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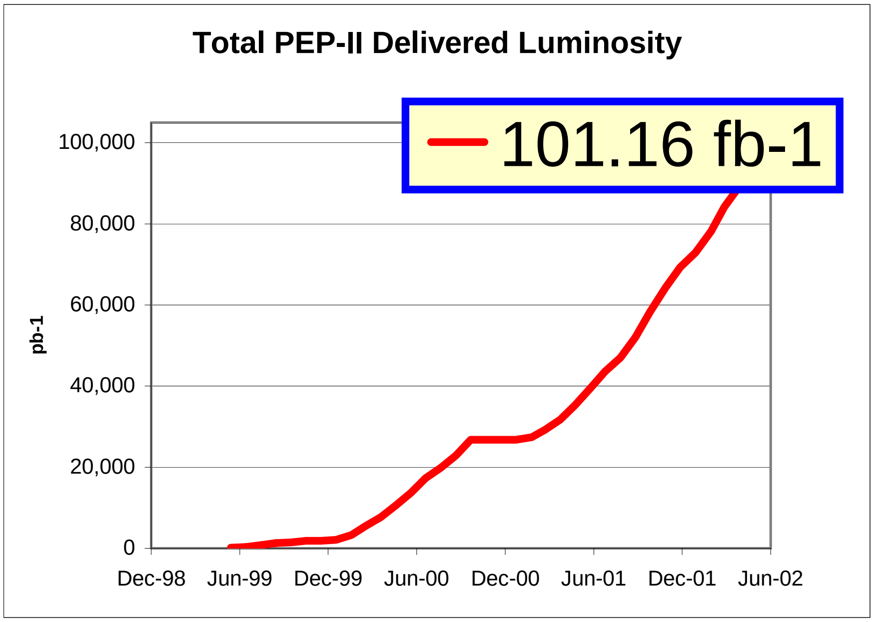
1. FY2002 Progress for PEP-II B-Factory Program

The year FY2002 has been a very good year for PEP-II in terms of luminosity and integrated luminosity. The peak luminosity reached $4.602x10^{33}/cm^2/s$, which is over 1.5 times the design. Furthermore, PEP-II has now delivered a total of 101 pb^{-1} of data to BaBar on the Upsilon 4S resonance. This data sample is the largest high energy physics data sample ever produced. This data sample has allowed BaBar to conclusively demonstrate CP violation in the B-meson system.

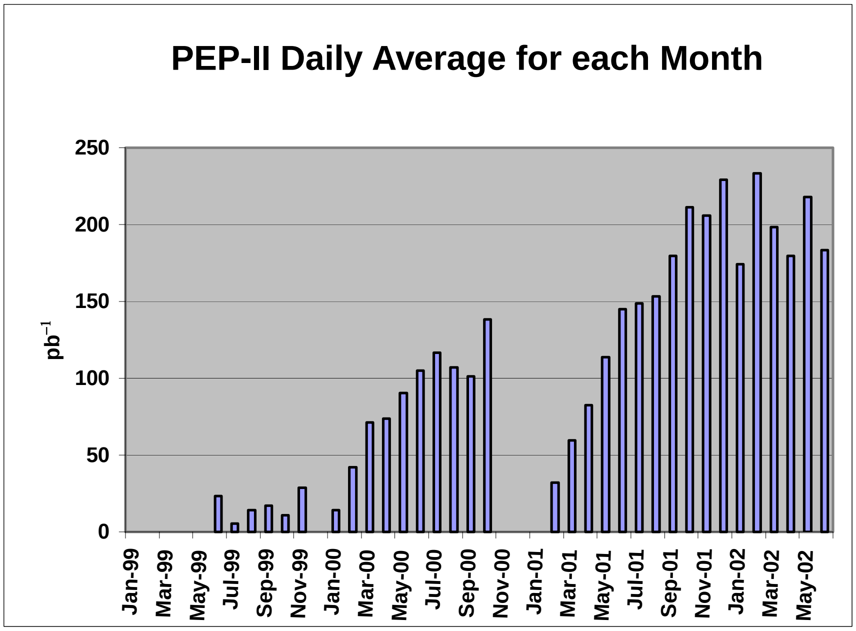
PEP-II operated for colliding beams for nine months this year with a short break over the end-of-year holidays. The accelerator was turned off for maintenance and upgrades on July 1st. The luminosity started at 4.214x $10^{33}/cm^2/s$ on October 1, 2002, and steadily grew to 4.602x $10^{33}/cm^2/s$ in March of 2003. The luminosity from April through June was essentially constant as the beam currents were limited because of excess heating of the vacuum chamber bellows adjacent to the beryllium chamber at the interaction point inside BaBar. The four-month down from July into November was needed to upgrade the Forward IFR in BaBar, install two new RF stations in PEP-II and to add cooling to these over heated bellows near the interaction point.

During the year, accelerator physics studies have concentrated on raising the beam currents, reducing the temperature of the Be chamber bellows, and lowering the beta*s. Lowering the temperature has involved adjusting the longitudinal waist position of the positron beam while adjusting the RF phase of the electron beam. This action has given the chamber temperature a headroom of about 10% to the trip point. Thus, the currents were raised by about 10%. The HER and LER beam orbits, after slow degradation over the previous months, were re-steered and significantly improved. The dispersion and coupling were corrected. Both the vertical and horizontal beta*s were lowered about 5 to 10% giving a measured higher luminosity. 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 but the performance in collision is not yet sufficient to try the new tunes during BaBar delivery shifts. 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 a little data with trickle charging but more work needs to be done before full time use is tried. In the future, the luminosity increases will come from reducing beta*s still further, from the higher beam currents with the new RF stations, and from moving the tunes towards the half integer which reduces the effects of the beam-beam interaction.

As of July 1, 2002, corresponding to the start of the down time, here are the present PEP-II delivery records. The peak luminosity is $4.602x10^{33}/cm^2/s$ in 800 bunches with 1775 mA of positrons (LER) and 1050 mA of electrons (HER). The best shift (8 hrs) is 108 pb^{-1} of integrated luminosity delivered to BaBar. The best 24 hours is 309 pb^{-1}. The best week is 1.87 fb-1 and the best month (May) 6.66 fb^{-1}. The total integrated luminosity delivered to BaBar since May of 1999 is 101.2 fb^{-1}. BaBar has logged about 96% of this data. Again, this is the world's largest high-energy physics data sample.



The accelerator is in the middle of a planned four-month down which started in July and will end with a turn-on in mid-November. The work in the summer down was geared towards further luminosity and stability gains. The sixth and seventh RF stations are being installed in the HER of PEP-II to raise the current towards 1.4 Amperes. The support tube inside of BaBar has been temporarily removed to allow for additional cooling of a bellows unit near beryllium chamber. To reinforce this temperature reduction, a new "crotch chamber" has been installed in the Q2 magnet at the forward end of BaBar to reduce the locally lost higher order modes power by a factor of four. New vacuum bellows near the Q2 chambers are being built and installed to absorb twice the HOM power. Additional work includes new x-ray masks near the RF cavities to reduce their tripping rate, new abort kickers to reduce the abort gap in the bunch trains to 2.5% of the circumference to reduce RF beam gap transients, and additional x-y beam position monitors at the sextupoles to reduce tune errors from orbit displacements.


PEP-II Daily Average for each Month
pb⁻¹
250
200
150
100
50
0
Jan-99
Mar-99
May-99
Jul-99
Sep-99
Nov-99
Jan-00
Mar-00
May-00
Jul-00
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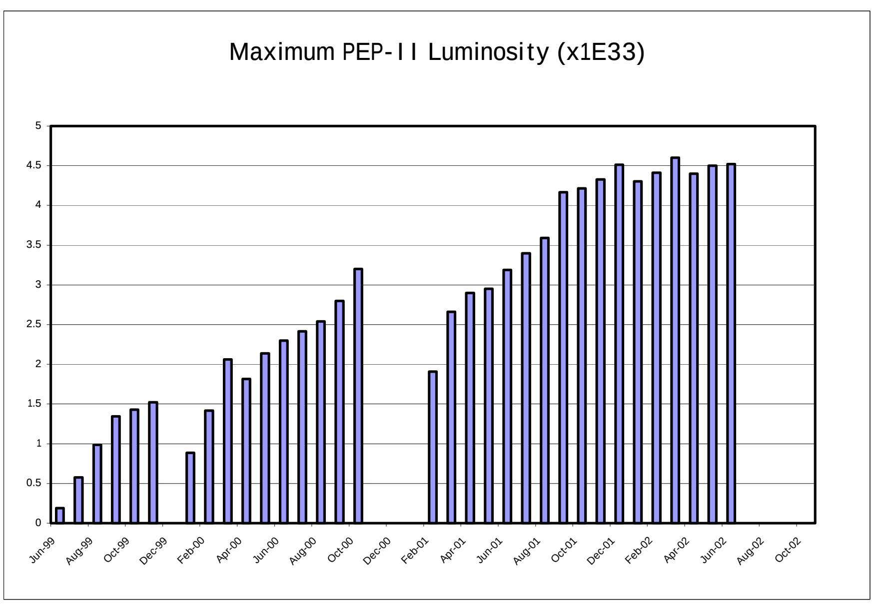
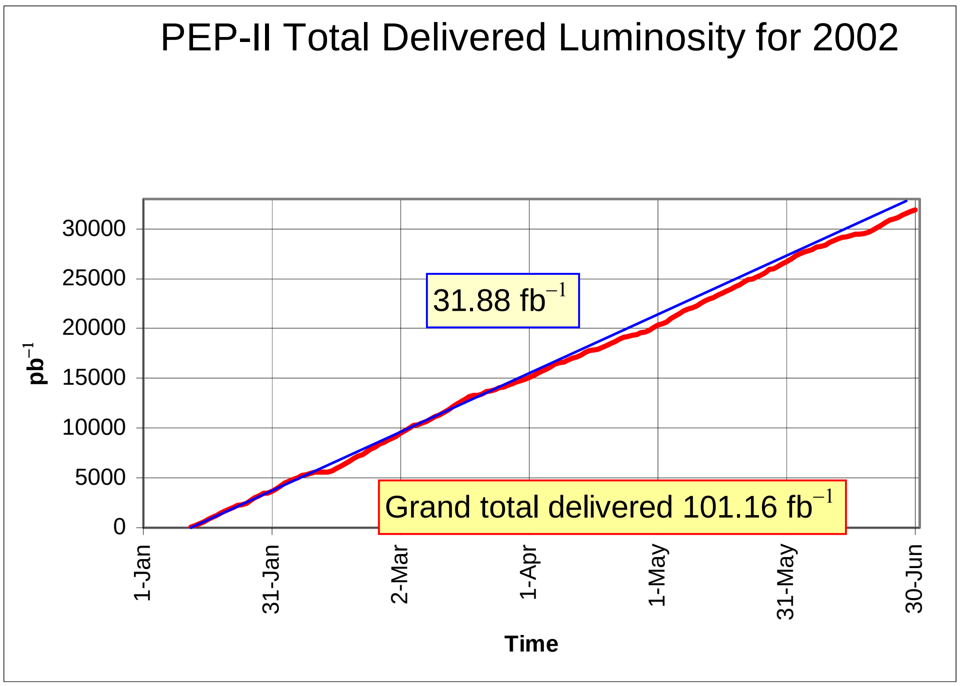
Nov-01
Jan-02
Mar-02
May-02


Maximum PEP-II Luminosity (x1E33)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Jun-99
Aug-99
Oct-99
Dec-99
Feb-00
Apr-00
Jun-00
Aug-00
Oct-00
Dec-00
Feb-01
Apr-01
Jun-01
Aug-01
Oct-01
Dec-01
Feb-02
Apr-02
Jun-02
Aug-02
Oct-02

2. FY02 Progress in BaBar: CP Violation Studies at the PEPII B Factory (Marcello Giorgi)

The BaBar detector in Interaction Region 2 of PEPII has been in full operation since November 1999, after receiving its first beam in May 1999. The goals of the experiment are to perform a comprehensive study of CP violation in the B_d meson system, to carry



out high-sensitivity searches for and measurements of rare B decays, and to make precision measurements in the charm and τ sectors. The 4π detector, with excellent vertex detection and particle identification, and the asymmetric energies of the PEP II beams, were specifically designed for precise measurements of CP-violating time-dependent asymmetries expected in the B system. Non-zero values of CP violation are allowed in the Standard Model, where they appear in the CKM matrix and can be described by Unitarity Triangles. To date approximately 91 million B events have been accumulated at the Y(4S), corresponding to an integrated luminosity of ~84 fb^{-1}. This summer, BaBar published an update of its first conclusive observation of CP violation outside the neutral kaon system, obtained by measuring the phase sin2β via the theoretically unambiguous processes $B_0 \rightarrow J/\psi K_s$, $B_0 \rightarrow J/\psi K_L$, $B_0 \rightarrow \psi(2s)K_s$, etc. By now this is becoming a precision measurement, with the BaBar result being the most precise obtained so far. Time-dependent asymmetry measurements were also performed in rare charmless decays, e.g. $B^0 \rightarrow \pi\pi, B^0 \rightarrow \rho\pi$, etc., to measure the phase α, together with direct CP asymmetry searches; preliminary measurements were obtained for branching fractions of DK modes, that will be used in the future to infer the third phase γ. Rare neutral current flavour changing decays mediated by penguin processes were also observed.

The BaBar Collaboration consists of approximately 600 scientists from 74 institutions in 9 countries (Canada, China, France, Germany, Italy, Norway, Russia, United Kingdom, and the United States). Approximately half of the collaboration is based in the US. A large number of PhD theses based on BaBar results are presented to Universities in North America as well as in Europe. At the moment 149 members of BaBar are Graduate students and 110 have postdoctoral positions.

Detector operations and computing in FY2002. At the beginning of FY 2002 PEP II and BaBar were in continuous operation: since October 2000, with a short shutdown during the 2000 and 2001 holiday periods. Both PEPII and BaBar performed remarkably well getting the records of produced and collected luminosity far beyond the design values, with Run II extending for almost 18 months.

Just before the Christmas 2001 shut down on 12/23, in 24 hours PEPII delivered an integrated luminosity as high as 308.8 pb^{-1} of which BaBar was able to record 303.4 pb^{-1}; in the week of October 21-27, the weekly record was obtained (1.836 fb^{-1} delivered, 1.790 pb^{-1} recorded).

Before the restart of the operations in January 2002, a major intervention was made to repair a relevant number of front-end electronics cards of the resistive plate chambers (RPCs) of the muon detection system (Instrumented Flux Return or IFR).

Run II continued smoothly until the summer shutdown of July 1st, 2002. In this period a new record in the monthly-integrated luminosity was obtained: about 6.7 fb^{-1}, in May 2002. Altogether since the beginning of the operations in 1999, PEP II delivered 101.16 fb^{-1} of which BaBar collected 95.42 fb^{-1}. Since 2000 (Run I + Run II), PEPII delivered about 98.6 fb^{-1}; with an extraordinarily high efficiency in the detector operation and in the data collection. BaBar recorded 93.8 fb^{-1}; about 11% of the total luminosity was collected at ~40 MeV below the Υ(4s) in order to measure the continuum background and subtract it from the sample of candidate B decays.

The new computing model, based on a distributed system with TIER-A centers set up for BaBar in various regions was already partially in operation as planned: the Lyon CCIN2P3 center was fully active during FY2002, complementing the SLAC computing resources. Simulated events production involved a several sites, with a large contribution from UK and other universities and laboratories in the collaboration. Altogether with a considerable coordination effort, the available resources allowed processing the data and the Montecarlo events needed for physics analysis in a timely way. By the time of the summer HEPC in Amsterdam, a large part of the data collected in Run II were processed, reconstructed and analyzed, giving among others the most precise measurement of sin 2β.

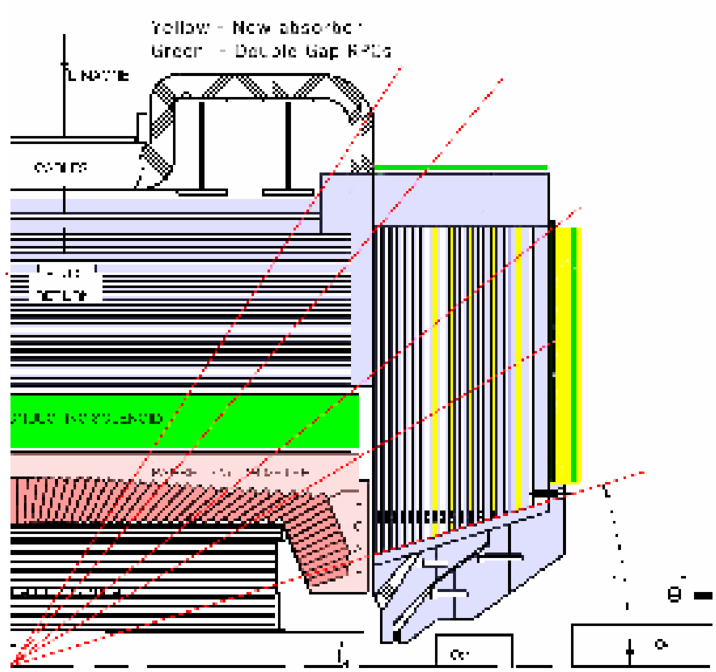
The support given by the International Finance Committee (IFC), and in particular by the various funding agencies, allowed two more TIER-A centers to be set up; one in Italy and the other in UK. Soon another computing center in Karlsruhe will become operational as TIER-A for BaBar. Although the BaBar computing model has shown its effectiveness in allowing the production of a impressive number of physics results produced almost in real time, it should be re-evaluated to see if it can cope with the expected increase in PEP-II luminosity in the coming years. Following the suggestions of the recent Internal Review on computing and the recommendations of the IFC, a new Computing Model Working Group has been recently set up, with the charge of proposing modifications and improvements to the model, if needed. A report to the Collaboration will be given before the end of FY2002.

Activity during the shutdown. The major activity on the Detector during the last part of the FY2002 was focused on the reinstallation of the improved forward end cap RPCs of the IFR detector subsystem. All the old chambers were removed and replaced with new RPC, built under a more accurate program of quality control and assurance, by a renewed and reinforced IFR Team. Five of the eighteen layers of RPCs were replaced by brass plates to improve muon filtering. A belt of chambers around the forward end cap was added and in each of the external slots 18 and 19, separated by 10cm absorber, double layers of RPC were inserted, improving the efficiency and redundancy for muon detection.

