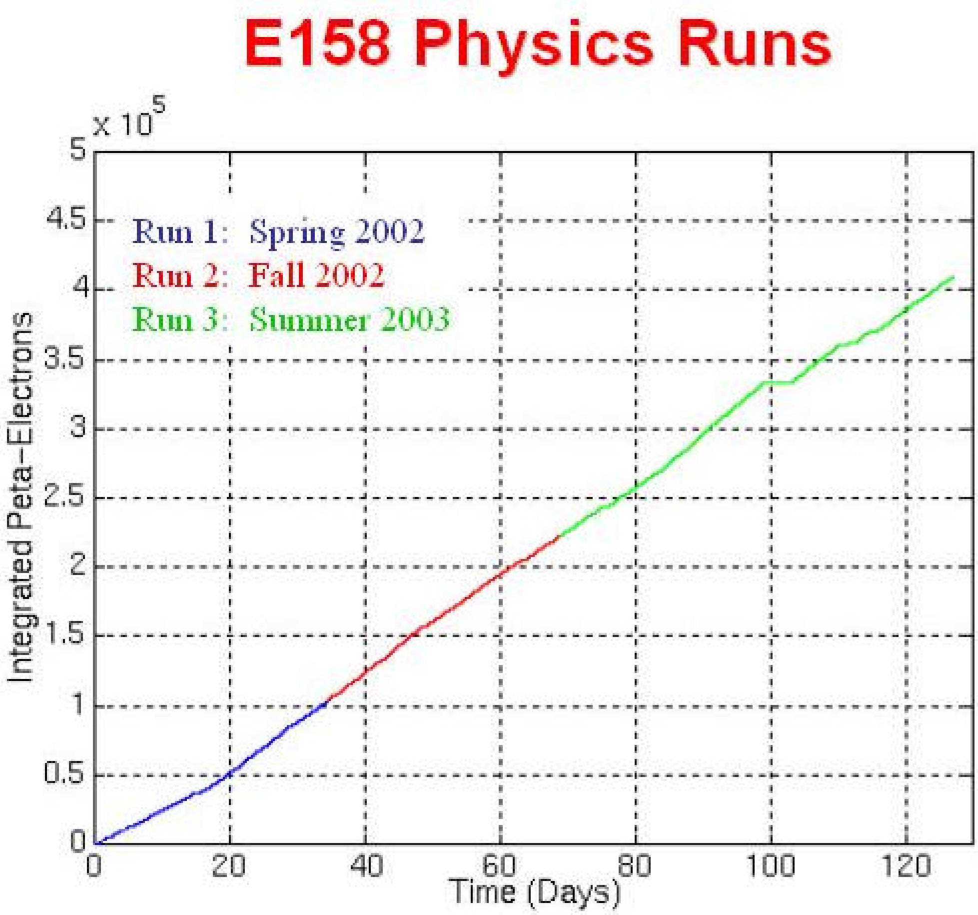


Figure X.

5. FY03 PROGRESS FOR THE NEXT LINEAR COLLIDER RESEARCH AND DEVELOPMENT by Dave Burke and Albe Larsen

In FY2003, several important events occurred related to next-generation linear colliders. Principal among these were international reaffirmation that the next machine needed at the leading edge of high energy physics research is a TeV center of mass energy linear collider[2],[3],[4] and the publication of the International Linear Collider Technical Review Committee's (ILC-TRC) second report[5], commissioned by the International Committee for Future Accelerators (ICFA) and prepared by experts from around the world**.** This report concluded that "Upon studying all machines, the ILC-TRC did not find any insurmountable obstacles to building TESLA, JLC-X/NLC or JLC-C in the next few years, and CLIC in a more distant future."[6] Note that this report reflects a single design for the NLC and the JLC X-band machines, exemplifying the close collaboration between the SLAC-led U.S NLC collaboration and the Japanese collaboration. The JLC-X is now called the GLC and is referred to as such except in direct quotations.

The ILC-TRC report also outlined what it regarded as critical R&D items that should be addressed to ensure that the design specifications for each machine could be achieved, without long delays in commissioning. They divided these items into R1 and R2 categories, with R1 having the highest priority for solution. For the GLC/NLC technology, these items are:

- The validation of the presently achieved performance (gradient and trip rates) of low group velocity structures—but with an acceptable average iris radius, dipole mode detuning and manifolds for damping—constitutes the most critical Ranking R1 issue.
- The other critical element of the rf system is the dual-moded SLED-II pulse compression system.…As far as the 75 MW X-band PPM klystron is concerned, the Working Group considers the JLC-X PPM-2 klystron proof of existence (although tested at only half the repetition rate). A similar comment can be made regarding the solid-state modulator tested at SLAC.[7]

The R2 goals for GLC/NLC include[8] a requirement for a full test of the 75 MW PPM klystron at the specified repetition rate, and an integrated test of klystrons with the solid-state modulator, the

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[2] C. Quigg, "Next Steps," Closing Talk at Snowmass 2001 Summer Study on the Future of Particle Physics, *op. cit.*

[2]The Science Ahead, The Way to Discovery," Report of the DOE/NSF High-energy Physics Advisory Panel, Subpanel on Long Range Planning for U.S. High Energy Physics, January 2002. See http://doe-hep.hep.net/lrp_panel/.

[3] Elementary Particle Physics: Revealing the Secrets of Energy and Matter," Committee on Elementary Particle Physics, National Research Council (National Academy Press, 1998), Bruce Winstein, chairman.

[5] *International Linear Collider Technical Review Committee Second Report 2003,* G. A. Loew, chairman and editor, SLAC-R-606, 2003.

[6] *Ibid*. p. xxxvi

[7] *Ibid*., p xxxviii

[8]*Ibid*. p. xl.

dual-moded SLED-II system and several damped and detuned structures installed in an accelerator environment with LLRF and controls systems operating.

The international impact of the ILC-TRC report has been the formation of an International Linear Collider Steering Committee (ILCSC) and the formation of national or regional organizations to evaluate the two principal designs (the TESLA and the NLC/GLC) and to plan a process to down select between the two. In the United States, the U.S. Linear Collider Steering Group (USLCSG) is evaluating designs and ongoing R&D. As the world's experts in linear collider development, SLAC staff and the NLC collaborators are key participants in the national task forces established by the USLCSG Accelerator Subcommittee to evaluate the consequences of the linac technology options with respect to accelerator design, siting and conventional facilities, cost and schedule, and collider availability. The NLC group's strategy is to support strongly and participate in the option evaluation and international selection process. SLAC leadership's goal is to establish the NLC/GLC X-band technology as the preferred choice, but to prepare for strong participation regardless of the technology chosen.

The design, construction, and utilization of a TeV-scale collider will assuredly be an international effort, and consequently, the R&D has been approached from the beginning through international cooperation. Collaboration with the Japanese has been especially close. Groups at SLAC and KEK have focused their efforts on similar technologies and design strategies, and have reviewed and consolidated their efforts at workshops held over the past several years. The collaboration with KEK coordinates key areas of research on low beam emittance and high-energy acceleration. Semiannual International Study Group (ISG) meetings are held to review progress and to plan work for the next period of research. The two groups have arrived at a common design and technology for the collider.[9] SLAC also has entered into other important collaborations for R&D. Major collaborations with U.S. laboratories include Fermilab, Lawrence Berkeley National Laboratory, Lawrence Livermore National Laboratory, and recently Brookhaven National Laboratory. A Memorandum of Understanding with the Department of Physics at the University of British Columbia is in place. There are also collaborations with Oxford, Brunel and Royal Holloway Universities in the U.K and with the Budker Institute in Russia. A Memorandum of Understanding has been established with CERN and X-band structures built at CERN are now being tested in the NLC Test Accelerator at SLAC.

The impact of the aforementioned activities on the NLC group has been to intensify a plan already in place to complete and fully test the 8-pack integrated test facility while pressing ahead with work on structures, solid-state modulators and 75 MW PPM klystrons. In addition, the collaborative work with Fermilab on site evaluation and conventional facilities has increased, as has work on industrial production of structures. To this has been added significant reevaluation of cost and schedule for both X-band and superconducting machine designs.

The Eight-Pack Project

[9] "GLC Project: Linear Collider for TeV Physics" (Asian Committee for Future Accelerators, Japan High Energy Physics Committee, High Energy Accelerator Research Organization), 2003. See http://lcdev.kek.jp/RMdraft/.

The 8-Pack project presents a demonstration of an entire system design of high-power rf components which will enable rf power from klystrons to be combined, manipulated and transported. The power will be sent initially to water-cooled loads (phase 1), but ultimately will be transported to accelerator structures on the NLCTA beamline (phase 2). This system uses a SLED-II power compression scheme which utilizes planar components in an overmoded rectangular geometry to do the rf manipulation and transmission. Phase 1 of the project was fabricated and assembled in FY03 and, at the end of the fiscal year, is ready to begin high power testing and operations.

The advances in the 8-Pack project completed in FY03 were substantial.

Four XL-4 50 MW klystrons were installed on the 8-Pack test stand. While these klystrons are not candidates for use in the NLC, they are work-horse X-band power providers which have given thousands of hours of reliable performance in a number of installations at SLAC. The combined power of the klystrons is more than ample for the 8-Pack testing program. In FY03 the klystrons were mounted into their sockets and connected to their support and ancillary equipment.

In FY03, the 8-Pack solid-state modulator was connected to the XL-4 50 MW klystrons. The modulator high voltage power supply was installed and checked out. The modulator control system was programmed and commissioned and now provides control for the modulator and manages safety interlocks for the klystrons. The modulator was successfully used to drive the four klystrons to full power at a repetition rate of 30 Hz in lifetime and stability tests. Improvements to the modulator are continuing in order to achieve reliable continuous operation at 60 Hz.

The low-level rf (LLRF) controls and monitoring system was fabricated and tested. The LLRF system provides the drive, amplitude and phase control to the klystrons, and detects and records power levels throughout the 8-Pack rf system. The LLRF system also provides for system interlocks to protect the equipment from rf faults. The LLRF system was used with the four XL-4 klystrons, powered by the modulator, to drive power into local water cooler loads in a successful test of the loads' power handling capacity.

In FY03, all of the high power components required for this system have been fabricated and cold tested. The successful cold tests of the individual components validated the design of the components as well as the concept of controlling rf power through phase manipulation. The components have been assembled into the complete phase 1 system. Cold testing performed as a part of the assembly procedure showed no unsolvable system faults. The 8-Pack system will begin phase 1 operations at the beginning of FY04.

In FY03, the design for phase 2 of the 8-Pack project was complete. All high power rf components needed for installation in phase 2 are now in fabrication. The existing klystrons, modulator and LLRF systems being tested in phase 1 are all fully capable to carry out phase 2 operations. The installation of components and high gradient accelerator structures will be done in the first half of FY04 with phase 2 operations scheduled for the middle of the fiscal year.

Ongoing R&D

Replacing electromagnets with permanent magnets remains a goal for the NLC Collaboration, and utilizing Fermilab's experience in the area of permanent magnets for accelerator beams is a critical part of this. This area has been underfunded over the last year due to the need to complete the Eight-Pack Project. The testing of a standard quadrupole electromagnet for stability of the magnetic center with respect to changes in current and cooling water temperature was completed. The permanent magnet testing for the magnetic center movement with respect to the magnetic field on axis is in process, with each improvement in magnet design garnering improved stability results. Radiation testing of the permanent magnetic materials in radiation conditions that mimic the backgrounds expected in different areas of the machine have been delayed.

Electrical systems work included continued advances in a unique solid-state modulator designed for improved energy efficiency, higher reliability, smaller size and lower cost.

Significant progress continued on several fronts:

1. The prototype 8-Pack solid state modulator was moved to NLCTA and installed along with four (4) XL-4 50 MW klystrons. IGBT protection circuit development continued to enable one half the installed cards of the 8-Pack to drive the four tubes successfully to full power, but at a reduced repetition rate of 30 Hz. Improvements to heat sink structures are continuing in order to achieve reliable 24/7 running at 60 Hz.

2. The first five cell and board structures for the new DFM modulator design were delivered from LLNL and are beginning tests at SLAC. The new units have a far superior oil cooling system and more robust board-to-cell 2-piece connectors. The boards have new higher voltage rated IGBTs that will run at 4 kV instead of 2.2 kV, greatly reducing the number of boards and cells. The decision was made not to build up a second 8-Pack but to switch to a 2-Pack design which better matches the new baseline SLED topology for the NLC. Instead an aggressive effort is underway to field a 2-Pack that can drive two of the new 75 MW XP klystrons. The 2-Pack will use a single short stack of 15 cells and a conventional style matching transformer. This is less efficient than the ultimate design which has only a single integrated transformer; that design will be completed during FY04. The target for the completed first unit is December 03, after which it will be moved to the NLCTA for rf testing and production parts testing.

3. The new design requires improvements to protection circuits which are underway. The newer IBGTs can withstand the needed currents and operating voltages, but transients which occur under various fault conditions must be limited by a combination of feedback control and diversion of voltage and current spikes. LLNL developed a diode protection module that works well, and board feedback circuits are being worked on. In addition, a new set of controls with improved diagnostics (e.g. for temperature) need to be implemented.

4. New IGBT topologies are being modeled and tested. Initial units have been successful and negotiations with vendors to provide prototypes are in progress. Work will continue through FY04 with the goal of testing a new design on a 2-Pack during FY05.

5. The 8-Pack was set up in NLCTA to run from a 2 kV 150 kW switching power supply that was received, installed and successfully tested although some regulator improvements were necessary. Since changing to a 2-Pack strategy, a new effort is underway to design a modular power supply for each driver board, providing 4 kW at 4 kV average power. This will be a high speed switching supply of very high efficiency running from 480 VAC that will eliminate the need for a large bulk supply. Each module will have built-in controls, diagnostics and remote monitoring. The first prototype is under construction.

Progress in instrumentation and global controls systems R&D was slow again this year due to diversion of resources to the 8-pack program. The cavity BPM program continues into prototyping and testing on the KEK ATF.

The resolution requirement for NLC linac BPMs is 200-300 nm rms. Bench evaluation of a cold-test prototype for the NLC cavity BPM shows resolution of better than 80 nm for cw excitation, limited by mechanical stability of the test fixtures. Electrical centering with respect to the mechanical center appears to be excellent, but it has not been possible to measure precisely enough to verify that the NLC stability requirement (< 1 micron per 24 hours) is met. Beam tests with three existing (6.4 GHz) cavities at the KEK ATF show resolution of approximately 50 nm. Further improvement of this resolution is expected in the coming year. The theoretical limit of such cavity position monitors for NLC-like beams is about 1nm. Achieving such resolution would allow yet another way of demonstrating mechanical alignment and stabilization at the level needed for a linear-collider. The recent realization that cavity BPMs produce a bunch-tilt signal potentially useful for NLC linac emittance control led to confirming measurements at the ATF nanoBPM experiment.

Fast data streaming architectures for NLC continue to be pursued through R&D, aimed also at upgrading the existing SLAC Control System Micro Farm and Front End Processors. The first Front End Crate Controller (FECC) board will be tested in the first quarter of FY04. Hardware achievements have included the following: Migration has been completed of the noise-tolerant link, the bus structures, and the CAMAC interface from the Virtex-II FPGA design platform as well as the external SHARC to the Virtex-II Pro with embedded PowerPC. The addition of BITbus support to hardware was completed, and the mode was added to convert this hardware to alternative use as a PNET transmitter for the Master Pattern Generator. FECC board artwork was generated, test circuit boards fabricated and components procured, and loading of first two test boards was initiated.

Software work has included the following: The real-time operating system was re-implemented on an embedded PowerPC platform, with support for DMA CAMAC interface hardware instead of programmed I/O hardware. Existing support was ported for booting, link message passing, 360 Hz trigger interface, and CAMAC access (local from FECC and remote from PC) to a PowerPC platform. Software support was added for BITbus hardware (local from FECC and remote from PC) on PowerPC platform; local FECC access was added to the PNET transmit mode. Integration was started of PCIL-FECC support into PC-micro CAMAC access software. Ethernet boot support for PC-micro implementation was started. Migration continued of the 360 Hz application code from the PC-micro high priority interrupt routine to the FECC application layer; and conversion continued of the communication between PC-micro iRMX jobs and the 360 Hz application code from a shared memory model to the remote networked link model (TEG).

Progress on an SBIR program that has resulted in a much longer-lived cathode (over 100,000 hours) for the microwave tube (helix TWT) that provides the input rf signal to the klystron slowed down this year, possibly due to the generally poor economic climate in Silicon Valley. Plans remain in place to purchase some of these devices for the NLC Eight-Pack Project in FY04 if a solid pre-production model can be demonstrated (the Eight-Pack Project requires reliable 24/7 operation). Another SBIR project (by Diversified Technologies) produced a high-voltage pulse modulator that is a hybrid of a solid-state switch and a conventional pulse-forming network. The hybrid modulator has been received at SLAC, where it is being integrated into a new high-power test stand that will increase the capacity for klystron testing. For the 75 MW klystron, four such tubes have so far been produced by one microwave tube company with a minimum of two more planned over the next year. These tubes have met all the requirements for the NLC except for average power, due to limitations of the modulator in Japan used for testing. As part of the collaboration program with KEK, one of these tubes is currently at test on a modulator at SLAC that has no such limitation. An SBIR project continues to work on developing a gridded gun for the sheet beam klystron development program. Sheet beam klystrons may some day become a cheaper and more reliable alternative to the conventional, cylindrically symmetric klystrons currently in use for linear accelerators.

Fermilab's charter on structures is to develop industrial sources of parts and structures, and they are well on the way of completing the first goal. The strategy is to initially develop the structure capability at Fermilab so that it can be demonstrated to a company, and this is also well along, with Fermilab now building structures in batches of two or three at once. SBIR projects are developing novel devices and technologies to assist in structure manufacturing processes: A non-contacting, interferometric coordinate measurement machine is nearing completion (by Red Cone Research in Colorado); a precision air gauge is being developed for real-time QC of the curved surfaces internal to X-band structure cells (by Surface Manufacturing in Auburn, California); Robotic technology for automated stacking and alignment of accelerator cells is being developed (by Zmation, Inc., in Portland, OR). Novel rf components that may become part of the linear collider's rf pulse-compression system are being developed as well: a multi-megawatt circulator, solid state and plasma switches.

In the Main Linac, efforts were concentrated in the three areas of rf sources (klystrons), rf components to compress and distribute the rf power, and accelerator structures that apply the rf to the particles being accelerated.

The 75-MW klystron program has had much more favorable results this year, due in part to the large number of devices that have been built and tested. A total of four very similar tubes have been built by a microwave tube company in Japan under the guidance of SLAC's collaborator KEK, and a rebuild of a SLAC tube is presently at test at SLAC with at least two more coming in

FY04. One of the Japanese tubes is also at SLAC for testing. Aside from the very technical differences that would be noted by a klystron engineer, these tubes have effectively identical designs except for the magnetic focusing structure for the permanent magnets and the degree of cooling along the body of the tube (where the rf is generated and interception of the beam can produce cooling challenges). Several of the Japanese tubes have demonstrated the peak power and pulse width required, but not the average power due to limitations in the maximum repetition rate possible with the modulator. One of these tubes is now at test at SLAC on a modulator that has no such limitation, and the tube has been processing somewhat slowly but fairly monotonically. The SLAC klystron now at test has demonstrated all of the necessary requirements, including average power, simultaneously, but has been rebuilt in the attempt to remove a periodic break-up in the collector current and rf pulse. The cause of this break-up may not yet be known but does not appear to be fundamental (it has not shown up on any of the other tubes, SLAC or Japanese, and does not cause any other symptoms such as gas outbursts that would be a cause for concern).

An entire system design for the rf components that would enable rf power from the klystrons to be combined and sent initially to water-cooled loads but eventually to accelerator structures was developed. This system will use two electromagnetic modes to reduce the length of round waveguide required, and a compression scheme called SLEDII that utilizes planar components in an overmoded rectangular geometry to do the rf manipulation. All of the components required for this system have had both their electrical and mechanical designs completed. With the exception of two components, all of the cold tests (using low levels of rf) have been performed, and most of the final components are in various degrees of fabrication. This system will become operational in the second half of FY03.

The focus of the structure design program is to arrive at a design that preserves the necessary wakefield attenuation while at the same time providing the accelerating gradient needed without either damage or excessive breakdown events. Much progress was made in improving high-gradient performance in FY03 . The advances result from an aggressive experimental program, which in the past year has included the testing of six structures of the basic design being considered for the NLC. One of these structures had all of the essential linear-collider features and essentially met the 65 MV/m performance requirements (at 60 MV/m, breakdown rates well within spec were achieved). More details about these tests are included in the section on the NLCTA.

Extensive field geology and environmental survey work was accomplished in California with valuable input from the California Department of Water Resources as well as from published academic researchers who were familiar with the specific geology of the various possible NLC California sites. Using geo-technical data as a basis, actual tunnel construction costs for the California NLC beam housings were projected by tunnel construction engineers located and experienced on the US West coast. In parallel, and independently, a cost survey of 23 previously constructed US tunnels, from seven different US states, was completed by a mid-west consulting engineering firm. All of the tunnels selected had, to various degrees, the same geology as that anticipated for the NLC. Gathered together, this information was used to develop a project tunnel cost probability distribution for the NLC that spans the full range of geology and site conditions anticipated to be found at the various NLC sites.

Further work was completed to quantify stability and vibration for the NLC. Ground motion and cultural noise measurements were completed on and through native California sandstone, in Los Angeles and at SLAC. In Los Angeles, the parallel underground tunnels of the Metropolitan Transit Authority were examined and found to be very similar to those planned for the NLC. Tunnel diameter, tunnel spacing and native California sandstones were fairly representative of the NLC underground housings. Spectral transfer functions were derived from measurements between vibration sources and sensors, along and between the parallel MTA tunnels. At SLAC, similar measurements were taken with identical procedures and equipment where an operating accelerator was available to provide accelerator specific cultural noise. In addition, actual NLC accelerator structures with support girders were examined to provide vibration and stability data. An 80 foot deep, quiet, concrete pit was used with gravity fed cooling water to isolate the accelerator girder from cultural noise transmitted through the floor and through the cooling fluid stream.

At the NLCTA accelerator, the NLC 8-pack utility support systems were completed and a substantial seismic upgrade was completed to comply with the new and more rigorous SLAC seismic standards. Extensive fire protection upgrades were also completed.

The NLC Test Accelerator – NLCTA

During FY01, an aggressive R&D program was launched to develop X-band accelerator structures that meet NLC performance requirements. This program continued to be a major focus of the NLC R&D effort in FY03, involving the concerted efforts of groups at SLAC and FNAL, and the ongoing collaborative efforts with the KEK JLC group on structure development. As in previous years, the testing of prototype structures is done exclusively at NLCTA, where up to four structures can be operated at a time (since 2001, power from its two linac rf stations has been used to process 25 structures, with over 15,000 hours of operation logged at 60 Hz).

The past year saw the transition from testing experimental structures (so called T-Series structures) to testing those designed for use in the NLC/JLC (so called H-Series structures). The former had been built to examine how performance depends on structure length and group velocity. This study was motivated by the pattern of damage observed in the 1.8-m structures: the high group velocity (> 5% c) portions incurred extensive pitting and phase change with operation above about 50 MV/m, while the low group velocity portions remained relatively unscathed.

Seven T-Series structures were built with different lengths (20, 53 and 105 cm) and initial group velocities (5% c and 3% c). By mid-2002, six structures had been tested and showed that breakdown-related damage decreased significantly at lower group velocity and that structure length had little effect on performance. However, the breakdown rates in the input and output coupler cells were noticeably high at 70 MV/m, the NLC design gradient (unloaded) at that time. For the 3% c structures, the coupler rates were generally > 0.3 per hour while for the other 59 cells combined, they ranged from < 0.1 per hour to 0.3 per hour (a total rate of < 0.1 per hour with 400 ns pulses is required for operation in the NLC for this length structure).

An autopsy of the input couplers revealed melting on the edges of the waveguide openings to the cell, and extensive pitting near these edges and on the coupler iris. It was subsequently realized that the waveguide edges see large rf currents and the associated pulse heating can be significant if the edges are sharp. By design, the edges in the T-Series structures were much sharper (76-µm radius) than those in the 1.8-m structures (500-µm radius) where this problem was not seen. Simulations showed that the pulse heating for the T-Series structures was in the 130-270°C range, well below the copper melting temperature, but high enough to produce stress-induced cracking, which can enhance the heating.

To see whether reducing the pulse heating would help, a structure was built using an input coupler design with lower peak currents (a 'mode-converter' type) and an output coupler with larger radius (3 mm) edges. For the regular cells, a previously tested T-Series design (53 cm, 3% c) was used. This structure performed very well, with no enhancement of the coupler breakdown rates relative to the other cells. For the full structure, the breakdown rate at 90 MV/m with 400-ns pulses was about 1 per 25 hours. All structures have since been made using similar couplers.

Although the T-Series structure results were encouraging, their average cell iris radii are too small in that the resulting wakefield is unacceptably large for operation in the NLC. Thus, the next step was to develop NLC-compatible versions. The first task was to increase the iris size while keeping the low group velocity and maintaining a reasonable shunt impedance. This required both thickening the irises (from about 2 mm to 4 mm) and increasing the phase advance per cell (from 120º to 150º). The structures were also detuned and their lengths were optimized for efficiency (the 'standard' length is 60 cm). The resulting designs (H-Series) require higher input power relative to comparable T-Series structures (about 50% more at 3% c). To date, eight such structures have been tested at high gradients. None of these structures showed an enhanced coupler breakdown rate.

One test of note is of a 90-cm, 3% c design (H90VG3), which was built to investigate the feasibility of longer structures. It requires 30% more power for the same average gradient as the standard design (H60VG3). When processed, it reached 75 MV/m with 400-ns pulses before being limited by 'spitfests.' These series of breakdowns were close to each other in location and in time. Such events were observed in the 1.8-m structures at lower gradients, and in the T-Series structures at higher gradients. In all cases, they become noticeable at roughly the same structure input power level (60-80 MW).

At 65 MV/m, which is the current NLC design gradient (unloaded), the H90VG3 breakdown rate was about 1 per hour, but the spitfest nature of the events was still apparent (a rate of less than 1 in 6 hours is required for this longer structure). About 70% of the breakdowns occurred within 5 minutes of the previous one, although there were periods of up to 25 hours without any breakdown. A study of the dependence of trip rate on gradient and pulse width showed that at a fixed breakdown rate, the gradient scales as the -1/6 power of pulse width. At 61 MV/m and 400 ns pulse width, a breakdown rate of about 1 in 10 hours was achieved.

Roughly half of the breakdowns at 65 MV/m occurred in a few cells (three near the front and one in the middle). After the run, these 'hot' cells were examined using a boroscope. In the interior cell, a 100-µm piece of material that was pitted by breakdown was seen on the outer wall. No obvious foreign material was seen in the upstream cells and a more thorough autopsy is underway. So far the material in the interior cell has been identified to be stainless steel.

Another test of note is of a H60VG3 design whose middle six cells have manifold slots for wakefield damping. They were included to test whether pulse heating near the slot openings leads to breakdowns such as those in the sharp-edged couplers. To reduce this possibility, the slot openings were rounded to minimize the heating. A 43 °C temperature rise is expected at 65 MV/m with 400-ns pulses, which is believed to be safe based on the sharp-edged coupler operation experience.

This structure processed fairly quickly (˜ 50 hours) and achieved 80 MV/m with 400-ns pulses before spitfests began to limit further gains. During this period, there was no obvious breakdown rate difference between the slotted and non-slotted cells. At lower gradients, a few hot cells became apparent, including a slotted one. These cells accounted for about two-thirds of all breakdowns. Since only one of the six slotted cells was hot and hot cells occur elsewhere, the breakdown enhancement in the slotted cell is probably not slot related. (Also, a more recent structure with all slotted cells did not show any slot related problems).

During a 32-day run at 65 MV/m, the average trip rate was 0.21 per hour for this mixed-cell structure (< 0.1 per hour is required). Large day-to-day fluctuations occurred (up to 0.7 per hour) from ‘flare-ups’ in the hot cells. The spitfests were much reduced at this gradient, with 25% of breakdowns occurring within 5 minutes of the previous one. At 60 MV/m, the breakdown rate was well below 1 in 10 hours. A subsequent boroscope examination of this structure did not show any obvious contaminates in the hot cells.

The H-series results thus far show that in structures with essential NLC/JLC features, reasonable processing times are possible and that breakdown rates close to those required can be achieved (damage rates also appear acceptable). Nonetheless, more operating overhead is desired, and a new version of the 60-cm structure design was recently adopted that has a smaller average iris radius (a/?=17%) than the present structures (a/??18%). Decreasing the radius increases efficiency and will likely improve high-gradient performance due to the lower (7%) input power required. The transverse wakefield is about 20% larger, which is not expected to impact significantly the control of emittance growth in the NLC linacs.

The main goal within the next year is to operate eight such structures at 65 MV/m in the NLCTA. Tests of experimental structures will also continue, including ones aimed at achieving significantly higher gradients. One test will be of CERN-built, X-band structures with molybdenum irises.

6. FY03 PROGRESS IN ADVANCED ACCELERATOR RESEARCH

Advanced Accelerator Research Department A by Ron Ruth

Accelerator Research Department A has worked on a wide variety of topics this past year. The work has three main thrusts: performance enhancement of current accelerators at SLAC such as PEP-II, research and design for near-future facilities such as NLC or upgrades to PEP-II, and research in fundamental aspects of accelerator and beam physics. The department is divided into several groups, each of which is discussed below.