Other detector improvements during the shutdown:

Silicon Vertex Tracker (SVT): some modules, that could not have been read due to bad connections during RUN I and II, were recovered.

Detector of Internally Reflected Cherenkov light (DIRC): New time digitizers (TDC2 project) were built and are ready to be installed. They will allow the operation of the detector under increased background conditions.



In the above figure a longitudinal section of the forward end cap is sketched.

To increase the material thickness of the detector and therefore for an improved muon filtering, brass plates are installed in five of the eighteen slots originally occupied by RPC.

A belt of RPC was also added externally around the end cap.

Physics analysis and results: The achievement of a very long and efficient data taking period was matched in FY2002 by prompt data processing, with key physics analyses providing a large number of the results presented at 2002 winter and summer conferences. In the same period thirteen physics papers were submitted. At least twenty more preliminary results, presented at these conferences, are close to be submitted for publication in the coming months.

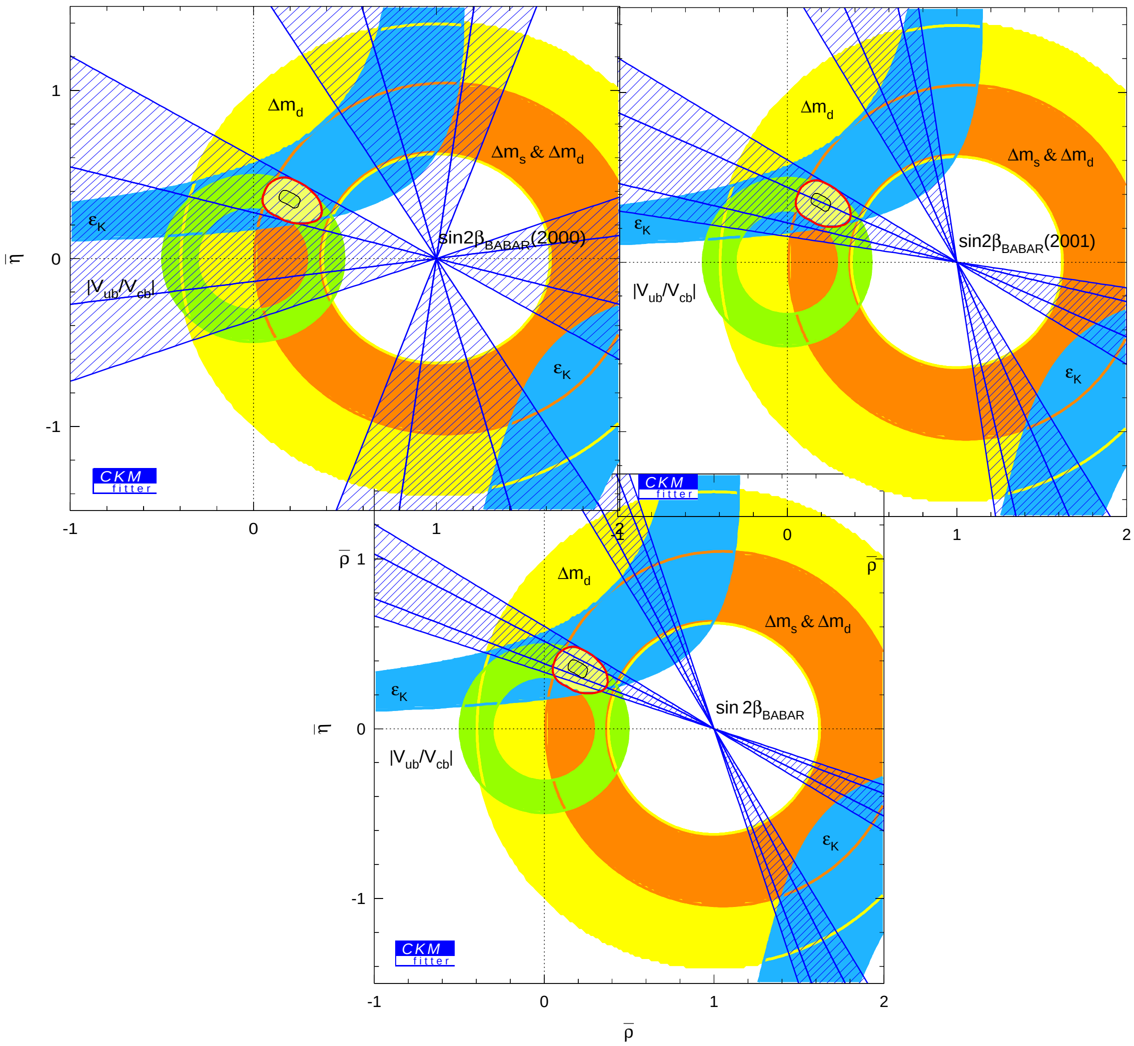
A few highlights extracted from this activity:

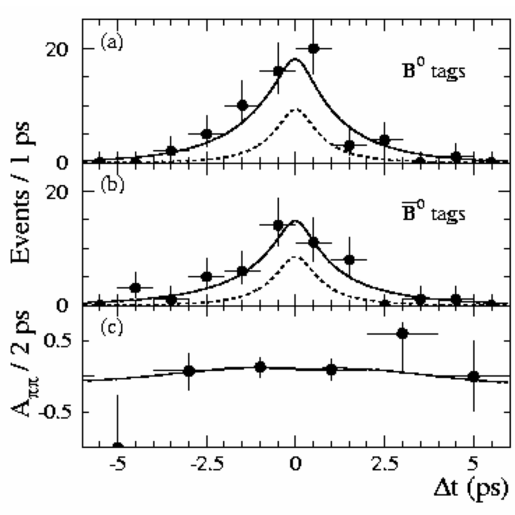
The first observation of CP violation outside the neutral kaon system, published in FY2001, was updated on the full RunI+II data sample, giving the best measurement available to date. The CP violating phase is extracted from time dependent CP asymmetries in the interference between mixing and decay of neutral B mesons to CP eigenstates containing charmonium. The BaBar result is: $\sin(2\beta) = 0.741 \pm 0.067(\text{stat}) \pm 0.034(\text{syst})$; the direct CP violation parameter $|\lambda| = 0.948 \pm 0.051(\text{stat}) \pm 0.030(\text{syst})$ is compatible with unity. Both results are in agreement with the Standard Model expectations. The following figure shows the evolution of the regions allowed by the BaBar $\sin(2\beta)$ results with increasing data sample, in the (ρ, η) plane, where different direct and indirect experimental determinations of the CKM matrix parameters can be compared. This measurement, after establishing CP violation in the B meson sector, opens the way for a high precision study of possible violations of the Standard Model in CKM unitarity triangular relations.

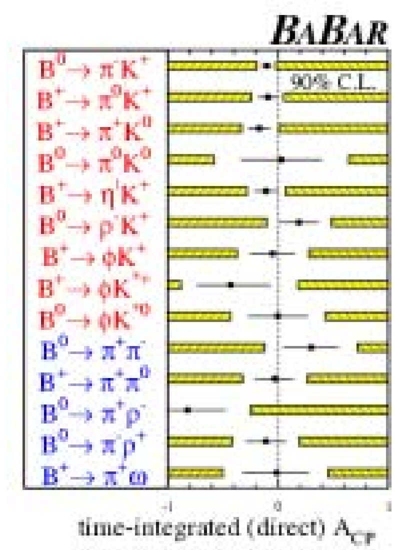
Time dependent CP-violating asymmetries were also measured in the decays of neutral B mesons to π+π- CP eigenstates, as a first step towards the determination of the CKM phase α. This initial measurement of the effective value of $\sin(2\alpha)$, not corrected for possible Penguin contributions, gives: $\sin(2\alpha_{eff}) = 0.02 \pm 0.34(\text{stat}) \pm 0.05(\text{syst})$, an interesting first step complemented by initial measurements of other channels, like $\pi^0\pi^0$ and $\rho\pi$, that will be relevant for a determination of the corrected $\sin(2\alpha)$.

Time-integrated direct CP asymmetries were searched for in a number of charmless two-body and quasi-two-body decays, giving several upper limits and some effects at the two standard deviations level that will need further investigation at higher integrated luminosity.

Other important results included, among others, measurements of branching fractions of radiative penguin decays, and exclusive decays to open charm that could be used for future studies of the CKM phase γ.


Δm_d
Δm_s & Δm_d
ε_K
sin2β_BABAR(2000)
sin2β_BABAR(2001)
sin 2β_BABAR
|V_ub/V_cb|
CKM fitter
ρ̄
η̄


(a)
B^0 tags
(b)
B̄^0 tags
(c)
Events / 1 ps
A_ππ / 2 ps
Δt (ps)


BABAR
90% C.L.
time-integrated (direct) A_CP

Upper figures: evolution of the allowed regions in the plane from the BaBar sin(2β) measurement as compared to other experimental constraints, from the Osaka preliminary results to those based on the Run I+II data sample.

Lower left: Time dependent CP asymmetry measurement in $B\rightarrow\pi^+\pi^-$.

Lower right: Some measurements of direct CP asymmetries in charmless B decays.

Operations: After November 15, 2002, PEPII and BaBar will restart the operations with the goal of running smoothly until August 2003 with increasingly higher luminosity. According to present estimates, in the period from November 2002 to July 2003 we expect an additional integrated luminosity of about 60 fb^{-1}, with an increase of about 60% in the available data sample.

The detector all together will be significantly improved.

To cope with higher rate, prototype work on the charged track trigger upgrade is well advanced; determined effort has to be put in FY2003 to fully implement it.

However, the most crucial detector issue is still the muon identification system. The present IFR barrel suffers from a continuous decrease of efficiency; by 2005, without a major intervention, BaBar would have a very poor muon identification.

An ad hoc committee is being set up to review different detector technologies and propose soon to the Collaboration a system that should be efficient, reliable and ready to be installed at latest in 2005.

Meanwhile, spare SVT modules have been built at INFN-Pisa and UCSB with contributions by the other institutions of the SVT collaboration; all the radiation hardness tests so far indicate that the present detector would operate without any appreciable degrading of its performance at least up to 2005.

A project to replace the present radiation monitors of SVT (SVTRAD), based on silicon PIN diodes, with diamond sensors is in progress and R&D has started.

Physics analysis and results: The present long shutdown period, with a stable data set, is used by analysis groups to refine their preliminary studies for publication. Approximately twenty papers will be submitted in the next months. At the same time, new analyses are developed in several sectors. Some of them will profit of the overall larger data set of more than 140 million BB pairs, expected for summer 2003, and of the improved calibration and reconstruction provided by the updated software. To this end, the entire RunI+II sample will be re-processed, and more detailed event information made available to the analyzers in a new data format.

Among the higher priority measurements, continued attention will be given during FY2003 to decay channels related to sin(2β), not containing charmonium, to charmless decays for the measurement of $\sin(2\alpha)$, to a number of decays that have potential for measurements of γ, like $DK\pi$ modes, and to improved measurements of the |Vub| and |Vcb| CKM elements via semileptonic B decays. With increasing integrated luminosity, an interesting possibility is to fully tag the events by exclusively reconstructing one of the B mesons in the pair in some of the many exclusive B decays, with an efficiency of the order of 0.1%. This technique can significantly reduce backgrounds in searches for rare final states with missing energy from neutrinos, and is already well developed in BaBar. The discovery potential of the experiment is not limited to B decays, and will be pursued also in other sectors that, like the charm sector, are accessible to BaBar.

3. FY 2002 Progress in Particle Astrophysics (Elliott Bloom)

The Particle Astrophysics program was centered on GLAST plus a number of much smaller activities in FY2002. You will read about GLAST progress in another section of this report. This section will focus on the smaller activities, USA data analysis, analysis of guest observer and archival data, GLAST science efforts, and modest work on possible future projects.

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. USA was successfully launched on February 23, 1999 aboard the US Air Force ARGOS satellite. USA science operations began in May 1999. Observations ceased on November 16, 2000. 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 fiscal year, numerous conference and seminar presentations, two archival papers, and one Stanford Applied Physics Ph. D. have resulted from this work. The topics of these papers and posters focused 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, and the extreme electromagnetic fields near the surface of the neutron stars and the horizon of the black hole.

Work has continued on various topics using archival and guest observer data. We have been successful in having new proposals 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:

1. X-ray spectroscopy of the iron K line in a Seyfert galaxy using proprietary Chandra diffraction grating data (data reduced, paper in preparation).
2. Spectral study of galactic winds in nearby active galaxies (paper submitted).
3. Transmission spectroscopy of gas in galaxies located in the line of sight to quasars; (paper accepted for publication).

4. X-ray spectroscopy of blazars using the XMM satellite (data received, reduced and being analyzed).
5. Modeling of gamma ray emission in MeV blazars (paper in press).

SLAC personnel are leading the GLAST Dark Matter Science Working Group.

Work has intensified this year in expanding our understanding of the possible sources of DM for which GLAST can set significant limits. Approximately Bi- weekly telecon/Web meetings are continuing.

We have also been involved in some new initiatives at a low level of effort:

1. AstroE2 is now scheduled for launch in January-February of 2005. T. Kamae and G. Madejski of SLAC and most Japanese GLAST-LAT members were AstroE members from the time of AstroE1. 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. Its Hard X-ray Detector (HXD) is capable of detecting many Gamma-Ray Bursts with microsecond timing, and should be able to localize GRBs to a few arc-minutes at least in one direction. Work is proceeding on these possibilities to prepare for the AstroE2 launch.

2. Work on Constellation X (ConX).
   ConX is a major new X-ray telescope being developed as a NASA mission. The projected launch date for Con X is about 2011. Currently Elliott Bloom is a member of the ConX Facility Science Team, and Greg Madejski is a panel member contributing to the development of the mission. Meetings are typically held 2-3 times per year with the venues alternating between Goddard Space Flight Center and the Center for Astrophysics at Harvard.

3. Semiconductor Compton Telescope R&D.
   Faculty and staff at SLAC have been developing a semiconductor based Compton telescope to explore the low energy gamma ray sky. The instrument will be based on double-sided Si strip detectors and CdTe strip detectors. It will measure the energy and direction of the recoil electron and the total energy of the incident gamma ray. The optimum energy range for this instrument is 100keV to 1MeV. In 2002, we developed a low noise readout chip with *IDE, Norway* and a low capacitance a few silicon strip detectors with *Hamamatsu Photonics*.

4. FY02 Progress in Particle Astrophysics Program (Tsuneyoshi Kamae)

The GLAST group has been focusing on the design and development of the Large Area Telescope (LAT) detector for NASA's Gamma-ray Large Area Space Telescope (GLAST) mission. FY02 was the second full year of work since start of the project, and considerable progress was made toward achieving and documenting the final instrument design.

The instrument will be launched into Earth orbit to detect gamma rays from astrophysical sources. It consists of a layered silicon-strip-detector tracker, a cesium-iodide (CsI) calorimeter, a plastic scintillator anticoincidence shield, and associated electronics, mechanical structures and thermal radiators.

Technical work focused on developing a fully integrated preliminary design and developing and verifying production methods. Structural test models of the tracker and calorimeter were built and vibration tested to demonstrate the integrity of the structural design. These models used the flight design configuration, materials and assembly processes.

Finite element models for analysis of the structural and thermal performance of the instrument were developed. These models were used to guide and validate the predicted performance of the preliminary design. They will be correlated with vibration and thermal test data to improve the fidelity of the models. The correlated models will be integrated with a finite element model of the spacecraft and launch vehicle structures to provide a complete end-to-end analysis of the flight configuration.

Final specifications were completed for several long lead procurement items. Competitive procurements were conducted, vendors were selected and production was initiated for the silicon strip detectors for the tracker, CsI crystals for the calorimeter, and photomultiplier tubes for the anticoincidence shield. Approximately 4,600 silicon strip detectors (of a total of 11,500) were fabricated and testing during FY02, and 200 CsI crystals (of 2,100) were produced for use in the calorimeter. The contract for photomultiplier tubes was placed during Summer 2002 with production scheduled to start in the Fall.

Progress in electronics development focused on application-specific integrated circuit (ASIC) design. Each of the three primary detection elements (tracker, calorimeter, anticoincidence shield) uses a mixed analog/digital custom ASIC for the front-end electronics. Three prototype versions of the tracker and calorimeter chips were produced during FY02, and these designs are now considered suitable for flight production. The first prototype version of the ASIC for the anticoincidence shield was also produced, and the design will be completed in FY03. Prototype versions of the three digital readout controller ASICs for use with the front-end ASICs were also produced and are working.

Flight software work concentrated on establishing the architecture of the detector readout hardware and data processors, and on designing the pattern-recognition filters used to separate gamma rays from charged particle background. The work established the number and configuration of flight processors needed and the time needed for on-board processing.

Ground software development focused on building and validating a simulation model of the LAT using GEANT 4. The model is being used to support analysis of the instrument performance and to evaluate the filter functions to be employed in the on-board flight software. Track reconstruction algorithms were also developed in support of these efforts.

Approximately 600 documents were generated during FY02. These include design descriptions, analysis reports, drawings, specifications, presentation materials, internal and external review reports, project plans and related documents. They are accessible through the LAT Project website at http://www-glast.slac.stanford.edu.

Considerable programmatic progress was also made during FY02. The project was extended by 6 months to achieve better alignment with the NASA spacecraft development plan. The project schedule and cost estimates were reworked to provide a more realistic and complete project plan, and a definition of completion was agreed upon and incorporated in the management plan. Staff was added to strengthen the system engineering and integration and test efforts, and a Chief Engineer was appointed to achieve better integration of design activities. NASA selected a spacecraft contractor late in the fiscal year, and this is leading to finalizing the definition of the LAT interfaces.

The DOE/NASA Implementing Arrangement was signed, and most MoAs with the LAT international partners were signed. The remaining two are complete with signatures pending finalization of foreign internal funding arrangements.

Several reviews were conducted during FY02. A joint DOE/NASA Preliminary Design Review (PDR) was held in January 2002. A series of SLAC-internal reviews, chaired by Marty Breidenbach, were conducted. A DOE review of the Project Management Control System was held in July, leading to certification of that system. The DOE CD-1 approval was signed off. A joint DOE/NASA review in July resolved thermal design issues remaining from the PDR, and led to a recommendation for project baseline approval. An External Independent Review committee appointed by the DOE Office of Engineering and Construction Management separately reviewed the project and validated the recommendation for CD-2 (baseline) approval.

5. Fixed Target Program – E158

End Station A Experiments

E158 – During FY2002, the E158 experiment successfully carried out the final commissioning and took a 5-week production run at design current. Two main issues had been identified for further improvement during the previous fiscal year during the first commissioning period in spring 2001. First, the photon background in the detectors was found to be larger than expected by a factor of 5. A new set of collimators was designed by September 2001, and fabrication was completed in November. Secondly, the electronics for the detector signals was found to have significant nonlinearity and common mode noise. Improvements to the electronics were implemented and tested during the months of September thru December 2001.

After improvements to the apparatus were made in Fall 2001, the beam and experiment were commissioned in a final engineering run in Jan-Feb 2002. On March 1 2002, an internal review was held, led by Charles Prescott, in which the experiment was awarded full stage 2 approval. During that review, significant improvements in the performance of the beam, the spectrometer, and the detectors were demonstrated based on the results of the Feb 2002 engineering run.

In late April 2002, E158 began a physics run at full design luminosity. The machine delivered stable beam at a repetition rate of 120 Hz, with a peak charge of 5.5 x 10^{11} at 45 GeV and 3.5 x 10^{11} at 48 GeV. A major accomplishment of the accelerator department was the delivery of high luminosity beam at an efficiency exceeding 60% against the clock, running the long pulse beam to E158 interleaved with beam delivery to PEP-II. Another major accomplishment was the small 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.

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

By the end of May, about 16 Coulombs of charge were delivered to the experiment. The anticipated error on the physics asymmetry is 23 parts per billion, with the standard model expectation for the raw asymmetry being about 110 parts per billion. Active feedback systems maintained the helicity-correlated charge asymmetry in the beam to be zero to better than 0.3 parts per million and the beam centroid position difference to be zero to better than 10 nm. Redundant monitors ensured that the charge asymmetry was accurate to better than 5 parts per billion and the position difference was accurate to better than 2 parts per billion. The control of the charge asymmetry over the duration of the 5-week production run is demonstrated in Figure 2. It can be seen that the average correction is well below 1 part per million and that two monitors agree to within 5 parts per billion.

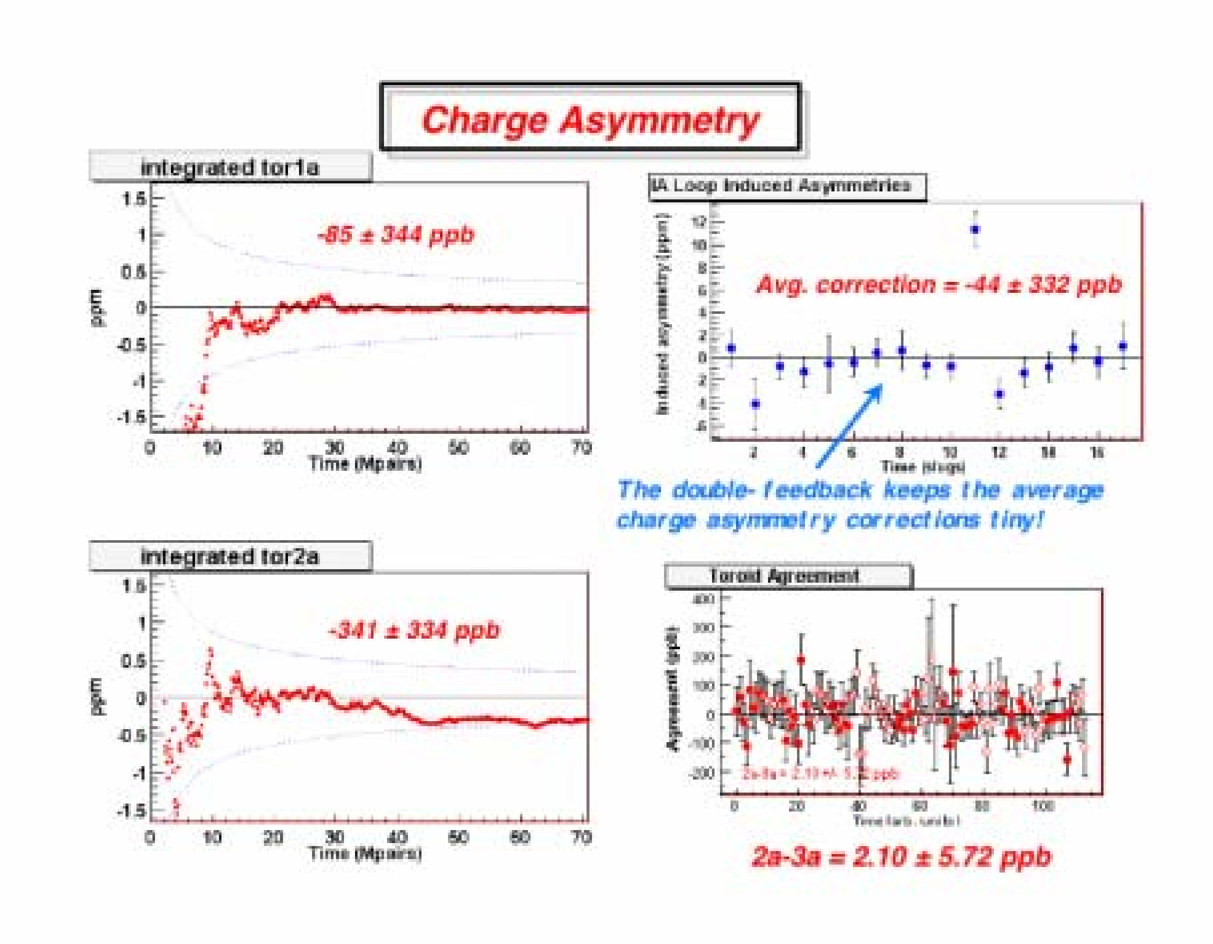


Figure 2: Control of the helicity-correlated charge asymmetry during the E158 physics run.

The analysis of the data is in progress. The quality of the asymmetry data is excellent. The data behaves statistically and the corrections due to random and systematic variations of the beam parameters are small. An important crosscheck on the data is the behavior of the raw asymmetry when a half-wave plate is inserted into the laser beam, and when the beam energy is changed from 45 to 48 GeV. Both of these changes are expected a sign change in the measured asymmetry but leave the magnitude of the asymmetry unchanged. This is a powerful probe of potential source of false asymmetries. The E158 data shows that the asymmetry remains unchanged in magnitude under these changes. These characteristics are demonstrated in Figure 3.

At the end of the run, it was determined that the E158 spectrometer needed two additional collimators to further reduce the systematic error from backgrounds. These collimators were designed, fabricated and installed by SLAC personnel by late September 2002, in time for the next run of E158, which began on October 1, 2002.

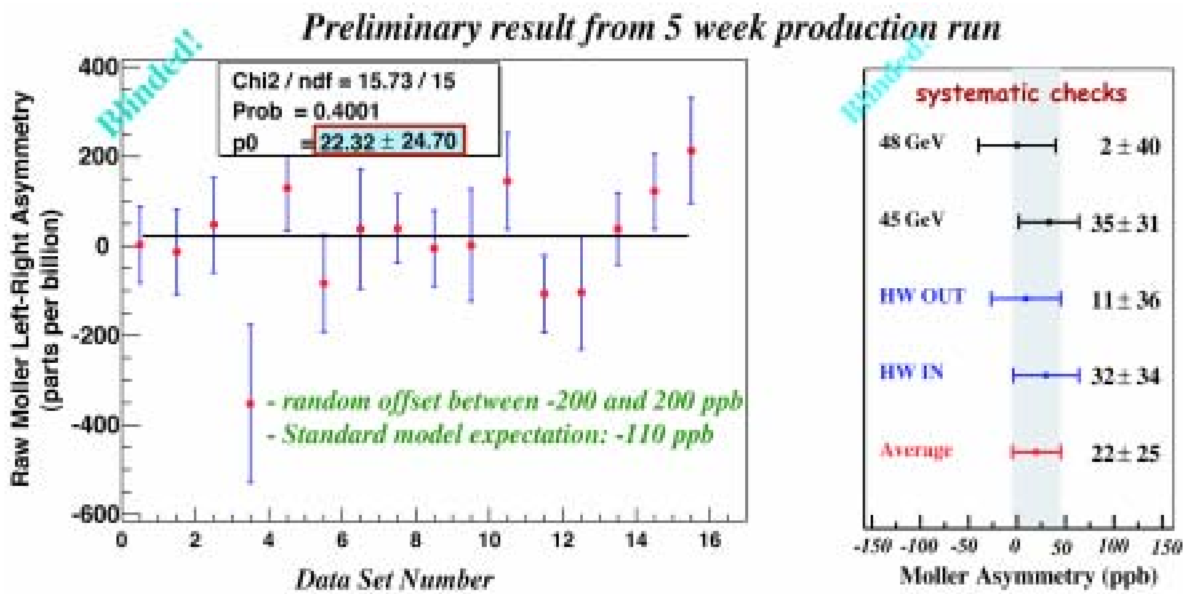


Figure 3: On the left is shown the left-right asymmetry in the main calorimeter signal, with the data set broken into 16 independent samples. On the right is shown the same data set broken up into two different beam energy samples and two different half-wave plate states. All the data are consistent as emerging from one parent distribution**.**

On October 1, 2002, E158 began a second data-taking run. It is anticipated that E158 will double the statistical sample by November 15, 2002. E158 expects to publish the data from Run I, which was completed in May 2002, by early 2003. The data from run II would then be analyzed and preparations would continue for the third and final run of the experiment, anticipated for October 2003.

In FY04, we plan to accumulate the full statistics approved by the EPAC. This would measure the electroweak mixing angle to an accuracy of 0.35%. The measurement would establish the running with respect to momentum transfer of this fundamental parameter for the first time, constituting a stringent test of the Standard Model at the level of electroweak radiative corrections. The limits on possible new physics signatures such as new neutral gauge bosons would be as sensitive as that anticipated from Run II at the Fermilab Tevatron. The anticipated results from E158 are shown in Figure 4, which shows the running of the fundamental electroweak parameter, the weak mixing angle, as a function of the energy scale of the electroweak interaction.

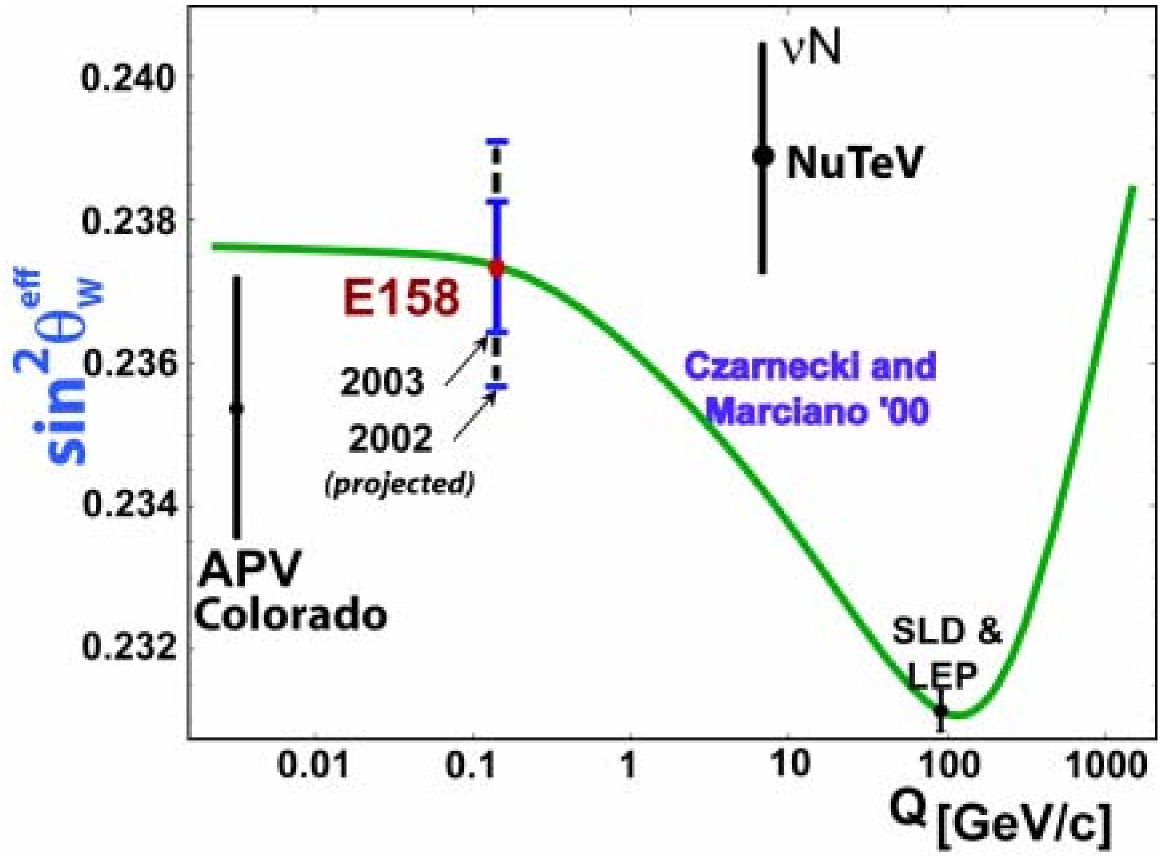


Figure 4: The anticipated errors from various runs of the E158 experiment are shown for the weak mixing angle as a function of the momentum transfer *Q,* along with other published measurements.

In FY05, the E158 collaboration plans to analyze the full statistics of the experiment and publish the final results. These results should either point to new physics beyond the standard model or set stringent and unique limits on new physics at the TeV scale, in a manner that is very complimentary to high-energy collider limits.

6. FY02 Progress for the Next Linear Collider R&D (Albe Larsen)

In FY02, work toward the NLC has focused in the following areas:

1. Development of enabling technologies especially rf power delivery where work on klystrons and solid-state modulators is critical;
2. Redesign and test of structures to meet the 70 MV/m high gradient requirement for NLC is a critical metric that has now been achieved, while independent work has validated wakefield suppression and detuning;
3. Manufacturing techniques of structures that form the tunnel through which the positrons and electrons will travel, to achieve high-gradient acceleration and control of beam properties continue to be evaluated;
4. Development of cost-effective optics decks including beam-position monitors, magnets and magnet movers;
5. Reexamination of final-focus requirements;

6. Continued evaluation of permanent magnets as possible candidates for many of the NLC electromagnets, offering the possibilities of both initial cost and operating cost reductions;
7. Industrialization of structures manufacture;
8. Phase I of the 8-Pack facility has proceeded on schedule, and a prototype solid-state modulator has been installed, along with a complement of XL-4 50 MW/m klystrons.

Fermilab, now over two years into this collaboration, has more clearly defined its work scope. Some excellent work on permanent magnets is underway and site and conventional facilities work is now well integrated with the efforts at SLAC. Work on structures manufacture on a commercial scale also draws on Fermilab's expertise. Collaborative efforts continue in the US with the Lawrence Berkeley and Lawrence Livermore National Laboratories and our newest partner, Brookhaven National Laboratory, internationally with the KEK National Laboratory for High Energy Physics in Japan, the University of British Columbia in Canada, Oxford University in Great Britain, and the Budker Institute (BINP) in Russia, and through a number of DOE SBIR awards, which have increased in total number and in the range of technologies being explored.

The basis of the NLC design is found in the *Zeroth Order Design Report*[1] published in 1996. Since then, work has continued to improve and refine the design, and in the past three years following the 1999 Lehman review, to reduce overall project costs. A new NLC 2001 configuration incorporating these changes has been adopted with Web documentation available. The *2001 Report on the Next Linear Collider*[2] was submitted to the Snowmass 2001 meeting in July, and further refinement of the baseline rf system is being documented as part of the International Linear Collider Technical Review Committee (ILC-TRC) initiated by ICFA. Both the beam parameters and the NLC collider layout have been modified to provide greater energy flexibility. The final ICFA ILC-TRC report showing these changes will be published in late 2002.

To expand the physics capabilities of the collider, the NLC now has an asymmetric layout of the two interaction regions (IRs). One IR is optimized for high energy, 250 GeV to 1 TeV, and is configured so that it is ultimately upgradeable to multi-TeV. The other IR is optimized for precision measurements at lower energy, 90 to 500 GeV, but is capable of being used at energies up to 1 TeV. This configuration was motivated by the recent breakthrough in the design of the final-focus optics which makes the system more compact, allowing beams of up to 2.5 GeV to be focused in a system less than 1-km long. To capitalize on the multi-TeV potential, it was necessary to eliminate bending between the linac and the high-energy IP. The linacs are no longer collinear but are oriented with a shallow 20-mrad angle between them to produce the desired crossing angle. The beams to the second IR are bent by about 25 mrad, which is acceptable because they are at lower energy. This IR has reasonable luminosity up to 1 TeV and a 30-mrad crossing angle for

[1] The NLC Design Group, "Zeroth Order Design Report for the Next Linear Collider," LBNL-5424, SLAC-474, UCRL-ID-124161, UC-414, May 1996.
[2] The NLC Design Group, "2001 Report on the Next Linear Collider," LBNL-47935, SLAC-R-571, UCRL-ID-144077, Fermilab-Conf-01-75-E, June 2001.

compatibility with a possible γγ option. LLNL has worked on design of a γγ interaction region, and introduced the idea at Snowmass 2001. Since then, the physics community has embraced the idea and is studying the physics possibilities. The collimation system has also been redesigned to take full advantage of features of the new final-focus optics, reducing its length even further. The new beam-delivery system is about 1.6-km long (per side), compared with more than 5 km for the original ZDR design.

The configurations of the injectors and main linacs have also evolved as a result of R&D and cost reduction studies. The concept of a central injector complex was evaluated for potential cost savings, and many configurations with and without shared components considered. Any centralized injector requires transport lines to bring the beams to the end of the linacs and the extra tunnels. Together, these more than offset any potential savings, so the baseline design is for separated injectors. A central injector design is still being considered for the Fermilab site because it can be located entirely on existing laboratory land. In the new configuration, the main linacs have become slightly longer to deliver full energy for the higher bunch current of the new parameters described below. In addition, to maximize luminosity at lower energies, non-accelerating bypass lines have been added to bring the low-energy beams to the end of the linac. These lines can also be used to transport the beam during staged installation of the rf components.