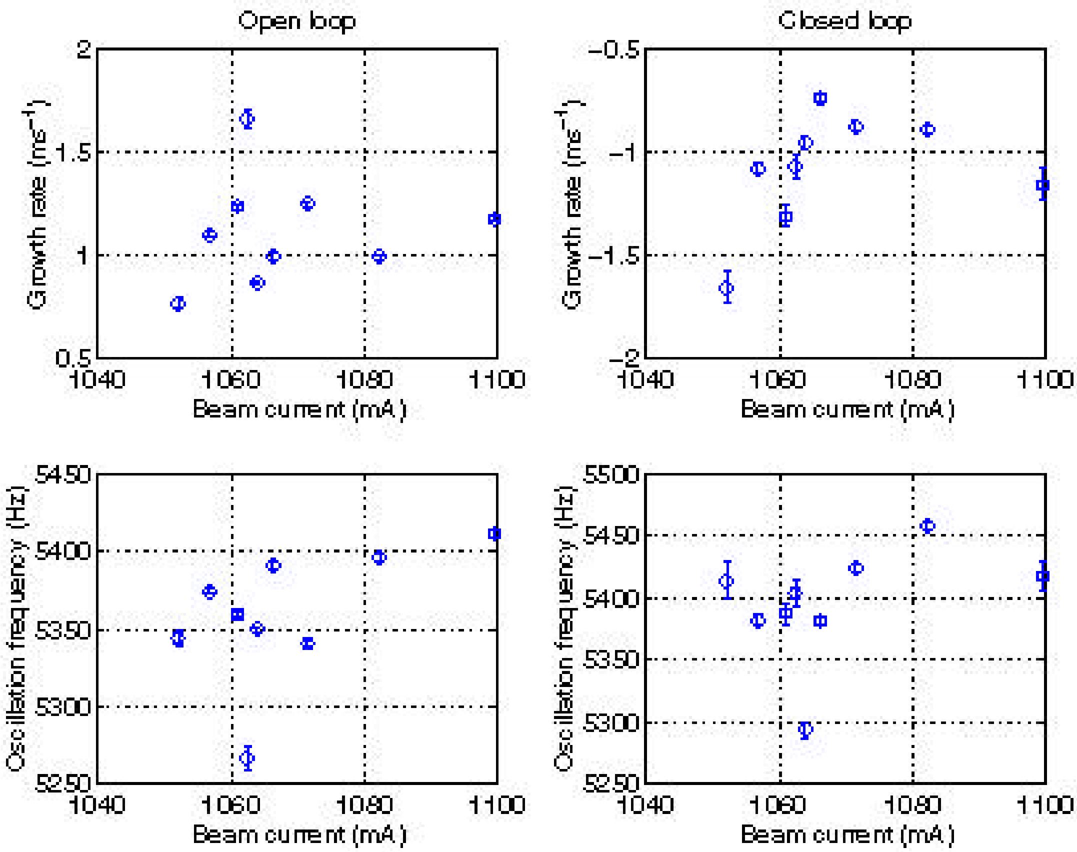
Electronics Research

The Electronics Research group in ARDA combines interests in particle beam dynamics with technology development of fast signal processing and feedback control systems. The group's pioneering hardware and software instability control systems have been implemented at PEP-II, the LBL ALS light source, the Italian Phi-factory DAFNE, the German BESSY-II light source and the Korean POSTECH light source. The PEP-II systems contribute to the record luminosities achieved in the B- factory, and are required to control the beams for both LER and HER in production luminosity running. Electronics Research combines SLAC staff with Stanford graduate students in Applied Physics and Electrical Engineering to provide both accelerator physics and detailed technology skills for accelerator projects. During the year the group has published results in a PRST paper and several conference papers, and Dmitry Teytelman presented an invited talk at the 2003 Particle Accelerator Conference.

The group has been central in machine physics studies to better understand the interactions of the PEP-II RF systems, with their complex impedance-reducing feedback architectures, and the longitudinal dynamics of the machine. During the year we have focused on better understanding the high growth rates on in-cavity longitudinal modes, through machine physics experiments and numeric simulation and analytical studies. From these efforts we have better quantified the importance of klystron saturation effects, and are better able to understand how saturation effects reduce the effectiveness of the impedance control in PEP-II. These studies are crucial in predicting the operation of PEP-II for any of the upgrade scenarios being proposed.

Our measurements show that the impedances driving these in-cavity longitudinal modes are roughly 5 to 20X that expected from the initial system design. The figure shows detailed measurements of the growth and damping rates of mode -3 in the HER at 1 A operating currents. From these measurements it is possible to predict the control margin at higher currents, and investigate control techniques required for higher currents. The rapid growth rates measured (of order 1 1/ms) are at the limit of control for the existing LLRF and feedback systems. We have begun a hardware effort to develop a special low-group delay "woofer" control path for the PEP-II LER and HER. We expect to begin machine studies with this control channel this year.

The second figure is a simulation model study which shows the importance of saturation effects in the PEP-II klystrons, and shows the significance of saturation levels in increasing the instability growth rates. From these studies we can see that for the saturated operating points the growth rates increase significantly, and are in rough agreement with the measured growth rates. We must continue to refine these models and use this information in the design of the RF systems for any upgrade path for higher currents in the PEP-II machine.


Open loop
Closed loop
Growth rate (ms^{-1})
Beam current (mA)
Oscillation frequency (Hz)

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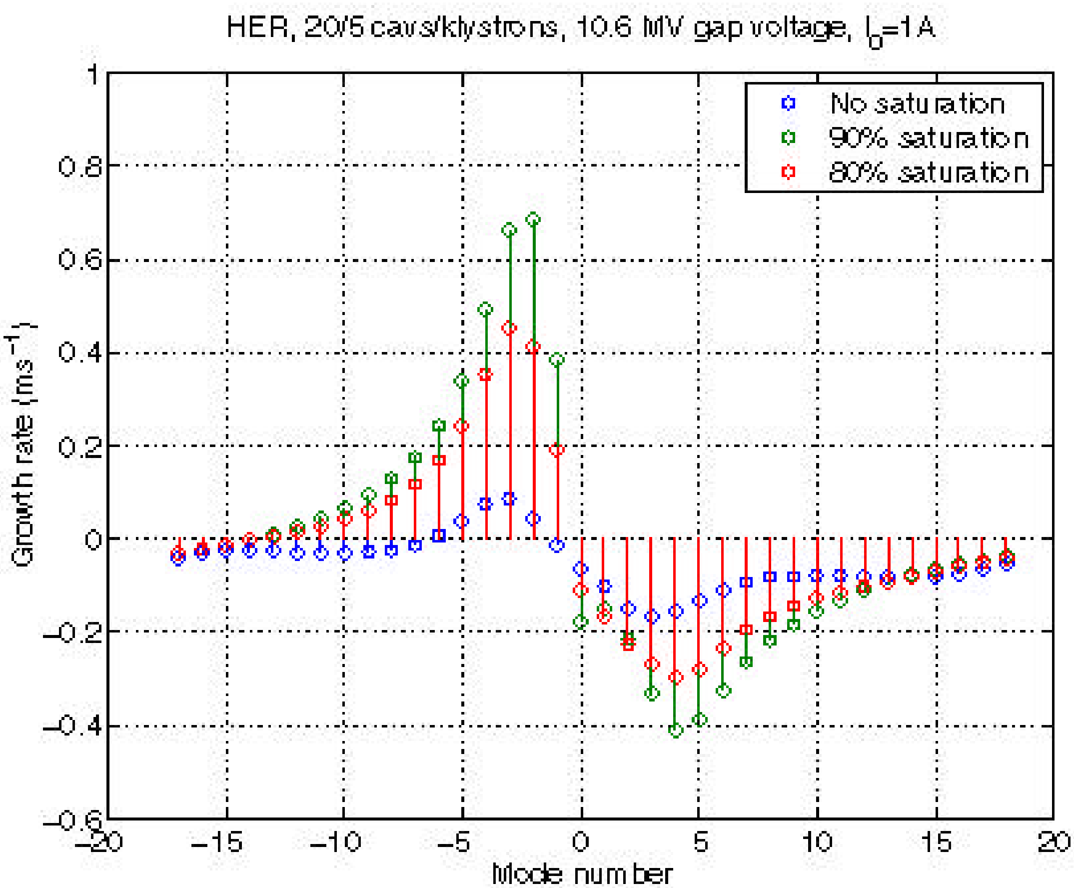
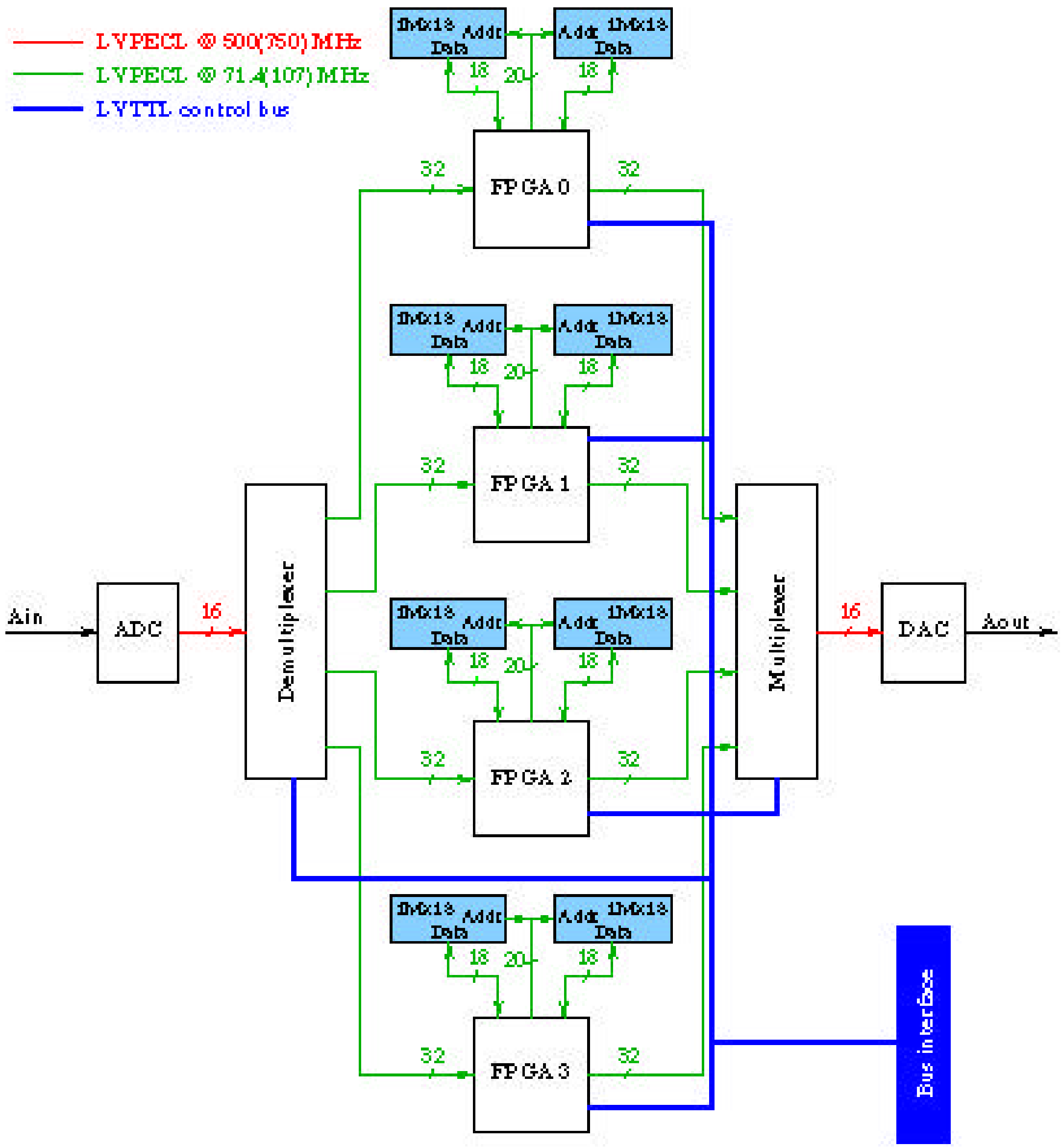


Measured growth rates for Mode -4 in PEP-II

Our group has continued to develop high-speed signal processing systems, and this year we have continued the detailed circuit and signal processing system designs for a 1.5 GSample/sec. feedback processing channel. This new architecture is of direct applicability to PEP-II and other collider needs, and can implement either longitudinal (downsampled) or transverse (non-downsampled) processing systems. It represents a significant advance in the processing speed and density previously achieved. The initial development has been done in conjunction with Dr. Makoto Tobiyama of KEK, and has progressed to include a significant funding component under the US-Japan Cooperative Program in High Energy Physics. Last year's simulation efforts have been expanded to include the detailed design of the detailed ECL and signal processing circuitry for 1.5 GS/sec. processing, including various hardware diagnostic structures required to verify a physical prototype. The figure details the multiplexed signal processing functions which are divided into 4 parallel computational channels. This construction effort is part of our collaboration with KEK and LNF-INFN to build a demonstration system to operate at one of the laboratories. This project is serving as the initial research project for Liane Beckman, a Stanford Ph.D. student in Electrical Engineering.



Our group also has added two new Ph.D. students, Navid Hassenpour and Yubo Zhou, both from the Stanford Electrical Engineering department. Navid's initial research assignments center on the dynamics of low coupled-bunch modes in PEP-II, particularly the applicability of a low group delay processing channel used in conjunction with the LLRF systems to damp in cavity modes. Yubo's initial research has centered on high-resolution beam position monitor techniques and circuits of applicability to NLC type machines.

Collective Effects

A large effort of the Collective Effects Group was devoted to exploration of beam physics in the Linac Coherent Light Source (LCLS) including methods of beam conditioning and techniques to shorten X-ray pulse duration. We also conducted studies of instabilities and impedances for PEP-II upgrade, and coherent synchrotron radiation (CSR) instabilities in rings.

Short X-ray pulses in LCLS. A proposal was made, with detailed calculations, to produce sub-femtosecond x-ray pulses with the LCLS FEL. The idea involves the use of a thin slotted foil in a bunch compressor chicane to emittance-spoil all but a very narrow time-slice of the electron bunch. Detailed calculations, including the transition radiation wakefield of the foil and the FEL dynamics, were used to show that a 2-fs FWHM pulse width is immediately possible in the LCLS (see Fig. 1), with the further possibility of pushing this scheme into the sub-femtosecond range.

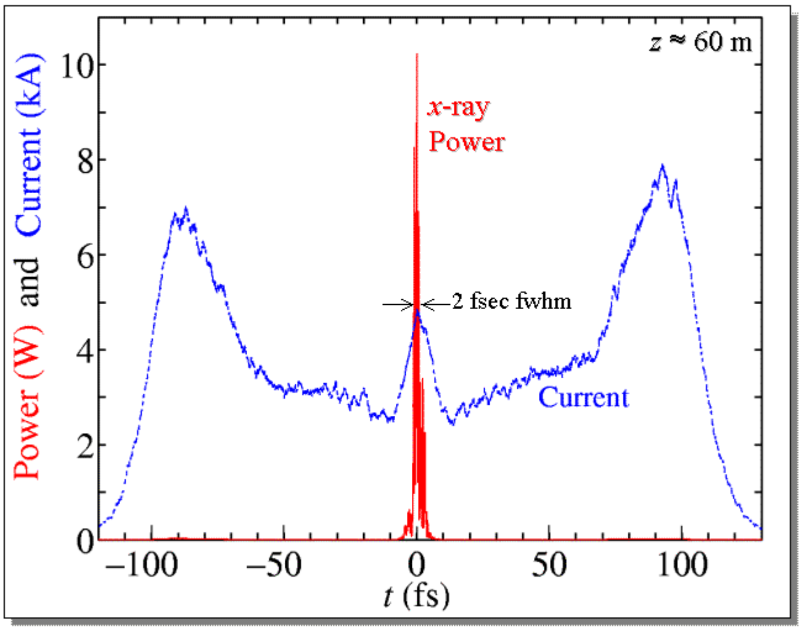


Fig. 1. Power (red) and current (blue) for LCLS beam with a thin slotted foil.

Space-charge instability in LCLS. The recent progress includes studies of longitudinal space charge effect in the LCLS linac. Beam modulation due to the longitudinal space charge (LSC) was analyzed with a modified integral equation that takes into account acceleration in the linac and is compared favorably with the space charge simulations using Parmela. Microbunching instability due to CSR, LSC and linac wakefield were evaluated and different options of damping the instability were explored. As a means to suppress the instability, a laser-electron beam heater system has been studied which may damp the cold-beam instabilities in the LCLS. This involves a laser-electron beam interaction within a short undulator to energy-modulate the beam. The first bunch compressor chicane then dissipates the modulation leaving only an incoherent energy spread which serves to Landau damp the instabilities.

Beam conditioner for short-wavelength SASE FEL. A study has been made (PRST-AB, **6**, 030701, 2003) of an electron beam conditioner, composed of strong solenoid magnets, which may ease the transverse emittance requirements for future x-ray FELs. This study showed that conditioning of the beam might have a side effect that results in projected emittance growth directly related to the amount of conditioning. A more recent study showed that this side effect can be mitigated in a sequence of relatively short solenoids in a beam line, and indicate a promising approach toward practical applications of conditioning for X-ray SASE FELs.

Beam stability in PEPII upgrade. The impedance model of the Low Energy Ring of PEP-II was revised and coded into a Mathematica notebook in a format that can be easily used for stability analysis (see Fig. 2). A collection of formulae for instability analysis was compiled, coded in Mathematica and applied to the stability analysis of PEP-II.

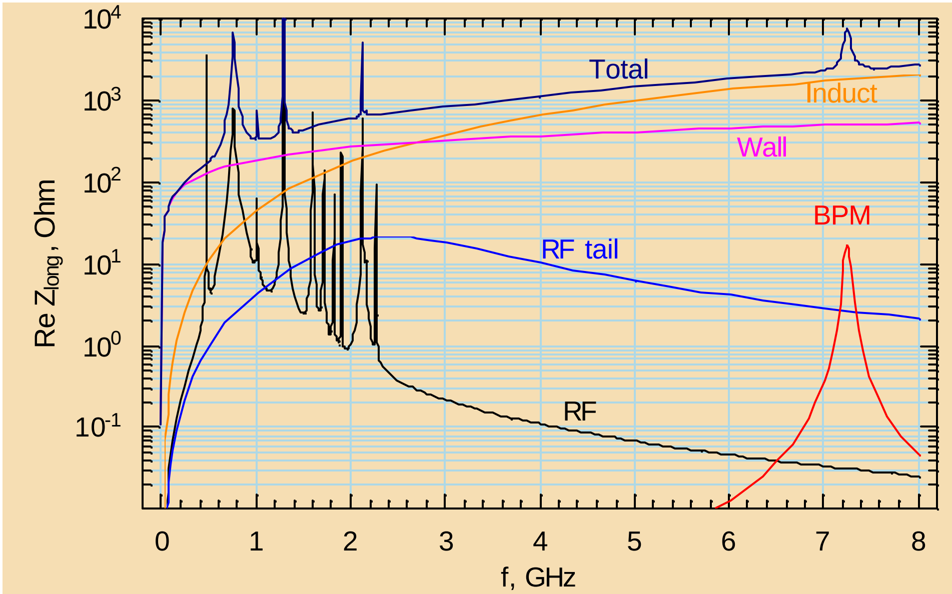


Fig. 2. Longitudinal impedance of the Low Energy Ring of PEP-II as a function of frequency. Indicated are contributions of various components of the ring.

CSR instability in rings. CSR instability for single modes was studied including effect of shielding caused by finite beam pipe aperture (Phys. Rev. ST Accel. Beams **6**, 064401 (2003); **6**, 080701 (2003)). A system of equations for the beam-wave interaction was derived and its similarity to the 1D free-electron laser theory was demonstrated. In the linear regime, the growth rate of the instability was obtained and nonlinear evolution of the single-mode instability, both with and without synchrotron damping and quantum diffusion, was also studied.

Equilibrium distribution of a single nonlinear resonance. In the proximity of a nonlinear resonance, the beam distribution in a storage ring is distorted depending on how close is the resonance and how strong is the resonance strength. In the 1-dimensional case, it is well known that the particle motion near the resonance can be described in a smooth approximation by a simplified Hamiltonian. In contrast to a proton storage ring, where the equilibrium beam distribution is readily solved to be any function exclusively of the Hamiltonian, for an electron beam, this is not true and the equilibrium distribution is more complicated. The Fokker-Planck equation near a single resonance for an electron beam in a storage ring was solved and the result was then applied to obtain the quantum lifetime of an electron beam in the presence of this resonance (Phys. Rev. ST Accel. Beams **6**, 094001 (2003)). Resonances due to multipole fields and due to the beam-beam force were also considered.

Lattice Dynamics

In the past year, we continued the work of improving the optics in the PEP-II accelerators. The main achievement was to move both rings to near half-integer tunes while keeping the beta beating under control using the model independent analysis (MIA). As a result, the PEP-II luminosity increased more than 20% reaching a peak luminosity of $6.5x10^{33}cm^{-2}s^{-1}$. That was more than twice of its design luminosity. More importantly, MIA has become a part of analysis tools routinely use in the operation to measure the lattice functions and make correction if necessary.

Quickly and completely measure lattice functions at the interaction point. We have investigated a new method of measuring the complete lattice functions including the coupling parameters at any azimuthal position in a periodic and symplectic system. In particular, the method is applied to measure the lattice functions at the interaction point where the beams collide. It has been demonstrated that a complete set of lattice functions can be accurately measured with two adjacent beam position monitors and the known transformation matrix between them. As a by-product, the method also automatically measures the complete one-turn matrix. This work is published in Physics Review E **68**, 036501 (2003).

Study the beam-beam effects in the presence of a finite crossing angle. We introduce a symplectic method to handle a large and finite crossing angle in the beam-beam interaction. This method is implemented in a parallel computer program to simulate three-dimensional effects in the beam-beam interaction utilizing the technique of particle-in-cell. The results of simulation are compared with analytical solutions, simulations with a well-known existing code from KEK, and experimental observations. This work is being written for publication in a journal.

Recently, the beam-beam simulation code has been speeded up by a factor twenty after the implementation of a better scheme for the longitudinal slicing. Each simulation takes only eight hours to complete on a parallel supercomputer. The simulation results are being benchmarked against the experimental measurements at PEP-II. Agreements are very good.

Since a crossing angle is currently being considered in the PEP-II upgrades, this code has become an important tool to evaluate the beam-beam performance for the new design. The preliminary results showed 40% degradation of the luminosity due to 6 mrad crossing angle. The study will be presented to the machine advisory committee meeting in October.

Build up of electron cloud in the presence of solenoid field. Collaborating with Furman and Pivi from LBL, we have augmented an existing code to include solenoid fields and used it to simulate the build up of electron cloud due to electron multipacting in the PEP-II positron ring. We find that the distribution of electrons is strongly affected by the resonances associated with the cyclotron period and bunch spacing. In addition, we discover a threshold beyond which the electron density grows exponentially until it reaches the space-charge limit. The threshold does not depend on the bunch spacing but does depend on the positron bunch population. This work has been orally presented at the Particle Accelerator Conference 2003 in Portland, Oregon. It is also submitted to a journal for publication.

Model-Independent Analysis for PEP-II Optics Improvement. This year has been a very productive year for applying MIA to PEP-II. MIA has helped PEP-II in improving machine optics, particularly the PEP-II low-energy ring (LER) optics, to achieve peak luminosity above 6.5e33/cm^2/s before 2003 summer shutdown.

MIA is a high-precision tool for measuring and analyzing the transverse orbits in storage rings. Through improved SVD-enhanced Least Square fitting of the Greens functions and phase advances, MIA can obtain a computer virtual machine that matches the real physical machine optics. MIA can then go on to find a better approachable machine model that only requires a limited amount of magnet correction to improve the real machine. With MIA, we have been able to achieve the difficult job of bringing the coupled LER working tune to near half integer while fixing the beta-beat and reducing the linear coupling. This is how the PEP-II peak luminosity jumped before the 2003 summer shutdown.

On the technical side, the reason we can achieve the above is that we have been able to improve MIA detailed SVD-enhanced fitting process so as to enhance fitting convergent rate for accuracy and computer speed. Over the last year, we have been able to enhance the computer speed for MIA fitting by about 5 times.

Design new lattices for PEP-II upgrades. Design a lattice with low-momentum compaction factor for PEP-II High Energy Ring (HER). At present, the PEP-II bunch length and vertical beta function at the Interaction Point (IP) are about of the same size. To increase luminosity, it is planned to gradually reduce the IP beta function. For the maximum effect, bunch length has to be also reduced to minimize luminosity loss caused by the hourglass effect at IP. One of the methods to achieve a smaller bunch length is to reduce momentum compaction factor. We investigated a lattice option for the HER where the nominal 60 degree cells in four arcs are replaced by 90-degree cells to reduce momentum compaction factor by 30% and bunch length by 16%. The increased focusing in 90-degree cells results in 40% stronger arc quadrupoles and 150% stronger arc sextupoles due to reduced dispersion and larger chromaticity. Tracking simulations predict that dynamic aperture for this lattice will be more than 10 times the rms size of a fully coupled beam for a horizontal emittance of 30 nm and IP beta function of 1cm. This work is published as SLAC-PUB-9810.

Studied the lattices near half-integer resonance. Beam-beam simulations predict that the luminosity could be increased near a half-integer resonance. However, effects of the resonance and its synchrotron sidebands significantly enhance betatron and chromatic perturbations that tend to reduce dynamic aperture. In the study, chromatic variation of horizontal tune was minimized and optimized with local sextupoles in the Interaction Region. Dynamic aperture was calculated using tracking simulations in LEGO code. Dependence of dynamic aperture on the residual orbit, dispersion and distortion of beta function after correction was investigated. This work is published as SLAC-PUB-9812.

Accelerator Structures

The work on accelerator structures consisted of theoretical design studies, fabrication and experiments. The R&D has been focused primarily on NLC structures.

We face two major challenges in designing NLC X-Band accelerator structures. The first is to demonstrate stable, long-term operation at NLC gradient to lower the machine cost, and the second is to strongly suppress the beam induced long-range wakefield to achieve high luminosity. Our program involves the collaborative efforts of a number of departments at SLAC, KEK and FNAL.

Structures for High Gradient Tests.
Work on high gradient testing structures continued to be our high priority task in the past year. The extensive studies and summarization of the results in high gradient research will lead us to select the best possible RF parameters for the NLC prototype structures.

Four traveling-wave structures with low group velocity (H60VG3N-6C, H90VG3N, H75VG4S18, H60VG3S18 and H60VG4S17) and one pair of standing wave structures (SW20a375) have been designed, built and five of them were high power tested. The awareness of pulse heating has led to design changes in accelerator cups with pie-shaped dipole coupling slots and rounded slot corners as shown in Figure.1. Six cups with theses features were machined and inserted into the H60VG3N structure. The testing results showed that the slots are acceptable for the NLC operation in respect of both RF breakdown rate and breakdown related damages. After that we fabricated a structure H60VG3S18 as shown in Figure 2, all its regular cups have new shaped HOM slots.

Figure 1. Accelerator cups with pie-shaped and corner rounded dipole mode coupling slots for reduction of RF pulse heating.

Figure 2. The first accelerator structure with all regular cups slotted.

In order to study the possible improvement in reducing RF breakdown rate and damages at high gradient operation, a CERN made structure with molybdenum irises is being tested under a joint R&D program. The RF processing is progressing slowly.

More Standing Wave Structure Studies.
From earlier standing wave structures test we have obtained some encouraging high gradient performance. Following the structure SW20a565, which resemble the low dipole mode frequency end for damped detuned SW structures, two SW20a375 to resemble the high dipole

mode frequency end were tested in this year. For all above structures, the average breakdown rate at 55 MV/m was acceptable for NLC loaded operation condition without discernible shift in frequency. In order to speed up the R&D for room temperature linear collier, we temporarily hold the effort to build the SW prototypes of damped detuned structures.

Improvement to Obtain More RF Gradient Margin

After careful examination in all NLC beam dynamics issues, we have reduced the average aperture a/λ from 0.18 to 0.17. The previous high power tests showed no damages in inline tapered front end cells, and there is evidence that the power dissipation and surface field are relevant factors to cause breakdown and damages. Therefore, we have introduced stronger but smooth detuning/tapering in the front end with lower gradient and slightly higher gradient in output end while maintaining a/λ=0.17 and similar efficiency. Figure 3 shows the electrical field profiles for different structures.

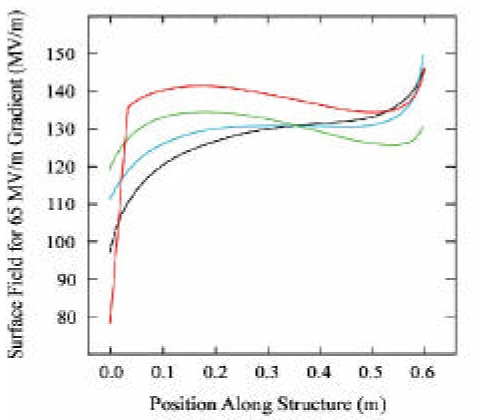


Figure 3. Comparison of maximum surface field on irises for different accelerator structures at average accelerating gradient of 65 MV/m. Red is for H60VG3N (a/λ=0.18), light blue is for H60VG3S17 (a/λ=0.17) and black is for the optimized H60VG4S17, its field in the front end is even lower than 5% reduced field for H60VG3S18 (green).

New Designs for Fundamental Mode Couplers and HOM Couplers

The fact of high breakdown rate in input couplers has made us to pay a special attention to the coupler design in recent years. Several coupler designs with much lower surface field and pulse heating have been designed and tested. Waveguide coupler has advantages in easy mechanical machining and HOM damping, we have designed this type of fundamental mode couplers for new H60VG4S17 and future structures. Figure 4 shows the computer simulations.