The NLC beam parameters have been re-optimized to provide higher luminosity by taking advantage of successful R&D on diagnostics and techniques to control emittance dilution. The beams now consist of trains of 190 bunches of 0.75×10^{10} particles separated by 1.4 ns. The number of bunches has increased while the single bunch charge has been lowered. This reduces the expected emittance dilution and more than triples the luminosity, providing greater physics potential. Successful tests of structure position monitor resolution and extensive simulations of beam-based alignment algorithms lend confidence in the viability of these parameters. There have also been detailed studies of the linac feedback systems that have allowed us to understand the limitations seen in the SLC and devise improved algorithms

There has also been substantial progress on R&D for the electron source, collimators, and stabilization. Recent studies with different cathode doping have demonstrated that the polarized electron source will be able to produce the full NLC bunch train with 80% polarization. Run 1 of SLAC's E-158 experiment produced beam with parameters approaching the beam parameters of the injector proposed for the 500-GeV NLC machine. The pulse charge for the E-158 beam approaches that required for NLC. (The polarized source can actually produce up to 30 x 1011 electrons in 270 ns.) It is a factor 15 times higher than that used for SLC operation and has a pulse structure similar to that proposed for NLC.3. A prototype 'consumable' collimator, which can be rotated to a new position if damaged by the beam, has been constructed and tests demonstrate a proof of principle of this technology. Progress has also been made on a more-experimental prototype 'renewable' collimator that would use liquid metal to restore continuously the collimator surface. Experimental studies of collimator wakefields have begun using a

[3] Woods, Michael B., **A Successful Run 1 for SLAC Experiment E-158,** NLC News, Vol. 3, No. 9, Sep. 2002

new wakefield test setup installed in the SLAC linac. The initial results indicate that the wakefields are significantly less than predicted theoretically, but consistent with 3-D MAFIA electrodynamic calculations. Study of prototype carbon collimators from DESY have also been completed that show significantly worse wakefield characteristics. Considerable theoretical progress has been made in understanding collimator systems. Two different studies are under way to develop possible methods for stabilization of the final NLC quadrupoles, the elements with the tightest vibration tolerance. At SLAC, inertial sensors are being used to stabilize a simple object and extensions of these tests to more realistic prototypes are planned. Special inertial sensors, capable of working in the high magnetic field environment of the detector are also being developed. A parallel effort at the University of British Columbia is using an optical interferometer. These studies are augmented by an extensive program of ground-motion measurements and modeling to quantify site and equipment requirements. A study conducted in the SLAC linac last year demonstrated very low ground motion at the NLC representative sites in California, and studies in process are designed to quantify vibrations caused by near and in-tunnel noise sources. Extensive ground motion measurements continue this year at both SLAC and Fermilab using a hydrostatic leveling system developed with the Budker Institute in Russia.

One of the benefits of having Fermilab join the NLC Collaboration is their competence in permanent magnet development, used most recently in the new recycler ring for pbars. Replacing electromagnets with permanent magnets, primarily in the Main Linac, is a potential cost reduction, and would have the added benefits of increasing the reliability of the magnet systems and reducing potential vibration sources from the cooling water needed for electromagnets. In support of this, four different styles of prototype permanent magnets have been constructed at FNAL and measured there, and at SLAC. The biggest concern with permanent magnets is the stability of the magnetic center when the strength of the magnet is varied. The four prototypes were evaluated with respect to the change in their magnetic centers with a 20% change in field (required if the beam-based alignment technique is used to align the quadrupole magnets to the beam). The best candidate was selected and the design is being enhanced. The same data were also taken on the prototype NLC electromagnet so a baseline performance was available. Both the permanent and electromagnets are also being evaluated for the change in center position with a change in the ambient temperature. Another area being explored is the sensitivity of various magnetic materials under NLC-like magnetic conditions to NLC-like radiation to see the impact on the field amplitude or uniformity.

Electrical systems work included continued advances in a unique solid-state modulator designed for improved energy efficiency, higher reliability, smaller size and lower cost. In early FY02, the full-scale prototype assembly was completed with installation of the 1:3 step-up transformer and assembly started in the third quarter, then tested to the full 500-kV output into a water load. Subsequently, the water load was replaced with three 5045 klystrons operating in diode mode which were tested up to 420 kV, considerably above their rating. The voltage was then increased deliberately to cause tube arcing, which unfortunately destroyed about 25% of the IGBTs. The next six months was spent investigating IGBTs and designing and adding protection devices on the driver boards.

At the present time, the unit is operating to full voltage and current specifications using a 4.5- kV IGBT from a different manufacturer, allowing 8-Pack progress to continue while corrective measures are investigated further. The IGBT failure mode has been traced to very uneven current distributions inside the hybrid circuit device during the fast pulse transients, causing current overload of certain chips depending on the location inside the packaged hybrid. A new IGBT layout has been designed in the lab and will be tested shortly.

The 500-kW power supply was received, installed and successfully tested although some regulator improvements were necessary. An additional 150-kW power supply was purchased, installed and tested for operating the unit in Phase I of the 8-Pack location (see below). The larger supply will remain in the lab for testing the second full prototype modulator, now under construction. For this unit, first samples of both magnetic cells and IGBT driver boards are nearing completion; IGBTs, Metglas and storage capacitors all have been delivered. Before full assembly, a "short stack" of 10-20 cells will be constructed to allow full-power testing and fault testing of individual boards. Since this unit uses a new 6.5-kV IGBT, fault tests will have to be conducted and corrective measures taken if necessary before assembly of the full stack.

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. Some aspects of fast data streaming architectures for NLC are being pursued through R&D, aimed at upgrading the existing SLAC Control System Micro Farm and Front End Processors.

Noticeable progress continued in obtaining industrial sources of supply for key NLC components. An SBIR that has resulted in a very low cost design for the microwave tube (helix TWT) that provides the input rf signal to the klystron entered a new phase, where a much longer-lived cathode (over 100,000 hours) was added, greatly improving the potential availability of the rf drive chain for the klystron. Plans are in place to purchase some of these devices for the NLC Eight-Pack test in FY03. 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. One of the 75-MW klystrons discussed earlier had its rf section (the cavities that amplify the rf) and the magnets that focus the beam, manufactured by a California microwave tube manufacturer. A smaller tube manufacturer in Japan has manufactured three similar tubes. An SBIR project is 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.

Following the successful testing of the first prototype 75-MW klystron and the diode to 3.2-μs pulse width operation, two more klystrons were fabricated and tested. While both tubes operated and produced X-band rf, they were not able to explore the 3.2 μs/120 Hz pulse repetition rate frontier that was intended. In one tube specialized cavities designed to suppress an unwanted mode did not work as expected, and in the other high voltage standoff problems in the electron gun and magnetic imperfections that lowered the rf efficiency of the tube limited the usefulness of the data that could be taken. At least one of these tubes is being rebuilt with these observed problems corrected, and work is proceeding on a modified design to add back some of the features found on the first successful 75-MW klystron. Together, KEK and Toshiba have produced a 70-MW, 1.5-μs klystron that, based on extrapolation from operation at 25 Hz and measured thermal properties, will operate at 100 Hz.

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 SLED-II 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 has been made in understanding high-gradient performance in the last year. The advances result from an aggressive experimental program, which has included the completion of tests of three pairs of low group traveling wave structures ('T' series), an initial test of a pair of high phase advance traveling wave structures ('H' series), and operation of three pairs of standing wave structures. A brief summary of the results from these studies is included in the section on the NLCTA. Most significant, however, has been the achievement of the NLC design gradient of 70 MV/m in a 53-cm, 3%c structure that has been measured with 400-ns pulses for many hours at 73 MV/m with a breakdown rate of about 0.04/hour and at 85 MV/m with a breakdown rate of 0.5/hour. In order to understand better the mechanisms involved in rf breakdown of accelerator structures at X-band, the rate of building structures has been increased from approximately one per year to one per month. Since most of the breakdowns at operating gradients have been occurring in the structure couplers, coupler design has been emphasized over the last year, resulting in designs that appear to break down no more frequently than and possibly even better than an average non--coupler cell. The present testing combines these couplers with structures that vary in length and initial rf group velocity with a goal of selecting the best overall combination. This is estimated to be completed by late FY03. While the structures currently being built do not have all the features that would be present in an NLC structure, they have demonstrated that many lower-cost/conventional approaches can be utilized in fabricating both parts and finished structures.

Shallow, bored-tunnel configurations have been explored by the joint SLAC-Fermilab Conventional Facilities team and compared to cut-and-cover tunnel configurations. Although generally more expensive by some margin, the shallow, bored-tunnel configurations allow more flexibility in site selection and offer attractive sites in closer proximity to existing research laboratories. Many green-field laboratory costs may be avoided by maximizing the use of existing nearby research laboratory infrastructure; potential cost saving is being evaluated. NLC attributes as they interact with the local site and environment are being explored. Of substantial impact to beam stability is local cultural noise and vibration. Field measurements have confirmed several sites in California to be sufficiently quiet, stable and suitable for the NLC. For the NLC cooling systems, an optimization study has revealed that a fully distributed decentralized cooling system matched to a site-specific California climate reduces life-cycle costs by $100M and lowers overall NLC power consumption at 0.5 TeV to under 200 megawatts.

During FY00 the SLAC and Fermilab directors established an NLC Machine Advisory Committee (MAC) to provide oversight and guidance to the directors. The MAC has broad representation in both technical expertise and in global distribution, with most of the world's major accelerator laboratories represented. The NLC MAC has now met five times, with its next meeting scheduled for November 2002. It continues to offer valuable R&D guidelines. The NLC News, requested to fulfill a need for monthly communication, is now nearing the end of its third year of publication. An active pre-conceptual design R&D program will continue in FY03.

The NLC Test Accelerator – NLCTA

During FY01, an aggressive R&D program was launched to develop X-band accelerator structures that reliably meet the NLC unloaded gradient goal of 70 MV/m. This program continued to be a major focus of the NLC R&D effort in FY02, involving the concerted efforts of a number of departments at SLAC and the ongoing collaborative efforts with the KEK JLC group on structure development.

As part of this program, a series of six structures was built (called the T-Series) with different lengths (20, 53 and 105 cm) and initial group velocities (5% and 3% c) to study how these parameters affect high-gradient performance. The initial group velocities are much lower than the 12% c of the earlier, 1.8-m structures that incurred significant rf -related damage at gradients of 45-50 MV/m. These values were chosen because the downstream, lower group velocity portion of the 1.8-m structures showed little damage.

After assembly of the T-Series structures, they went through a preprocessing procedure that included 'wet' and 'dry' hydrogen firing at 950 °C, a two-week vacuum furnace bake-out at 650 °C, and a one-week in-situ bake-out at 220 °C. The program of high-gradient tests was carried out at the NLCTA, which delivered a total of 3000 hours of high-power rf at 60 Hz for this purpose.

The rf processing of the T-Series structures started at higher gradients (55-65 MV/m) than those (35-45 MV/m) for the 1.8-m structures. In addition, much less damage was observed in these structures at gradients above 70 MV/m than in the 1.8-m structures at gradients of 50-65 MV/m. After processing to 80-85 MV/m, the breakdown rate at 70 MV/m was dominated by events in the input and output couplers. The breakdown rates in the body of the structures (i.e., excluding the couplers) at 70 MV/m were close to acceptable for the NLC/JLC at the design pulse width of 400 ns. For the three 53 cm, 3% c initial group velocity structures that were tested, the breakdown rates were < 0.1, 0.2 and 0.3 per hour, respectively, while the goal is < 0.1 per hour.

An autopsy of the input coupler of one of the structures revealed severe damage and some melting on the edges of the waveguide openings to the cell, and extensive pitting near these edges and on the coupler iris. The waveguide edges see large rf currents that are a strong function of their sharpness, and the associated pulse heating can be significant. By design, the edges in the T-Series structures were sharper (76-µm radius) than those in the 1.8-m structures (500-µm radius). Recent calculations have shown that the pulse heating for the T-Series structures is in the 130-270 °C range, well below the copper melting point, but high enough to produce stress-induced cracking, which can enhance heating.

Based on these observations, a 53 cm, 3% c structure was built with couplers designed to have much lower pulse heating. This structure is currently being tested and has performed very well, with no obvious enhancement of the coupler breakdown rates relative to the other cells. Overall breakdown rates of about 0.04 per hour at 73 MV/m and 0.5 per hour at 85 MV/m have been measured with 400-ns pulses. All future structures will be made with couplers similar those used in this test.

Although the results from the T-Series structures are very encouraging, their average cell iris radii are too small to meet NLC/JLC short-range wakefield requirements. To increase the iris size while maintaining a low group velocity, a structure design with thicker irises and a higher phase advance per cell (150º instead of 120º) design has been adopted. Two such structures (H-Series) have been built, one 60-cm long with an initial group velocity of 3% c, and the other 90-cm long with an initial group velocity of 5% c.

These structures are also being tested at the NLCTA. Unfortunately, they have the earlier; T-Series type couplers as they were built before the coupler pulse-heating problem was discovered. Making the problem worse, the H-Series structures have lower shunt impedance than the T-Series structures, so the pulse heating is relatively high, and indeed the coupler breakdowns have limited the structure processing to lower gradients than that achieved with the T-Series structures. In addition, at short pulse lengths where the coupler events did not dominate, the processing rate was much slower than that for the T-Series structures. The larger iris thicknesses of the H-Series structures are certainly a contributing factor, but they do not explain the full difference.

The best results have been achieved with the 60-cm, 3% c structure, which so far has been processed to 68 MV/m with 400-ns pulses. During FY03, several H-Series structures with improved couplers will be tested; culminating in one that is fully damped and detuned for wakefield suppression

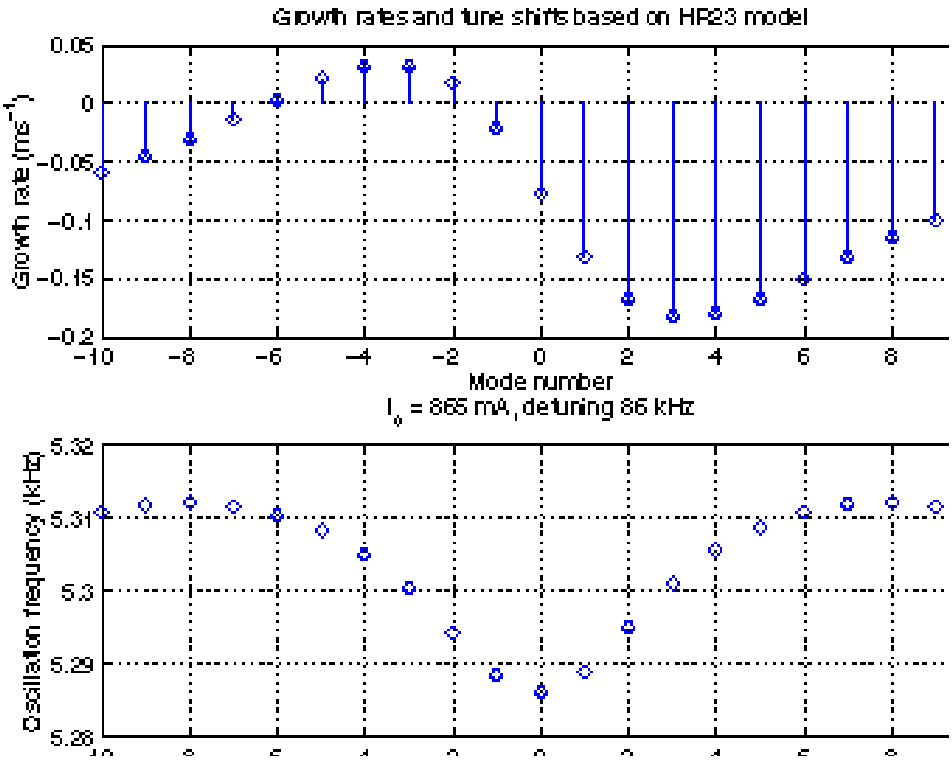
7. FY02 Progress in Advanced Accelerator Research

Advanced Accelerator Research A

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 PEPII, research and design for near-future facilities such as NLC or upgrades to PEPII, 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.

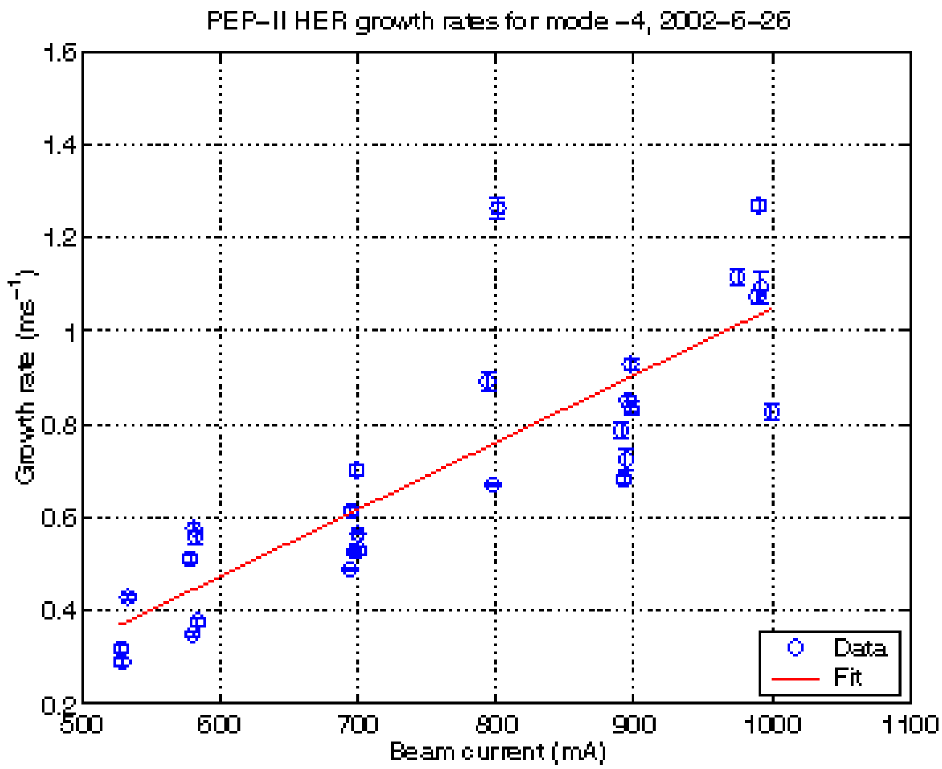
The group has been central in machine physics studies to better understand the interactions of the PEP-II RF systems, with their complex impedance-reducing feedback architectures, and the longitudinal dynamics of the machine. The figure presents an experimentally derived estimate of the machine impedance for the longitudinal modes within the RF system bandwidth. The impedance is calculated using the measured transfer function of a PEP-II RF station through the RF cavities, which is used to fit a seven-parameter model of the RF system to the measured frequency response.