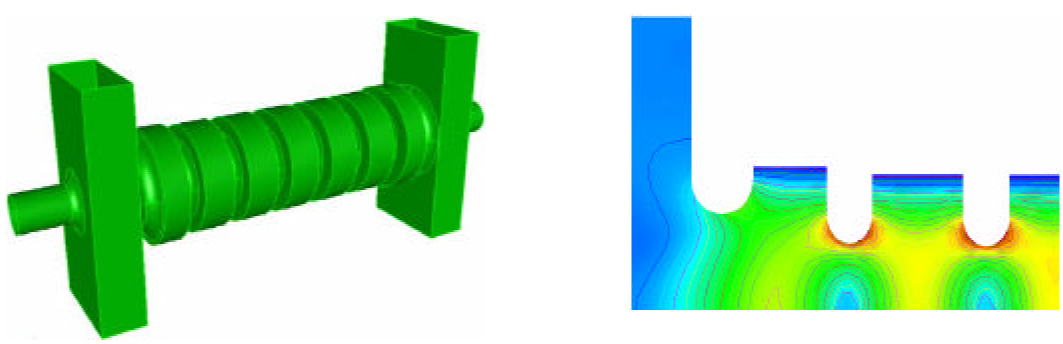


Figure 4. Design for the input coupler of H60VG4S18 structure. The left is a simulation model and right is a plot for electrical filed distribution.

Also, we have designed several High Order Mode (HOM) couplers; they will be cold tested and applied to the new interleaved H60VG4SL17 structures. The full tests will include ASSET wakefield measurement and high power operation in the next year.

Theoretical and Experimental Studies

The long range wakefield calculation program has been rewritten in a FORTRAN version which automatically minimizes the RMS and the standard deviation of the sum wakefield. We have finalized the interleaved dipole mode spectrum, which leads to the design for the NLC prototype structures. By judging the emittance dilution and phase space for NLC beam trains traversing through whole main linac, the cell-to-cell as well as the structure-to-structure frequency tolerances and alignment tolerances were specified for both random and systematical cases. Also, the structure bow tolerances and angle wake tolerances were carefully analyzed.

The higher frequency dipole bands for various structures and RF pulse propagation through structures were also investigated.

The progress has been made in wire measurement - the new technology to quickly and inexpensively analyze the wakefield suppression properties for accelerator structures. Using a 300-micron brass wire, the measurements of the structure S-parameters were used to calculate the impedances for monopole band and higher dipole mode bands. The test results for a SW structure and a short TW structure showed a reasonable agreement with computer simulation.

Figure 5 shows a SW structure under wire measurement.

Figure 5. Wire measurements set-up.

High Power RF

During this fiscal year, we concentrated on building and verifying the detailed designs for a high power Dual moded SLED-II system. The system is shown in Fig. 1. Four 50 MW klystrons will power a fully dual-moded resonance delay line pulse compression system. Both the transfer lines and the delay lines are dual-moded.

The modes carried by the transfer lines are controlled by the rf phases of the different klystrons. The modes in the delay lines are controlled by a set of mode converters at the input and the end of each delay line. By manipulating the modes in both the transfer lines one could achieve, no pulse compression or a pulse compression ratio of 4. The total output power is 200 MW for 1.6 microseconds, and 600 MW for 400 nanoseconds.

We have adopted a general philosophy in our designs. Most of the manipulation of rf systems are made with planer components. These are rectangular waveguides with all manipulations are made in the H-plane. Two modes are allowed to propagate: the TE_{01} and the TE_{02} modes. Because manipulations are only two-dimensional the height of the waveguide is a free parameter, which is used to reduce the field and losses in the system. In this system we increased the height of most of the rectangular components to reduce the electric field level to approximately 45 MV/m. The waveguide cross-section is close to a square. We were careful not to increase the height more than necessary to avoid complications that result from increased level of overmoding.

To transport the rf signal circular waveguides are used. These carry the TE_{01} and the TE_{11} modes. Connections are made between circular and rectangular waveguides using a special types of tapers; mode preserving circular-to-rectangular tapers. These convert the TE_{10} rectangular mode into the TE_{11} circular mode and the TE_{20} rectangular mode into the TE_{01} circular mode. All vacuum functions, connection flanges and pumpout devices are implemented in circular waveguides. Also the diagnostic devices were implemented, i.e.; mode selective directional coupler, in circular waveguides.

The highly overmoded delay lines carry both the TE_{01} and the TE_{02} modes. Because these two modes have no axial wall currents the design of the connection flanges is simplified.

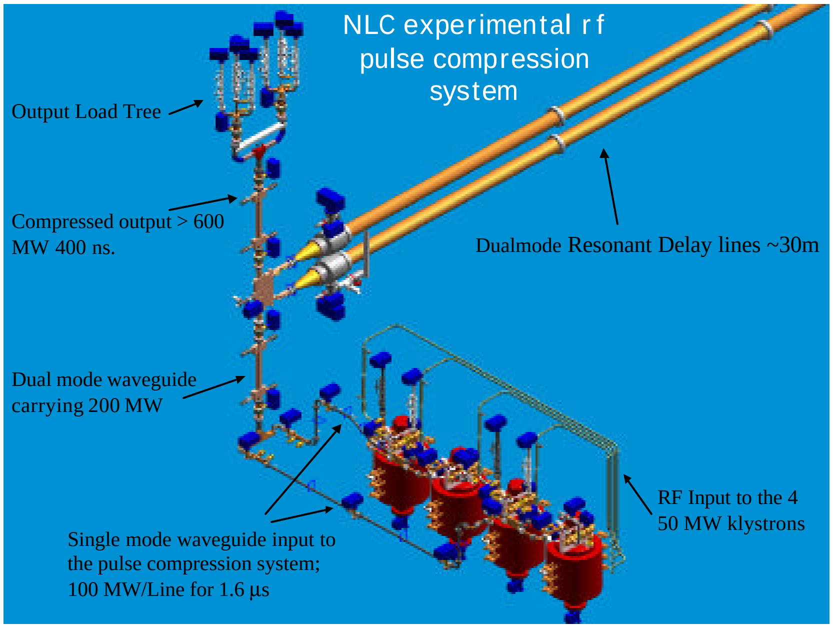


Figure 1: Dual Moded Sled-II System Schematic

The design of the transfer line and the pulse compression head is shown in Fig. 2. The four klystrons are divided into two banks each contain two klystrons. Each two klystrons are combined together to produce, essentially, a single rf source with an output power of 100 MW for a 1.6 μs. These two 100 MW rf source feeds the combiner (see Fig. 2). The combiner launches two modes in the system. The weight of each mode is dependent on the relative phase and amplitude between the two banks of klystrons. The system is designed such that if the launched mode is the TE_{20} rectangular (TE_{01} circular) then the power is directed to the delay line and the compressed pulse is launched at the output towards the load tree in the same mode. On the other hand if the launched mode is the TE_{10} rectangular (TE_{11} circular) the power is directed to the loads at the same mode without pulse compression.

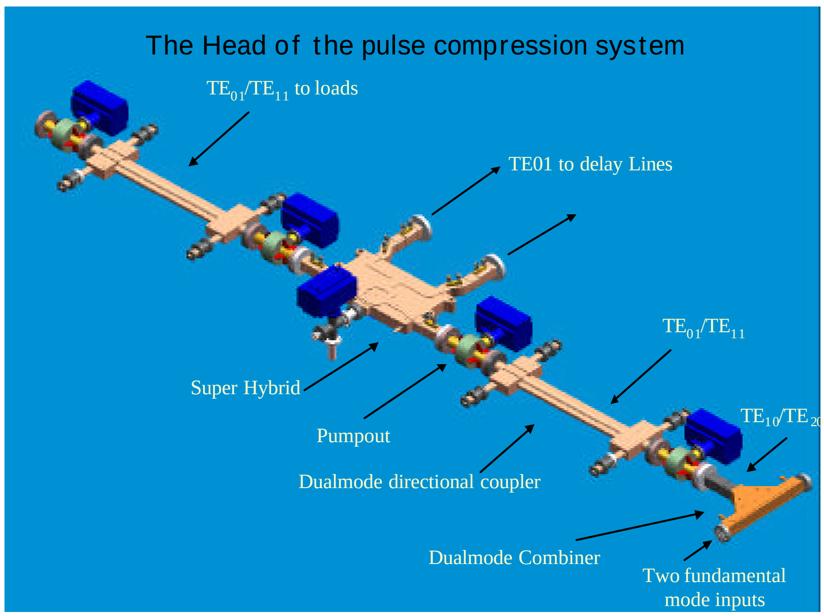


Figure 2. Dualmoded SLED-II Head.

Detailed measurements were performed for every part of the system. This resulted in small modifications to some designs. Finally the overall system response was measured. This is shown in Fig. 3. The measurements are done through the mode selective directional coupler and it shows a system gain close to 3.1. This theoretical value for the gain is about 3.3. It is believed that this slight loss of efficiency is due to the poor construction of the delay lines. The output pulse is also flat in both amplitude and phase indicating a near perfect operation for the dual moded tapers and mode converters at the end of each delay line.

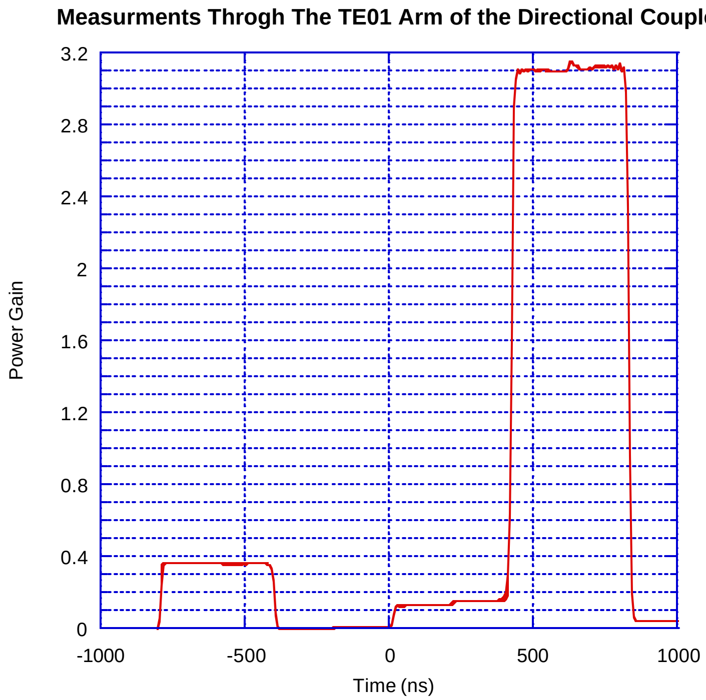


Figure 3. Measured system response through the mode selective directional couplers.

Our effort to understand the breakdown phenomenon in RF structures and components continued. A waveguide made out of molybdenum was tested. The results, to date, indicate the molybdenum is not superior to copper in terms of high field breakdown threshold.

In collaboration with KEK several single cavity traveling wave structures were built and tested. These cavities are going to be fed with rf power using the so called modes converter couplers. We plane to test copper cavities cleaned with high purity water jets and compare them with cavities cleaned with standard techniques. Also different cavities with different materials are being tested.

First nonreciprocal device was tested at high power resulting in an operation at power levels near 3 MW at 11, .424 GHz. This first test revealed several errors in our engineering designs. The device has now been redesigned, and will undergo testing at high power in the next few weeks.

Work with high power rf semiconductor devices continues. A P-I-N diode arrays has been designed, which are specially combined in overmoded waveguides. These hold the promise of an efficient high power source and switch operation. Now, the detailed physics of their operation modes is being examined.

Astrophysics Group

During the past year the group's activities have been on theoretical and experimental studies of particle astrophysics and cosmology. Specifically, the theoretical research has been focused on the nature of dark matter and dark energy, while the experimental activities centered around the program on Laboratory Astrophysics. The group now consists of four senior physicists, two postdoctoral research associates, and one graduate student. The group also has four visiting students from the Center for Cosmology and Particle Astrophysics (CosPA) in Taiwan. Most of the research projects have been carried out in collaborations with world-leading theorists and experimental groups. The major activities are the following.

Theoretical Activities

- Black Hole Remnants as Dark Matter

Together with R. Adler and D. Santiago (both at Stanford), P. Chen proposed a "generalized uncertainty principle" (GUP) where gravity effects are included. The GUP predicts the existence of a fundamental length, which happens to be the Planck length. By applying this GUP to black hole evaporation, it was shown that BHs cannot evaporate entirely, but should leave with a remnant at Planck mass ($\sim 10^{19}$ GeV). Such remnant from primordial black holes is an interesting candidate for dark matter. The three authors published this work in 2001, and had received the 3rd Prize from the Gravity Research Foundation for this work. R. Adler and P. Chen published another paper this year that further investigates the possibility of such a link between BHR and dark matter. When combining this theory with the "Hybrid Inflation" model of A. Linde and others, P. Chen has recently found that the abundance of BHR is in the right order of magnitude for the dark matter. Issues related to the details of the inflation model, as well as a deeper understanding on the nature of the fundamental length through string theory, are now pursued by P. Chen and M. Shmakova. P. Chen and K. Thompson also collaborate with R. Adler in the study of the cosmology of the post-inflation "black hole" epoch.

- Weak Gravitational Lensing

J. Irwin has developed a novel approach, based on his theoretical expertise in particle beam optics, to the weak gravitational lensing analysis. It is proposed that higher multipole, such as sextupole, moments beyond the conventional quadrupole moment, can in principle be extracted from observation, which would provide extra information in the gravitational lensing studies. Applying this new method to the Hubble Deep Field data, Irwin and Marina Shmakova have found evidence of the existence of sub-galactic dark matter structures. They have posted a paper on the arXiv to report on this finding. P. Chen has now joined the collaboration to further extend this study. A Summer student of P. Chen, Ken Shen (Harvard), has made contributions during the summer.

- Cosmic Plasma Wakefield Acceleration

A new acceleration mechanism has been recently introduced by P. Chen, T. Tajima, and Y. Takahashi (Phys. Rev. Lett., **89,** Oct. (2002)). Ultrahigh energy cosmic rays (UHECR) with energies above the Greisen-Zatsepin-Kuzmin (GZK) limit ($\sim 5\times 10^{19}$ eV for protons originated beyond the local galaxy cluster) have been observed by several recent experiments. This posts an acute challenge to astrophysics. So far the theories that attempt to explain this phenomenon can be generally categorized into the "top-down" and the "bottom-up" scenarios. The top-down scenario assumes UHECR to be some unknown heavy particle. The drawback is that it relies on exotic physics beyond the standard model and the fine-tuning of particle lifetime. The bottom-up scenario, on the other hand, assumes that UHECRs are actually ordinary particles but are accelerated to extreme energies. In addition to the challenge of the GZK limit, it also lacks an efficient acceleration mechanism. The new mechanism that Chen et al. proposed is based on the plasma wakefields excited by the Alfven shocks in the relativistic plasma that is exploding from the epicenter of a gamma ray burst (GRB). In the example given by the authors, the acceleration gradient is ~10^{16} GeV/cm. With such high efficiency, super-GZK energy can be reached in the close vicinity of a GRB.

Experimental Activities

- E-165: Fluorescence in Air from Showers (FLASH) Experiment

Recent observations of ultra-high energy cosmic rays reported super-GZK events above 10^20 eV. However, the two major experiments, the ground-array air shower detector AGASA and the High Resolution Fly's Eye (HiRes) fluorescence detector, exhibit an apparent discrepancy in the observed absolute flux and in the spectral shape. Because of the importance of the physics involved, both groups are currently studying systematic effects that might contribute to the discrepancy. One such effect is the air fluorescence yield.

A proof-of-principle experiment, T-461, using the SLAC FFTB beams to trigger air fluorescence was carried out successfully in the FFTB in June 2002. A formal proposal (E-165) by a five-institution international collaboration, “FLASH”, was approved later in November 2002. The first of three runs of this experiment in FY2003 has been carried out successfully in September 2003. It is expected that major results will be published before the end of this year.

In all, 25 physicists, students, and engineers participated in the successful test run from the University of Montana, Rutgers University, SLAC, the University of Utah, and the National Taiwan University Center for Cosmology and Particle Astrophysics.

- Research and Development of other LabAstro Experiments

R&D effort has been underway in preparing LabAstro experiments beyond FLASH. One major direction is an experiment to investigate into astrophysical dynamics involved in cosmic particle accelerations and jet-plasma interaction. Simulations on the Alfven-wave induced plasma wakefield acceleration has been under development by K. Reil and several international collaborators. Simulations on jet dynamics has been pursued by J. Ng and R. Noble at SLAC. It is hoped that by this time next year the group will be ready to look into the designs of these experiments guided by the simulations.

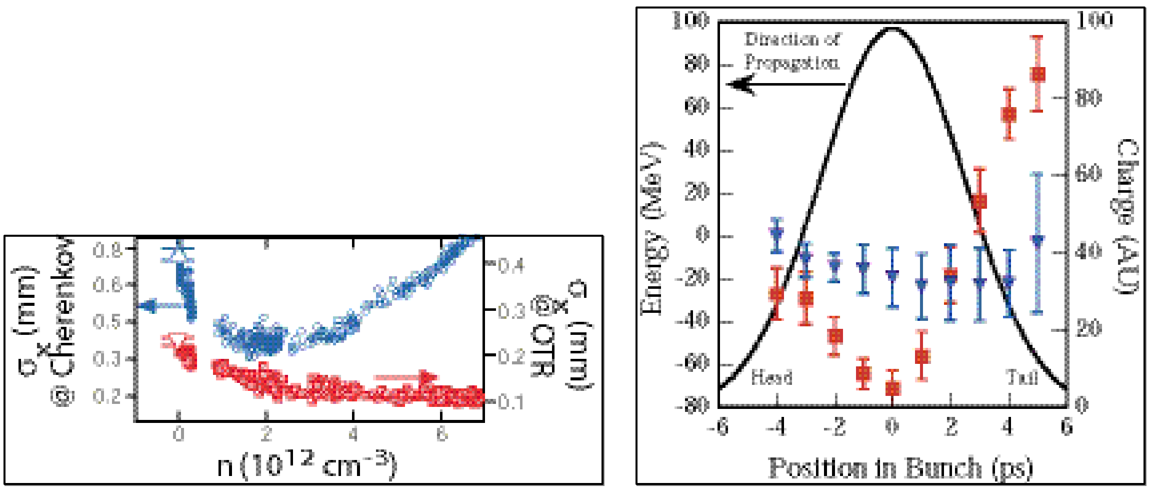
Advanced Accelerator Research B by Bob Siemann

Accelerator Research Department B (ARDB) conducts research into the physics and technology of accelerators with a strong emphasis on high gradient acceleration and advanced concepts.

A UCLA, USC, SLAC/ARDB collaboration is continuing with an experimental program to study all aspects of beam driven plasma wakefield acceleration. The SLAC beams offer a unique opportunity for this, and there have been nine experimental runs (as experiments E157, E162, and E164) for a total of ten and one-half months of beam time from June 1999 through April 2003. The E157 data have been analyzed, and the results have been published. Analysis of the E162 data continues with three results, discussed below, published already.

Measurements of the interaction between positron beams and plasmas are possible only with the SLAC beams, and two papers have been published on the transport and acceleration of positrons. They were:

- M. J. Hogan *et al*, "Ultrarelativistic-Positron-Beam Transport through Meter-Scale Plasmas", Physical Review Letters **90**, 205002 (2003)
- B. E. Blue *et al*, "Plasma Wakefield Acceleration of an Intense Positron Beam" Physical Review Letters **90**, 214801 (2003)



POSITRON RESULTS Left panel: (Hogen *et al)* Time-integrated measurements of the positron beam spot size vs plasma density from the two profile monitors downstream of the plasma exit. Right panel: (Blue *et al*) Measurement of energy dynamics within a single positron bunch. The blue triangles are plasma off, and the red squares are plasma on.

In addition, a time resolved measurement of the plasma focusing of an electron beam has been performed. High-contrast, sub-picosecond measurements clearly showed multiple focii within a beam bunch.

- C. O'Connell *et al*, "Dynamic Focusing of an Electron Beam Through a Long Plasma", Physical Review Special Topics – Accelerators and Beams **5**, 1121301 (2002)

The E157 and E162 experiments were performed with a 0.6 mm long bunch. The acceleration gradient has been calculated to vary as the inverse of the square of the bunch length, and our emphasis is turning to short bunches. Experiment E164 is in progress. The main features are a 0.1 mm long bunch and a new, higher density plasma source. During the first E164 run (March and April 2003) we measured significant beam generation of plasma. This was unexpected, and it is an important result that shows the way to making long plasmas and to achieving high energy gain as well as high accelerating gradient. The second E164 run is scheduled for October 2003, and, using a modified plasma source, we expect to measure significant acceleration. An additional experiment, E164X, has been approved to extend these measurements to even shorter bunches, 0.02 mm, and higher plasma densities. E164 and E164X will be important next steps needed to access the potential of plasma accelerators for extending the energy frontier of particle physics.

Lasers have extraordinary potential as accelerator power sources. Their large fluence leads to the possibility of high gradients. This was realized soon after the invention of the laser, but, until recently, the laser has not been a practical power source because of low efficiency. Recent developments have raised the efficiency of solid state, mode-locked lasers to well above 10%. This has changed the situation, and laser driven accelerators have become a major activity of the ARDB program. Our laser acceleration studies are wide-ranging and have both experimental and theoretical aspects.

The experimental work started at the Hansen Experimental Physics Laboratory on the Stanford campus, and is now being moved to SLAC as experiment E163, which will be located at the NLCTA (Next Linear Collider Test Accelerator). E163 will *1)* continue earlier proof-of-principle research, *2)* bunch the beam at an optical wavelength, and *3)* measure acceleration in multiple-cell structures. Designing and building the E163 infrastructure has been a major activity during the past year. The shielded experimental area has been completed, and two major technical systems have made substantial progress. The laser driven RF gun has been completed and tested at high power, and the laser system needed for the accelerator and experiment has been purchased and commissioned. The technical systems are based on ORION designs, and the facilities are being designed to be compatible with ORION. (The ORION Center is discussed in more detail below.) The coming year will be devoted primarily to completing E163, which will involve building an RF system, a laser room and the experimental beamline.

In addition to building the infrastructure needed for E163, we are preparing the experiment itself. An inverse free electron laser, which will bunch the beam, has been designed and fabricated. We are also measuring damage in optical materials because damage will determine the achievable acceleration gradient.

Theoretical work is ongoing with the goal of designing an energy efficient, manufacturable laser accelerator structure. Emphasis has been on photonic crystal structures. We are using electromagnetic field calculating codes and scale models for measurements. Recent publications and presentations at the Particle Accelerator Conference have stimulated substantial interest. Relevant ARDB papers are

- Benjamin M. Cowan, "Two-dimensional photonic crystal accelerator structures", Physical Review Special Topics – Accelerators and Beams **6**, 101301 (2003)
- B. Cowan *et al*, "Photonic Crystal Laser Accelerator Structures", 2003 Particle Accelerator Conference

A UCLA, USC, Stanford, and SLAC/ARDB collaboration has proposed a user-oriented center for the development of advanced accelerator concepts. The ORION Center for Advanced Accelerator and Beam Physics would bring together a critical mass of faculty, staff scientists and students with the goal of advancing our knowledge of high energy density beams, advanced technologies for particle acceleration, and basic beam physics. Beams from the SLAC Final Focus Test Beam and from the NLCTA would be used for experiments. The major technical component needed for the NLCTA experiments is a laser driven RF gun, and the gun being designed and constructed for E163 is the same as the gun needed for ORION experiments. The ORION Facility at the NLCTA will provide beam lines and experimental space for 60 and 350 MeV beams. This space will have to be substantially larger than that needed for E163. A proposal has been prepared and submitted to the DOE Offices of High Energy Physics and Basis Energy Sciences and to the NSF to fund the research activities of the university participants in ORION, and construction of the ORION facilities in SLAC Field Task Proposals.

An ORION workshop was held in February 2003 to get input on technical parameters and facilities from prospective users. Over 80 prospective users attended, and there were many exciting ideas for experiments in laser and plasma based acceleration, and in a new direction – laboratory experiments related to astrophysical phenomenon.

The ARDB research program would not be possible without collaborations with colleagues from UCLA, USC, Stanford, and the Technion. They are an integral part of every one of our activities. This research would also be impossible without our students, and their education is an important part of our program. During the past year Brent Blue received a PhD from UCLA for his work on E162, and Tomas Plettner received a PhD from Stanford for laser acceleration experiments. There are six ARDB graduate students at the present time, and students from our collaborating institutions are working with us for their dissertations. David Pritzkau, a former ARDB student, was the recipient of the 2003 prize for an outstanding thesis in beam physics from the Division of Physics of Beams of the American Physical Society for his thesis "RF Pulsed Heating".

7. FY02 PROGRESS IN ADVANCED COMPUTATIONS RESEARCH by Kwok Ko

Work in FY03 has continued to focus on parallel code development, collaborations in computer science and applied mathematics, and electromagnetic modeling. While the activities were evenly divided between supporting Lab programs (e.g. LC and PEP-II) and the SciDAC project, they have been organized as one integral effort geared towards large-scale simulation. Additional collaborations beyond SLAC include FNAL on beam simulations, STAR Inc. on GUI development, ANL on RFQ cavity calculations, PSI on cyclotron modeling, and Genencor on pathway analysis. Highlights of progress made in all these areas are summarized below.

Parallel Code Development. A new finite element code for calculating S-parameters of open structures based on the Omega3P framework has been developed for SLAC's parallel electromagnetic code suite. Named S3P, it has shown capable of solving matrices of size as large as 30 millions using the direct solver WSMP, and more than 90 millions by combining the conjugate gradient solver with a multi-level pre-conditioner. Similar results have been obtained with the eigensolver Omega3P using such solvers so that it has become possible to model very large accelerator structures with these frequency-domain codes. The implementation of advanced features such as mesh refinement and fast frequency sweep in S3P has begun.

Development has also started on a new parallel time-domain code T3P that uses an implicit Newmark-Beta time integration scheme to avoid the late time instabilities that have plagued Tau3P. This code is based on tetrahedral elements which allow for much easier meshing compared to Tau3P's hexahedral meshes, and can be extended to higher-order methods in a straightforward way. Initial testing of basic functionalities in the code has been done and the focus has turned to the important development of wakefield calculation and S-parameter extraction. T3P will replace Tau3P as the main time-domain solver upon completion of these implementations.

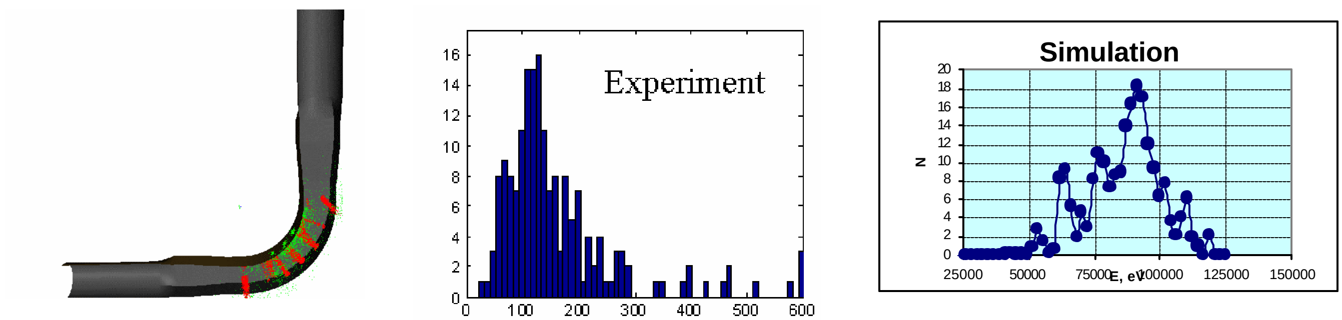


Fig. 1: Comparison of X-ray spectra from Track3P simulation versus measurement for the NLC X-band waveguide bend. The left figure shows primary (red) and secondary (green) emissions in the bend at steady-sate.

Another code that has received increased attention in the past year was Track3P which uses the fields from the suite of parallel field solvers to calculate the trajectories of particles emitted from structure surfaces. It has been benchmarked against high-power test data from a 90-degree X-Band waveguide bend. Good agreement has been found between the measured X-ray spectrum and that inferred from the simulation (Fig. 1), validating the surface physics module within Track3P that models primary and secondary emissions. The parallelization of Track3P is in progress**.**

Collaborations in Computer Science and Applied Mathematics. Under SciDAC, the ACD has established a number of collaborations with the ISIC's and with institutions supported by SAPP to further enhance the code capabilities for enabling ultrascale simulations. Several of them have concentrated on meshing and discrete-ization issues involving members of the TSTT ISIC. Specifically, the ACD worked with Sandia to generate high-quality meshes for Tau3P simulations through better CAD models and mesh smoothing based on quality metrics. With the help of RPI, adaptive mesh refinement has been incorporated into Omega3P in improve the accuracy and efficiency of cavity wall loss calculations (Fig. 2) while the collaborations with LLNL include stabilization schemes for Tau3P as well as high-order basis functions for Omega3P.