Using the fitted RF model, it is possible to compute an estimate of the impedance per mode within the cavity bandwidth, and hence a growth or damping rate. The model agrees with the experimental measurements in predicting low-number negative modes as the fastest growing. For mode -4 the model predicts a growth rate of 0.04 ms^{-1} at 865 mA.

Our group also has quantified the actual growth rates for the installed and configured systems. As seen in the figure below, Mode -4 is most prominent with a measured growth rate of ~0.8 ms^{-1}. From the slope of the fit we extract the driving impedance of 877 k.

The model and experimental measurements differ greatly in growth rate - the measured transients are 5 to 20 times faster. Understanding this surprising discrepancy in the instability growth rates, and the effectiveness of the RF system in controlling these impedances will be of critical importance in achieving higher PEP-II operating currents in the next year.



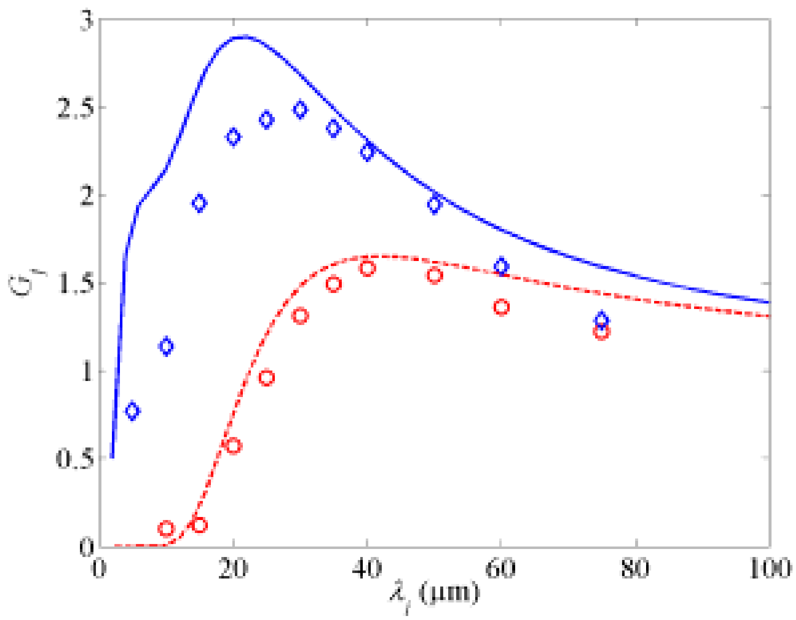
Measured growth rates for Mode -4 in PEP-II

Our group has continued to develop high-speed signal processing systems, and this year we have completed the core electronic 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. We have simulated the complete processing architecture at the full 1.5 GSample sec. rate and are now embarking on a collaboration with KEK and LNF-INFN to build a demonstrating system to operate at one of the laboratories.

Our group is hosting Dr. Makoto Tobiyama of KEK this year and he is joining us in the detailed design and system development. This project is also serving as the initial research project for Liane Beckman, a Stanford Ph.D. student in Electrical Engineering who has joined our group in the past year.

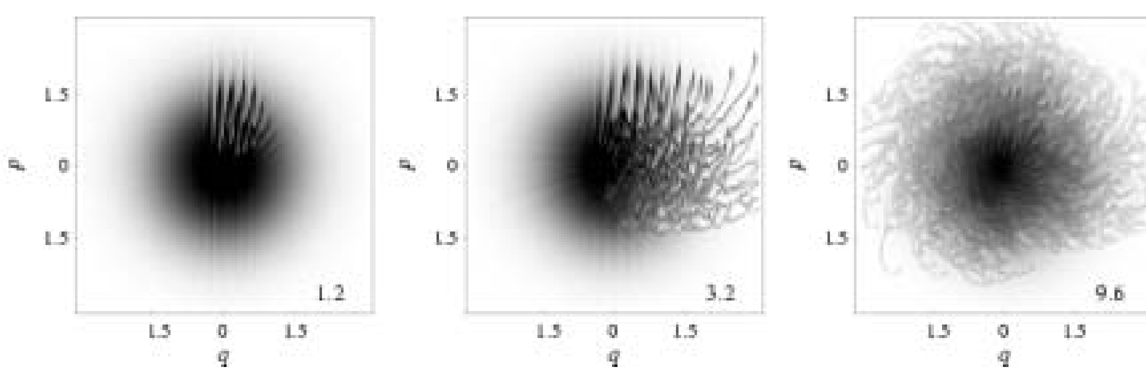
Collective Effects. The Collective Effects Group continued studies of instabilities and impedances with the focus on the coherent synchrotron radiation (CSR) effects in electron machines.

CSR Induced Instabilities in Rings and Bunch Compressors**.** A large set of computer simulations of the CSR effect in LCLS bunch compressors was carried out and compared with the analytical theory. The theory predicts that introducing an additional energy spread in the beam can mitigate the instability. To this end, a superconducting wiggler was included, as an option, in the design of the LCLS bunch compressor BC2. The result of the simulation with and without the wiggler, and comparison with the analytical theory, are shown in the figure below, where the red color refers to the case without, and the blue – with the wiggler. The symbols are the result of the simulation, and the lines are the theory.



Gain curves as functions of wavelength for an initial perturbation in the LCLS second bunch compressor with (red) and without (blue) a wiggler.

The development of the CSR instability has been also studied numerically for a small, low energy storage ring. It was shown that above a certain current threshold, which agrees fairly well with the linear theory, the nonlinear calculation gives a rapidly developing instability leading to microstructures on the phase-space distribution and bunch profile. The instability quickly reaches a sort of “saturation”, in which micro bunching largely washes out. The figure below shows the evolution of the distribution function and the bunch form.



Phase space of the beam showing development and saturation of the CSR instability.

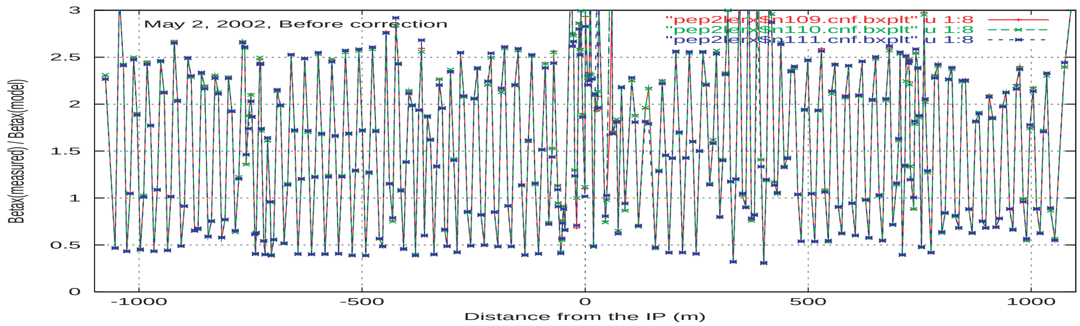
The same computer model mentioned above, but augmented to include Fokker-Planck terms, accounts for the main features of the observations of recurrent short bursts of infrared radiation which have been observed at storage rings of several synchrotron light sources (SURF III, NSLS-VUV, MAXLAB, BESSY, ALS).

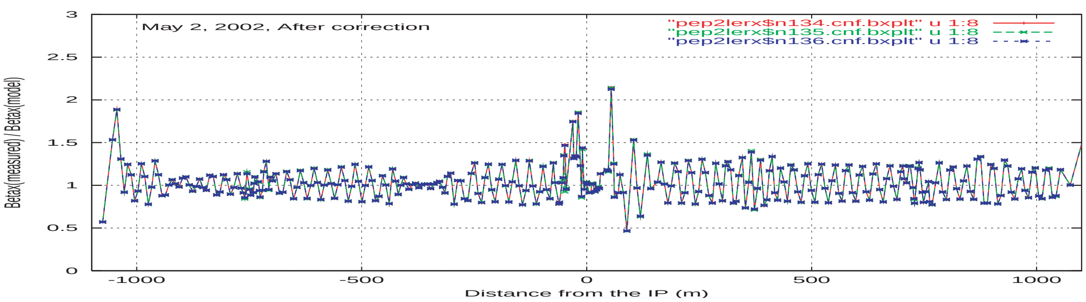
More recently, the CSR instability was also studied for the NLC damping rings, where it can be caused by the radiation in the wigglers.

Roughness Impedance**.** A cylindrically symmetric beam tube with small, periodic corrugations has been used in the past as a model for roughness impedance. Using a perturbation theory, we calculated the impedance of a structure with small corrugations on a rectangular beam pipe and confirmed the result numerically using a field matching technique. For the purpose of experimentally studying roughness impedance, a rectangular geometry may be easier to fabricate than the round model.

Electron Cloud**.** Electron cloud remains a hot issue both for the B-factories and for the NLC damping ring (DR). The adverse effects in the B-factories were observed experimentally both at KEK and SLAC and have implications on the coupled bunch instability and e-cloud head-tail single bunch instability. In a qualitative analysis of the problem, the effective wake field of the e-cloud was derived analytically. The result is in good agreement with simulations carried out for the NLC. Effect of the e-cloud on the proposed upgrade of the PEP-II B-factory to higher luminosity was also analyzed.

Lattice Dynamics. Over the past year, we worked extensively to improve the machine optics for the PEP-II. First, we designed the new optics near the half integer for both rings. These lattices were successfully implemented during the machine development. The closeness of the tune to the half integer resonance caused a 250% measured β beating in the Low Energy Ring as shown in the first plot in the following figure. To reduce the beating, we upgraded the object-oriented library: LEGO to analyze fully coupled orbit data for the entire ring. Based on the analysis, we lowed the setting of a skew quadrupole inside the interaction region and reduced the measured beating to 30% as shown in the second plot in the figure. Much more refined analyzing work are required as we move the tunes ever closer to the half integer to increase the luminosity.





Since the development of a self-consistent and two-dimensional beam-beam simulation code [Phys. Rev. ST Accel. Beams **4**, 011001 (2001)], we have extended to the code to the third dimension to include the effects of a finite bunch length. The newly added physics include the hourglass, phase average, synchro-betatron resonances, and pinching effects. As a result of the development, we have invented a new and efficient topology suitable for parallel computing of the beam-beam collision to minimize the communication among distributed processors. The three-dimensional program runs fully parallel on the supercomputers at NERSC facility. We have gained a factor 24 with 32 processors in the SP (IBM computer). It is capable to realistically simulate the beam-beam interaction in both traditional symmetric e^+e^- colliders and the newly constructed asymmetric ones such as the PEP-II at SLAC. The code is being used to further optimize the performance of the PEP-II and its upgrade.

We have numerically studied the head-tail instability caused by an electron cloud in positron storage rings using a simple model. In the model, the positron beam is longitudinally divided into many slices that have a fixed transverse size. The centroid of each slice evolves dynamically according to the interaction with a two-dimensional electron cloud at a given azimuthal location in the ring and a six-dimensional lattice map. A sudden and huge increase of the projected beam size and the mode coupling in the dipole spectrum are observed in the simulation at the threshold of the instability. Even below the threshold, the vertical beam size increases along a bunch train that has 8.5 ns bunch spacing. Above the threshold, a positive chromaticity can damp down the centroid motion but has very little effect on the blowup of the beam size. The results of the simulation are consistent with many observations at PEP-II.

<u>Tevatron Simulations</u>: The goal of these simulations is to understand the poor antiproton lifetime performance of the Tevatron at the injection stage (150 GeV). The assumption is that the lifetime degradation is caused by incoherent resonances induce by the long-range nonlinear beam-beam forces in the crossing points of the beam helices.

As opposed to the usual dynamic aperture calculations, we are trying directly to calculate lifetimes, i.e., we track a large number of particles for a large number of turns and record the particle loss rate. We have developed a specialized code optimized for fast calculation of particle transport through a circular accelerator with parasitic beam-beam crossings. Our simulations include the Tevatron's 72 parasitic crossings and require approximately 100 processors on the NERSC facility for a reasonably accurate simulation. Preliminary results have been encouraging, displaying the right signature of lifetimes with respect to cogging stage/emittance/charge.

We recently visited FNAL to reconcile our simulation runs with the actual machine. It turns out that the machine is currently limited by the physical aperture in the vertical plane near the Lambertson magnet. That leads us to expect a strong vertical emittance dependence of the lifetime; we will run a series of simulations to confirm this. Also, we learned that the cleanest lifetime signature is probably not the dependence on cogging stage, but on bunch number within a cogging stage; we will do simulations varying the bunch number within a cogging stage.

Moreover, our machine model currently neglects nonlinearities in the arc magnets, lattice chromaticity, and emittance growth due to gas scattering. We will have to study what level of accuracy in the representation of the actual machine is required to reproduce the experimental results.

Model Independent Analysis (MIA) technique applied to PEP-II.

The principal function of these high-precision tools is to measure and analyze the transverse orbits in storage rings to accurately estimate the linear machine parameters for checking the machine quality and guiding the machine optics correction. They are being applied to the PEP-II rings.

After obtaining about 2000-turn BPM buffer data of the beam resonantly excited at the horizontal and vertical tunes, two pairs of conjugate linear transverse orbits are obtained with high resolution (2-orders-of-magnitude enhancement) through FFT filtering.

These two pairs of conjugate linear transverse orbits allow for the calculation of Green's functions and phase advances between BPMs. With an SVD-enhanced Least Square fitting of these Green's functions and phase advances, one can obtain a virtual machine (a fitted model for the real machine) in a computer for easier practice of choosing appropriate variables such as skew quads, etc, to obtain a wanted model that is with better desired optics characteristics, such as lower beta beatings, lower linear couplings, and lower IP betas. One then adjusts and corrects the real machine, based on the chosen variables through fast MIA fitting iterations until the real machine optics is as much close to that of the wanted model as possible. We expect extensive practice of MIA for improving the PEP-II LER and HER once the machine operation resumes in November 2002.

Upgrade of the SLC linac lattice for the experiment E158.

Lattice of the SLC linac had been upgraded to allow a simultaneous operation of different energy beams for the LER and HER rings and E158 experiment. The quadrupole focusing and the profiles of phase advance and beam energy in the linac had been modified to reduce chromatic variation of the betatron amplitude for different energy beams. The extraction lines to PEP-II rings had been updated as well. These modifications contributed to the successful operation of the E158 experiment.

Tuning knobs for the NLC Final Focus.

Local correction systems (tuning knobs) had been designed to correct linear and high order optical aberrations at the NLC Interaction Point (IP). Based on horizontal (x) and vertical (y) offsets of the Final Focus sextupoles, the five linear knobs can independently compensate longitudinal shift of the x/y beam waist at IP, x/y dispersion and the dominant coupling term. The non-linear knobs based on sextupole rotations, and sextupole, octupole and decapole strengths provide orthogonal tuning of the major second, third and fourth order geometric and chromo-geometric aberrations.

Particle tracking simulations in the Final Focus showed that the knobs are capable of correcting rather conservative field and rotation errors in the Final Focus reducing the IP beam size growth from the initial 10-50 times blow-up to 5-20%. The residual IP growth can be further reduced for more optimistic errors. Good orbit correction in the Final Focus is required for the most effect from the tuning knobs.

Injector Studies:

Collaboration on CLIC Test Facility 3 (Two Beam Linear Colliders). The purpose of the CERN Linear Collider (CLIC) Test Facility 3 (CTF-3) is to build a model of the two-beam power source envisioned for CLIC or for other Multi-TeV linear collider designs such as those proposed by SLAC physicists. The test facility will be built at CERN and SLAC is a major Collaborator. SLAC's contribution to the CTF-3 project is the design of the injector and the thermionic gun and the construction of the thermionic Gun.

In FY2002, SLAC completed the detailed design of the injector beam line. The injector beam line components are under construction currently with regular consultation with SLAC concerning construction details.

In FY 2003, SLAC will continue to participate in the detail design of individual components such as the various bunchers and diagnostics systems. We will also modify the beam line design in coordination with the mechanical design process. Finally, at the end of FY2003 SLAC will participate in the commissioning of the CTF-3 injector at CERN.

Collaboration on Fourth Generation Light Source at Spring8 in Japan. The purpose of the Spring8 Free Electron Laser is to provide a reliable 4-th generation light source as part of the Spring8 complex. A High brightness reliable beam from the injector is a critical requirement for this facility. Prof. Tsumoru Shintake of "Spring8" has proposed that a high brightness beam can be achieved from a Thermionic Injector with the gun running at very high voltage, 500 kV. If this effort is successful, it will be well known that thermionic injectors can run reliably for very long periods of time with mean time to failures measured in years.

In FY2002, SLAC signed a memorandum of understanding with "Spring8" to participate in the "Spring8" FEL project by designing the injector in collaboration with "Spring8". A preliminary layout of the injector has been completed, while detailed simulations to achieve the high brightness beams are ongoing.

In FY 2003, SLAC will continue the detailed design of the injector beam line and its components, such as the gun, the bunchers, the pulsers and the diagnostics.

Accelerator Structures. The work on accelerator structures consisted of theoretical and design studies, fabrication and experiments. We face two major challenges in designing X-Band accelerator structures for an electron-positron linear collider. The first is to demonstrate stable, long-term operation at NLC gradient, which is required to keep the machine cost low, and the second is to strongly suppress the structure long-range wakefield, which is required to achieve high luminosity. During the past year, the major emphasis has been on proving high gradient operation, although dipole wakefield suppression studies are continuing. This R&D program involves the collaborative efforts of a number of departments at SLAC, KEK and LLNL.

The six structures in the T-Series were built with different lengths and initial group velocities. The methods of cell manufacturing and cleaning for these structures also differed. For three of the structures, the cells were fabricated using poly-crystal diamond turning by a vendor near SLAC, and three were made at KEK using single-crystal diamond turning. Before assembly, the KEK cells underwent little (0.3 μm) or no etching as part of their cleaning procedure, while the SLAC cells were more deeply etched (either 1.5 or 3.0 μm). After assembly, all structures went through a pre-processing procedure that included 'wet' and 'dry' hydrogen firing at 950 °C, a two-week vacuum furnace bake-out at 650 °C, and a one-week in-situ bake-out at 220 °C. The program of high gradient tests took place at the NLCTA, which delivered a total 3000 hours of high-power RF at 60 Hz during this period.

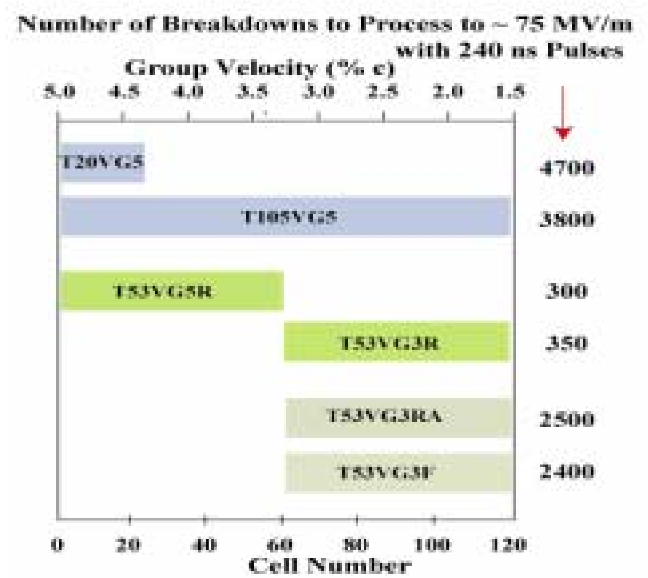
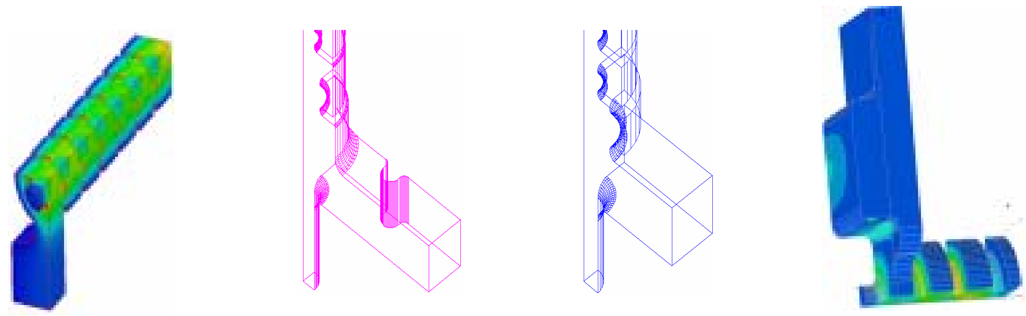


Table 1. T-Series High Gradient Test Structures

The breakdown rates in the body of the structures (i.e., excluding the couplers) at 70 MV/m gradient are close to acceptable for the NLC/JLC. For the three 53 cm, 0.03 c initial group velocity structures that were run at the NLC/JLC design pulse width of 400 ns, the breakdown rates were < 0.1, 0.2 and 0.3 per hour, respectively (the goal is < 0.1 per hour). The breakdown related damage was measured by the change in the RF phase advance profile along the structures. Finally, the net phase change in the body of the 53 cm, 0.03 c structure after 1200 hours of operation, including processing, was only 0.5º.

After processing to 80-85 MV/m, the breakdown rate at 70 MV/m was dominated by events in input and output couplers. The RF signature of these events was different from those in the body and was similar structure-to-structure. An autopsy of the input coupler of one of the structures revealed severe damage and some melting on the edges of the waveguide openings to the cell, and extensive pitting near these edges and on the coupler iris. The waveguide edges see large RF currents that are a strong function of their sharpness, and the associated pulse heating can be significant. By design, the edges in the T-Series structures were sharper (76 µm radius) than those in the 1.8-m structures (500 µm radius). The predicted pulse heating for the T-Series structures is 130-170 °C, well below the copper melting point, but high enough to produce stress-induced cracking, which can enhance heating.

Several coupler designs with much lower pulse heating have been proposed. They are illustrated in Figure 2 with the field patterns shown in two cases. Type (a) is a traditional coupler with a 3 mm full radius at the edges of the coupling irises. The temperature increase due to pulse heating is less than 50 °C for a 70 MV/m gradient and 400 ns pulses. Type (b) and (c) use rectangular TE to circular TM mode converters with different matching designs. Type (d) has an RF choke in order to increase acceleration in the coupler cavity. The pulse heating for (b), (c) and (d) is negligible.



(a) (b) (c) (d)

Figure 1. Several couplers with low pulse heating.

Test structures with type (a) and (b) couplers were fabricated. The type (b) input coupler in T53VG3MC structure has showed superior properties in August-September, 2002 test.

Although the results from the T-Series structures are encouraging, their average cell iris radii are too small to meet NLC/JLC short-range wakefield requirements. To increase the iris size while maintaining a low group velocity, a structure design with thicker irises and a higher phase advance per cell (150^{o} instead of 120^{o}) design has been designed. Two of these structures (H-Type) have been built, one 60 cm long with an initial group velocity of 0.03 c (H60VG3R), and the other 90 cm long with an initial group velocity of 0.05 c (H90VG5R). The structures have been installed in NLCTA and now are under high power test. During the next year, several more H-Type structures will be tested,; culminating in one that is fully damped and detuned for wakefield suppression. The renewed awareness of pulse heating has also led to design changes in the manifold slots for damped structures. Figure 2 shows the new accelerator cup design for the H-Type Damped Detuned Structure (HDDS).

Figure 2. HDDS cup with pie-shaped dipole mode coupling slots. The temperature rise due to RF pulse heating is reduced from 70^{0}C to about 25^{0}C by rounding the slot edges with a 0.5-mm radius on the disk and a 2-mm radius at the cell radius.

Encouraging high gradient performance was obtained in early standing wave structures, SW20PI and SW20a565. After processing, the average breakdown rate at 55 MV/m was about 0.1 per hour per structure during a several hundred hour period, which is about a factor of two higher than desired for these short structures. No discernable shift in frequency (< 100 kHz) was measured in either structure after 600 hours of operation. Two SW20a375FC structures with much lower ratio of surface field to accelerating field, improved fat coupling iris coupler and RF choke cavities are being fabricated and will be tested in early 2003. In a parallel effort, we are still studying detuned SW structures.

Other Theoretical Studies:

1. We are making a significant push toward the NLC structure finalization and optimization in a rather broad parameter space.
2. We have improved the equivalent circuit analysis. A speed enhancement of a factor of 100 or more has been achieved in the calculation of the spectral function and wakefield. Also, the wakefield computation has been optimized so that the wakefield can be minimized routinely as several parameters are varied. This has allowed several thousand spectral function calculations to be made whilst the square of the RMS and the standard deviation of the sum wakefield was minimized.
3. Theoretical and simulation studies on breakdown mechanism and high gradient operation issues will be continued.
4. In order to verify the wakefield suppression, a wakefield measurement scheme using a coaxial wire is being developed.

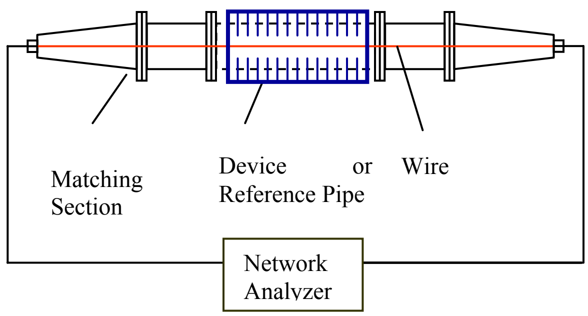


Figure 3. Wire system for wakefield measurements.

High Power RF. During this fiscal year, we finalized the detailed design for a high power Dual moded SLED-II system. This system should be able to produce 400 ns pulses at power level above 600 MW at X-band. A compact and efficient reflective mode converter, located at the end of the transmission line, converts the TE01 mode to the TE02 mode and vice versa. This has the effect of doubling the delay of the transmission line for a given length.

a)

b)

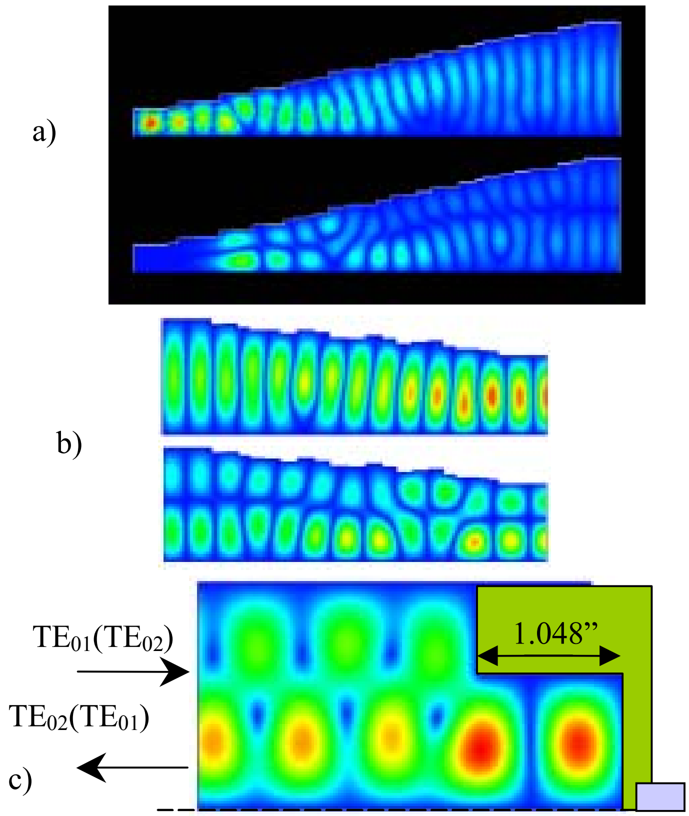
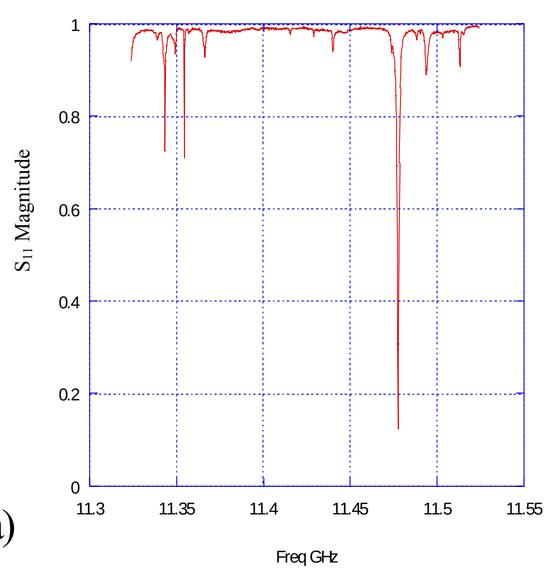


Figure 1: Radial profiles and field patterns of tapers for a highly overmoded, two-mode reflective delay line: a) input taper, b) end taper, c) reflective mode converter.



a)

b)

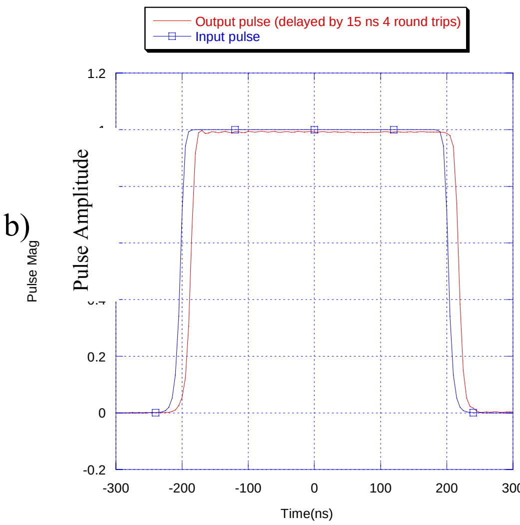


Figure3: a) Measured frequency response and b) constructed time response of the dual-moded taper assembly.

The delay line waveguide diameter is 6.725". At 11.424 GHz, these waveguide are highly overmoded. Tapering up and down to the input waveguide diameter requires a set of dual-mode tapers. The taper designs are shown in Fig. 1 and the measured response of the input and output taper is shown in Fig. 2. The tapers were designed using optimization algorithms, which run over a fast mode matching simulators. These design techniques proved quite useful, and we have been able to design tapers and mode converters for 4 and even 10 mode delay line. These techniques could reduce the size of any future pulse compression system by a factor of 10 or more.

Research in accelerator structure couplers revealed the importance of transient pulse heating over edges. We have redesigned most of our planar components so that the peak temperature rise during the pulse is less then 10 C^{o}. We built a special set of standard adaptors for cold testing these overmoded components. Most of our components are now cold tested with an outstanding performance; they have extremely low insertion and transmission losses. The result of cold testing agreed well with simulations.

Our effort to understand the breakdown phenomenon in RF structures and components continued. Because of the complexity involved in simulating breakdown phenomena in a traveling wave accelerator structure composed of tens of cells, we thought of a concept for a single cell traveling-wave accelerator structure. To this end we needed to design a low field accelerator structure coupler suitable for this test setup. This coupler was designed and actually proven to be advantageous even for a real accelerator structure. This so-called mode converter coupler, was tested at high power and contributed to the success of a stable x-band 70 MV/m accelerator structure.

Our theoretical ideas for non-reciprocal devices using ferrites and garnets in over-moded waveguides have now been put into engineering designs. We built and cold tested a non-reciprocal phase shifter that uses the circular TE_{01} mode. This cold test agreed well with the simulations. We are now in the process of high power testing this device.

We are also examining several techniques for building high power over moded semiconductor switches. We are using silicon on insulator technology so that the device could be built over a very thin active silicon layer. This will minimize the total charge carriers needed for switching hence improve both efficiency and speed of the device.

Advanced Beam Concepts. During the past year the group's activities has been largely migrated to theoretical and experimental studies of particle astrophysics and cosmology. The main focus has been the nature of dark matter and dark energy, as well as astrophysical phenomena under extreme conditions. The group now consists of three senior physicists, one term physicist, two postdoctoral research associates, and one graduate student. 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.

- **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. Irwin is currently preparing a formal paper to report on this.

In addition, he and Marina Shmakova now collaborate with Tony Tyson and coworkers at Bell Labs in applying this new methodology to actual data analysis. The eventual goal is to participate in the analysis of the data from the Large-area Synoptic Survey Telescope (LSST) for the study of dark matter and dark energy.

Early Universe Code Development

We are developing a computer simulation code to study the evolution of the early universe. This effort is led by Kathy Thompson and joined by many in the group. The Phase I effort is focused on developing the code that simulates the evolution of the universe from the inflation epoch to the decoupling epoch. Different theoretical models will be employed with an aim to find their different predicted signatures or imprints on the cosmic microwave background (CMB) or gravitational waves.

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 $\sim 10^{16}$ GeV/cm. With such high efficiency, super-GZK energy can be reached in the close vicinity of a GRB.

Experimental Activities:

- **High Energy Laboratory Astrophysics (HELA)**

An international workshop organized by the group on Laboratory Astrophysics using High Intensity Particle and Photon Beams, was held in October 2001. The intent was to explore the possibility of using beams from particle accelerators, such as the one at SLAC, to address some critical issues in astrophysics. 70 scientists attended the workshop and near 40 presentations were given. It was generally agreed that such high intensity particle as well as photon beams should be powerful tools for calibrations of high energy astrophysics observations, for investigations of underlying dynamics in high energy-density astrophysical phenomena, and for bench-marking large scale astrophysical simulations codes. Since the workshop, the group continues to push for an international collaboration for further developing such a program and facility at SLAC.

- **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 five-institution, international collaboration led by this group at SLAC and the HiRes group in Utah has recently (August 2002) submitted a proposal (E-165) to measure carefully this yield using SLAC's beams.

A proof-of-principle experiment, T-461, was carried out in the FFTB in June 2002. The apparatus, consisting of two PMT's viewing the interior of a gas chamber, was located at an air-gap about 15 meters upstream of the FFTB beam dump. SLAC was able to deliver beams ranging from 2×10^8 to 1.5×10^{10} electrons per pulse at 29 GeV energy at a rate of 10 Hz. The fluorescence yield was measured for dry air, pure nitrogen and various mixtures at pressures ranging from 3 to 760 Torr. The yield and the signal time structure are consistent with air fluorescence.

In all, 21 physicists, students, and engineers participated in the successful test run from the University of Montana, Rutgers University, SLAC, and the University of Utah.

Advanced Accelerator Research B

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 we have had eight experimental runs (as experiments E157 and E162) for a total of nine months of beam time from June 1999 through December 2001.

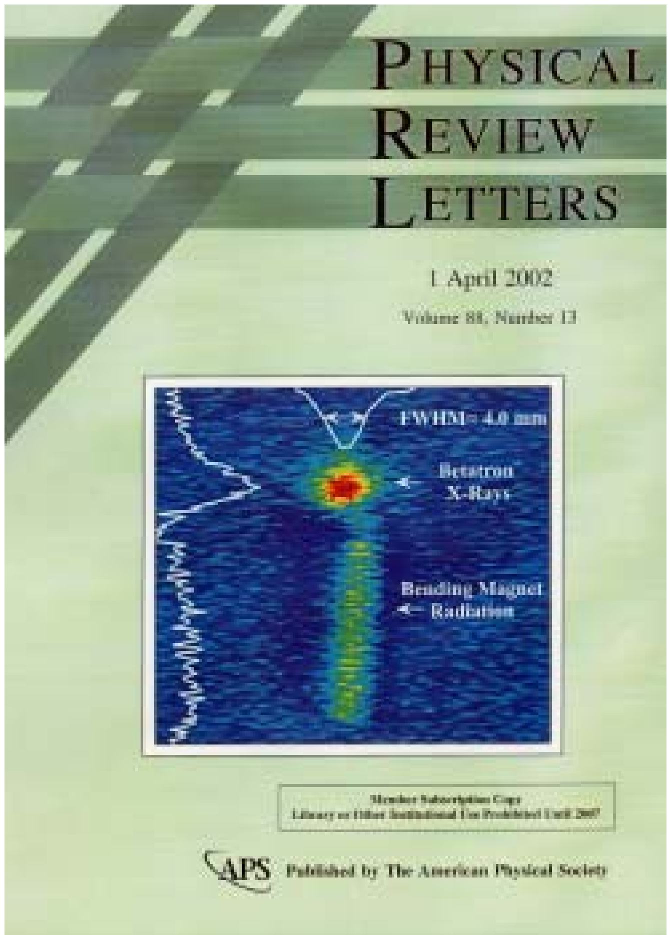
Analysis of the E157 data was completed during the past year, and several papers were published based on these data. They were:

- Shuoqin Wang *et al*, "X-Ray Emission From Betatron Motion In A Plasma Wiggler", Physical Review Letters **88**, 135004 (2002) – Measurement of the X-ray production from betatron oscillations in a plasma.
- C. E. Clayton *et al*, "Transverse Envelope Dynamics of a 28.5 GeV Electron Beam in a Long Plasma", Physical Review Letters **88**, 154801 (2002) –

Measurement of the stable propagation of a high-energy electron beam through a 1.4 m-long plasma.