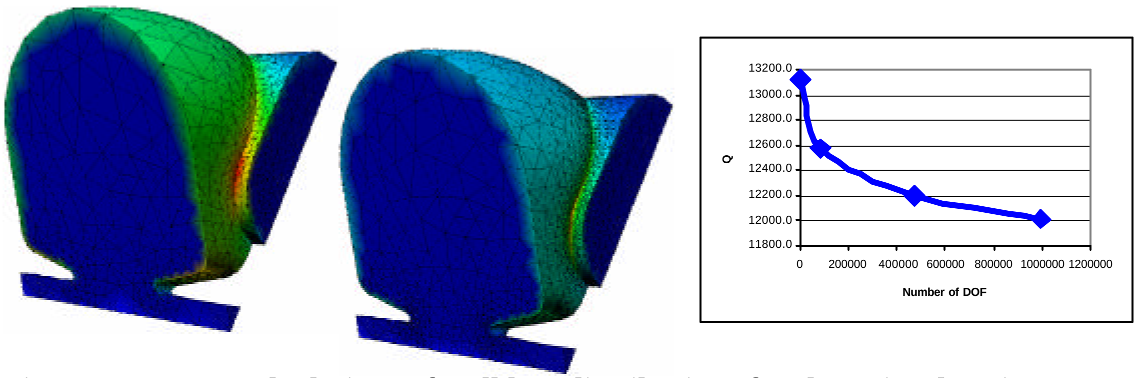


Fig. 2: Omega3P calculations of wall loss distributions for the Trispal cavity at two successive levels of adaptive mesh refinement. The right figure shows the convergence of cavity quality factor with degrees of freedom.

In the area of solvers and performance, there have been major efforts involving LBNL and Sandia that have led to significant advances in Omega3P and Tau3P respectively. As part of the TOPS ISIC, LBNL first exploited the advantage of using direct solvers such as SuperLU in speeding up the solution of the linear systems in Omega3P. ACD and Stanford (SAPP) followed this approach and incorporated the direct solver WSMP which improved Omega3P's performance even further. Another important implementation is the AV formulation that greatly improved Omega3P's iterative solver. Also working with LBNL and Sandia, substantial gain in the parallel performance of Tau3P has been achieved (a factor of 3 in speedup) through more optimal domain decomposition using alternate partitioning tools in Sandia's Zoltan library.

SciDAC's SAPP program also supported collaboration with UC Davis on advanced visualization whose goal is to develop new tools for exploring large, 3D, multiple field and particle data sets to facilitate accelerator design and analysis. The project has benefited ACD's dark current simulation effort by helping to visualize primary and secondary particle trajectories and their relationships with the field variations in the structure, and the work has led to a PhD thesis by a UCD student doing this research entirely at SLAC.

Electromagnetic Modeling. The ACD continued to participate in the Linear Collider accelerating structure R&D through simulation. Using the ACD's parallel EM codes, efforts have been devoted to cell optimization, wakefield calculation, and dark current studies that are centered around the 55-cell baseline design. For cell design, Omega3P has been used to study how group velocity, phase advance and beam aperture affect RF heating and acceleration efficiency. Dimension tables for machining have been generated for several test structures of both the Detuned (DS) and Damped, Detuned (DDS) types to explore performance over a suitable range of parameter space. Power and HOM couplers have also been designed and modeled for some of these structures.

Fig. 3: Full model of the NLC 55-cell H60VG3 detuned structure.

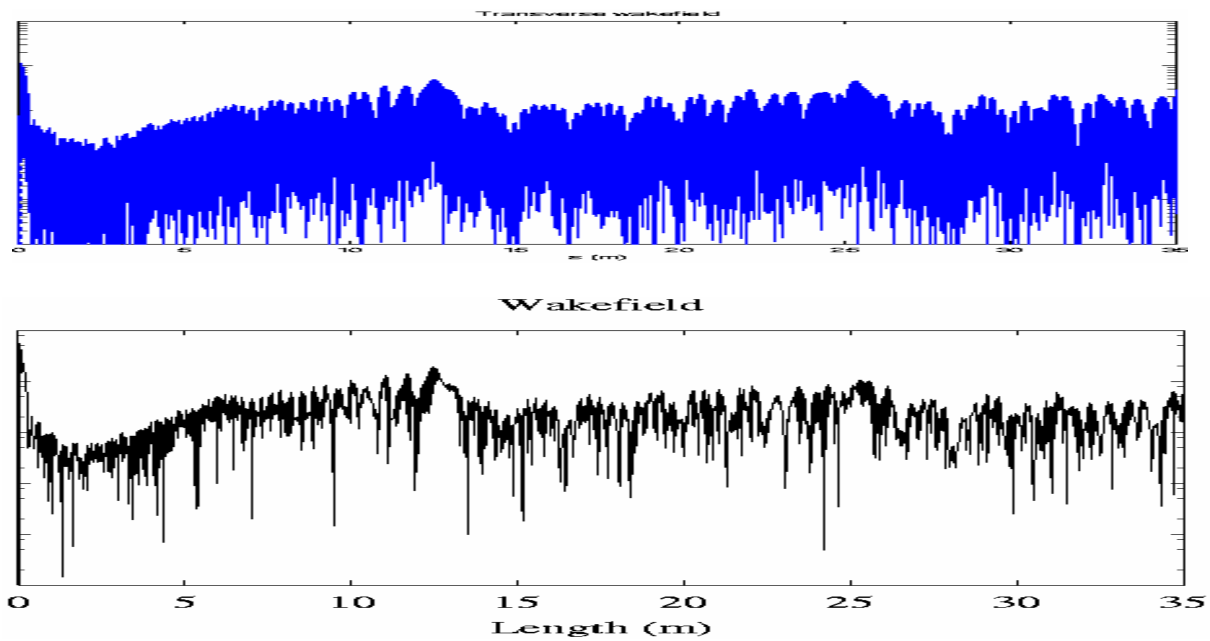


Fig. 4: Transverse wakefields in the H60VG3 detuned structure obtained in the time domain using Tau3P (Top) versus the 1st band result calculated in the frequency domain using Omega3P/S3P (Bottom).

For wakefield and dark current simulations, only the H60VG3 detuned structure has been considered (Fig. 3). The dipole wakefields was obtained in the time-domain using Tau3P with a bunch length that covers the structure response up to the 6th dipole band. Fig. 4a is the computed wakefields showing the effect of Gaussian detuning. Fig. 4b shows the wakefields in the same structure calculated in the frequency domain by summing all 55 modes in the 1st dipole band. Here, Omega3P was used for finding the trapped modes whereas the modes loaded by the waveguides in the input/output couplers were treated by S3P. There is remarkable agreement between the two solutions indicating the 1st dipole band is the dominant contribution. Work is in progress to include the higher bands (up to 6th) in the frequency domain calculation for a complete comparison, and to apply the same analysis to the H60VG3 structure with manifold damping included.

Track3P has been developed for end-to end simulation of dark current generation and capture particularly in high-gradient Linear Collider structures. For traveling waves, Track3P uses the fields from a Tau3P simulation in calculating surface emissions and particle trajectories. It is necessary to simulate the full RF pulse length in order to include the peak field enhancement in the structure during the transients as measurement has shown correlation between increase in dark current and shorter rise time. The simulation is ongoing on the H60VG3 detuned structure and the results will be helpful in answering many questions about dark current such as its energy spectrum, fraction captured and capture behavior, energy deposited in the structure, and the transverse field induced etc.

Progress has also been made in the evaluation of beam heating in the PEP-II IR where Tau3P simulations with beam have become possible thanks to the help from the TSTT ISIC in constructing a high quality mesh. The ability of Tau3P to avoid late time instabilities still depends on mesh quality in spite of a low pass filter. Time-domain calculations have great advantages over frequency domain analysis because the fields are excited directly by the beam in one run, and the boundary conditions terminating the beam pipes are properly enforced (matched instead of perfectly conducting). Fig. 5 shows three snap shots in time of electric fields generated by a beam bunch during transit through the center beam pipe of the IR. Time-domain simulation of the IR upgrade taking into consideration the entire geometry from crotch to crotch as well as the actual beam paths is well under way.

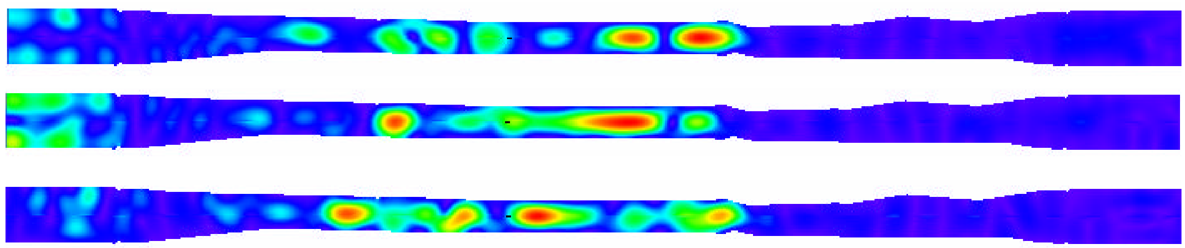


Fig. 6: Time snapshots of electric field patterns excited by a beam traversing the PEP-II central vertex chamber.

8. FY03 HIGH POLARIZATION ELECTRON SOURCE DEVELOPMENT by Ed Garwin, Bob Kirby and Takashi Maruyama

The Physical Electronics Group (PEL) contributes to SLAC's accomplishments in a number of areas, by using vacuum and materials expertise to support the development of novel electron sources, detectors and accelerating structures. These areas include NLC R&D programs for the production of particle-free breakdown-resistant copper surfaces, and surface analytical research on high electric field structures for advanced accelerator research.

PEL engages in a continuing research program with Experimental Group A, ARDA's Sources and Polarization Group and the University of Wisconsin on the development of high-polarization high-current semiconductor electron sources, originally for E-122, then for the SLC and currently for the NLC and End Station A experiments. For the past ten years, strained GaAs photocathodes have been used for the SLAC polarized electron source. Strain is incorporated in the GaAs layer when GaAs is epitaxially grown on a thick $GaAs_{1-x}P_x$ buffer layer. A large phosphorus fraction produces a larger lattice-mismatch and therefore a large strain. However, if the GaAs layer exceeds a critical thickness, the strain is relieved by producing misfit dislocations. To produce a strain large enough to achieve the valence band energy splitting, it is necessary to use a lattice-mismatch as large as 1%, where the critical thickness is only about 10 nm. In practice the optimum strained layer thickness to achieve both high quantum efficiency and high polarization is ~100 nm. The strained GaAs layer is ten times thicker than the critical thickness, limiting the peak polarization to 78% and the quantum efficiency to 0.3%. This critical thickness problem can be solved in principle by using the superlattice structure of GaAs and GaAsP. Supported by a DOE SBIR Phase II program, we are investigating strained-superlattice photocathodes based on GaAs and GaAsP in collaboration with SVT Associates, who grow such wafers using molecular-beam-epitaxy (MBE). Several high quality wafers have been grown, yielding a peak polarization of 86%. The charge output does not show any surface charge limit behavior, producing a maximum charge of 2.5×10^{12} e^- in 75 ns. The charge output corresponds to more than six times the proposed NLC train charge. The End Station A experiment, E158, required a beam intensity of 8×10^{11} e^- in a 370 ns pulse. A newly developed photocathode was installed in the SLAC polarized electron injector in May 2003, and ran successfully for E158 Run III. The beam polarization measured by the Moller polarimeter in End Station A was 90%.

To overcome the surface charge limit effect, recent photocathodes use the high-gradient-doping technique consisting of a thin (10 nm), very-highly-doped (5×10^{19} cm^{-3}) surface layer with a lower density doping (5×10^{17} cm^{-3}) in the remaining active layer. However, to achieve high quantum efficiencies, a negative-electron-affinity surface is required, which in turn must be prepared on an atomically clean surface. The conventional way to achieve a surface free of all surface oxides and carbon-related contaminants is to heat the crystal to 600° C for about 1 hour. After only one hour at this temperature, diffusion of the dopant in the thin, highly-doped layer results in the re-appearance of the surface charge limit effect. Therefore, high temperature heat cleaning should be avoided. An atomic hydrogen cleaning technique has been developed for removing oxides and carbon-related contaminants at relatively low temperatures. High quantum efficiency GaAs photocathodes can be prepared at the lower heat-cleaning temperature of 450°.

Particles and inclusions on accelerator rf components can lead to irreversible breakdown damage in high surface electric fields. Previous PEL electron microscopy analysis of particles and grain boundaries on copper demonstrated an association of the latter with electric breakdowns, showing that vacuum heat cleaning is useful in preventing such events. Then, pursuing our investigations into breakdown on clean high-field structures, we focused in FY2003 on three tracks: 1) Autopsy and electron microscopic (SEM) examination of three NLCTA-tested prototype full accelerating structures, 2)measurement of contamination levels and particle-loads on small pieces of structure material (coupons) that have accompanied the manufacture of real structures and, 3) use of a modified atomic force microscope (AFM) to generate and characterize field-emission (the first requirement for the occurrence of breakdown events) from nanometer-sized areas on as-fabricated copper structure material. The structure autopsies show that near clean-room technique in fabricating structures is essential to reducing particle and gas loads that lead to breakdowns. Further, careful attention must be paid to the structure vacuum bake environment in order to prevent adding non-native contamination (for example, the evaporation of manganese from the stainless steel vacuum bakeout chamber) to the last steps of structure preparation. A collaboration on structure witness coupons included KEK (diamond-machining of copper coupons) and Cornell University (DC high voltage-generated breakdowns) and showed that breakdowns can occur on surfaces that are free of particles or contamination, at electric field levels currently used in the NLCTA. This is in agreement with autopsies of NLCTA structures that show that most breakdowns have no visible particle residue or defect in the resulting craters and, therefore, must have some not-yet-identified cause for the onset of field emission. The results of the autopsy and breakdown investigations (1 and 2) dovetail with the AFM investigations (3), suggesting a sub-surface cause for anomalous local field-enhancement that promotes field emission at field levels significantly lower than that predicted for ideal surfaces.

9. FY03 PROGRESS IN FRACTIONAL CHARGE AND MASSIVE PARTICLE RESEARCH by Martin Perl

Substantial progress was made in improving our technology for searching for fractional charge particles in meteoritic material. This material that comes from asteroids formed about 5 billion years ago is one of the least processed material in the solar system, and is one of the best candidates for containing fractional charge particles. It is believed that the asteroid material is about one million times more likely to contain fractional charge particles, if they exist, compared to terrestrial material.

The improvements in our technology were made in the following areas. It was learned how to make a stable suspension of powdered Allende meteorite in oil. Also automated three aspects of the drop production were developed. The drive voltage of the drop ejector is now automatically controlled to produce drops at uniform average velocity even though there is some sedimentation into the ejector aperture over time. The mean charge distribution of the drops is now automatically kept at zero by controlling the bias voltage of the neutralizer. The drop stream is now automatically centered between the voltage plates. The data analysis software has been expanded and made more sophisticated so that large data sets can be summarized easily.

Preliminary search data has been acquired so as to set the final data selection cuts in preparation for our usual "blind" carrying out of the main search.

Silicone oil drops were used to carry out a precise comparison of four different ways of measuring the radius of spherical drops: measurement of the terminal velocity of the drops falling in air, measurement of the terminal velocity of drops of known charge moving in an electric field, measurement of the Brownian motion of the drops, and direct optical sizing. This study has been submitted for publication to the Review of Scientific Instruments.

Help has been provided to researchers in the Department of Molecular Pharmacology of the Stanford Medical School to develop a method for printing precise patterns of cells using inkjet technology with the aim of developing artificial organs and neuronal circuits. SLAC is supplying the ejectors and some other equipment as well as technology guidance.

Additional studies on how to look for massive stable particles in matter have been carried out but have not found to be practical.

10. FY03 PROGRESS IN TEST BEAM PROGRAM by Ted Fieguth

The Test Beam Program did not have access to beam time during the first half of FY03 because the two major areas normally used for these tests were dedicated to other purposes. End Station A, the site of many tests, was occupied by the E158 experiment, while the FFTB, where most tests have been performed, was undergoing structural modifications in preparation for the SPPS experiments. In June, however, thanks to the cooperation of the SPPS management, two successful tests were completed during nighttime running while SPPS installation took place during the daytime.

T-465 Magnetic Electron Pulse Duration Diagnostic, Roger Carr, Hans-Christof Siegmann (SSRL)

The experimenters are focused on exploring the ultimate speed of magnetic switching and understanding the underlying dynamics of ferromagnetic spins. The fastest and most efficient magnetic switching is achieved by letting the magnetization M precess about a magnetic field B present for a time τ. The condition for such precessional switching is that $B\tau$ reaches a certain value, depending upon material properties.

The magnetic field pulses produced by a bunch of relativistic electrons passing through a metallic magnetic thin film can produce the shortest and strongest magnetic field pulses known so far. The magnetic field penetrates into a surface layer of the metals to the skin depth, which is much deeper than the thickness of typical magnetic thin films. If the electron bunches are compressed at constant total charge Q as it is done in SPPS, then $B\tau \propto Q$ = const. Then one can test magnetic switching on a time scale ranging from $10 \text{ x } 10^{-12} \geq t \geq 0.1 \text{ x } 10^{-12}$ s as given by the length of the SLAC-electron bunch in the laboratory frame. So far, magnetic switching is performed with magnetic field pulses of more than 100 $\text{x}10^{-12}$s duration. Therefore, the present experiment explores an entirely new time domain in magnetic switching.

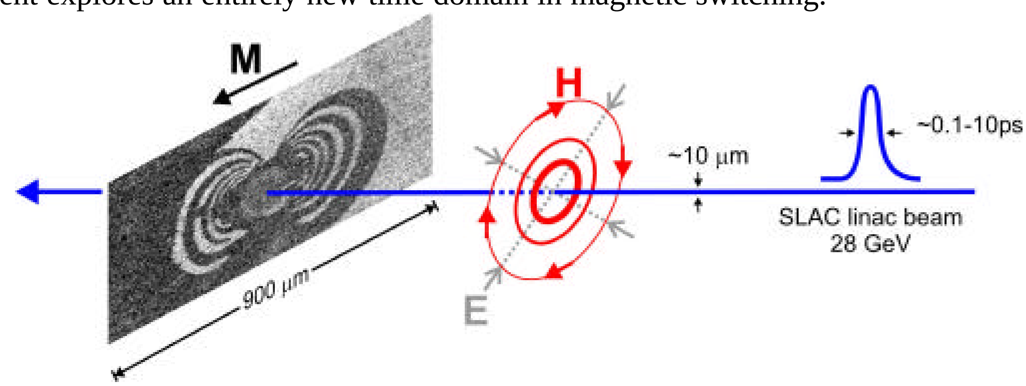


Figure 5

In Figure 1, is shown the actual switching pattern produced by passage of a single electron bunch in an extremely thin film of Fe and imaged by a spin sensitive scanning electron microscope. The Fe-film consists of 15 atomic layers in a single crystalline state grown by epitaxy on the (110)-surface of GaAs. Prior to exposure to the electron bunch, the film was magnetized in the direction labeled **M**.

The magnetic pattern has been obtained with a Gaussian pulse of length $\tau = \pm 2.3 \text{ x } 10^{-12}$ s. The figure 8-shape of the pattern reflects the lines of constant precessional torque **T** = **M** x **H.** Up to 10 switches of the magnetization back and forth can be distinguished as one moves closer to the center of the electron beam.

To switch by uniform precession (i.e., a coherent motion of the spins in the uniform precession mode with the wave vector q = 0) requires exciting this mode of the magnetization at a relatively low frequency of the order of Gigahertz. This mode is the one that can switch the magnetization into the other direction in a deterministic and reliable fashion. On the other hand, exchange driven modes of the spins are excited by frequencies extending well into the Terahertz range. Sizeable exchange fields are generated that produce torques on the magnetization M in various directions leading to a random motion of the magnetization after the external field pulse ceases to exist. As the pulse length, τ, shortens and higher frequencies increase in amplitude we may suspect that it may become not possible to avoid the excitation of these exchange driven modes leading to stochastic switching of **M.** This random motion of the magnetization leads to a randomness in magnetic switching undesired in applications.

First experimental results suggest, indeed, that the compressed pulses of SPPS produce random switching of the magnetization. In Figure 2, are shown magnetization patterns generated by two pulses, the first with one SPPS pulse of $\tau \approx 0.1 \times 10^{-12}$ s length and the second the pulse of $\tau = 2.3 \times 10^{-12}$ s length as in Figure 1 (magnification increased). The two Fe-films are almost identical, with similar magnetic properties as demonstrated by the coercive field H_c which is 25 Oe and 20 Oe respectively. It is clear that the switching depends on τ and not just on ($B\tau$), and it looks as if the switching proceeds in a random or stochastic way with the short pulses. We propose that the stochastic switching is due to the random fields produced by the excitation of the higher spin wave modes in the short magnetic field pulse.

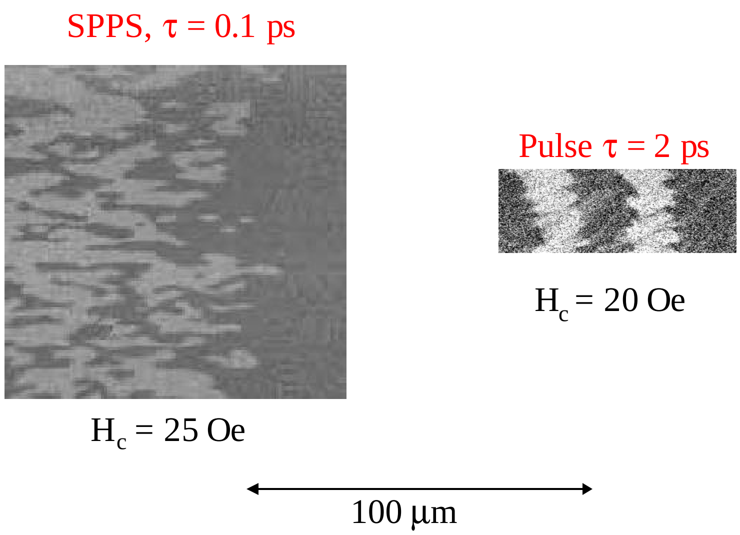


Figure 2

The results suggest that the spread of the switching fields provide a measure of the length of the electron bunches. Measuring this spread for instance by the magnetic resistivity might provide an effective and simple way to determine the length of the electron bunches. At the same time, the results obtained so far point to an ultimate limit for the speed of magnetic switching. This limit is due to the tendency of the spins to assume a chaotic motion due to the non-linearity of the exchange coupling. Clearly, this experiment provides a unique technique to explore the dynamics of ferromagnetic spins underlying all magnetization dynamics. Further experiments with improved techniques are being planned.

T-466 UCLA Electromagnetic Calorimeter Prototype, Prof. Charles A. Whitten Jr., UCLA

The UCLA Intermediate Energy Physics and Relativistic Heavy Energy Ion Group, has developed over the past year a new technology for the construction of a very compact electromagnetic calorimeter (perhaps the most compact in the world to date) using a new technique that utilized tungsten powder and imbedded scintillating fibers.

The main objectives for this R&D were to develop methods which would lead to a very compact calorimeter with good energy resolution, high granularity, good hermeticity, the ability to work in magnetic fields, possessing fast response and affordability.

Although the final design of a particular calorimeter is driven by the physics program of a given experiment, the conceptual requirements listed above should be common for the next generation of detectors for high energy and relativistic heavy ion experiments.

The density of the medium in the calorimeter tower defines its dimensions, and to keep a calorimeter compact, one wants to make the medium as dense as possible, keeping at the same time the ratio between the active and passive materials at a reasonable level so that fluctuations in visible energy will not dominate the energy resolution.

The final composite has a density of approximately 11 g/cm^3. The dimensions of active medium are 22x22x120 mm^3 (the tower depth is equivalent to a thickness of about 20 radiation lengths). There are 500 single-clad, square (0.25 x 0.25 mm^2) Bicron BCF-12 scintillating fibers inside of each tower spaced by 1 mm.

Testing the Calorimeter

During 36 hours of a beam time at the FFTB, 360k total events were taken for 10, 5 and 1 GeV electrons. The calorimeter towers were scanned in both the longitudinal and transverse directions to get information about uniformity of response.

Preliminary results show that energy resolution of prototype towers is around 20%/sqrt(E) which is twice as much as expected. A large variation of response was observed across the surface, in particular when the beam pointed in between the towers. Both longitudinal and transverse scans indicate that the medium of the towers is far from homogeneous.

Thus, a better technique to combine fibers with powder needs to be developed. The light yield from the towers is around 400 photoelectrons per GeV, which is approximately 70% that expected.

Although the desired energy resolution for this prototype was not reached in our first attempt, the information from the T466 test run should allow us to set requirements on the uniformity of the density and fiber spacing inside the towers which will achieve the design goal.

11. FY03 PROGRESS FOR THE EXO DOUBLE-BETA-DECAY R&D PROGRAM by Peter Rowson

SLAC groups SLD (M. Breidenbach, C. Hall, A. Odian, P.C. Rowson and K. Wamba) and A (C. Prescott) have been collaborating with the Stanford Physics Department group of G. Gratta, and with others, in an R&D program to test the feasibility of a novel large-scale double-beta-decay experiment. This experiment, known as EXO (for Enriched Xenon Observatory) proposes to use a large quantity (>1 ton) of Xenon enriched in the Xe^{136} isotope as both a decay and detection medium. The double beta decay process,

$$Xe^{136} \rightarrow Ba^{136++} + e^{-} + e^{-} \ (+\ 2\nu)$$

can proceed in the two neutrino($2\nu\beta\beta$) mode expected from the Standard Model (and which has already been observed in several nuclei other than Xe^{136}), or possibly in the neutrinoless ($0\nu\beta\beta$) mode. The $0\nu\beta\beta$ process is expected to occur only if neutrinos are Majorana particles, and at a rate proportional to the square of an “effective” neutrino mass, and hence its observation would serve a mass measurement and as the first demonstration that Majorana neutrinos occur in nature. Xenon’s excellent calorimetric properties (necessary to distinguish the broad beta spectrum of the electron energy sum in the $2\nu\beta\beta$ process from the line spectrum in the two-body $0\nu\beta\beta$ decay), readily achievable high purity, and lack of worrisome radioactive isotopes make this element an attractive candidate for a low background experiment. In addition, we propose to operate the rare decay search in a coincidence mode, by identifying the Barium daughter nucleus of double beta decay on an event-by-event basis. Barium identification is accomplished by a laser florescence technique that is sensitive enough to observe a single ion and, in principle, to distinguish the various Barium isotopes.

To date, the R&D efforts at SLAC and Stanford have focused on a liquid xenon (LXe) TPC design, where the Barium identification would be accomplished by removing the ion from the LXe using a electrostatic probe, and then delivering the ion to an as-yet-unspecified laser system. The campus group has successfully constructed and operated a laser-illuminated ion trap for Barium and has observed single Barium ions. In addition, they have demonstrated state-of-the-art energy resolution in LXe (which occurs at electric fields >4 kV/cm) and have preliminary results showing resolution enhancement when the scintillation light produced in xenon, in addition to ionization, is collected.

Prototype devices that do *not* employ Barium identification are presently being designed. It is our intention to construct a ~100 kg prototype for use in the DOE operated underground facility WIPP (Waste Isolation Pilot Plant) in Carlsbad NM. This prototype would collect useful data for TPC performance, would definitively observe $2\nu\beta\beta$ in Xe^{136} for the first time, and would accumulate the large number of $2\nu\beta\beta$ decays needed to characterize this important background.

SLAC Activities

At SLAC, we have constructed a xenon purification system that is operated at ultra-high vacuum along with a xenon purity monitor (XPM). The purifier employs a heated Zirconium metal getter to remove non-noble gas contaminants (nominally to the 0.1 ppb level), as well as distillation capability (to remove Argon). The XPM drifts electrons produced from a UV-laser-illuminated cathode in LXe across a gap and measures the transport efficiency. The XPM was upgraded this year to include a longer drift region (60 mm was increased to 109 mm) for improved sensitivity to impurities We have confirmed electron lifetimes as high as 4 ms in purified LXe in this way (more typically, results are ~1 ms), and have reproduced electron drift velocities available in the literature. In addition, we have recently replaced our cold-finger/liquid-nitrogen (LN) cooling system for the XPM with a refrigerator that cools HFE-7000, a hydroflouroether, into which the XPM is submerged. The HFE may serve as both a coolant and a radiation shield for the prototype detector, and also alleviates safety concerns regarding large volumes of LN at the WIPP underground facility. The new HFE-based system is working well.

We have continued a series of experiments to test the feasibility of electrostatic ion extraction from xenon. The "probe-test cell" incorporates a movable electrostatic probe, and an instrumented (PMTs, Si barrier detectors) volume for LXe or gaseous Xe containing a pair of HV electrodes. One of the electrodes holds a weak U^{230} source which undergoes two α decays and emits Th^{228} and Ra^{222} ions into the Xe. We have seen that the probe tip, if set to negative potential, collects radioactive ions (thorium and radium α decays confirm presence of the species). The apparatus has been used to measure ion mobility in LXe, an important issue as the barium ions will be produced in an electric field. The result obtained for thorium ions (0.24 ± 0.02 cm^2/kVs) confirms the low mobility of metal ions in LXe observed by other groups. Recently, the probe was replaced with a "cryoprobe". The cryoprobe is equipped with internal plumbing that functions as a Joule-Thompson expansion cooler, using high pressure argon gas. The probe tip is thereby cooled to below the freezing point of xenon, and ions are trapped in xenon ice. By this means, we have demonstrated that captured ions may be released by thawing the xenon ice, preventing irreversible attachment to a bare metal or dielectric probe tip.

Work is underway studying light collection technologies for the prototype. As mentioned earlier, if ionization collection is supplemented by the collection of the 175 nm scintillation light produced in xenon, improvements in energy resolution are possible.

We are measuring the performance of large area amplification photodiodes (LAAPDs) and various wavelength shifters that may be appropriate for photodetection. Monte Carlo simulation using GEANT are helping to guide this effort.

Development of a prototype of ~100 kg size for installation at WIPP continues. The prototype will incorporate a ~15 cm drift region, a maximum electric field of 5 kV/cm, and a detection plane consisting of crossed wire grids and/or pads. Radiopurity issues make various plastics attractive materials for the construction of the detector vessel. At SLAC and Stanford, test of polycarbonate and Teflon are underway. In particular, the XPM has been used to show that polycarbonate does not seem to degrade LXe chemical purity, and further tests will confirm this and examine other materials. The design of a full scale device incorporating Barium identification will follow pending the results of our R&D effort.

12. FY03 PROGRESS IN THEORETICAL PHYSICS by Michael Peskin

The research of the Theoretical Physics Group ranges from the development of fundamental theories such as M-theory, string theory, and higher dimensional theories at very short distances to detailed calculations and tests of theories directly relevant to high-energy physics experiments at SLAC and elsewhere. Projects in Theoretical Physics tend to be short-term, responding directly to new data and to new ideas that have been put forward in the community. This section gives a list of current projects in the theory group and a necessarily limited projection to future years.

Physics at the Next Linear Collider – The Theory Group is intensively involved in all aspects of physics related to the development of the next-generation linear electron-positron collider. Much of the work involves understanding how to use the unique capabilities of the linear collider environment, such as beam polarization, highly efficient heavy-quark tagging, and the possibility of backward-scattered photon beams, to test aspects of new physics at very high energies that would otherwise be inaccessible. It includes analyses of linear collider experiments on the most familiar models of the next energy scale in physics, including studies of the measurement of the parameters of the spectrum of supersymmetric particles of possible strong interactions coupling to the Higgs sector and the top quark. It also includes exploration of a wide variety of newly-proposed models, some of which are discussed in later sections. Each phenomenon has a specific experimental realization at the linear collider, and we are making an effort to understand the systematic picture of how these effects can be found and distinguished. Complementing these theoretical studies, a general-purpose simulation program for LC events has been created that allows a theoretical calculation of any new process to be easily turned into an event generator incorporating realistic beam and polarization effects. In the pasts few months, we have been studying methods within this framework to make a more precise accounting of QCD radiation and photon initial-state radiation in the simulations. We expect to implement a much improved treatment of these effects later this year.

Physics at Bottom Factories – The Theory Group is intensively involved in all aspects of physics related to the physics of B factories, and the BABAR experimental programs in B physics and two-photon collisions. On one hand, members of the group have devised new methods for measuring the parameters of CP violation in the Standard Model from analyzing detailed aspects of specific rare B decay modes. At the same time, models of CP violation beyond the Standard Model have been intensively studied, as well as the reactions involving 'penguin' diagrams that are expected to probe for these effects most sensitively. In the current year, much of our activity will be devoted to understanding rare two-body B decays, especially the family of decays mediated by b-s transition penguin diagrams that seem to show an anomalous behavior with respect to the Standard Model expectation. We will also continue to work on the calculation of corrections to the factorization approximation in two-body B decays, using methods from QCD heavy quark effective theory and collinear-gluon effective descriptions.

Probes of New Physics at High-Energy Colliders – In support of the past and present experimental electron-positron collision programs at the SLC, LEP, and other high-energy colliders, the Theory Group designs tests which might validate the Standard Model at high energies or show a weakness that would call for new physical processes. These have included studies of lepton pair production in high-energy collisions and studies of rapidity gaps and color coherence in hadron production. We anticipate studies of the new Standard Model probes that high-statistics experiments at the Tevatron will make available.

Development of Quantum Chromodynamics – Although there is strong evidence that Quantum Chromodynamics (QCD) is the fundamental theory of the strong interactions, there is much room for improvement in the methods by which QCD is applied to compute predictions for specific processes. Members of the Theory Group have devised improved computational methods for QCD both for high-precision studies and for the extension of QCD calculations to new regimes. These include the development of 'commensurate scale relations' which aid in removing scale and scheme ambiguities from QCD calculations, and the development of renormalization schemes that are analytic in the quark masses. These also include applications of QCD to exclusive B decays, charmonium production at high-energy colliders, and hadron and lepton production from nuclear targets. Projects in the current year include studies of QCD light-cone wave functions and their application to exclusive hadron production and polarization effects in deep-inelastic scattering, and more fundamental investigations into the formalism of light-cone gauge theories.

Computational Perturbative Quantum Chromodynamics – The most challenging aspect of improving methods for QCD is that of devising methods for high-order Feynman diagram calculations. Members of the Theory Group have been devising methods to simplify the computation of diagrams involving essentially massless quarks and leptons participating in high-energy collisions. In terms of technical difficulties of QCD computations, the frontier now lies in the calculation of two-loop or NNLO corrections. These corrections are essential to interpret the Tevatron and the eventual LHC data to the few-percent level; for some processes for which perturbation theory converges slowly, the NNLO corrections are even needed to understand experimental measurements to order 1. Members of the theory group have been involved an important computation in this latter class, the evaluation of the cross section for Higgs boson production at the LHC. We are now also engaged in the precision QCD study of the Drell-Yan process. One of the goals of these calculations has been to develop new technical methods that will be broadly applicable in QCD analyses. We will continue to pursue this goal in the coming year as we work toward a complete uniform understanding of the QCD processes important for collider physics at the two-loop order.

Superstring Theory and M-Theory – Members of the Theory Group have been involved in studies of superstring theory and its possible relevance to elementary particle physics. Superstring theory may give a context for the solution of the cosmological constant problem, the question of why the observed cosmological constant is tens of orders of magnitude smaller than straightforward estimates in quantum field theory. Supersymmetry forces the cosmological constant to be zero, but only if it is an exact symmetry of Nature, not one that is spontaneously broken. It is a very important question whether there is an intermediate solution in which supersymmetry is broken but in such a way that the theory still controls the magnitude of the cosmological constant. Members of the Theory Group have developed a variety of approaches that provide partial, but not yet complete, solutions to this problem. A new direction of approach to this problem is related to the fact that the observed universe seems to contain a small positive cosmological constant. Though it is straightforward to construct string theories with negative cosmological constant, there were actually no known solutions with calculable positive cosmological constant until examples were discovered last year by members of our group. It will be very interesting to investigate the properties of these models further and to generalize them to obtain new insight into the physics of the cosmological constant.

Realistic Models with Extra Space Dimensions – Members of the Theory Group have played a central role in the recent development of models of elementary particle physics with large extra space dimensions. The inspiration for these models came from string theory constructions in which elementary particles are bound to a 'brane,' a subspace of a higher-dimensional universe. It was realized that, in theories of this type, the additional dimensions may be large, even macroscopic, and that gravity, cosmology, and elementary particle forces can be affected by the new dimensions at energies as low as those currently being probed in accelerators. Members of the group have explored the cosmology of these theories and their implications for experiments on gravity. A wide variety of tests have also been devised for effects of higher dimensions that can be carried out on present and future accelerators. Curvature and exotic gauge fields in the extra dimensions produce characteristic effects, and we have been trying to clarify how these would appear in experimental observations. Among the projects for the current year are the analyses of extra-dimensional effects at linear colliders discussed above. Other current projects are the study of the possible influence of new space dimensions on the spectrum of quarks and leptons, in which the weak connections between branes separated by a new dimension lead to the small mixing of flavors by the weak interactions. We also hope to investigate the consequences of string theory in large extra dimensions; in such models, the string scale can approach the weak-interaction mass scale, allowing the observation of string effects at colliders.

New Theoretical Methods – Other new theoretical methods being developed by the Theory Group include: applications of object-oriented programming techniques to simulation problems in physics; new methods for solving lattice Hamiltonian systems; light-cone Fock state methods in non-perturbative QCD, and non-perturbative studies of QCD in light cone quantization.

13. FY03 PROGRESS IN RF POWER SOURCE DEVELOPMENT by George Caryotakis and Bob Phillips

NLC Klystron Development

One of the XL-4 solenoid-focused klystrons that power the NLCTA was repaired during the past year. There are currently 13 of these 50-MW, X-Band klystrons in use or available for use. The fact that additional tubes have not been required is a testament to the life and reliability we are obtaining from this design. The 75-MW, XP series of PPM (periodic permanent magnet) focused klystrons continues to be the major effort in our RF power source development program. The permanent magnet structure of the design-for-manufacture (DFM) version of the XP-3 is attached to the klystron body as a clamshell to reduce construction cost. The XP3-2 suffered a gun failure when the gun ceramic was punctured by an arc at the maximum 3.2µsec pulse length.

The follow-on XP3-3 was put together from parts of both XP3-1 and XP3-2. This tube was designed to operate at 1.6µsec pulse length, 75-MW peak power, 120 pps rep rate. The tube met the specification in test, but at a somewhat reduced efficiency of 51% (55 % was obtained in computer simulation). XP3-IPP (integral polepiece) is a mechanically more robust version of the XP-3 in which polepieces are brazed to the barrel and ring magnets are fitted one magnet at a time onto the tube body.

The XP-4, currently being fabricated, is an rf design refinement of the XP-3 IPP that gives higher predicted efficiency and improved stability margin. The first of the XP-4 designs will be tested in the spring of 2004.

Klystron Manufacturing

In addition to the NLC developmental klystrons, SLAC's modern manufacturing facility produces replacements for the 242 klystrons that power the SLC. Manufacturing produced or repaired 25 of these tubes during 2003. One hundred percent yield was achieved in the building or rebuilding of these klystrons. The average running time between failures for the tubes in the gallery is now 70,000 hours and several klystrons have operated for over 100,000 accumulated hours (equivalent to more than 11 years of continuous running).

The factory has also been very busy building and repairing B-Factory klystrons (BFK) in the past year. Three of these 15 foot long klystrons have been built to the SLAC design. The third is presently being stacked for test while the others have gone through test and are in use. Two of the Marconi (European vendor) versions of the tubes have also been repaired by SLAC. The manufacturing group has also produced 10 high-gradient accelerating structures for the NLC in the past year.

Work for Others and Collaborations

Outside funded work for others and collaborations continue to be an important part of the work of the Klystron Department. This includes collaborations with small businesses on SBIR-funded developments and the development of a Compton X-ray source, for use in cancer research. The NIH funding of the Compton X-ray source came to an end during the past fiscal year. The current funding is by UC Davis for components and SLAC for labor. Progress during 2003 included accelerating the beam from an X-band rf gun to 7 MeV, completion of the assembly of a complete beam line system, and measurements of emittance and quantum efficiency of the cathode. The system has been successfully operated at near-design field gradients. The initial tests of the colliding of the photon and electron beams is scheduled for the next fiscal year.

The development of LIGA-based W-band klystron fabrication was continued in this past year. Alternative methods of LIGA using SU8 (epoxy photo resist) are being carried out.

Progress with the SBIR- funded collaborations with small business has included completion of the MacroMetalics contract for a TWTA driver for the NLC klystron. Four X-band tubes complete with power-supply and modulator were delivered to SLAC, along with the prototype of an S-band, 2-kW TWT for possible use in the NLC injector.

California Tube Labs (CTL) has completed its 12.5-MW power, X-band klystron that is a prototype for our six-beam, 75-MW multiple-beam klystron. Testing of this prototype tube has yet to be carried out.

The 500-kV, 3.5µsec, 500 amp, pulsed modulator based on an IGBT solid-state switch was successfully tested at SLAC during the past year. The IGBT switch that replaces the thyratron used in conventional modulators holds out promise for longer life and lower cost.

The Calabazas Creek Research 415-kV gridded sheet beam klystron gun has yet to be completed. This will be tested at SLAC when it is completed.

Asgard Microwave has obtained a Phase I SBIR contract for the development of a distributed high-power window based on the RIBLET junction. SLAC will be working with Asgard in the high-power testing of prototype designs. Success with this project could lead to a lower-cost, higher-power window that exhibits fewer moding problems.

14. FY03 PROGRESS IN RADIATION PHYSICS DEPARTMENT by Sayed Rokni

Radiation Physics Department (RPD) performs applied research in the areas of production, attenuation and interactions of radiation with matter, development and characterization of instrumentation, design of shielding and dosimetry for high radiation environments. Another important area of research in the Radiation Physics Department is the development, maintenance and benchmarking of radiation production, interaction and transport computer codes. Expertise in this area is also provided to others at SLAC in support of their research efforts.

Neutron Energy Spectra Research:

One of the main areas of research for the Radiation Physics Department is to make the shield-design process more accurate, thereby helping to reduce costs without cutting down on safety. Development of experimental techniques used in measurements of high-energy neutrons outside the shield is an important step towards achieving this goal. Analysis of the results from the experiment T-457, the collaborative SLAC-CERN-Tohoku University experiment to measure the spectra of neutrons after they pass through various thicknesses of iron and concrete shielding was completed last year. Neutron energy spectra outside the FFTB shield dump were measured up to 800 MeV and compared with the results from FLUKA. Two papers were submitted and published in the Nuclear Instruments and Methods. This experiment was also part of the Ph.D. thesis for a student from Tohoku University.

Also, in collaboration with the Research Division at SLAC the RPD's NE213 detector was modified to expand its dynamic range for measuring high-energy neutrons. The response-function of the detector was then measured experimentally at the Heavy Ion Medical Accelerator Center of the National Institute of Radiological Sciences (NIRS) in Japan using well-characterized neutron fields up to 800 MeV in energy. Preliminary analysis of the data has been completed in collaboration with the NIRS staff. Another part of this effort focused on development of a data acquisition system at SLAC for use with the NE213 spectrometer. As part of the Science Undergraduate Laboratory Internship program, two summer students implemented this goal successfully. Students developed a CAMAC-based Lab-View data acquisition system and used it in calibration of the SLAC NE213 liquid scintillator using different radioactive sources.

Induced Activity Studies:

This year, the Radiation Protection Group at CERN and RPD at SLAC agreed on plans to align their research activities together and start closer collaboration between the two groups. The collaboration areas include experimental benchmarking of the FLUKA code, measurement and simulation of detector responses in mixed photon and neutron fields, and the exchange of key personnel to accomplish this work. RPD staff members participated in a collaborative experiment with physicists from the Radiation Protection Group from CERN at the CERN-EU high-energy reference field (CERF). Seventeen samples of materials such as stainless steel, copper, concrete, soil and water were exposed to radiation fields by placing them behind and around a 50 cm thick, 7 cm diameter copper target. The copper target was irradiated by a positively charged (120 GeV/c) hadron beam. In order to identify short-lived and long-lived radioactive isotopes, the induced gamma emission from the irradiated samples was measured with a HP-Ge detector. In addition to the gamma spectroscopy, dose equivalent rate measurements were performed. The results will be benchmarked against simulations carried out with the Monte Carlo particle transport code FLUKA. Accurate estimation of the residual activation and dose rate are needed for minimizing the radiation exposure to workers involved in maintenance of accelerator beamline components, minimizing the amount of radioactive waste present upon decommissioning of accelerator facilities, and minimizing the impact of accelerator operation on the environment.

High-Level Dosimetry and Radiation Damage Studies:

RPD's Semiconductor High-Level Dosimeter (SHLD) system was used to check the gamma and neutron responses of the silicon photodiode and the polycrystalline diamond detectors during E158 experiment. Currently, BaBar is using silicon photodiodes to monitor the radiation damage to its silicon vertex tracker. Plans are to exchange the photodiodes with polycrystalline diamond sensors. SHLD reported the gamma and neutron doses based on the well-calibrated data during the E158 measurements. BaBar reported the gamma doses based on the charges collected by silicon PIN-diodes. The doses reported by the BaBar agreed with RP's within 50%. BaBar also reported the neutron doses that agree with RP's within a factor of two. The signals from the diamonds showed no leakage current change, but showed changes in the signal efficiency. The signal currents in the two diamond detectors dropped by 50-65% over the entire run.

Development and Benchmarking of the FLUKA Computer Code:

With hiring of Dr. Alberto Fassò, a co-author of FLUKA computer particle generation and transport code, implementation of features in the code that are needed for SLAC are planned. Specifically, the photo-production of muons has been added to a version of FLUKA developed for use at SLAC. In a first stage, the production of muon pairs has been implemented as an inclusive effect, suited mainly for shielding calculations. In this approach, based on a theoretical paper by Y. Tsai, the double-differential energy-angle distribution of one of the two muons is obtained by integrating over the corresponding distribution of the other muon. In this way, correlations are lost, but correct average doses and fluences can be obtained. G. Feldman and L. Keller had used a similar approach in the MUCARLO code. However, in MUCARLO, a further integration was performed on photon tracklength providing the energy spectrum of the muons but not their angular distribution. In the present implementation, the Tsai muon photo-production algorithm is fully integrated with the complete FLUKA transport system, including Combinatorial Geometry, magnetic fields, ionization losses with fluctuations, muon-nucleus interactions, etc. Some consolidation work is still needed to test and benchmark the coding of the new physical effect, and to add other FLUKA features such as input-driven user control of biasing parameters, calls to user routines and general statistics updates.

Comparison of Codes Used for Synchrotron Radiation Calculations:

STAC8 is an analytic code developed at SPRING8 laboratory at Japan. This computer code is a valuable tool for design of beamline shielding in synchrotron radiation (SR) facilities and is expected to replace the PHOTON code, widely used in beamline design. To verify the applicability, accuracy, and limitations of STAC8, a systematic study has been conducted over the last 2 years to compare STAC8 results with calculations using the FLUKA and EGS4 Monte Carlo codes. Doses due to scattered SR for a few beam-target-shield geometries were calculated, both with and without photon polarization. Several critical STAC8 input parameters have been examined to see their effects on dose results. Areas for expanding the STAC8 capabilities such as addition of the mirror-reflected lights and double-Compton light calculations, manually input a spectrum, were identified, implemented and benchmarked. Reasonable agreements were found between the STAC8 and Monte Carlo codes. The study results are being documented and will be presented at the 10th International Conference on Radiation Shielding.

15. FY03 Progress in SSRL OPERATIONS by Piero Pianetta

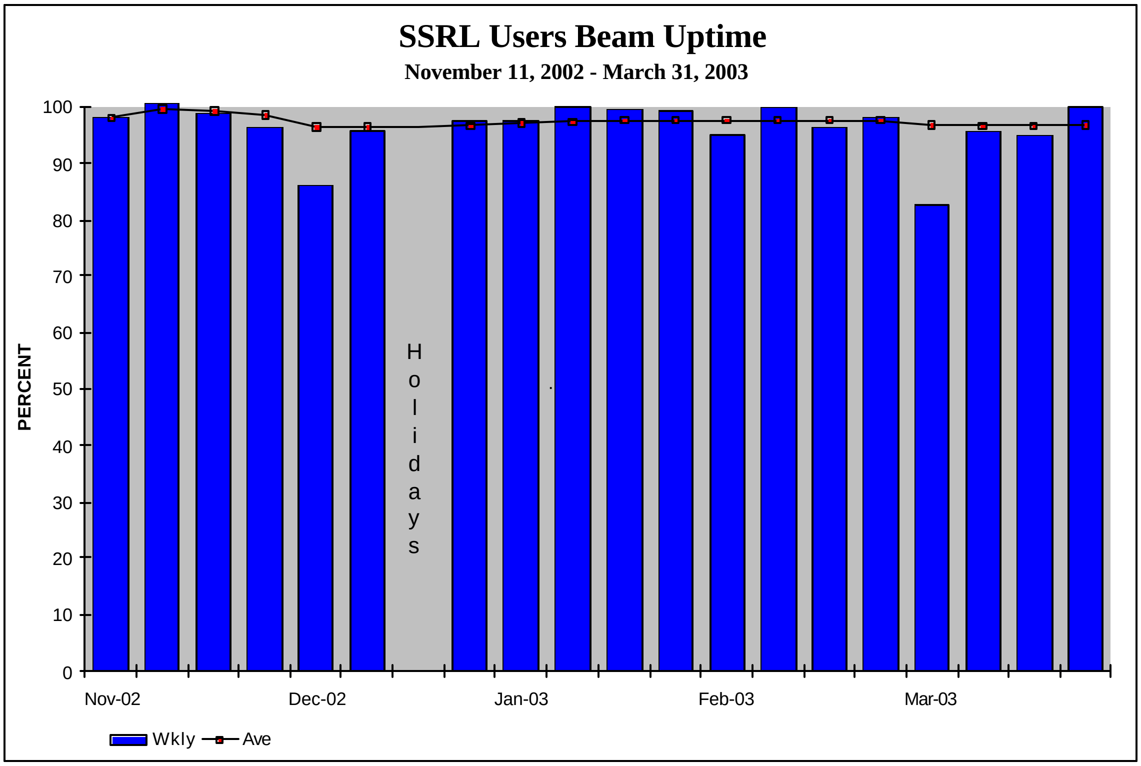
FY2003 User Experimental Run

The FY2003 user run (November 11, 2002 – March 31, 2003) delivered 96.8% of scheduled user shifts, accommodating the beam-time needs of approximately 338 (361 if you don’t subtract out facility proposals) unique proposals. SSRL supported 667 experimental starts on 31 beam line stations that were open for users in FY2003. The User Research Administration office badged and processed 867 users who came on-site to perform experiments.

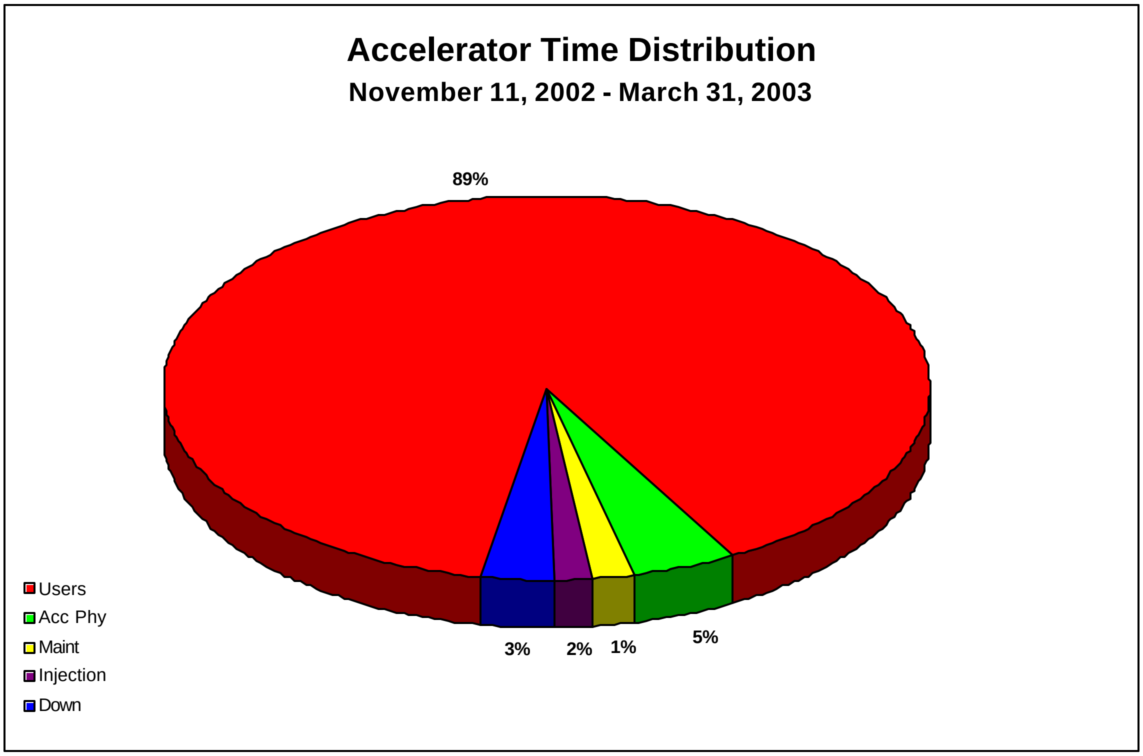
Competition for beam-time assignments remains extremely high. When averaged across all beam lines, the over-subscription rate was approximately 30% (user demand is 130% of available resources).

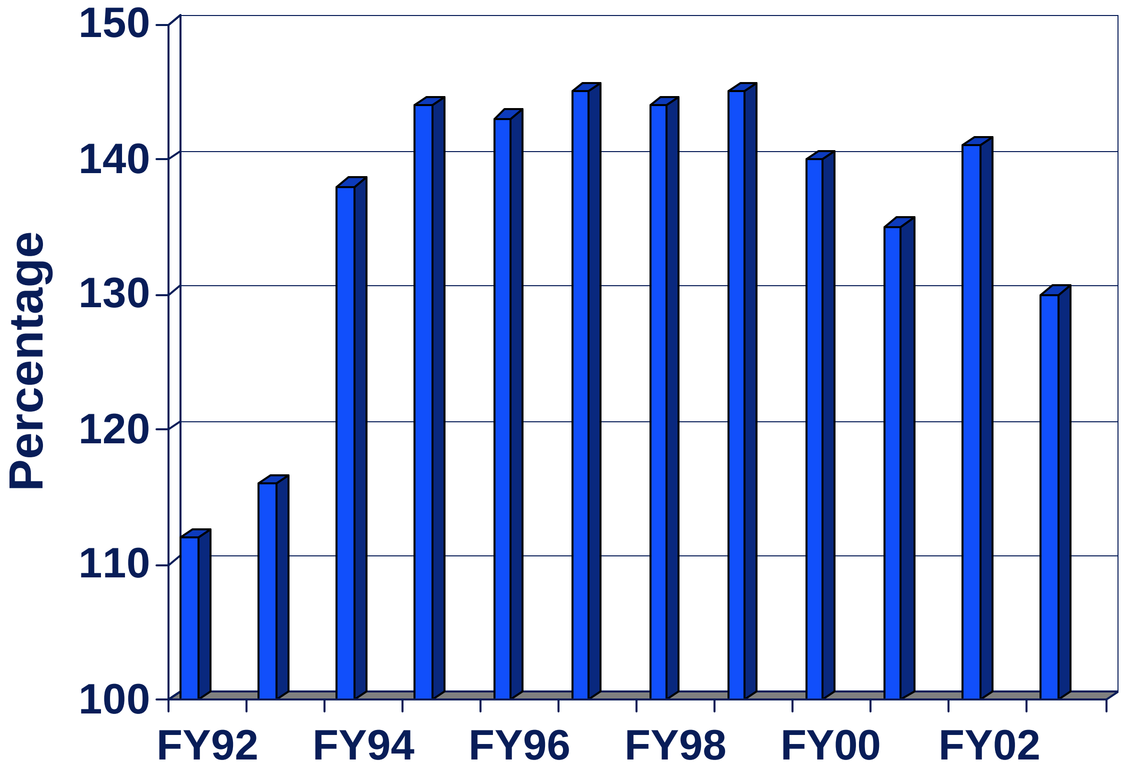
In FY2003, 1,720 SSRL users from over 20 countries received beam time. Of these users, approximately 89% were from the U.S., spanning 41 states and the District of Columbia. Users were predominantly from American universities (56%) followed by American laboratories (28%), American businesses (5%), foreign universities (9%), and foreign laboratories (2%).

2003 SSRL Users Weekly Uptime



2003 Run Time Distribution





SSRL User Demand Graph (FY92 – 03)

Distribution of the approximately proposals receiving beam in FY2002 (FY 2003 data not yet available):

Materials Science	13%
Physics	4%
Chemistry	14%
Polymers	2%
Medical Applications	4%
Biology/Life Sciences	44%
Earth Sciences	3%
Environmental Sciences	6%
Optics	1%
Engineering	3%
Other	6%

SPEAR Improvements and Accelerator Physics

The accelerator improvements in FY2003, and the plan for FY2004 and FY2005, reflect the transition from the SPEAR2 storage ring to the new SPEAR3 machine that is taking place in FY2003. The SPEAR2 accelerator program aimed to keep the high performance of the facility until it would be replaced by SPEAR3, and at the same time prepare the ground for SPEAR3 operation. The injector is undergoing a program of improvements that will make it more robust and reliable in view of the more demanding SPEAR3 requirements. Such improvements led to a considerably more reliable operation during the 2003 user run.

Turn-Turn Beam Position Monitors (BPMs) - The conceptual design of a parallel-button BPM RF-IF processor was completed and a production contract was awarded to an outside company. Funding has been provided for at least 24 of the beam position processing units and ancillary calibration components that will be used for first-turn, turn-turn, and multi-turn (high resolution) orbit acquisition. Digital IF processors have already been procured. Prototype versions of a key component for the processing system, the Test Tone Coupler, have been received from two outside companies and the one with superior performance has been selected. The processing system will enable quick beam turn-on after extended shutdowns, permit turn-turn beam dynamics studies, and enhance the existing high-resolution orbit measurement system, with channel-channel gain differences dramatically reduced by processing the calibrated test tone.

Average Current Monitors (ACMs) - The three ACM toroids and processing units that will be used to limit injection beam current and losses in SPEAR3 were installed and, in March 2003, were tested with beam. The ACMs have sufficient resolution to monitor an injected beam current of <0.5 nA, which will be the initial trip threshold for SPEAR3.

Injector RF Source Upgrade - An improved rf source having increased power (55 MW) over the old system (45 MW) was fabricated, assembled, installed and successfully tested. The source includes a new pulse-forming network enclosure, thyratron stand, controls and interlock system improvements. This project provides an improved and more reliable rf source for the SSRL injector.

Injector Pulsed Signal Monitoring - Development of the pulsed signal monitoring diagnostics is progressing well. When completed in 2003, the system will simultaneously record and monitor up to 48 time-varying signals. Each signal will be digitized and then the maximum, minimum, pulse height, pulse width, average, 1st moment, 2nd moment, integral, or even the value at a specific time window will be recorded in the on-line history database. The signal will also be sent to a multiplexer, so that any four of the 48 signals can be independently selected for both an oscilloscope in the injector building or for use in the main SPEAR control room. This project will improve our ability to record analog settings and to compare them for accelerator studies and diagnostics purposes.

The software controlling the digitizers and converting the signals to discrete numbers has been written and tested. Several prototype buffer amplifiers to send the raw signals to multiple destinations have been built and characterized. A final production type prototype amplifier is under fabrication.

Injector Upgrade Project - Work continued to ensure that the injector will provide reliable 3 GeV beam for SPEAR3. In the past, the injector has been run at 2.25 GeV to provide beam for SPEAR2. In FY2003, the injector was run for extended periods at 3 GeV, with full intensity beam ramped in the booster and steered down the BTS transport line. A few minor hardware issues were identified which are being addressed during the SPEAR3 installation shutdown.