In addition, a review of the E157 and some preliminary E162 results has been published

- C. Joshi *et al*, "High Energy Density Plasma Science with an Ultra-Relativistic Electron Beam", Physics of Plasmas **9**, 1845 (2002).



Cover of the April 1, 2002 Physical Review Letters with a figure from the E157 paper on X-ray emission from betatron motion (Shuoqin Wang *et al)*

Analysis is now concentrating on the E162 data. We have made measurements of focusing and plasma dynamics for 5 psec long positron and electron bunches. The former measurements were based on a streak camera, and the latter measurements used a novel experimental technique based on an energy chirp on the bunch and the E162 imaging magnetic spectrometer. Analysis of the positron data is nearing completion, and the electron results have been submitted for publication. Acceleration measurements have been a high priority goal. A draft of the electron acceleration results is being circulated within the collaboration, and results for the acceleration of low intensity positron beams are not far behind. Data on the acceleration of high intensity positron beams taken in December 2001 remains to be analyzed.

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 has been approved and is scheduled to run next year with a 0.1 mm long bunch and a new, higher density plasma source. Accelerating gradients of over 10 GeV/m are expected. We have also submitted a proposal, E164X, to extend these measurements to even shorter bunches, 0.02 mm, and higher 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.

We are collaborating with physicists from Stanford on an experiment being performed at the Hansen Experimental Physics Laboratory (HEPL) on the Stanford campus. There an open structure a fraction of a mm long is driven by a synchronized Titanium Sapphire laser. Gradients close to 1 GeV/m are possible. The major improvement to the experiment this year was the installation of an energy collimation system to make the signal clearer. Despite this, we did not observe laser acceleration during our 1½ week long run this year.

The scarce beam time at HEPL, led us to propose SLAC experiment E163. E163 would *1)* continue the proof-of-principle research started at HEPL, *2)* bunch the beam at an optical wavelength, and *3)* measure acceleration in multiple-cell structures. E163 has been approved, and building this experiment at the NLCTA (Next Linear Collider Test Accelerator) is a major ARDB activity. Major components are a laser driven RF gun, a shielded experimental area, and a room to house the experimental lasers. The technical components 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 designing E163, and the major construction activities are expected in FY2004.

In addition to experimental work, a collaboration of physicists from Stanford, the Technion, and ARDB has begun a theoretical study of laser driven accelerators. The goal is the design of an energy efficient, manufacturable structure. We have been able to derive a general framework for a laser driven accelerator based on efficiency, beam dynamics, heat dissipation, and the use of lithography or optical fiber drawing (Levi Schächter et al, Optical Accelerator: Scaling Laws and Figures of Merit, contributed to the Proceedings of the 2002 Advanced Accelerator Conference). We will be designing specific accelerator structures using electromagnetic field calculating computer programs, modeling them at RF frequencies, and testing them as part of the E163 experiment.

A collaboration consisting of UCLA, USC, Stanford, and SLAC/ARDB 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 has been included in the FY2004 SLAC Field Task Proposal. A second ORION workshop is planned for February 2003, to get input on technical parameters and facilities from prospective users.

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. Seung Lee (USC), Sho Wang (UCLA) and Brent Blue (UCLA) have or will receive their PhD's from E157 and E162, and Tomas Plettner (Stanford) will receive his PhD for the experimental laser acceleration work at HEPL. There are five ARDB graduate students at the present time, and students from our collaborating institutions will join them for the upcoming experiments.

8. FY02 Progress in Advanced Computations Research (Kwok Ko)

Research activities in FY02 have centered around the DOE SciDAC project, whose goal is the development of scalable codes for large-scale accelerator simulations on terascale platforms. Towards this end, the three groups in the Advanced Computations Department (ACD) – Accelerator Modeling, Computational Mathematics, Computing Technologies, have been organized to further improve Omega3P and Tau3P, and to apply them to tackle several key accelerator design issues. These include the heating analysis for the PEP-II IR upgrade, NLC structure design, peak field studies in high gradient structures, and dark current simulation.

The SciDAC initiative emphasizes the importance of collaboration between the application scientists who are doing the modeling and those in the computer science/applied mathematics (CS/AM) community who have been developing efficient tools to facilitate terascale simulations. In the past year, the ACD has worked closely with SciDAC members in other institutions who are either supported by the Scientific Application Partnership Program (SAPP), or are associated with the Integrated Software Infrastructure Centers (ISIC's). These collaborative efforts in the CS/AM area along with the contributions from all three groups in ACD are described in the progress summaries that follow.

PEP-II IR Heating Analysis. Eigenmode calculations with Omega3P have been carried out for the PEP-II IR chamber using the previous configuration that showed excessive heating during beam operation. The power distribution was obtained by summing the contributions from 330 modes in the 2-6 GHz range and found to be in qualitative agreement with measured data. The actual beam paths were considered in calculating the shunt impedance of the modes. A localized mode around 5 GHz with high loss has been identified near the problem area. Work is in progress to perform the same analysis on the PEP-II IR upgrade. Initial meshing issues with the new geometry were resolved with help from collaborators at Sandia who belong to the TSTT /ISIC. Under SAPP, Stanford made significant improvements to Omega3P that enable tightly-clustered eigenvalues, as is the case here, to be computed with better efficiency and much reduced memory requirement (50%). The new implementations are deflation algorithms, a thick restart, and a parallel library for symmetric matrix computations.

NLC Structure Design. The table of dimensions for a new damped structure with high phase advance (HDDS1) has been determined using Omega3P. The temperature rise around the damping slots due to RF pulse heating has been reduced to a tolerable level by rounding of the slot edges. Omega3P has been improved to now include a parallel direct solver, which has been developed at LBNL, and benchmark has been made against the existing indirect solver on a 47-cell section of the RDDS structure. Parallel performance comparison between the two solvers is underway. In addition, a convergence proof has been established for the filtering algorithm upon which the eigensolver in Omega3P is based and with it, the SCCM student Yong Sun completed his PhD thesis.

Peak Field Studies in High Gradient Structures. Using Tau3P, end-to-end modeling of an entire accelerator section has been carried out to study the peak field in the structure as a function of pulse rise time. The idea is to reproduce actual high power tests on the computer in order to better understand the mechanisms that limit present structures from reaching higher gradients. Preliminary results on a 30-cell structure indicate that the peak field during transients could be as much as 20% higher than the steady-state value. The calculation also provides the transient field distribution in the entire structure including the couplers that may shed light on RF breakdown and dark current capture issues. Simulations of other structures that have been high power tested are in progress.

SciDAC CS/AM collaborations on Tau3P in support of this study include the following: Working with Sandia quality metrics have been established so that correlations between simulation cutoff time due to long time instability and mesh properties such as smoothness and orthogonality could be identified. Empirical studies thus far show that mesh quality has a strong effect on stability. Working with LLNL higher order correction schemes to the present discretization method in Tau3P are being looked at with the goal to extend the stability cutoff time. Work is also continuing with LBNL on finding alternate parallel partitioning tools to ParMETIS that are within the Zoltan library to improve the Tau3P performance through better load-balancing/communication strategies.

Dark Current Simulation. The particle tracking module Ptrack3D with field input from Tau3P has been benchmarked against 2D trajectory results in axisymmetric cases. In actual structures, particle trajectories show rotation about the beam axis as a result of the 3D fields due to the power couplers. Work has started on benchmarking the code against dark current energy spectra obtained from measurement in sample test structures to validate the surface physics model within the code that include both primary and secondary emissions. To help with understanding the complex particle and field behavior involved in dark current generation, development of novel visualization techniques has continued in collaboration with UC Davis. The goal is to capture and simultaneously display all essential information from simulation, such as surface field magnitude, field vectors, trajectories of primaries and secondaries, as efficiently as possible.

Progress in Other Research Activities. Adaptive refinement techniques for eigenvalue problems have been explored in 2D using two approaches. The first is based on p-refinement, which increases the order of the basis function but keeping the same grid in the next solve. The second uses the h-refinement by interpolating the coarse mesh results onto a denser mesh as the initial guess for the refinement step. Comparison between the two methods is in progress to determine a promising approach to adopt for implementation in Omega3P. Dielectric material, both lossy and lossfree, have been incorporated into Tau3P and the first target application is the dielectric accelerating structure at Argonne. Also developed for Tau3P is a 2D Laplace solver that is useful for wakefield integration in cavities of complex cross sections. Finally, 3D gun optics calculations have supported the design of a sheet-beam klystron prototype presently under fabrication, and a Phase 1 SBIR collaboration with STAR Inc. has led to a Phase II continuation to further enhance the features of the GUI developed for Tau3P.

9. FY02 High Polarization Electron Source Development (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, surface analytical research on high electric field structures for advanced accelerator research, and precision beam size measurements at the FFTB (picosecond electron beam magnetic field switching in magnetic materials)

Cooperative research was completed with SSRL at the FFTB on Experiment T456, the response of magnetic matter to the ultra-short picosecond magnetic field pulses generated by the passage of the SLAC Linac 28.5 GeV electron bunch. Originally a collaboration with ETH-Zurich and IBM-Almaden and now SSRL, the experiment consists of puncturing magnetized films with a small diameter (several microns) 40 GeV electron beams. The de-magnetization response of the film to the passage of the electron beam's field is mapped off-site in a spin-mapping microscope. Such measurements determine the fundamental limit of magnetic theories at micron dimensions.

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. To overcome the charge limit phenomenon, high-gradient-doped strained GaAsP photocathodes have been developed. The electron-emitting active layer is doped at $5x10^{17}cm^{-3}$ with a 10-nm surface layer doped at $5x10^{19}cm^{-3}$. This lower-than-standard doping level in the active layer achieves high polarization, while the high surface doping solves the charge limit problem. The End Station A experiment, E158, required a beam intensity of $8\ 10^{11}\ e^-$ in a 370 ns pulse. Because the beam intensity requirement was difficult to meet using the standard SLAC photocathode structure, a newly developed photocathode was installed in the SLAC polarized electron injector in January 2002. The charge output was measured to be linear up to the maximum injector laser energy, producing a maximum charge of $2.3\ 10^{12}\ e^-$ in 100 ns. The charge output was observed to scale with the laser pulse length, reaching more than $8\ 10^{12}\ e^-$ in a 370 ns pulse. The charge output corresponds to ten times the E158 requirement and more than twice the proposed NLCtrain charge. The beam polarization measured by the Moller polarimeter in End Station A was 82%.

To achieve even higher polarization, we are investigating strained-superlattice photocathodes based on GaAs and GaAsP. A DOE SBIR Phase I award was made to SVT Associates, who grow such wafers using molecular-beam-epitaxy (MBE). Two test wafers yielded a record polarization of 86%. Based on the success of Phase I, a SBIR Phase II award has been approved, to further optimize the superlattice structure for higher polarization.

10. FY02 Progress in Fractional Charge and Massive Particle Research (Martin Perl)

We have begun 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 materials in the solar system, and is one of the best candidates for containing fractional charge particles. We believe that asteroidal material is about one million times more likely to contain fractional charge particles, if they exist, compared to terrestrial material.

In the course of developing more reliable suspensions of powdered meteorite in oil for use in drop-on-demand technology, we have made several contributions to this technology, for example the introduction of internal mixing in the drop ejector.

Working with a researcher from the School of Pharmacology of UCSF, we have been studying whether a colliding drop technique can be used to make liposome-coated, aqueous-center drops of uniform diameter for drug delivery. This might provide a more controlled method for the chemotherapy treatment of cancer. In order to accomplish this we have build an apparatus that allows the controlled collision of two different drops, each produced by our drop-on-demand technology.

A member of our research group, Eric Lee, has written the definitive book on microdrop generation, the book will be published early in FY2003. This book is a major contribution from SLAC to the industrial and scientific use of small drops, and is based on ten years of fundamental and applied research at SLAC on small drop generation and use.

11.FY02 Progress in Test Beam Program

During FY02, five test beam experiments were conducted:

T-457 Measurement of Neutron Energy Spectra Using Bonner Multi-Sphere Spectrometer, T. Nakamura (Tohuku University, Japan), S. Rokni (SLAC), FFTB. Measure neutron energy spectra outside the FFTB dump shield from thermal energies up to 800 MeV and compare with results from FLUKA code.

T-460 Characterization of Askaryan Effect in Rock Salt, P. Gorham, University of Hawaii; Manoa, Honolulu, D. Saltzberg, FFTB. Measurement of Čerenkov radio emission and its polarization from electromagnetic showers generated by gamma rays in rock salt.

T-461 High Atmosphere Fluorescence, P. Chen (SLAC), P. Sokolsky (University of Utah) FFTB. Measurement of detection efficiency for beam induced fluorescence of near atmospheric air. This is the first part of a series of investigations and more refined measurements of the light producing signal mechanisms of the HiRes Ultra High Energy cosmic ray detector.

T-462 Magnetization Dynamics of Soft-Magnetic Films, H. Siegmann, J. Stohr (SLAC) FFTB. Research on the response of magnetically soft films to the ultra short magnetic field pulses of the FFTB electron beam.

T-464 Correlation of Linac Transverse Deflection Cavity with FFTB Streak Camera, M. Hogan (SLAC) FFTB.

T-457 Measurement of Neutron Energy Spectra using Bonner Multi-sphere Spectrometer. This research is a continuation of T-451 and T-454, and measures neutron energy spectra outside the FFTB dump shield from thermal energies up to 800 MeV and compares those to results from FLUKA code simulations. An international collaboration consisting of physicists from Tohuku University, CERN, and SLAC made measurements in early June 2002 using a Bonner Multi-sphere Spectrometer and an NE213 scintillation counter. The studies covered a wide range of energy and several discrete thicknesses of extra concrete shielding.

Whereas the earlier measurements had focused on the high-energy part of the neutron spectrum, this study also covered the low-energy part of the spectrum. This is the first time that the neutron spectra were measured over such a wide range of energies and through the shielding enclosure of a high-energy electron accelerator. The results of this experiment will be used to benchmark shielding calculations in particle accelerators.

T-460 Characterization of Askaryan Effect in Rock Salt. In T-444, the Askaryan effect was experimentally verified. Using silicon dioxide sand as a shower and absorption medium, it was conclusively shown that selective scattering and absorption processes in a photon induced high-energy cascade lead to a net negative charge excess, which results in coherent radio Čerenkov emission. The technique of radio-frequency detection of high-energy cascades from neutrinos and other high-energy particles of cosmic origin has received renewed interest as a result of detection of very energetic cosmic rays ($\geq 10^{20}$ eV, and above the GZK cutoff [See also T-461]). T-460 was the next step to further characterize the Askaryan process, particularly the cascade energy and radio frequency ranges over which coherence of the emission is obtained as well as to test the validity of polarization tracking of the shower. A stack of ~3 tons of pressure-molded rock salt blocks were used as the cascade shower medium during a one week period in June 2002. This medium is attractive since subterranean rock salt deposits show promise of large radio-transparent masses required for cosmic neutrino detection. The tests had four main goals:

1. Polarization tracking. The expected co-and cross-polarized ratios were observed in the dual-polarization antennas imbedded in the salt brick stack. It is expected that further analysis of the data will allow the quantification of the precision of particle track estimates based on the polarization measurements with good accuracy;
2. Extension of energy scale. The experiment allowed the extension of the range of the energy scaling of the Askaryan effect by well over four orders of magnitude of beam intensity, thereby exceeding the goal of T-444;
3. Coherence roll off at high frequencies. Askaryan Čerenkov radiation was observed up to a frequency of 15 GHz, which exceeds the previous measurements by a factor of 3. The signal-to-noise ratios appear to be high enough to facilitate measurement of the spectral roll off;
4. Transition radiation. Measurements of the rf transition radiation from the Askaryan charge excess were completed. A preliminary analysis of this transition radiation signal compares very well with a value calculated for the Bremsstrahlung shower.

Primary electron beam energy was 28.5 GeV with 10^9 to 2×10^{10}/pulse and 1 to 10 Hz. Bremsstrahlung radiator thickness varied from 0.01% to 1% of a radiation length.

T-461 High Atmosphere Air Fluorescence. 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 underlying physics, both groups are currently investigating systematic effects that might contribute to this discrepancy. One such effect is air fluorescence yield. T-461 is a proof-of-principle experiment, which was conducted in the FFTB between June 10 and June 16, 2002. The experimental apparatus was installed in an air-gap approximately 30 m upbeam of the FFTB beam dump and consisted of a gas-filled fluorescence chamber the interior of which was viewed by two PMTs. The electric beam energy was 28.5 GeV with pulse intensities varying from 2×10^8 to 1.5×10^{10}/bunch and 10 Hz. The fluorescence yield was measured for dry air, pure nitrogen and various mixtures at pressures ranging from 3 to 760 torr. The observed yields as well as the signal time structure are consistent with air fluorescence. Although detailed analysis remains to be completed, it was found that a strong, perhaps quadratic, dependence of the nitrogen fluorescence rate and the beam intensity appeared above $\sim 2 \times 10^9$ per pulse. This may have been caused by avalanche ionization due to the intense beam fields. Consequently, considerable time was spent with lower electron beam fluxes, clear down to 5×10^8 per pulse (which is below the range of the FFTB beam position monitoring instrumentation). It was found to be possible to study pressures as low as 3 torr, almost two orders of magnitude lower than was expected ahead of the experiment. A linear rise in light yield with pressure was observed to saturate at ~100 torr. The yield ratio between air and nitrogen was observed to be 1:5.5, settling a disagreement between previous workers. The determination of absolute yields awaits a detailed measurement of the light collection efficiency of the optical system, but the results already exceed what the collaboration anticipated. A total of 21 physicists, students, and engineers from the University of Montana, Rutgers University, SLAC, and the University of Utah participated in the successful test run. A proposal (E-165) to more carefully measure this yield using SLAC's beams has been submitted for consideration.