Work was done to better understand and control the electron beam in the BTS line that transports the electrons from the booster to SPEAR. The steering magnets were replaced with new magnets strong enough to steer the 3 GeV beam. An additional steering magnet was installed to improve the beam trajectory and transmission down the BTS. The BTS survey was analyzed to determine the position of new magnets required for SPEAR3. Average current monitors (ACMs), required for the radiation safety system for 3 GeV injection, were built and installed in the BTS and preliminary commissioning was completed.

In order to implement the new BTS optics for SPEAR3, a better understanding of the present optics was needed. Improvements were made to the system of screens measuring the beam shape along the BTS and a model of the BTS optics that successfully predicts the measured beam sizes was developed. With this new model, the beam transmission efficiency between the booster and SPEAR was improved.

Two new BPMs are being installed in the BTS near the SPEAR septum magnet as part of the SPEAR3 Upgrade Project. These BPMs will help operators establish and maintain an optimum electron trajectory entering the septum and SPEAR ring.

Synchrotron Light Monitor (SLM) - Substantial progress was made on the new high-resolution UV beam line that will be used to measure properties of the SPEAR3 electron beam. The beam line utilizes a built-in ID port in the main vacuum chamber and a room previously used for BL1 controls. The control room has been refurbished and an optical bench, internet and video connections, AC power, and alignment monuments have been installed. The front-end of the beam line underwent final design review and long-lead mirror components are on order. The mechanical movers for the x-ray block and first mirror underwent final review in April, 2003. A lead radiation protection box in the control room passed Radiation Physics review and has been fabricated. To simplify mirror manipulation, electronic mirror position and read-back devices have been replaced with mechanical equivalents. The SLM beam line is scheduled for completion and installation in early 2004.

Control System Upgrade - EPICS Channel Access Servers have been implemented in SPEAR computer control system over the last two years. They are now being used by the beam line support group to access SPEAR status information. The first VME-based EPICS IOCs, developed for the SPEAR3 control system, were successfully incorporated into the SPEAR2 control system and gave us some valuable experience with these new implementations. These EPICS system developments have been greatly expanded for the SPEAR3 control system.

SPEAR3 Upgrade Project

The original overall project schedule called for completion of technical systems by April 1, 2003, followed by their installation in the second half of this fiscal year.

In general most of the technical components were completed prior to April 2003; however, some components, particularly for the vacuum, rf and instrumentation and control systems, are continuing into October 2003. This production schedule is not significantly impacting the projected installation completion set for the end of October 2003.

Magnets and Supports - All of the support rafts for the main ring magnets and vacuum chambers have been pre-assembled and installed in the SPEAR tunnel. The septum magnet was completed, assembled with its vacuum chamber on a support raft, and installed in the tunnel. LCW manifold headers are complete and installed. The BTS injection magnet raft is complete and installed.

Vacuum System - In the first half of FY2003, the assembly welding, and vacuum processing of all 42 standard and four matching cell chambers were completed. The remaining eight matching cell chambers were completed by mid-April. Assembly of the final chambers within the magnet rafts was completed in June. These chambers have been mounted on magnet rafts and installed in the tunnel. Fabrication of straight section chambers and bellows assemblies will be complete in October 2003 and installed by the end of October.

Magnet Power Supplies - All magnet power supplies have been fabricated and tested. Buidling118 refurbishment has been completed and the power supplies installed.

RF System – The four SPEAR 3 RF cavities have been received from Accel Instrumentation in Germany, assembled with their windows, loads and ancillary components at SLAC, tested to full power, and installed in the SPEAR tunnel. The SPEAR3 klystron, which failed during temporary use by PEP-II, has been repaired and delivered to SLAC for high power testing, which will be complete in mid-October 2003. The klystron High Voltage Power Supply has been installed and will be tested by mid-October. Assembly and installation of the the low-level rf system (LLRF) will be complete by the end of October 2003. High power testing of the complete SPEAR 3 RF system is scheduled for mid-November 2003.

Instrumentation and Controls - Work on the computer control system progressed well with the successful implementation of several EPICS IOCs and the testing of various data acquisition components. The hardware design of the digital control components for the corrector power supplies was completed and final programming is in progress. Commercial BPM processing units are being tested and the data acquisition system is being configured. The injector rf signal generator and timing modulator was completed; fabrication of the computer-interfaced controller for this system will be complete by the end of October 2003.

Average Current Monitors for the Beam Containment System (BCS) have been installed and testing will begin in October 2003. Detailed design of other BCS components, namely the Long Ion Chamber processors and the Stored Current Interlock, will be complete by mid-October, with installation scheduled for mid-November. The PLC-based machine protection systems for vacuum and magnet cooling have been configured and testing will begin in late October. Remote processing units for the Orbit Interlock have been completed and the central processing unit will be complete by the end of October.

I&C equipment racks have been installed and installation of hardware in the racks is in progress.

Cable Plant - The Phase 1 Cable Plant Installation contract consisting of DC and vacuum system cables was completed on March 24, 2003. The majority of this work involved long haul cables for the project plus installation of the east and south ring trays, the injection kicker cables, and HV cables for the rf system. Phase 2 of the Cable Plant Installation contract, which began in late August 2003, completes installation of the cables to components in the tunnel, B118, and other equipment areas, and will be complete on October 22. Phase 2 includes the installation of cable trays in the tunnel.

Beam Line Front-ends – All beam line front-end components are complete with the exception of the BL 10 movable mask, which will be ready by the end of October 2003. Final installation of the front-end vacuum components will be finished by mid-November, and shielding installation will be completed in early December. Most of the front-end components have been fabricated.

Facilities - Most of the conventional Facilities work for SPEAR3, including East and West straight section shielding modifications, new AC power distribution, VESDA tunnel alarm system, and B118 seismic retrofit, was completed as planned during the normal shutdown periods of the last three years. The remaining work, including some additional shielding modifications, more AC power installation, and the LCW and HCW system installations, will be described in Installation section.

Environmental Health and Safety - Work towards comprehensively assessing the shielding and design parameters for SPEAR3 was completed. Documents that cover the beam loss scenarios and shielding requirements are available and have obtained SLAC Radiation Safety Committee (RSC) approval. Shielding for 100 mA SPEAR operation will be in place by early December 2003, and that for 500 mA operation will be installed by September 2004. The Personnel Protection System and Beam Containment Systems proposals are complete and are presently in final review by the RSC.

The Accelerator Readiness Review was held September 9-11, 2003. This review addressed the following items:

- Identification of equipment and systems having safety importance - Hardware Readiness.
- Identification of procedures necessary for safe operation - Procedure Readiness.
- Identification of personnel necessary for safe operation and define minimum training requirements - Training Readiness.

No critical findings were identified in the review that would impede SPEAR 3 start-up, but a list of items needed for project completion was developed, including:

- SLAC Fire Marshall to perform life safety review to ensure no there are no issues related to aisle space and emergency preparedness – COMPLETED.
- Hazard analysis of compressed gas used for LION system is needed – COMPLETED.
- Required lock-out of beam lines not ready for 100 mA or 500 mA operation should be specified on the Beam Authorization Sheet.
- An interlock to abort stored beam when a vacuum pressure of >50 nTorr is detected should be considered to avoid excessive bremsstrahlung production.
- A review is needed to assure proper integration of ring electrical hazards into the PPS Electrical Hazards interlock.
- All required safety, certification and operations procedures to be completed before ring commissioning.

The incomplete items will be completed by the end of November 2003.

In addition to the above concerns, the ARR identified five noteworthy practices in the SPEAR 3 project, including the use of the SLAC Citizen Committees to address safety issues, the 24/7 beam line operator coverage plan, the B118 design and layout, the use of travelers and other quality control documentation to manage hardware production, and the use of SLAC's CAPTAR system to document the cable plant.

Accelerator Physics – Development of graphical accelerator control applications using the commercial software product MATLAB continued. The closed-orbit correction program, magnet control panels ("knob" panels) and orbit feedback were tested extensively on SPEAR2. To simplify computer connections with the on-line accelerator, a parallel software library was developed to provide communication via the Channel Access protocol in EPICS. After initial development at SSRL, oversight of the Channel Access programs has been transferred to the SNS at ORNL. In a second collaboration (ALS at LBNL), a middle layer of software programs has been added to further simplify simulation of on-line machine control. Finally, a "pseudo" SPEAR3 parameter server was developed so that programs can communicate in the "online" mode prior to startup. The overall package has been used to develop high-level graphical machine control programs for SPEAR3.

Work continued on the MATLAB version of the accelerator optics debugging program, LOCO. The code was used to analyze the optics of ALS, the Aladdin storage ring, SRRC, and NSLS X-ray ring. Work to debug and improve the code continues.

Other accelerator physics group efforts included simulations of the off-energy dynamic aperture and non-linear coupling into the vertical plane, completion of the specification for the synchrotron light monitor and beginning of its construction, completion of specifications for the DCCT, development of the magnet polarity test plan, specification of magnet transfer functions for the control system, and development of the SPEAR 3 commissioning plan. A working group has been established to study low vertical beta and lower emittance lattice variations.

Installation - The SPEAR3 installation plane was initiated on schedule on March 31, 2003 following the final user operation period and shutdown of SPEAR2, and is scheduled for completion by mid-November. The installation plan comprised 6 major contracts: SPEAR 2 removal and SPEAR 3 magnet raft installation, tunnel and B118 concrete floor installation, floor hole-drilling and raft mounting plate grouting, B118 installation (AC power, power supplies, equipment racks), Phase 2 cable plant installation, and LCW modifications and installation. The first four contracts were completed on-time and on-budget, and the cable plant is expected to be complete on-time and on-budget in late October. In addition to the major contacts, other installation activities have been completed, including rf cavities, rf HVPS, HCW system, straight section supports, East and West instrumentation rooms, insertion devices, beam line front ends and miscellaneous other systems. Straight section vacuum chamber components and bellows will be installed during October, with vacuum leak-checking and pump-down taking place in late October and early November. An alignment survey will be conducted before locking up the ring for system hot tests in mid-November. The ring will be opened again for the first week in December in order to complete installation of beam line components and radiation shielding and to perform a final alignment.

First beam to SPEAR3 and the beginning of commissioning is scheduled for December 10, 2003. Beam for user experimentation is expected sometime in March 2004.

Fourth Generation Source Development

Project Authorization Milestones

Critical Decision 1 was approved for the LCLS on 16 October 2002. Since Project Engineering Design was considered a "new start" for FY2003, no funds could be authorized for this activity until March 2003. LCLS plans for "Long-Lead Procurements" in FY2005 underwent an SC-81 review in May 2003. Results of the review were favorable, and served as a basis for approval of Critical Decision 2A (CD-2A) in July of 2003. The Department of Energy plans to allocate $30M to LCLS in FY2005 for Long-Lead Procurements.

Environment, Safety and Health

The Environmental Assessment Document for the LCLS (DOE/EA-1426) was approved in February 2003. This document supported the Finding of No Significant Impact on the environment and health conditions at SLAC and in the surrounding area.

Management

With one exception, all positions in the LCLS management organization were filled in FY2003:

- Chief Engineer
- Injector Subsystem Manager
- Linac Subsystem Manager
- Undulator Subsystem Manager (work to be managed by Argonne National Lab)
- X-ray Transport/Optics/Diagnostics Subsystems Manager (work to be managed by Lawrence Livermore National Lab)
- X-ray Endstation Subsystems Manager
- Conventional Facilities WBS Manager

The unfilled position is that of LCLS Controls Systems Manager. Candidates for this position have been identified and are undergoing evaluation.

Responsible physicists have been named for each of the organizational units listed above. These physicists are responsible for providing physics performance specifications necessary to carry out engineering design of each subsystem. They are also responsible for determining that LCLS hardware has met the original physics performance specifications.

Resource-loaded schedules for the long-lead procurements were prepared for the May DOE review. Preparation of an integrated schedule began in July of 2003. The Project placed a contract for support of the Project Management Control System Database, effective through April of 2004.

Scientific/Technical

Engineering design is making good progress in all areas of the accelerator. Emphasis has been placed on technical requirements and estimated cost and schedule for FY2005 long-lead procurement items, which include:

- All laser, mechanical, RF and electrical systems and components for the injector
- All chicane bend magnets for the LCLS linac
- A superconducting wiggler for the LCLS linac
- An x-band RF system for the LCLS linac
- The magnet blocks, permendur poles and “strongback” support for the LCLS undulator magnets
- An undulator magnet measurement facility at SLAC

A layout of the injector has been prepared, and the design of the injector/linac radiation shield wall has been completed and approved by the SLAC Radiation Safety Committee. Physicists from SLAC and BNL, supporting the LCLS injector design effort, made the first measurements of the intrinsic “slice” energy spread of an electron beam from at the SSRL Gun Test Facility photoinjector.

Input physics specifications have been prepared for all long-lead procurements in the linac, and engineering design is in progress.

Measurements of the prototype undulator have resumed, for the purpose of checking the long-term mechanical and magnetic stability of the prototype.

Efforts on x-ray transport/optics/diagnostics systems have emphasized modeling of the power density on first optical components, tests of light x-ray beam monitor resolution and tests of concepts for direct measurement of x-ray pulse duration.

Concepts for the layout of x-ray experiment stations were developed and reviewed by an external committee. The review was supportive of the proposed layouts.

Alternative layouts for conventional facilities have been developed. The new layouts are intended to simplify future expansions of the LCLS to a multi-undulator configuration.

The LCLS Scientific Advisory Committee (SAC) has been formed. The SAC will evaluate proposals for new x-ray instruments for the LCLS science program.

Considerable progress has been made in all areas of accelerator physics related to the LCLS. An exhaustive comparison of computer codes for modeling and design of RF guns was completed. The comparison confirmed the reliability of programs used to design the RF gun and chicanes. Significant aspects evaluation took place during the “Start-to-End simulation workshop held in Zeuthen, Germany at a workshop sponsored by DESY and SLAC. Important new results have been obtained in the study of coherent synchrotron radiation instability effects in the high-current

LCLS electron bunch. Methods for control of this instability have been identified and are incorporated in the LCLS design.

Possibilities for future expansion of LCLS operational capabilities (in the operations phase after completion of the Project) were studied by a team of physicists from SLAC and UCLA. A promising outcome of this study is the identification of a possible means of producing x-ray pulses as short as 1 femtosecond by collimating the electron beam in the middle of the first bunch compressor. Other possible enhancements of LCLS operational capability include extension of spectral coverage from 250 eV to 24-30 keV x-rays, increase of peak power to 100 GW, and increased average power. A report of these potentials for expansion has been submitted to the Journal of Synchrotron Radiation for publication.

New Beam Line Facilities and Beam Line Improvements

General Improvements – Most of the beam line activities in FY2003 were focused on the SPEAR3 upgrade. This included removal of the in alcove beam line components at the beginning of the shut down and reinstallation and realignment once SPEAR3 has been installed. The beam line steering system which provides feedback to the SPEAR orbit control program will be upgraded by replacing the current amplifiers and high voltage power supplies which are reaching the end of their life due to unavailability of parts. This will provide increased reliability and stability needed for SPEAR3 operation. In addition, there will be continued development on the hardware needed for VXI-based motor control and data acquisition systems. As mentioned above, a VXI system was successfully implemented on BL7-3 in FY2002. As more experience is gained, SSRL intends to implement these systems as beam lines are upgraded for SPEAR3. With the upgrade of the BL10 machine protection system all of the SSRL beam lines and accelerators will have been brought up to a modern, maintainable standard.

BL11-2 was made available for full user operations and commissioning was completed on the BL11-2 grazing incidence spectrometer, the multi-altitudinal positioner for the 30-element Ge detector array, and the curved Laue transmission analyzer. Finally, design and optics procurement has been initiated on a KB-based hard x-ray microprobe that will deliver sub-micron beam spots.

Beam Line Upgrade Project – In FY2003 the focus of the beam line upgrade project is the installation of beam line front-ends and the upgrade of selected optical elements, masks, and beam containment systems required for increased current operations of SPEAR3.

Front-Ends – Final assembly of the new 500 mA capable front-end masks and other components will be completed and the front-ends installed during the SPEAR3 accelerator installation down. In-alcove radiation shielding will be upgraded for 3.0 GeV injection and 500 mA operations of SPEAR3.

BL1, 2, 3, and 8 – In addition to the front-end installation, the bend beam lines have been realigned as required by the relocation of the SPEAR3 bend source point. A few selected masks, filters, and windows will be replaced to permit initial operation of these beam lines on SPEAR3.

Additional beam containment structures (hutches) will be designed and built in FY2003 and FY2004 as required for safe operation of SPEAR3.

BL4 – The new 20-pole insertion device and associated vacuum chamber was installed in September 2003. While progress on upgrading the beam line components will be limited owing to funding constraints, some optical components such as the LN monochromators and associated entrance slits will be fabricated in parallel with similar components on other beam lines to exploit fabrication cost reduction from quantity discounts. The central station, BL4-2, will be operational when SPEAR3 is commissioned albeit with the wiggler field reduced to limit the power intercepted by the beam line masks.

BL5 – The BL5-1/2 SGM and its associated gratings have been delivered. The M_0 mirror system as well as the slits, masks, and beam containment systems will be installed and ready for operation at the outset of SPEAR3 accelerator commissioning.

BL6 – The BL6 ID vacuum chamber is currently in fabrication. Though the schedule is tight, the vacuum chamber should be ready for alignment with the ID and installation in SPEAR at the end of the SPEAR3 installation down. The design of the BL6-2 M_0 and M_1 mirror vacuum and mechanical systems is largely complete and fabrication has commenced. (The mirrors themselves are already in house.) Many of the beam line masks are assembled, though a few systems are still in the design phase. Design, fabrication, and assembly activities continued throughout FY2003. The beam line will be ready for operation at the outset of SPEAR3 accelerator commissioning. The motion control system for the beam line will be based on the new SSRL standard VXI system.

BL7 – The new 20-pole insertion device and associated vacuum chamber was installed in September 2003. Originally, it was planned to temporarily decommission BL7 at the outset of SPEAR3 operations until the beam line upgrade was completed. To minimize the impact on the user community, however, the central station, BL7-2, will be operational when SPEAR3 is commissioned albeit with the wiggler field reduced to limit the power intercepted by the beam line masks. The complete beam line upgrade will be finished in early FY2005.

BL9 – Fabrication of the BL9-2 LN monochromator is underway with final assembly and installation scheduled for the summer of 2004. Design of the BL9-1 focusing monochromator was completed. A number of masks and slits are in various stages of fabrication and assembly. Design of the remaining masks will be completed in FY2003. While these remaining components will be installed in FY2004, the beam line, which was originally designed for 200 mA operations, will be operational at the outset of SPEAR3 accelerator commissioning.

BL10 – The thermal design and analysis of the BL10-1 M_0 mirror was completed in the first half of FY2003 with delivery scheduled for October 2003. Design of the remaining masks and slits was completed in FY2003. The beam line, which was originally designed for 200 mA operation, will be operational at the outset of SPEAR3 commissioning.

BL11 – The newly installed BL11-3 optics were commissioned in the first two quarters of FY2003. First light was obtained on November 25, 2003, and various modifications to the beam line alignment and tuning were conducted over the next few months to optimize the beam. The branch line underwent user commissioning, and, in the closing days of the run, several experiment shifts were provided to users. Aside from the new front-end and the installation of some additional graphite filtration into existing graphite systems for 500 mA operations, BL11 is fully ready for SPEAR3 500 mA operations.

SSRL Instrumentation and Control Software – During FY2003 the development of the new version of the SSRL instrument and control software (ICS) has continued. Initial installation and commissioning is took place during late 2003. Initially this software will probably be used on the existing OpenVMS computers, with some peripheral programs running on Microsoft Windows based computers.

In addition ICS developments will include: (a) ICS interface to the SPEAR EPICS control system. This will enable data acquisition programs to monitor SPEAR parameters, such as current and steering information. Ultimately ICS based software will be able to use this interface to control EPICS based devices; extend support to VME and CAMAC hardware installed using adapter cards in existing VXI instrumentation crates; and evaluation of new Windows 2000 instrumentation driver software (evaluation copy received April 2003). It is anticipated that this new software will provide improved stability and support for VME hardware; and extension of the existing automatic data-backup features. At present this feature is implemented at the acquisition program level within the XAS-Collect software. It is planned to provide low-level support for data transfer/backup facilities in an operating system independent manner.

SSRL also has an increasing amount of network based instrument control and data acquisition software. While some of these programs use proprietary syntaxes, they are nevertheless potentially vulnerable to disruption from network-based attacks. In order to reduce exposure, it is planned to install a dedicated network firewall to isolate the beam line computer environment. Access from the outside will be limited and restricted to encrypted protocols which are felt to be secure. Care will be taken to ensure that this does not impact the planned remote access features of XAS-Collect or other programs.

Facilities and Infrastructure - A new LCW distribution system which provides for all the beam lines in a unified way will be completed. This replaces the original system whose capacity had been reached and thus will allow for future beam line expansion. An LN distribution system will be installed to provide a steady supply to the LN cooled monochromators included in the Beam Line Upgrade Project. This distribution system will include insulated piping to all the monochromators being fed from the existing LN storage tank. As more LN cooled monochromators are installed, it is anticipated that additional storage capacity will be required. A number of smaller projects have also been undertaken. These included the Building 118 seismic retrofit, a new actinide storage room for BL11-2, an auxiliary air handling unit for the Building 137 computer room and an electrical circuit evaluation for Building 120 and 131.

Highlights of the Scientific Program—Materials, Molecular Environmental Science and Structural Molecular Biology Research

Research carried out by SSRL staff and associated Stanford faculty and students is described in this section and covers a broad set of disciplines: (1) Complex Materials and Strongly Correlated Materials; (2) Magnetic Materials; (3) Chemical Physics of Surfaces and Liquids; (4) Structural Properties of Novel Materials; (5) X-ray Physics; (6) Bonding and Structure at Practical Semiconductor Interfaces; (7) Imaging with Coherent X-rays; (8) Small and Wide Angle Scattering Studies of Soft Matter; (9) Molecular Environmental Science; (10) Structural Studies of Inorganic and Biological Materials; (11) Scientific and Educational Gateway Program; (12) Nano-scale Ordering in Complex Oxides: Model Systems for Local Probes; (13) Nano-scaled Magnetism in the Vortex State of high-T_c Cuprates; (14) Nano-scale Electronic Self-Organization in Complex Oxides; and, (15) Nano-Magnetism. Areas (12) through (15) are collaborative efforts of the SSRL X-ray Laboratory for Advanced Materials and the Stanford University Geballe Laboratory for Advanced Materials.

1. Complex Materials and Strongly Correlated Materials

For Shen's programs, important progress was made to understand the universal nodal velocity in p-type materials. This is a very striking and unusual result, especially when this universality is observed from a doping range spanning from 3% to 30% while the other properties have changed significantly. This universality is likely to be of importance in understanding the fundamentals of charge motion in CuO_2 plane. Due to materials chemistry issues, all prior high-resolution investigations of superconductors have been done on p-type materials. This has been extended to the problem of the n-type material by investigating the low-lying self-energy effects. This work complements the Greven effort on the lattice effect.

Deeply underdoped cuprates are particularly interesting because they provide insights on the initial stage of doping Mott insulators and the possible emergence of local superconductivity even though the global phase coherence has yet to set in. This also is interesting as a way to test the recent theoretical proposal by Laughlin. Recent breakthroughs in material synthesis enable the ARPES investigation in this doping range. Shen has investigated two complementary materials systems on this issue, namely that of $La_{2-x}Sr_xCuO_4$ and $Ca_{2-x}Na_xCuO_2Cl_2$.

Greven's work on the structural phase diagram and charge-order phenomena in the layered manganite is being extended to cover a wider range of doping. Neutron scattering is being used to arrive at a comprehensive understanding of the magnetic phase diagram and spin correlations. Using the magnet facility, a deeper understanding of the intriguing phase transition of the RFIM is being developed. Moreover, EXAFS experiments (in collaboration with Prof. F. Bridges, UC Santa Cruz) of the colossal magnetoresistance manganites have been conducted in order to better understand the magneto-structural properties of this important class of materials.

In a major recent breakthrough, Greven has succeeded in growing samples of the mercury-based superconductor $HgBa_2CuO_{4+d}$ (Hg1201) that are two orders of magnitude larger than the previous world record. Hg1201 exhibits the highest superconducting transition temperature of all the single-layer cuprates, and it is the material with the simplest crystal structure. The new samples are large enough to allow the first detailed scattering, ARPES, and STM experiments of this model superconductor.

Laughlin has been exploring the properties of his new exact solutions and reconciling them with experiments of highly-correlated materials. He also expects to study the low-energy photoemission universalities reported by Lanzara et al. [Nature **412**, 510 (2001)] and explore the possibility that they are actually magnetic in nature and caused by a nearby phase transition. He also plans to investigate the technological implications of coulombic distortion of spectroscopic properties, particularly in optics.

Doniach continues to work on correlated electron systems and other complex materials. Work on a bosonic theory of electrical conductivity on transition metal oxides was started. This is expected to provide a model of high temperature conductivity in compounds such as the ruthenates and nicklelates.

On other complex materials, a discovery was made on anomalous sub-picosecond density fluctuations in water as part of a program of computer simulation of complex materials. Although not a typical complex material, water remains a mystery in many ways. Its properties also pertain in an essential way to work going on at SSRL by Anders Nilsson, showing that the standard models of water give a poor representation of inter-molecular correlations in liquid water. This is also relevant to work proposed at SSRL by Nilsson and Hari Manoharan on inhomogeneous catalysis on the nanoscale. A proposal for sub-picosecond measurements of this effect at the SPPS is being prepared.

2. Magnetic Materials Research

The data rate for the writing process in magnetic recording is limited by the speed with which the magnetization reverses in an individual bit. In conventional longitudinal recording, magnetization reversal occurs upon application of an inverse field through domain nucleation and wall motion and takes place on a nanosecond time scale. Experiments to test the ultimate limit of the time needed to induce reversal are rare and are typically limited to small fields created by strip-line techniques involving short current pulses. At present only one technique is known to produce magnetic fields of the ultrashort duration and sufficient field strength required to test the limits of magnetic recording – the magnetic field surrounding a relativistic, high current, ultrashort electron pulse created in a linear particle accelerator. We have been using this method to study ultrafast magnetic switching. After exposure, the sample is removed from the beam line and the magnetization pattern is inspected with a high resolution x-ray microscope. These magnetization patterns directly display the areas where the magnetization has switched after being exposed to the ultrashort field pulse. The recorded precessional reversal can be modeled by a calculation based on the Landau-Lifshitz equation with damping and reveals the dynamics of the process.

We have used the above method to probe for the first time precessional switching in magnetically hard single domain particles, such as used in perpendicular magnetic recording media. Switching on the picosecond time scale can only occur via precessional reversal where the magnetic field is at a finite angle to the magnetization in order to create the necessary torque.

Whether a magnetic particle in the media switches its direction of magnetization depends on the direction of the applied field, its strength and duration, and media characteristics.

We have analyzed the recorded switching pattern generated by a state-of-the-art magnetic recording material. In the case of multiple applied field pulses the patterns are statistically independent of the history and can be predicted knowing only the first pulse pattern. This indicates thermally activated switching. However, this is at odds with the known fact that the switching pattern is stable for years. The puzzle is resolved by our second observation that the activation volume for the precessional switching is smaller than the volume of the particle (grain size) and the formulation of a new model. It assumes that the individual magnetic particles switch independently but not homogeneously. Rather, the magnetic anisotropy inside the particle and near the particle surface are sufficiently different that the core of the particle, which has a lower anisotropy, switches first and helps to drag the harder particle shell into the new magnetization direction. This model is of great importance since it explains one of the existing paradoxes of magnetic recording technology, the fact that the material can be switched fast yet is magnetically stable for years.

3. Chemical Physics of Surfaces and Liquids

The main focus of this research program is to use x-ray spectroscopies to address important questions regarding chemical bonding on surfaces, during catalytic reactions and in aqueous solutions. X-ray emission spectroscopy (XES) and x-ray absorption spectroscopy (XAS) provide an atom specific projection of the electronic structure. Problems related to systems in catalysis, energy technologies, electrochemistry, molecular environmental science and biology are studied using XES, XAS and density functional theory (DFT) calculations. Probing hydrogen bonding and the structure of liquid water in aqueous systems are new and novel applications of x-ray spectroscopic techniques. Instrument development is an important part of the activity to provide new spectrometers, and enable measurements at high gas pressures and at liquid interfaces.

New models of the structure of liquid water were proposed based on XAS experiments. These models go against the existing understanding based on theoretical simulations. New insights into the fundamental understanding of the hydrogen bond in ice were discovered, based on XES, XAS measurements and DFT calculations. XAS measurements of supercritical water at 200 bar pressure were taken by the x-ray Raman technique utilizing hard x-rays at the APS.

4. Structural Properties of Novel Materials

Under the general heading of Novel Materials, there are two major subgroups being explored. One is the local structure of non-crystalline materials, the other is the near-surface structure of thin films.

Non-crystalline Solids – Despite the great potential payoff, determining the partial pair distribution functions for non-crystalline materials by anomalous x-ray scattering (AXS) continues to be a very difficult, infrequent undertaking. This is because it involves the solution of an ill-conditioned matrix equation, making the technique very susceptible to data errors. Mathematical regularization methods can be applied to decrease the sensitivity to random errors, but such methods are unable to address systematic errors, such as those associated with the removal of inelastic scattering via theoretical calculations. The latter problem has been approached by removing inelastic scattering in the experiment using new analyzer instrumentation consisting of a variable-curvature graphite analyzer crystal followed by a position-sensitive linear detector. Data analysis has illustrated the significant impact of removing inelastic scattering in this manner rather than relying on calculated values of Compton and resonant Raman inelastic contributions. It has been demonstrated that the AXS analyzer instrumentation plays a vital role in improving the quality of partial pair distribution functions collected from non-crystalline materials. The AXS analyzer formed an integral role in Dr. Ishii's thesis, which was completed during FY2002. She has taken a position in disc-drive media development.

The AXS analyzer has been applied to the study of the local structure in Zr-based bulk metallic glasses containing small (4%) amounts of Ta. These glasses are found to have significantly higher plastic strains to failure than similar alloys containing Ti, and electron microscopy indicates differences in structure on the nanometer length scale. Although it was not possible to observe an anomalous scattering effect at the Ta K-absorption edge with 4% Ta, a change in the local environment around the Zr atoms could be observed due to the presence of the Ta. The Zr differential distribution function (DDF) exhibited a more ordered set of shells with the addition of Ta. This work was performed in collaboration with Todd Hufnagel of Johns Hopkins University. The results were published in Physical Review B in January 2003.

Using the anomalous x-ray scattering (AXS) analyzer instrumentation, local structure of the phase separation endpoint in the sputter-deposited Mo-Ge amorphous alloys has been determined. This alloy is of particular interest because it acts as the conducting phase in a percolative metal-insulator transition but has a composition with no crystalline analogue. The local structure has been found to be unlike that in the nearby intermetallic crystals, and the phase separation is consistent with a solid solubility limit in the alloy. The chemically-specific distribution functions obtained using the AXS analyzer instrumentation have also been shown to have very low uncertainties. Since Dr. Ishii's graduation we have been preparing manuscripts both describing the research using the improved version of the diffracted beam analyzer and also a manuscript on the analyzer itself, which has been submitted for the SRI2003 conference.

Thin Film Structure – Perovskite ferroelectric materials such as $Pb(Zr_xTi_{1-x})O_3$ (PZT) are strong contenders for non-volatile memory applications. For them to be useful they need to have a high remnant polarization, which is controlled by the domain structure in the film. The domain structure, in turn, is controlled by the crystalline phases and orientation of those phases within the film. A set of PZT films of various thicknesses were measured to determine the crystalline phase. As the film thickness increases from 70 nm to 400 nm, the structure changes from rhombohedral to tetragonal. The films were studied using Grazing Incidence Asymmetric Bragg (GIAB) scattering. With this geometry the incident angle is set close to zero, such that the beam is parallel to the surface. The penetration depth of the beam can be as little as 3 nm for very flat surfaces. As the incident angle is increased, the penetration depth increases slowly out to near the critical angle for total external reflection. Above the critical angle the penetration depth is several hundred nm and increases rapidly as the angle increases. Thus the structure of the material can be "depth-profiled". This technique has been used to show that for the thicker films the tetragonal film overlays the rhombohedral film rather than transforming to tetragonal above some thickness. This work is being performed with Paul McIntyre of Stanford University and has resulted in a paper in the Journal of Materials Research (2003).

5. X-ray Physics

The anticipated arrival at SSRL of new x-ray sources with novel characteristics (SPPS in 2003, SPEAR3 in 2004, LCLS in 2008) will permit the study of new aspects of the interaction of x-rays with matter. Such studies will lead to the development of new analytical tools, as well as new techniques for characterizing and manipulating x-ray beams. This program will concentrate on the special characteristics of the new x-ray sources, in particular the very high brightness and the sub-picosecond pulse length.

The SPPS began operation in May 2003. It provides both a powerful tool for research in its own right, as well as a way to conduct critical accelerator and x-ray optics R&D for the LCLS. This running period was used for commissioning of the x-ray beamline, for assessment of the beam stability, and for investigation of the precision with which the x-ray pulse can be synchronized with an external pulsed optical laser. With a charge of 3.4 nC per bunch accelerated to 28 GeV and a 2.5 m long undulator SPPS generated pulses of x-rays 80 fsec long (full-width-half-maximum) with a peak brightness of the order of 10^{25} photons/(secxmm^{2}xmrad^{2}x0.1% band-width) and 10^7 photons per pulse in a 0.1% bandwidth. In addition, various techniques were used to study the ultrashort electron and x-ray pulses. The electron pulse length was measured through its electro-optical effect on a nearby dielectric material, which in turn shifts the polarization of an ultrafast laser pulse. The x-ray pulse length was studied through the phenomenon of non-thermal melting, in which an ultrafast laser pulse disrupts the atomic structure of a crystal surface and changes the x-ray Bragg reflectivity. Diffraction measurements on TTF-CA (and a several other crystalline materials) indicated that individual diffraction frames with reasonable intensity should be obtainable in the order of 30-50 pulses from an optimized SPPS

6. Bonding and Structure at Practical Semiconductor Interfaces

The sample preparation techniques for depositing metals onto silicon wafers surfaces from ultra-pure water (UPW) were perfected and a full set of XANES data was collected for various copper concentrations in UPW ranging form 1 ppb to 500 ppb. The data, obtained in our total reflection x-ray fluorescence (TXRF) facility, is being analyzed in order to develop a model for the deposition process both from an energetic and kinetic point of view. It was found that carefully timed sample preparation maintained the metallic character of the nanoparticles deposited from deoxygenated UPW and that the subsequent oxidation of these particles when they were exposed to air could be followed with the XANES measurements. Furthermore, the size of the deposited copper nano-particles could be precisely determined as a function of the copper concentration in UPW by measuring the fluorescence intensity as a function of the incidence angle of the primary x-rays and fitting this curve to theoretical model calculations. These results are consistent with Atomic Force Microscopy (AFM) measurements on the same samples.

In addition, because of the versatility of the TXRF technique as well as of the SSRL TXRF end-station, a number of collaborations were initiated with outside users on projects involving chemical state identification of trace element concentrations in a variety of materials. Of special interest is a collaboration with John Bradley of the Institute for Geophysics and Planetary Physics at Lawrence Livermore National Laboratory. He is studying interplanetary dust particles (IDPs) to better understand the origins of the solar system. IDPs are particles which existed before the coalescence of matter into the sun and planets that form the solar system. As such these particles, typically between 4.5 and 9 billion years old, are windows into the pre-solar environment and can be used to determine what sorts of super-novas were the origins of our solar system. The elemental ratios (e.g. Fe/Ni and Fe/S) within the IDPs are an important clue into the origins of the particles. Also, the oxidation state of the Fe, especially the ratio of metallic Fe to oxidized Fe (both Fe^{I} and Fe^{II}) are important for determining what happened to the particle during its capture in the earth's atmosphere.

7. Imaging with Coherent X-rays

We carried out the first experimental recording of the diffraction pattern from intact Escherichia coli bacteria using coherent x-rays with a wavelength of 2 Å. By employing the oversampling phasing method, a real space image at a resolution of 30 nm was directly reconstructed from the diffraction pattern. An R-factor used for characterizing the quality of the reconstruction was in the range of 5%, which demonstrated the reliability of the reconstruction process. The distribution of proteins inside the bacteria labeled with manganese oxide was identified and this distribution was confirmed by fluorescence microscopy images.

We also developed a new experimental approach to the direct determination of the absolute electron density of nanostructured and disordered materials. By calibrating the incident coherent x-ray flux and the diffraction pattern intensity and using the oversampling method, we directly determined the absolute electron density of a porous silica particle at ~ 9 nm resolution. This general approach can be used for the quantitative characterization of nano-crystals and non-crystalline materials at nanometer or better resolution.

We will continue to apply this imaging technique to determine the 2D and 3D structures of biological and materials science samples at a few nm resolution. The experiments will be carried out on the coherent x-ray beam lines at SPring-8 and the Advanced Photon Sources. The samples will be prepared in the laboratories of our collaborators. We will also improve our imaging reconstruction algorithm and develop a software package for the orientation determination of single molecules based on a series of the 2D diffraction patterns.

8. Small and Wide Angle Scattering Studies of Soft Matter

The SAXS program continues strongly in providing academia and industry with vital analysis tools to further research in nano-scale materials science. FY2002 saw seven full publications arising from materials science research performed on BL1-4. Two of these publications were directly concerned with investigating novel forms of elastomeric polypropylene (PP) where synthetic procedures carefully tailor the degree of crystallinity, and thus the elastomeric qualities of the bulk. Novel elastomeric properties have been observed in tailored fractions of PP and have been investigated using complementary techniques of wide-angle x-ray scattering (WAXS), SAXS, birefringence and scanning microscopy methods. These results are vital for industry: plants currently operating above the revealed optimum deformation rates are now enabled to save substantial electrical and environmental costs by reducing extrusion speed while retaining or improving the desired bulk rheological qualities in the finished product. The quality, profit and environmental implications of this procedure for industry are difficult to overemphasize.

A further publication characterized the structures of various polyelectrolyte block copolymer micelles in dilute aqueous solution as a function of pH and ionic strength. The chemistry of the copolymers provokes the formation of micelles with electrostatically neutral, weakly charged, and highly charged coronae, respectively depending on the pH of the solution. Increasing the ionic strength causes the micelle corona to shrink as the salt screens electrostatic repulsions within the corona. In various copolymers syntheses the ionic strength causes the micelle aggregation number to increase by screening the electrostatic repulsions between chains. Trends in the corona thickness with varying fractional charge and ionic strength were compared with a number of theoretical models providing additional insight into the micelle structure, and suggest these molecules as potentially very helpful in medical drug-delivery applications.

9. Molecular Environmental Science

Molecular Environmental Science (MES) research at SSRL focuses on the fundamental molecular- and nano-scale processes that control contaminant and nutrient behavior in aqueous systems, soils, and sediments, including sorption reactions at environmental interfaces, precipitation and dissolution processes that affect the potential bioavailability of heavy metal contaminants, and microbial processes that transform contaminant species into more (or less) bioavailable forms. The ultimate goal of this research is to develop deeper understanding of these processes, which lead directly to more sophisticated cost-effective remediation technologies. Synchrotron-based x-ray absorption spectroscopy (XAS), x-ray diffraction (XRD), x-ray scattering (XS), x-ray standing wave (XSW) spectroscopy, and photoemission spectroscopy (PES) techniques provide unique information on the chemical and physical forms of contaminants and nutrients in the environment.

Chemical and Microbial Interactions at Environmental Interfaces. Molecular interactions that occur at interfaces among solids, aqueous solutions, natural organic and plant matter, microorganisms, and atmospheric gases play a critical role in controlling the speciation, sorption, transport, and potential bioavailability of environmental pollutants; however, they are not well understood because of the complexity of these interfaces and the difficulty of studying interfacial reactions under in situ conditions. By using a reductionist approach in which carefully chosen model systems of increasing complexity are studied with molecular-level probes, synchrotron-based studies are currently being conducted in the following areas as part of projects funded by the Department of Energy (BES and EMSP), the Environmental Protection Agency, and NSF (Chemistry): (1) the geometric and electronic structures of the surfaces of environmentally relevant hydrated solids; (2) the structure of water at solid-aqueous solution interfaces and in the vicinity of non-polar hydrophobic organic molecules sorbed on solid surfaces; (3) the mode of interaction of aqueous metal-ion pollutants such as Cr, Sr, Hg, Pb, and U, and oxoanions such as NO_3-, SO_4^{2-}, PO_4^{3-}, AsO_4^{3-}, and SeO_3^{2-} with these surfaces and with organic ligands and microbial organisms; (4) the structure and bonding of the aqueous and surface complexes of these ions; (5) the rates and mechanisms of abiotic and biotic reaction pathways of redox-sensitive metal(loids) such as Mn, Co, As, Se, and U; (6) the interactions of organic molecules, such as humic substances, with environmental solids at the molecular level; (7) the effects of microbial biofilm coatings on solids on sorption and transformation reactions of heavy metal and organic pollutants; (8) the chemical speciation and transformation of heavy metals such as Zn, As, Hg, Pb, and U in contaminated soils and sediments; and (9) genomic-level interactions of microorganisms with mineral surfaces and inorganic and organic pollutants. Whenever possible, our model system studies are coupled with laboratory studies of contaminated environmental systems, which provide important constraints in choosing appropriate model systems for study.

Chemical Interactions of Small Molecules and Bacteria with Metal Sulfide Surfaces X-ray photoemission and absorption spectroscopy studies have been conducted to better understand the interaction of water, peroxide, aqueous Cr(VI), and Thiobacillus ferrooxidans with clean surfaces of FeS_2(100) (pyrite), which is the leading producer of acid mine drainage world-wide. This work on pyrite indicates that the surface chemistry of pyrite is more complex than reported in the literature. We have also carried out PES and Fe L-edge XAS studies of the interaction of peroxide with FeS_2(100), which revealed extensive oxidation of sulfur and iron and represents an end-member study of reactivity. Most recently, we have examined the effect of T. ferrooxidans on pyrite oxidation and have found out that relatively sparse populations (one bacterium/cm^2) can generate a sulfate-rich layer with little iron on the (100) surface. Such bacteria are known to increase the kinetics of pyrite oxidation enormously in nature, yet the mechanism by which they do this is not well understood.

Decarboxylation of Short-chained Carboxylic Acids on Pyrite (100) – C 1s, O 1s, and S 2p photoemission spectroscopy has been used to follow the decarboxylation reaction of acetic acid on pyrite (100). It has been found that each carbon atom in the adsorbed species interacts with the pyrite surface independently, resulting in a weakening of the C-C bond between methyl and carboxyl carbon atoms. Most recently, we have coupled synchrotron PES studies with FTIR spectroscopic and quantum chemical studies of the interaction of oxylate and other simple dicarboxylic acids with metal oxide surfaces. Several manuscripts describing this work are currently being prepared.

Molecular Investigation of Sulfate Complexation on Fe-oxide Surfaces –We found that sulfate forms primarily outer-sphere and H-bonded complexes on a-FeOOH (goethite) surfaces at pH > 3.0. Below this pH, significant inner-sphere complexation of sulfate occurs. Similar behavior was observed on ferrihydrite and hematite surfaces. A manuscript describing this work is in preparation.

Interactions of Metal Ions with Biofilm-coated Mineral Surfaces – A combination of x-ray standing wave measurements and grazing-incidence XAFS measurements has been used to study the interaction of Pb(II) and Se(IV,VI) with a-Al_2O_3 (0001) and (1-102) and a-Fe_2O_3 (0001) surfaces that are coated by a Berkholderia cepacia biofilm. At Pb(II) concentrations common in natural waters (10^{-6} M or less), the presence of a monolayer biofilm has essentially no effect on the normal reactivity of the metal oxide substrates with Pb(II), indicating that the biofilm does not block reactive surface sites and the functional groups of the biofilm do not compete effectively with surface sites for Pb(II). This finding is contrary to common assumptions about biofilm coatings on metal oxide surfaces. Se(VI) was found to be rapidly reduced to Se(0) on B. cepacia coated a-FeOOH surfaces when the bacteria were alive, but no such reduction was observed when the bacteria are dead. This finding has major implications for the bioavailability of Se in contaminated soils. Another major finding of this work is highly insoluble Pb-phosphate (pyromorphite) that are formed when Pb(II) interacts with B. cepacia.

XAFS Spectroscopy Studies of Zn- and Hg-contaminated Soils –The chemical speciation of Zn(II) in contaminated soils in northern France was studied. A major finding of this work is the first report of Zn-layered double hydroxides (LDH) in a complex environmental sample. In a separate project, we also have studied the chemical speciation of mercury in contaminated mine wastes and have found various forms of Hg, some of which are potentially more bioavailable than others. Colloidal HgS (cinnabar) was found to be the primary colloidal form of Hg in these wastes, which refutes earlier hypotheses that suggested that the main colloidal form of Hg(II) is as adsorbed species on nanoparticles of iron oxide.

XAFS, Micro-XAFS, and Micro-XRD Studies of Uranium in the Hanford Vadose Zone – We have made excellent progress in characterizing the major forms of uranium in the vadose zone beneath the Area 300 Tank Farm. Boltwoodite, a relatively insoluble sodium uranyl silicate, was found to be the major phase containing uranium in these sediments.

Uranium Attenuation and Biogeochemical Cycling of Manganese in the Environment – Three manuscripts were composed (in review and/or in press) describing (a) U(VI) attenuation in permeable reactive barriers and (b) by microbes (P. fluorescens) in the presence of iron oxides. A third manuscript (c) describes the structures of Mn oxides produced by the common Mn(II)-oxidizing bacterium, P. putida. Two additional manuscripts were composed (in submission) describing (d) the fundamental mechanisms and (e) the mineral products of Mn(II) oxidation by spores of the bacterium Bacillus. sp., strain SG-1. Experiments were completed in which the interactions of common anions (chloride, phosphate, nitrate, perchlorate) with U(VI) sorbed on Fe-oxide mineral surfaces were investigated. EXAFS experiments were completed in which the mechanisms of sequestration Co(II), Cu(II), and U(VI) in biogenic Mn oxides were characterized. A novel in situ transmission synchrotron XRD cell and experimental method were developed to allow x-ray scattering characterizations of poorly-crystalline biogenic Mn oxides under fully-hydrated, undisturbed conditions. Experiments were initiated in which this technique will be used to characterize a suite of biogenic Mn oxides.

10. Structural Studies of Inorganic and Biological Materials

XAS Studies as a Probe of Electronic Structure / Contribution to Function

Copper – Ligand K-edge and metal K- and L-edge x-ray absorption spectroscopy (XAS) methodologies have been combined to characterize the electronic structure of 4- and 5-coordinate model complexes with relevance to red and blue copper centers in metalloproteins. Sulfur K-edge measurements demonstrate a less covalent thiolate-Cu interaction in the 5-coordinate model (15% Sp) as compared to the 4-coordinate model (52% Sp). XAS at the Cu L-edge indicates that the Cu d character in the HOMO of the 5-coordinate model has increased relative to that of the 4-coordinate model. S K- and Cu-K edge and extended x-ray absorption fine structure (EXAFS) studies of the 5-coordinate red copper protein from Nitrosomonas europaea have been initiated and will be correlated with the studies of the model complexes. A Cu K-edge XAS study of a [(diketiminate)Cu]O_2 complex has been completed, and confirms that copper is in a +3 oxidation state at the unusual Cu^{III}-O_2^{2-} monomeric site. These results are supported by the Cu-ligand distances obtained from analysis of the associated EXAFS data. A parallel Cu L-edge XAS study also confirms the +3 oxidation state of the metal. Finally, a Cu K-edge XAS study of the unique 4-copper cluster of the nitrous oxide reductase Cu_Z site has been completed. It established that the fully reduced cluster, which has a total spin of S_{total}=1/2, is a $1Cu^{II}/3Cu^{I}$ oxidation state mixture.

Heme-Copper Oxidases – Cytochrome c oxidase (CcO) is the terminal enzyme in the respiratory chain that catalyzes the $4e^-$ reduction of O_2 to H_2O. In an attempt to understand its heme-copper oxidase system, model complexes containing peroxo- and oxo-bridged heme-copper units have been studied using metal K-edge and L-edge spectroscopies. Initial EXAFS analyses of data from both the Cu and Fe edges indicate the presence of a metal-metal vector in both complexes. Studies of the Fe K-edge pre-edge transitions, which reflect the electronic 1s? 3d excitations, indicate differences in the extent of axial interaction on going from the peroxo-bound to the oxo-bound complex.

Iron – Phenylalanine hydroxylase (PAH) initiates the detoxification of high levels of neurotoxic L-Phe-based metabolic products. Dysfunction of PAH can lead to phenylketonuria, PKU, a genetic disorder resulting in postnatal brain damage and severe, progressive mental retardation. Previous XAS work has shown the active site of wild type (WT) PAH to convert from six- to five-coordinate upon binding of co-substrates, where the ligand lost has been identified by EXAFS as a water ligand. XAS has now been used to investigate the structural changes upon binding of the co-substrates tetrahydrobiopterin and L-phenylalanine in two disease-causing PAH mutants which form a hydrogen bond pair near the co-substrate binding site. XAS pre-edge and EXAFS results show that, upon co-substrate binding, the R158Q mutant converts from a six- to five-coordinate form, similar to the case of WT PAH, while the E280K mutant contains a six-coordinate site with or without co-substrates. These studies provide molecular level understanding of disease states, which are leading to new mechanistic insights into catalysis.

XAS pre-edge studies of the active site of 2,3-dihydroxybiphenyl 1,2-dioxygenase (DHBD) with and without substrate, in conjunction with other spectroscopies, have been undertaken to investigate the effect of substrate binding on the active site geometric and electronic structure. The uncomplexed DHBD active site has been shown by pre-edge analysis to be a distorted square-pyramidal site attributed to a short equatorial Fe-Glu bond. Substrate binding effects a redistribution of the pre-edge intensity, indicative of a shift to a less distorted square-pyramidal site, consistent with the shift of the open-coordination-site to become trans to Glu. Consistent with other spectroscopy studies and with density functional theory (DFT), these studies show that the five-coordinate Fe^{II} site is thoroughly stable with respect to reaction with O_2 due to the relatively weak Fe^{II}-O_2 bond.

Bleomycin (BLM) is an anti-cancer drug commonly used to treat head and neck cancer, Hodgkin's disease, and testicular cancer. The Fe^{II}-bound active form of the drug is characterized by a somewhat distorted octahedral active site. While EXAFS analysis of has shown little geometric change in the iron active site upon binding of substrate DNA, XAS edge studies have shown a decrease in the intensity of the Fe K-edge pre-edge transition, indicating a decrease in distortion from octahedral geometry. These and other results combined provide new insights into the binding of the drug to DNA.

The initial development of an L-edge methodology to describe differences in covalency in non-heme iron model complexes has been completed. Fe L-edge spectra have been obtained and analyzed for a series of high- and low-spin, ferric and ferrous mononuclear iron complexes. It has been found that the normalized L-edge intensity is a quantitative method for determining average covalency. Using the TTXAS suite of computer codes, a method has been developed in which the ground state electronic structure is projected onto a hypothetical excited state allowing for direct calculation of the charge transfer pathways to individual d-orbitals. This differential orbital covalency (DOC) is important for the electronic description of complexes with charge transfer satellites, and is essential for the description of low-spin octahedral sigma-donor ferric systems, where the transition to the lone t_{2g} hole has a covalency significantly different than the e_g set of "d" orbitals.

Iron-Sulfur – Over the past several years, methodology has been developed to probe metal-ligand bond covalency by quantifying the XAS pre-edge intensity of a ligand K-edge transition. This method has been successfully used in the past to understand the electronic structure of mononuclear and multinuclear protein active sites and related model complexes of iron-sulfur electron transport proteins. Differences between the HiPIPs and ferredoxins, both Fe_4S_4 active sites, were described in FY2001. These studies have now been extended to several additional HiPIPs and ferredoxins from different organisms. The HiPIPs from different organisms are internally very similar in electronic structure, whereas the ferredoxins, which display less covalency than the HiPIPs, vary amongst themselves. In order to understand these effects further, the experimental results for these Fe_4S_4 clusters were correlated to DFT calculations. These show that electronic relaxation is very important in the reduction of a ferredoxin but not for the oxidation of HiPIPs. Point mutations made to alter the hydrogen bonding to the thiolate sulfurs in HiPIP was also studied and found not to have any significant effect on the covalency, although the redox potential changed. Similarly the covalency did not change significantly in different organic solvents of varying dielectric constants; again, however, the redox potential varied considerably. Thus dipole interactions change the redox potentials of these clusters without significantly altering the covalency of the ligands.

Sulfur K-edge XAS studies of model complexes and proteins having Fe_3S_4 cores were initiated. Initial results indicate the feasibility to identify spectroscopically markers for and obtain information on three chemically different sulfurs in these complexes: μ-2 and μ-3 coordinated sulfides and terminal thiolate ligands. The corresponding protein active site was found to be far less covalent and the decrease of covalency was correlated to extent of H-bonding to these sulfurs.

Nickel – XAS spectroscopic studies have been carried out for a well-defined redox series of nickel-dithiolenes ($[Ni(dmedt)_2]^Z$, where Z=-2, -1, 0), which provided the essential background to experimentally define and quantify bonding in non-innocent thiolate coordination for extension to the oxomolybdenum transferases. A new transition dipole integral has been developed for the dithiolene-S through correlation of XAS pre-edge energy positions of sulfide-, thiolate- and dithiolene-S. The experimental ground state wave functions of the nickel-dithiolene complexes have more than 50% S character demonstrating the non-innocent behavior of the dithiolene ligand. The S K-edge experimental results were correlated with spin-unrestricted, broken-symmetry density functional calculations. These show only limited spin polarization in the neutral complex, and delocalized, ligand-based ground states for the mono- and dianionic complexes. These combined XAS and DFT results were correlated with other spectroscopic features and provide insight into reactivity.

PES Studies of Electronic Structure Contribution to Function

Photoelectron spectroscopy (PES) and calibrated density functional methods have been used to evaluate the magnitude of core and valence electronic relaxation upon redox changes in the biologically relevant oxidation states of $[Fe(SPh)_4]^{2-/1-}$. These complexes serve as models for the electron transfer active site in the protein rubredoxin $[Fe(SCys)_4]^{2-/1-}$. The contributions of electronic relaxation to redox properties were evaluated with respect to their influence on the reduction potential (E°), inner sphere reorganization energy ?$_i$), and electron coupling matrix element (H_{AD}) for electron self exchange in rubredoxin. The results indicate that there is a dramatic transfer of electron density (~0.75 e^- for valence ionization) from the electron-rich ligands to the electron deficient metal center on oxidation via the low-energy ligand-to-metal charge transfer (LMCT) state. The redox process thus results in a loss of ligand electron density even though the redox active orbital is mostly Fe $3d_z2$ character. Additionally, the core PES studies reveal that there is little change in the Fe $2p_{3/2}$ ionization energy between the ferrous and ferric species, which suggests that the charge change on the metal is small. Electronic relaxation plays an instrumental role in charge redistribution and stabilization upon oxidation, which affects both the thermodynamics and kinetics of electron transfer.

From these studies it is concluded that electronic relaxation can lower the reduction potential of a high spin Fe site by ~0.5 eV, and greatly decreases the geometry change with redox leading to a >0.5 eV reduction in the reorganization energy. It also produces a reduction in the electronic coupling matrix element for covalent delocalization. Based on the last point the probability of protein-protein electron transfer over the surface of rubredoxin was also calculated.

Inorganics in Living Tissues

The high resolution beams available from tapered metal capillary microfocus optics in combination with chemical shifts in the near-edge portion of the XAS spectrum have been exploited to provide chemically specific images of tissues.

The first significant scientific use of new XAS imaging system included studies of the arsenic hyperaccumulating fern Pteris vittata, and iron deposits in the brain mushroom bodies of Drosophila melanogaster. This latter study included both wild-type and recombinant organisms containing human disease genes for Alzheimer's and Parkinson's diseases, as well as the classical Drosophila mutant known as fumble, which results in impaired coordination. Surprisingly, the recombinant flies exhibit many of the symptoms of the human diseases, and may provide a convenient animal model. Remarkable differences in localization of the iron and in the near-edge spectra of the iron deposits were observed between wild-type and mutant flies. Cellular resolution studies of developing zebrafish embryos were also carried out in which localization of iron between dividing cells was observed, together with transport of zinc within the developing embryo. Other studies in FY2003 included an investigation of the uptake and biochemistry in fish, and on the uptake and biotransformation of arsenic in both the sporphyte gametophyte generation of Pteris ferns, together with investigations of the morbitity of living samples following exposure to various doses of x-rays.

Theoretical Approaches to XAS Data Analysis

In order to enhance the usability of the DFT code StoBe an additional computer program was developed. This program, called CONVFIT, optimizes the convolution functions to match experimental spectra. Using CONVFIT it is planned to develop a basis set of convolution functions by optimization of the output of StoBe for a large number of sulfur compounds of known structure. This would allow a more rigorous approach to fitting the spectra of totally unknown species. The collaboration to develop and apply state-of-the-art ab-initio codes to determine and utilize multiple scattering in XAS continues. The refinement of the MS codes to interpret transitions near threshold (absorption edge and near-edge calculations) will also continue, together with systematic experimental studies on series of inorganics in order to test the method and its reliability. Results during FY2003 indicate that StoBe is superior in covalent systems, while FEFF can be used in systems that have a lot of ionic character (e.g. compounds of groups 1 and 2). The compute sever commissioned in FY2002, combined with the analysis tools MOL-OPT, and EXAFSPAK are currently being exploited to investigate the electronic structure of selected enzymes via simulation of the sulfur K near-edge spectra of the model compounds and the enzymes themselves.

11. Scientific and Educational Gateway Program

This continuing, joint effort with University of Texas at El Paso (UTEP) serves both the Mexican-American and Mexican communities in undergraduate and graduate education by engaging student scholars in science and engineering research programs at all levels. The excitement of the scientific opportunities presented by synchrotron-based research has been successfully used as a strong stimulus to attract and retain these students in science and engineering. The program provides travel support for Mexican-American and Mexican students and supporting faculty, technological support by an SSRL scientific staff member (Apurva Mehta), who also assisted participants in beam line operations and laboratory facilities, and a scientific staff member (George Meitzner) at UTEP, who developed and implemented computational tools and software for analysis of synchrotron data. These staff members train students in methods of data reduction and analysis, and jointly with SSRL staff scientists, develop collaboratory tools for remote access to instrumentation and data measured at SSRL. This program has been quite effective, as shown by the number of UTEP students participating in 2001-2003 (almost 40 in over 118 individual visits). These students and staff underwent training and carried out experiments on existing SSRL peer-reviewed proposals coordinated across five separate beam lines during the 2001-2002 runs. In addition, a proposal-writing course was introduced at UTEP (Pingitore) leading to 4 students receiving favorable ratings from the PRP and thus receiving their own beam time. SSRL staff worked closely with the UTEP faculty and staff to train and support the new students and their research efforts. In addition, during this period a new student was added (Myriam Perez) who is supported by the Gateway program and whose PhD research direction is shared by Dr. Bienenstock (SSRL) and Dr. Chianelli (UTEP).

These projects undertaken as part of this program made use of x-ray absorption spectroscopy (XANES and EXAFS, including carbon-edge soft x-ray technique and synchrotron x-ray diffraction (conventional and low angle).

The Chianelli group addressed structure/function relations in transition metal sulfide hydrodesulfurization (HDS) nanocatalysts in order to improve the performance of these important environmental catalysts. Carbon-edge NEXAFS demonstrated that transition metal environmental sulfides are characterized by carbided surfaces in their stable operating state. This revolutionizes our understanding of the operation of this class of catalysts and suggests improvements for the future. This understanding has permitted us to develop a novel class of amorphous and disordered catalysts whose structures are under investigation.

The Chianelli group studied the nature of the stable organic-inorganic pigment complex called Maya Blue, which is found throughout Meso-America and is renowned for its beauty and stability. Synchrotron XRD helped demonstrate new aspects of the structure of the complex materials. Understanding of this structure has led to a new class of environmentally friendly pigments that are now in pre-commercialization at UTEP. This group also has made progress in understanding the structure of petroleum asphaltenes that are components of heavy petroleum crude oils. The micellular structure of these materials has been confirmed by SAXS and WAXS studies. The results of this understanding is contributing to our ability to produce and refine petroleum as well as shedding light on the biological origins of petroleum hydrocarbons.

The Chianelli group initiated the study of the structure of $BaBi_4Ti_4O_{15}$ Aurivillius phases with the CIMAV group under the direction of Luis Fuentes. These materials are temperature-stable ferro-piezoelectrics of high current interest. Conventional x-ray diffraction studies have indicted that the structure is tetragonal. This is inconsistent with the physical properties of interest. High-resolution diffraction studies have now shown the structure to be orthorhombic in agreement with the ferro-piezoelectric properties. This clearly demonstrates the value of access to and user of the high-resolution synchrotron based diffractometer.

The Gardea group investigated the metal binding properties of a class of plants known as "hyperaccumulators". Information regarding the binding of metals in these plants can lead to implementation of a process known as phytoremediation for cleaning up toxic metals in the environment. XAFS studies of various plants demonstrated the feasibility of understanding metal binding in the "hyperaccumulators". In addition, the Gardea group studied the coordination of heavy metal ions to biomaterials. This investigation has great importance in the removal of toxic metals from contaminated sites and also in understanding the fate and transport of toxic contaminants in the environment. This investigation produced many publications in the best international journals in the environmental field.

The Gardea group studied the ability of plants to produce interesting nanoparticles. XAS demonstrates that alfalfa can take up and transport Au-bearing solutions through its roots and form Au(0) nanoparticles in its stems. Because of their conductivity and corrosion resistance, such gold nanoparticles may have important electronic applications. TEM images show that the Au nanoparticles possess specific, consistent morphologies.

With Dr. Gregory Lush, the Chianelli group has studied the properties of flat panel display devices made of thin layers of Ce doped SrS using WAXS techniques. A study has been initiated to identify any correlation between the performance of these devices and some factor identified by x-ray diffraction measured at the synchrotron. Because these are thin layer devices this has not been feasible using in-house x-ray diffractometers.

The Pingitore group studied trace elements in human bone. The incorporation of Sr, Zn, Pb, etc. in human bone is a topic that impacts archaeology, nuclear waste/terrorism, biomedicine, and environmental pollution. XAFS experiments demonstrated the feasibility of studying the replacement of Ca in bone with the elements of interest.

Research Training – Prof. N. Pingitore organized UTEP's first synchrotron radiation course, which was taken by five doctoral students who have and are continuing to perform experiments at SSRL through the Gateway Program. In addition to their experiments, writing and submitting competitive SSRL beam-time proposals was a major course thrust. The proposal writing was successful and four student projects received beam time through the normal, peer-reviewed, competitive process, demonstrating success with a crucial part of becoming independent synchrotron researchers.

As part of the Gateway Program, all students receive training in the use of CERIUS^2 (ACCELRYS Corp) modeling and simulation software. This software performs simulations and modeling of synchrotron data and explores the connection of this data to other properties of solids and molecules. For example, in the "Maya Blue" project synchrotron data defines the structure of the pigments and CERIUS^2 not only simulates the synchrotron diffraction data but also simulates optical and infrared spectra, further elucidating the solid-state properties of the pigments.

12. Nano-scaled Ordering in Complex Oxides: Model Systems for Local Probes

It is the goal of this program both to develop model systems for studying nanoscale phenomena in highly correlated materials, and to prepare these materials in forms that lend themselves usefully to real- and k-space probes ideally suited for studying their physical properties.

DOE funding for this research program began in September 2001. During FY2002, we focused on establishing viable synthesis routes for several of the materials of interest. Progress in each of these areas is summarized below.

Heavy Ions and Negative-U Interactions

During FY2003, we have begun to produce PbTe crystals with varying amounts of Tl-dopant. We are now in the process of carefully characterizing structural, compositional, thermodynamic and electronic properties of these materials, with the ultimate goal of systematically relating their observed electronic properties to carrier concentration and the Tl-content.

The first exciting result to emerge from this work is an observation of a Kondo-like anomaly in the resistivity of crystals with a small Tl content (i.e. significantly less than 1%). The anomaly does not seem to be correlated with a significant Curie behavior in the susceptibility, but we do observe a small negative magnetoresistance. We are currently working to better understand this effect and how it evolves into superconductivity at larger Tl concentrations. From a theoretical viewpoint, we note that the Kondo effect has its origin in the existence of two degenerate states. These might be spin-up and spin-down for a magnetic impurity. In the case of Tl-doped PbTe a magnetic impurity seems rather unlikely, since the negative-U effect favors paired electrons, but we must carefully establish this through further experimental work. There is, however, a rather exciting alternative scenario. The ions Tl^{+} and Tl^{3+} are believed to have the same energy in this material, and as such the two degenerate states that give rise to the observed Kondo-like behavior might arise from two-electron states: |0> and |??>. At low temperatures, the pair fluctuations would be quenched by a corresponding “pairing cloud” of conduction electrons, which could give rise to the upturn in the resistivity. At higher concentrations, impurity-impurity interactions might lead to an ordered state, probably superconductivity. This work has attracted theoretical interest, and we are currently designing experiments to test our hypotheses.

The second exciting set of experiments is taking place at SSRL. In collaboration with F. Bridges (UCSC), we are attempting to measure EXAFS spectra for Tl-doped PbTe to determine whether there are two distinct Tl-Te distances on the time scale of the x-ray probe ($\sim 10^{-15}$ s). The first experiments show clear fine structure beyond the Tl-edge, and we are currently analyzing these data.

During the remainder of FY2003 we will continue to work towards a systematic set of thermodynamic and transport measurements for a range of well-characterized Tl-doped samples, covering the doping range that extends from the Kondo effect to superconductivity. We are installing a He-3 cryostat and will soon be able to measure transport properties to 0.3 K in fields up to 9 T.

Charge Segregation in CuO with the Rock Salt Structure

CuO is a Mott insulator that normally forms with a monoclinic crystal structure. The goal of this work is to synthesize this material as a model system in a cubic rock-salt structure using epitaxial growth, and then study its electronic transport properties as a function of doping using k- and r-space probes. Contrasts with the cuprate superconductors are of obvious interest. Evidence for nano-scale charge stripes has already been reported for this material, which heightens our interest.

Last year we reported our study of the synthesis of CuO using in situ XPS. This work clarified some of the problems in synthesizing this material at low temperatures. This year we have focused on the installation and modification of our MBE-grade molecular beam synthesis system (MBS) in the Geballe Laboratory for Advanced Materials. It had previously been in another building. The modifications underway are substantial. Using an equipment grant from the NSF, we are extending the capabilities of this system to include pulsed laser deposition as well as electron beam evaporation. The system is also equipped with RHEED, XPS and an atomic oxygen beam.

Electronic Transport in Bad Metals

$SrRuO_3$ is unusual in that it is a rare example of a 4d itinerant ferromagnet. As we have documented in earlier work, it is also what is commonly referred to as a bad metal, in that its resistivity increases with increasing temperature beyond the Ioffe-Regal limit, and its optical conductivity shows distinctly non-Drude behavior. Both of these properties are reminiscent of those seen in the cuprate superconductors.

Recent theoretical calculations based on dynamical mean field theory as applied to highly correlated systems predict qualitatively the observed dc and optical properties. Quantitative tests are lacking, however. According to these theories, there should also be an associated suppression of the electronic density of states at the Fermi level. Other recent theoretical calculations predict that the superconducting proximity effect with a half-metallic ferromagnet (or even a highly spin-polarized metal) should lead to a triplet superconducting state in the ferromagnet, if it has a sufficiently long electronic mean field path. One long- term goal of this program is to test these striking theoretical predictions.

In collaboration with Andy Mackenzie, we have measured the spin polarization of $SrRuO_3$ using Andreev reflections at a $Nb/SrRuO_3$ interface. The data suggest a substantial spin polarization. As we have demonstrated in the past, the electron mean free path can be very long at low temperatures in this material. These works demonstrate that $SrRuO_3$ is an excellent candidate for the proximity induced triplet superconductivity mentioned above. During this year, in collaboration with Lior Klein, we also studied the angular dependence of the domain wall resistivity in $SrRuO_3$. Because of the exceptionally large domain wall resistance in this material, it is proving to be a very good model system for the study of spin-dependent scattering at planar interfaces – an issue central to understanding of spintronic devices.

Advanced Superconductors

Understanding the properties of the cuprates with the highest values of T_c is one of the major goals in the field of correlated electron systems. Very recently, we have made a major breakthrough in the growth of the single-layer (n = 1) material, $HgBa_2CuO_{4+d}$ (Hg1201), which is structurally the simplest of all the high-T_c cuprates. With optimized values T_c as high as 98 K, this material has been known to exhibit the highest superconducting transition temperature of all known single-layer cuprates. Our crystals have a volume of about 10 mm^3 each, which to the best of our knowledge exceeds that of samples grown by other groups by nearly two orders of magnitude. The superconducting properties of these crystals were refined through a heat treatment in an oxygen atmosphere. A subsequent measurement of the magnetic susceptibility yielded an onset T_c of 97 K and a sharp transition. Neutron diffraction confirmed the single-grain nature of our samples. These exciting developments have been very recent, and we expect to be able to further refine the growth conditions to obtain crystals of even larger volume. This will enable the first detailed scattering, ARPES, and STM experiments of this model superconductor.

We are extending our measurements relating structural perfection to physical properties of Bi2212. We are furthermore continuing the refinement of conditions for the growth of large single crystals of the double-layer bismuth-based superconductor in the largely unexplored highly-underdoped regime.

Field-effect Doping of Correlated Electron Materials

We anticipate that by applying a large electric field to strongly correlated systems that are close to an electronic instability, such as superconductivity or a metal-insulator transition, we will be able to continuously tune through the transition and hence gain a much deeper understanding of the complex electronic behavior in these materials. The research is of interest from both a fundamental viewpoint and also in terms of potential technological applications. Our initial research efforts seek to demonstrate that it is indeed possible to modulate the charge density in correlated electron materials by the required amount to produce an observable effect.

During FY2003 we have continued to develop suitable deposition techniques for gate dielectrics, and to characterize their performance. We are currently focusing on ZrO_2, and have achieved breakdown fields of up to 12 MV/cm for 4 nm films, with relative dielectric constants around 20. Our experiments are moving towards measurement of time-to-breakdown and establishing the temperature dependence of this property. Since many processes that lead to trap generation and eventually breakdown are activated, we anticipate that these films will have superior performance at cryogenic temperatures. These measurements not only enable our application, but also lead to a much clearer understanding of the processes that lead to breakdown in this material.

As the project progresses, we are moving towards the first experimental tests of our ideas for field-effect doping of correlated materials, and have identified two approaches for modulating the carrier concentrations. The techniques are topologically equivalent, but are significantly different in terms of materials processing. The first approach is to deposit ZrO_2 films directly on to MoS_2 crystals. Possible reactions at the interface will be determined by relative thermodynamic stability and also kinetics, and it is difficult to predict in advance whether the interface will be stable. If this proves a problem, we may employ a thin pacifying layer, such as Al_2O_3, as a buffer. The second approach is slightly simpler in terms of materials processing. We shall deposit InO_x films through a shadow mask on top of our Si / ZrO_2 films. This process reduces concerns over reactive Zr species, and uses established in-house technology. Although conceptually simple, these two approaches will require a great deal of development for our application, and we are currently working towards this end.

13. Nano-scaled Magnetism in the Vortex State of High-T_c Cuprates

This work explores fundamental physical processes which give rise to novel collective phenomena and self-assembled nano-structures resulting from high magnetic fields or complex synthesis processes. A proper understanding of them requires new experimental tools and radically different theoretical concepts. This project will combine material synthesis, neutron scattering and theory to investigate the antiferromagnetic vortex state of the high-transition temperature superconductors.

We reported the first observation of magnetic field induced antiferromagnetic (AF) scattering in the electron doped material $Nd_{1.85}Ce_{0.15}CuO_4$ in a paper entitled "Magnetic order and superconductivity in electron doped $Nd_{1.85}Ce_{0.15}CuO_4$" (accepted for publication in Nature). A particular advantage of the NCCO compound is its low Hc2, the upper critical field where superconductivity is completely destroyed. In the NCCO material, it is about 7 T, while the Hc2 for most of hole doped materials is above 60 T. Dai's group performed extensive neutron scattering experiments on this material, and found that the field induced AF moment increases linearly with the applied field, saturates near Hc2, and decreases as the field is further increased from Hc2 to about 14 T. The low field behavior agrees well with the theoretical predictions made by ourselves and our collaborators. Currently, our focus is on actively working towards the theoretical understanding for high fields. Our preliminary results indicate that the decrease of the AF moment with increasing field can be understood by its Zeeman coupling to the applied field, and would if confirmed represent a major breakthrough in the field.

This project is progressing extremely well, with the theoretical efforts strongly coupled to experimental work performed by collaborators at Oak Ridge National Laboratory.

14. Nonscale Electronic Self-Organization in Complex Oxides

Manoharan's group has made significant progress this year across several of the target areas of this research effort. The focus has been in the area of high-resolution scanning tunneling microscopy (STM), and the development of unique operating modes of STM for performing exquisitely sensitive local magnetic measurements. These results have been predicated on the technology of controlled atomic and molecular manipulation. The design and prototype testing of a state-of-the-art UHV STM system that performs at low temperature (down to 500 mK) and in the presence of a magnetic field on the order of 10 T has been completed. This effort was performed with funding external to this DOE grant, but has a direct scientific impact on the goals of this project. In particular, several design issues were specifically resolved in order to address the challenges of complex oxide materials and other novel superconductors.

The system comprises four main UHV sections. Three of these sections are UHV chambers that sit at room temperature and are supported above a double optical table setup for vibration isolation. A fourth UHV chamber sits at low temperature and is suspended inside the dewar via additional vibration isolation stages, while its vacuum section is connected via a gate valve to the rest of the system. The environment also enables the controlled introduction of other materials onto the sample surface, down to a light sprinkling of a just a few atoms or molecules over areas ~ 1000 Å x 1000 Å. In order to maintain ultra-low vibration levels at the STM stage while still cooling below 4 K, we designed and built a separate prototype cooling system based on the Joule-Thomson effect using Helium-3 gas. This system has demonstrated Helium-3 liquid base temperatures of 300 mK, enabling STM base temperatures of 500 mK, without the need for external pumps after an initial condensation cycle. The high field to temperature (B/T) ratio that this system achieves is critical for the magnetic detection work.

Kapitulnik continued the program for the study of ordered and disordered electronic structures on the surface of strongly correlated materials, and in particular high-T_c superconductors. Recently, STM studies in several laboratories revealed two new features on the surface of $Bi_2Sr_2CaCu_2O_{8+d}$. Both features were previously found in other high-T_c systems, mostly of lower transition temperatures. The first has been the discovery of inhomogeneities in the superconducting gap. The second feature has been the discovery of spin and charge density of states modulations in the cuprates. Here, theoretical and experimental evidence has been mounting in support of the possibility that their ground state exhibits spin and charge density waves (SDW and CDW), which are primarily one-dimensional (i.e., stripes) and which either compete with or promote superconductivity. Coexistence of CDW or SDW and superconductivity has previously been reported in the lower T_c materials and in the presence of large magnetic fields.

While the LDOS as a function of energy (i.e. bias voltage) may not show much structure, especially when taken at high energies, the corresponding Fourier transform can show more structure as it separates the various length scales in the different directions. Indeed we were the first to report [Howald et al. cond-mat/0201546 (2001)] that Fourier peaks at reciprocal space positions corresponding to four lattice constants. However, this interpretation is currently a subject of debate. To further establish our findings we introduced a thorough study of the peak at the quarter k-distance, introducing novel techniques that are able to distinguish non-dispersing collective effects from dispersing effects such as quasiparticle scattering interference. This analysis yields features that cannot be explained by alternative interpretation of the data in terms of quasiparticle interference.

The Shen group is working on optimally doped Bi2212 samples using the much better angular and energy resolution available recently. In particular, he measured the angular dependence of the superconducting gap with much higher precision and at much more angles than previous possible. This allows a much more precise determination of the anisotropic gap form, a result likely of significant value to better understand the nature of the pairing state as well as the recent STM data. In addition to cuprate superconductors, Shen has also performed detailed ARPES investigation of monolayer C_{60} films, a perfect model system for ARPES investigation examining the interplay between electron-electron interaction, electronic conduction and the electron-phonon interaction on the buckyballs of nanometer scale. For the first time, they have observed band dispersion as well as Fermi surfaces of k doped C_{60} monolayer single crystals [Yang et al., Science, in press]. This result provides a direct measure of the band width, and revealed the intricate interplay between the band width and electron-phonon interaction in a system where these two energy scales are almost equal.

The Moler group has performed the following studies: 1) we have measured the local mesoscopic magnetic noise in the very underdoped YBCO superconductors with unprecedented accuracy in search of vortex-like excitations that have been reported to exist in the normal state. Our search failed to turn up any novel magnetic phenomena. 2) We have imaged single trapped magnetic flux quanta in very underdoped YBCO. These images strongly suggest that the well-known Uemura plot is violated by an order of magnitude. 3) We have formed a collaboration with the Fisher group (funded under a sister grant) to study magnetic superconductors, which should exhibit a striking variety of nanomagnetic phenomena. 4) To facilitate these studies, we have fabricated Hall probes as small as 130 nanometers, and have demonstrated sub-milli-flux-quantum magnetic resolution in 130 nanometer Hall probe. The figures of merit for our current best Hall probes surpass those of any in the literature of which we are aware.

15. Nano-Magnetism

We have made significant progress in our studies of magnetic switching of nanoscale structures by injection of a spin polarized current. This is one of the forefront areas in magnetism research. In particular, the work explores novel opportunities to manipulate the magnetization on the nanometer length scale and picosecond time scale, based on utilization of the strong, short range quantum mechanical exchange interaction. It involves sample preparation, sample characterization, and direct imaging of the time dependent magnetization by photoemission electron microscopy (PEEM) measurements. Magnetic images are recorded by pump-probe techniques using magnetic excitations triggered by picosecond spin current pulses produced by an optical switch and 50 ps x-ray probe pulses from the Advanced Light Source in Berkeley.

The spin injection structure consists of patterned Co and Fe layers separated by a Cu layer. The required current density is generated by creating a small hole of less than 100 nm diameter into a SiO_x insulator, that is then filled to form a current channel for spin injection. A laser triggered optical Auston switch launches a picosecond current pulse that traverses the hole and becomes spin polarized in the Co layer. Its magnetization direction sets the spin polarization direction of the current. After traversing the Cu layer, which serves to decouple the Co and Fe magnetic layers, the spin polarized current is injected into the Fe layer which has a different magnetization direction than the Co layer. Its switching is observed either by PEEM from the top or in transmission by scanning transmission x-ray microscopy (STXM). The time resolution is limited by the width of the x-ray pulse created by the storage ring, which in principle, may be as short as about 30 ps.

16. SCIENCE EDUCATION by Helen Quinn

Pre-College Education

The major pre-college outreach program at SLAC this year was the Quarknet workshop which bought twenty high school teachers to SLAC for eleven days of lectures, tours and activities during the summer of 2003. The four 2002 quarknet teachers participated as leaders in this program, which was a jointly led by Stanford Physics Department and SLAC scientists. The teachers built a number of cosmic ray detectors which, after some further testing, are now beginning to be loaned out to their schools for classroom use.

SLAC continues to support local schools through its surplus equipment donation program and through tours for students in physics or physical science classes. In addition, SLAC staff volunteer to assist local schools in a number of ways, including invited presentations, judging at Science Fairs, answering e-mail science questions etc.

This year a group of SLAC staff assisted the robotics team from a local high school to develop their project, and the team used space and equipment at SLAC (after hours) to build and train their robots. The Young Physicists Program at SLAC also began an outreach effort in which four local high school students were offered the opportunity to engage in a research project mentored by YPP members.

Undergraduate Students

In summer 2003 25 undergraduate students from all around the country students undertook summer research internships at SLAC, under DOE's Science Undergraduate Laboratory Internships program each year. These students are housed on Stanford campus and carry out individual projects under mentors who are scientists working at SLAC. In addition a number of user groups bring undergraduate students to SLAC each summer, while a few more students are hired directly to work on specific tasks, such as programming. The communications office continued its program to bring science writing student interns to SLAC, and will continue to seek one or two such interns in each semester.

Postdoctoral and Graduate Students

SLAC continues to be the host for the research of large numbers of graduate students every year. These students either work with SLAC faculty, or with faculty from other institutions who carry out research at SLAC as users of the facility, either in the high-energy physics (HEP) program or within the SSRL laboratory. Students working at SSRL come from a broad range of disciplines including physics, chemistry and the biosciences. Many non-US students also come to SLAC with faculty from their home institutions who are members of the BaBar collaboration.

Likewise at the postdoctoral level SLAC remains a major training ground with young scientists either working as SLAC employees or coming here as members of user teams. This training plays an important role as can be seen by looking around the world and noting how many leaders in the field spent time at SLAC in their student or postdoctoral years.

Science Education at SSRL

Training courses at SSRL play an important role in teaching working scientists as well as graduate students from diverse disciplines how the tool of intense x-ray beams can be used to extend knowledge within their realm of interest. The now annual joint Stanford-Berkeley Summer School on Synchrotron Radiation was in its third year and held at the University of California, Berkeley, Clark Kerr campus. The Stanford-Berkeley Summer Schools are jointly organized by Stanford University, University of California at Berkeley, Lawrence Berkeley National Laboratory, and the Stanford Synchrotron Radiation Laboratory. The Summer School series provides lecture programs on synchrotron radiation and its broad range of scientific applications with a concentration in 2003 on the Physical Sciences. The goal of the school is to disseminate information about scientific opportunities in synchrotron radiation applications and train students on experimental techniques. It provides an interdisciplinary and intellectually stimulating environment for new and experienced researchers. Interaction between lecturers and students is accomplished through dedicated problem solving sessions and round table discussions.

The third annual Structural Molecular Biology Summer School was held at SSRL during September 16-19, 2003. The School focused on three synchrotron-based techniques: small angle x-ray scattering, x-ray absorption spectroscopy, and macromolecular crystallography, and the application of these techniques to biological problems. This year's Summer School was attended by 19 students (representing 6 U.S. states, Canada, and the U.K.) and was led by a team of 15 tutors. It consisted of two days of lectures, followed by a day and a half of practical sessions on a rotating schedule.

In addition, in conjunction with the 29th SSRL Annual Users' Meeting in October 2002, four workshops covering a broad range of applications of synchrotron radiation were held. On the Tuesday afternoon and Wednesday following the meeting, the four workshops titled "Experimental Opportunities with LCLS", "Opportunities in Catalysis Research Using Synchrotron Radiation", "X-ray Absorption Near-Edge Spectra in Analysis of Mixtures", and "X-ray Imaging and Spectro-microscopy: the Present and the Future" engaged about 120 participants.

17. FY03 PROGRESS ON SCIENTIFIC AND TECHNICAL INFORMATION MANAGEMENT by Pat Kreitz

Announcement records for all appropriate STI products were submitted in electronic form to DOE's Office of Scientific and Technical Information (OSTI). This year again shows an increase in STI products reported, for a total of 1075 announcements. The increase is due to several factors, including better reporting tools for identifying *leaked* papers; a concentrated ten-year leak clean-up effort; and better communication with authors.

All appropriate SLAC STI was made widely available on SLAC's publicly-accessible Web server, on average, within 72 hours of release by the Technology Transfer/Patent Review Office. Weekly and monthly lists of SLAC publications are provided as links from the top-level SLAC home page and via an email alert service.

In FY02, we started reporting preprints, preprint leaks, and reprints as defined below:

Preprint	Original manuscript submitted to SLAC for publication. When we publish preprints, we assign a preprint number and send an electronic report announcement to OSTI along with a link to the electronic version.
Preprint leak	Manuscript submitted to SLAC after publication elsewhere, but the original manuscript is available to SLAC. We assign a preprint number and report it to OSTI along with a link to our electronic version.
Reprint	Manuscript first published elsewhere—typically a journal—and the original manuscript is not available to SLAC. SSRL makes up the bulk of reprints. As required by the ethics of their scientific collaborations, SSRL scientists and users publish their papers in scientific journals before releasing them for SLAC publication. When we publish reprints, we assign a reprint number and report it to OSTI, but we do not provide a link to the text from the SLAC publications server. When the SPIRES-HEP literature database record for the paper has a link to the journal article, we link through that to the journal's version.

In FY02, SLAC began submitting reprint announcements, for both SLAC-HEP and SSRL papers reported by fiscal year. In order to provide additional time for the papers to be published in journals and then subsequently processed by SLAC, we changed the reporting period from fiscal year to calendar year, (see Table 2 below).

OSTI Preprint Announcements	FY00	FY01	FY02	FY03
Preprints	313	260	305	299
Preprint Leaks	19	69	207	435
Total submitted to OSTI	332	329	512	734
Leaks as percentage of total:	6%	21%	40%	59%*

**FY03 leaks reported increased significantly due to a major leak clean-up by Technical Publications and Library staff to identify and process all leaked publications back to 1993. The FY03 number covers 1993 – 2003 publication dates.*

OSTI Reprint Announcements	CY01	CY02
SSRL Reprints	328	296
SLAC-HEP Reprints	63	45
Total submitted to OSTI	391	341

Last year, we reported reprints by fiscal year. We have now changed to reporting the prior calendar year, as reflected above, and so have included calendar totals for 2001.

SLAC legacy document conversion project complete

This project is now complete, with all appropriate SLAC publication series dating back to 1962 available on the Web in full-text electronic format. Bibliographic data for each record is also included in the SPIRES-HEP literature database which provides links to alternate versions, such as on a journal's server. This conversion project, coupled with the ongoing publication of documents and reports, brings the total number of electronic preprints available on the SLAC Publications Web server to 11,076.

Technical Publications is also exploring a small number of more obscure legacy document series with appropriate groups to determine if we will publish them on the Web and process them as DOE-reportable STI.

Increased requests for electronic publishing

This year Technical Publications saw an increase in requests for electronic publishing. Six reports were published to CD and one to DVD in FY03, in contrast to only one report published on CD in FY02.

We also saw an increase in the number of conference proceedings published to eConf, our electronic conference repository for all SLAC conference proceedings. Upon request, we also publish proceedings for anyone interested in having their scientific proceedings permanently available. In FY03 we published 12 proceedings, six from SLAC and six from other institutions, with six additional submissions forthcoming. Last year we published four new proceedings to eConf, two of which were from SLAC.

Paperless archiving of STI

This year Technical Publications and the Archives Office worked together to develop a process for archiving STI that eliminates paper copies. Technical Publications will no longer print and maintain hardcopies of published papers and will instead provide electronic CD versions each month to the SLAC Archives Office. This process reduces costs associated with copying and maintaining hardcopies, and eliminates rescanning by the Archives Office.

Reduced printing costs

Technical Publications has been able to reduce GPO printing costs for standard SLAC-R documents by an average of $1000 per print job. This was achieved by reducing standard print quantities from 100 to 50, and whenever possible using DocuTech printing instead of offset. Since 1998, SLAC GPO printing costs have been reduced 86% (1998 budget was $350,000 and it is now $50,000).

Implement OSTI Harvesting System

In 2004, we plan to implement OSTI's new system for "harvesting" announcement records. Our system must be reprogrammed to comply with OSTI's XML database template. STI announcement records will then be automatically retrieved by OSTI on a regular basis and we hope to gain some labor savings. When this new system is implemented, we assume that we will no longer report numbers of announcement records since the harvesting system should capture these statistics. In fact, we will ask OSTI to share them annually with us.

Extend Leak Outreach

To improve author awareness and compliance with document registration policies and procedures, and thus reduce the occurrences of leaked papers, Technical Publications is developing new ways to communicate with authors. Following are some of the ways we plan to implement this program in FY04:

Pubs Week	Goal: increase author awareness of SLAC publishing policies and provide useful information to help authors prepare papers and use the registration and paper submission tools (idoc).	Semi annually, write an article in the SLAC newsletter describing SLAC's publishing policies, author responsibilities, and standard publishing processes; site-wide posters; distribute 'mock' business cards containing useful links and contact information; and hold a drawing for prizes for authors using the paper registration site (idoc) during Pubs Week.
Emails to graduate students	Goal: increase graduate and undergraduate student awareness of SLAC publishing policies.	Quarterly, new graduate students and their advisors will be sent an email reminder containing useful links and contact information. Undergraduate students will be contacted annually. The first email reminders were sent in July 2003.
Admin forum	Goal: increase administrative support awareness of the scientific paper publishing process at SLAC.	Semi-annually, at meetings attended by secretaries and administrative assistants, present overview, handouts, and answer questions about the publishing process at SLAC.