T-462 Magnetization Dynamics of Soft-Magnetic Films. This research is a continuation of T-456 and is part of an integrated program involving advanced fabrication and characterization of nanostructured materials. The emphasis of this program is on a unique nanoscale magnetization dynamics measurement using high-intensity and picosecond-duration magnetic field pulses delivered in the FFTB. Nanoscale magnetization switching is emerging as one of the central scientific topics in modern magnetism. It is also extremely important to magnetic recording technology since nanoscale and ultra fast magnetization switching is at the heart of future data storage devices.

Beam was delivered to the experiment installed at the focal point of the FFTB on June 14 and June 19, 2002. The run had four different purposes:

1. Complement previous experiments with future high density magnetic recording materials of the synthetic anti-ferromagnetic type;
2. Develop ideas to generate picosecond high current densities in solids for later use in spin injection and processional magnetization switching;
3. Examine the response of soft magnetic materials to the picosecond magnetic field pulses; and
4. Examine the role of paramagnetic/ferromagnetic interfaces in the damping of the magnetization procession.

A total of 10 thin film samples each 10*mm* wide and 8-10*mm* high were exposed in predetermined locations to one or several electron bunches. The electron beam energy was 28.5 GeV and the beam was exceptionally well focused with the aid of wire scanners at the location of the samples. The Gaussian distributed beam had a transverse width of 5.18 µm and a height of 3.38 µm, and produced magnetic field pulses in the laboratory frame of a 2 to 10 picoseconds duration. Data analysis under way using an electron microscope to measure the resulting response of the material to the picosecond circular high intensity magnetic field. The samples were made at Stanford University, UC Berkeley, Simon Fraser University in Vancouver, BC, and the IBM Almaden Research Center.

T-464 Correlation of Linac Transverse Deflection Cavity with FFTB Streak Camera**.** In preparation for E-164, test beam T-464 was conducted to correlate the bunch length measurements made with the deflecting cavity in Li29 to the measurements made by the E-157/E-162 streak camera set-up in the FFTB. The 100 µm bunch length that will be used in E-164 is below the temporal resolution of the streak camera. The deflecting cavity in Li29 will thus be the only bunch length diagnostic in E-164. Correlating the two diagnostics is important for continuity between D-162 and E-164. T-464 was conducted on June 8-9, 2002. The mean bunch length measured by the cavity in Li29 was 15% less than that measured by the streak camera, but within the 1-sigma spread in the measurements. The streak camera measurements were made after tuning the linac at the shortest bunch length and then changing the bunch length via the compressor cavity in the damping ring. Changes in the compressor voltage resulted in a fall off in charge transmission by up to 20% at the extremes. Changes to the charge transmission and other factors contributed to the relatively large spread in the experimental data. Although impractical in the time allotted for this test beam, future measurements should set the compressor voltage, re-optimize the phase ramp and linac steering, make a set of measurements and repeat for the required number of steps in compressor voltage.

12. FY02 Progress for the EXO double-beta-decay R&D program (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 60 mm gap and measures the transport efficiency. We have confirmed electron lifetimes of ~1 ms in purified LXe in this way, and have reproduced electron drift velocities available in the literature.

We have also started a series of experiments to test the feasibility of electrostatic ion extraction from Xenon. A "probe-test cell" has been built that 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 Ra^{222} ions into the Xe. We have seen that the probe tip, if set to negative potential, collects radioactive ions (Radium α decays confirm presence of the species). Studies are planned to test if the collected ions can be released (perhaps by appropriate probe design), and to measure the ion drift velocities and neutralization lifetimes in LXe.

We have also developed a conceptual design for a ~10 kg prototype apparatus, which we hope to test locally, and which we hope can be scaled up to ~100 kg for installation at WIPP. 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. The design of a full-scale device incorporating Barium identification will follow pending the results of our R&D effort.

13. FY02 Progress in E159/E160/E161 and ESA Photon Beamline (Perry Anthony)

The following was written about FY2002 work on these experiments. As of October 2002, all work has stopped pending clarification of future funding.

At their November 2000 meeting, the SLAC EPAC recommended approval of the E159/E160/E161 series of Coherent Bremsstrahlung Beam experiments. These experiments require the re-establishment of the Coherent Bremsstrahlung source and photon beamline in the A-Line leading to the ESA facility. FY02 has seen continued intensive design efforts on the part of the Real Photon Collaboration (RPC), the Accelerator Department, and the Experimental Facilities Department to finalize designs for the photon beamline and conduct the final conceptual design review for the first experiment, E160. E160 received a favorable review from the SLAC-based review committee headed by Research Division's Chief Engineer. This final conceptual design review was held on June 2, 2002.

Work to prepare the A-line structure for the re-installation of the photon beamline continued with the removal of additional magnets and dump line components, and installation of interim beam drift tubes (to replace components removed from the beamline that are not needed for current ESA experiments). Detailed designs of all beamline components have been completed, and planning has started for resurrection of the spent electron beam dump cooling system.

Substantial progress has been achieved on the refurbishment of the goniometer control system. New control electronics and a LabVIEW based user interface were developed to replace the original system. The original (1983) stepper motor performance and goniometer position control parameters were achieved with the new control system. Functionality of the “Micro-Syn” precision position readout system built into the goniometer axis was verified and control electronics designed.

Spectrometer designs for E160 have been completed, including the generation of detailed 3-dimensional magnetic field maps. Designs have been iterated to optimize detector resolution and physics design goals.

Optimizations of detector designs for E160 are well underway. Testing of phototube performance in simulated fringe fields expected from the spectrometer magnets was done to determine the best placement of mu-metal shielding and quantify maximum allowed fringe field strengths to determine detector plane placement. Final engineering drawings of these detector packages will be presented at the final design review.

Considerable effort has gone into the physics simulation of E161, and an improved method for identifying open charm events has been identified. Substantial work has gone into preparing the dilution refrigerator that will be used with the E161 polarized target.

Studies have been carried out to determine the feasibility of E159, re-using the high field target magnet used in previous ESA experiments (most recently E155). This magnet has a much wider central bore region than currently available commercial magnets. Current E159 simulations indicate that this larger bore is desirable to limit backgrounds from beam halo. This magnet would also be useful to other research and development efforts at SLAC in support of NLC.

During the summer of 2002, RPC research and development work at SLAC included the efforts of four visiting graduate students (including one from Yerevan, Armenia), two visiting undergraduate students, one student from the DOE Energy Research Undergraduate Laboratory Fellowship program, and a visiting scientist (from Yerevan).

14. Theoretical Physics

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 the 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 coming year, we are looking forward to improving this program to allow it to more easily incorporate multiparticle Standard Model background processes and a more realistic treatment of the transverse momentum smearing by initial-state radiation.

Physics at Bottom and Charm 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 delicately. Studies have also been made on precision measurements on tau pair production, including probes of CP violation in this sector to determine what can be learned. In the current year, much of our activity will be devoted to understanding rare B decays mediated by photon, Z, and gluon penguin diagrams, and to clarifying the theory of the CKM mixing parameter Vub. Both of these topics are newly illuminated by substantial data sets from the B factor experiments

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 the renewed running of 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. For the case of one-loop diagrams, information from analytic structure and unitarity, from the use of special gauge choices, and from selection rules of supersymmetry applied to subsets of diagrams, have been combined to give a complete accounting of QCD processes involving a total of 5 partons. Recently, these techniques have been extended to two-loop diagrams. Members of the Theory Group have been involved in the complete calculation of two-loop amplitudes for 4-parton quark and gluon reactions, and in the evaluation of the two-loop correction to Higgs boson production at the LHC. The new methods developed in this study have applications to a large number of other QCD processes, for example, inclusive jet production in hard-scattering and Drell-Yan processes. This approach will be pursued 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. One promising current direction is the study of nonlocal theories of quantum gravity, in which the form of the nonlocality derives from the addition of terms in the equations of motion that are simple in the field theory which is dual to the gravity theory through Maldacena's AdS/CFT correspondence. The constraints of duality give the hope that the gravity theory might appear local in microphysics experiments, while retaining a global nonlocality that controls the cosmological constant. Another direction being pursued is that of studying the effect on superstring models of including nonzero values of the higher-spin gauge fields present in these models, in particular, values that have nontrivial topology in the compact extra dimensions of string theory. This technique allows supersymmetry to be broken down systematically and in a milder fashion than more direct approaches. These and other approaches to this challenging problem will be pursued in the coming year.

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 creation of new unified gauge models based on model-building tools abstracted from brane and other string construction, and the detailed analysis of supersymmetry and its spontaneous breaking in models with branes. The realization of supersymmetry in extra-dimensional theories with branes is likely to lead to tests of brane and string theory ideas at the next generation of colliders; thus, it is anticipated that this will be a major area of study for the next few years.

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; non-perturbative renormalization of QED in light cone quantization

15. FY02 Progress in RF Power Source Development (George Caryotakis)

Two additional XL-4 solenoid-focused klystrons that power the NLCTA were fabricated during the past year, bringing the total to 13. Two additional tubes have been shipped to the "8-pack" Phase I to augment their testing program, and two of the XL-4 klystrons are slated for delivery to Fermi Lab in the next fiscal year to support tests. Serial numbers 5 and 6 were repaired during the past year and successfully returned to service. A second value-engineered, low-cost, DFM version of the X-75P1, XP3-2, was fabricated and tested. The XP3-1 was covered in last year's report. The XP3-2 was in part built by CPI, which is the old microwave tube division of Varian Associates. The CPI involvement is a part of the SLAC plan to more thoroughly involve industry in meeting SLAC's needs for power source development. XP3-1 was limited by oscillation problems while XP3-2 exhibited gun breakdown when the pulse length was increased by a factor of two (to 3.2 μSec). We are currently using parts from these two XP-3 klystrons to build a single klystron free of either of the shortcomings previously observed. A new klystron, XP-4, with improved cavity tunings for higher efficiency, (based on dozens of RF simulations) is currently in the advanced stages of design.

In the past year, the Klystron Department has become deeply involved in supporting the B-Factory program, both with fabrication and testing of PEP II klystrons and cavity and RF systems for the high energy ring. Five of the 15-foot long 1.2-MW, CW klystrons have been started. One was completed in this fiscal year, and a second is nearly completed. The first tube failed due to gun breakdown and has been set aside for later repairs. In addition, two failed European-manufactured klystrons (Philips) that were repaired by CPI, have been tested here at SLAC. A third was repaired by SLAC and returned to service. The Klystron Department also analyzed three failed Marconi-manufactured klystrons.

Outside funded work-for-others and collaborations with small business on SBIR-funded developments have become an increasingly important part of the work of the Klystron Department. Under the category of work-for-others are the development of a Compton X-Ray source for use in cancer research. NIH funds this work. A second is the design, fabrication and testing of a LIGA-based, W-band klystron, which is funded by AFOSR and AFRL.

The SBIR-funded collaborations with small business include the following:

1. MacroMetalics is building a 2-kW, low-cost, TWTA driver for the NLC klystron, based on a SLAC TWT design. Twenty of these tubes have been delivered to SLAC for use in the NLCTA and the Klystron Test Lab. A power supply modulator was added this past year to complete the TWTA package, and an S-band, 2-kW TWT, also designed by SLAC, compliments the X-band tubes for use in the injector.
2. California Tube Labs (CTL) is completing a 12.5-MW, peak power X-band klystron, which is a prototype for a 6-beam, 75-MW multiple beam klystron. This prototype will be tested in the Klystron Lab in the coming months.
3. Diversified Technologies Inc. (DTI) of Bedford, MA has completed and delivered a 500-kV, 3.5 μSec, 500-amp pulsed modulator based on an IGBT solid-state switch. The IGBT switch replaces the thyratron used in the conventional modulator for potentially longer life and lower cost.
4. Calabazas Creek Research is designing a 415-kV, gridded sheet-beam klystron gun that will be tested at SLAC. This gun is intended for use in the sheet-beam klystron that is currently being designed for the NLC by the SLAC Klystron Department. The sheet-beam klystron has the potential for

much lower cost and higher operating margin than the conventional pencil-beam klystron because of its much lower power density and gradients. A successful gridded version of the tube would also obviate the need for pulse compression in the NLC.

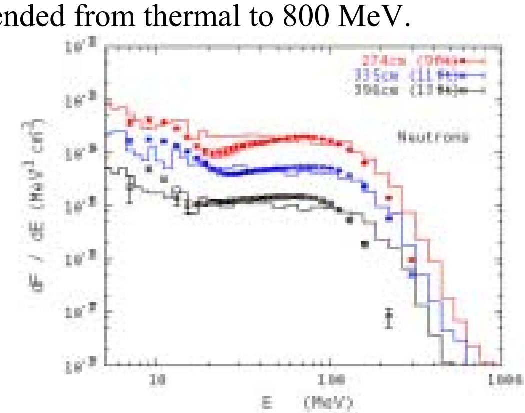
16.FY02 Progress in Radiation Physics Department (Sayed Rokni)

The Radiation Physics Department performs applied research in the areas of radiation production and attenuation, interactions of radiation with matter, instrumentation, shielding and dosimetry. The Radiation Physics Department is also involved in the development, maintenance and benchmarking of radiation transport computer codes. Expertise in this area is also provided to others at SLAC in support of their research efforts.

Induced Activity Studies:
In the T-439 experiment, which was performed in FY01, samples of aluminum, copper, iron, soil and water were irradiated in the stray radiation field generated by the interaction of a 28.5 GeV electron beam in a copper-dump in the Beam Dump East facility at SLAC. The specific activity induced in the samples was measured by gamma spectroscopy and other techniques. The analysis was completed this year and the results were compared with calculations using the FLUKA Monte Carlo code (Nucl. Instr. Meth. A484 (2002) 680). This research is expected to have value in the design of future accelerators, such as the Next Linear Collider.

Neutron Energy Spectra Research:
In a pair of experiments last year at the FFTB (T-451, T-454), it was clearly demonstrated that one can measure the energy spectra of high-energy neutrons produced, when a 28.5 GeV electron beam dissipates its energy in a beam dump. The experimental technique combined pulse-shape discrimination and time-of-flight methods using a NE-213 liquid scintillator, an idea originally developed at the Heavy Ion Medical Accelerator in Chiba, Japan by colleagues from Tohuku University. This year the SLAC-CERN-Tohuku collaboration completed another experiment (T-457) to measure the spectra of neutrons after they pass through various thicknesses of iron and concrete shielding. A key element of the T-457 experiment was the addition of Bonner Sphere detectors, allowing the neutron energy range to be extended from thermal to 800 MeV.

An example of the energy spectra results obtained in the T-457 experiment are shown in the figure on the right (solid points) for three concrete thicknesses. The histograms were calculated using the FLUKA Monte Carlo code.



The results from this experiment will be useful in benchmarking computer codes, such as FLUKA, that are routinely used in the design of particle accelerator shielding and two papers have been submitted to Nuclear Instruments and Methods (SLAC-PUBs 9210 and 9506). The primary goal of this kind of research is to make the shield-design process more accurate, thereby helping to reduce costs without cutting down on safety. At least one Ph.D. thesis is expected to come out of this project.

Concrete Transmission Measurements for Medical Accelerators:
The most common material used for the shielding of medical accelerators is concrete, which can be made by adding high-Z materials of different densities as aggregates in order to reduce the overall size of the shield, a very important concern for existing hospital facilities. These concrete mixes can have quite different attenuation characteristics for both photons and neutrons, but very limited information has been available up to now. To increase the general knowledge and understanding of the attenuation properties of high-Z loaded concrete, a collaborative effort was formed several years ago between the SLAC Radiation Physics Department and Varian Medical Systems of Palo Alto. Funding for this project was provided in part by the DOE's Energy Research Laboratory Technology Transfer (ERLTT) fund and Varian kindly offered the use of one of their Clinac 2100C medical linear accelerators for a period of one month. Using seven different concrete mixtures provided by three different manufacturers, a series of measurements were made with the Clinac 2100C operating at maximum electron energies of 6 and 18 MeV. Transmission curves were compared with calculations using various computer codes and a paper has been accepted for publication in Health Physics journal (SLAC-PUB-9279).

Development and Benchmarking of a New Version of EGS:
A two-year DOE Small Business Innovative Research (SBIR) collaboration continued this year in order to develop a new version of the EGS code (EGS5) together with a Visual User Interface (VUI). The primary feature of the VUI method allows the user to point, click and drag objects (e.g., cylinders, cones, etc.) on the screen to form complex geometries. This eliminates the very difficult task of writing geometry-descriptive code, a feature that is expected to be well received by the EGS user community. Both the EGS5 and VUI codes are still in the process of being carefully benchmarked for accuracy prior to official public release of the system to the public.

Comparison of Codes Used for Synchrotron Radiation Calculations:
Computer codes, such as STAC8 and PHOTON, are based on analytic/empirical models and are valuable tools because they are relatively easy to use and run quickly. However, to be of real use they must also be reasonably accurate. A systematic study was conducted this past year to compare STAC8 and PHOTON results with calculations using the FLUKA and EGS4 Monte Carlo codes. Doses due to scattered synchrotron radiation were calculated for representative beam-line geometries at the SSRL, both with and without polarization with various shields. Reasonable agreement was found between the codes and, more important, areas for improving the analytic codes were identified (SLAC-PUB-9507).

High-Level Dosimetry and Radiation Damage Studies:
Permanent magnets of the type that may be used in X-band klystrons for the NLC were exposed to radiation near the extraction magnet in the North Damping Ring and the absorbed dose was recorded using semiconductor sensors. These detectors were also placed in the vicinity of the CsI calorimeter in BaBar in order to help understand radiation damage to the PIN diodes. A poster presentation of this work was given at the 11th International Symposium on Reactor Dosimetry in Brussels, Belgium (18-23 August 2002) and a formal publication is forthcoming.

Sponsorship of Scientific Conferences:
In April of this year the Radiation Physics Department played host to the 6th International Conference on the Shielding Aspects of Accelerators, Targets and Irradiation Facilities (SATIF-6) at which 33 papers were given. A member of the staff also lectured at the 10th Course given at the International School of Radiation Damage and Protection (2-9 October 2001). This was the fourth time a member of the department was a co-director or a lecturer at the prestigious Ettore Majorana Centre for Scientific Culture in Erice, Italy.

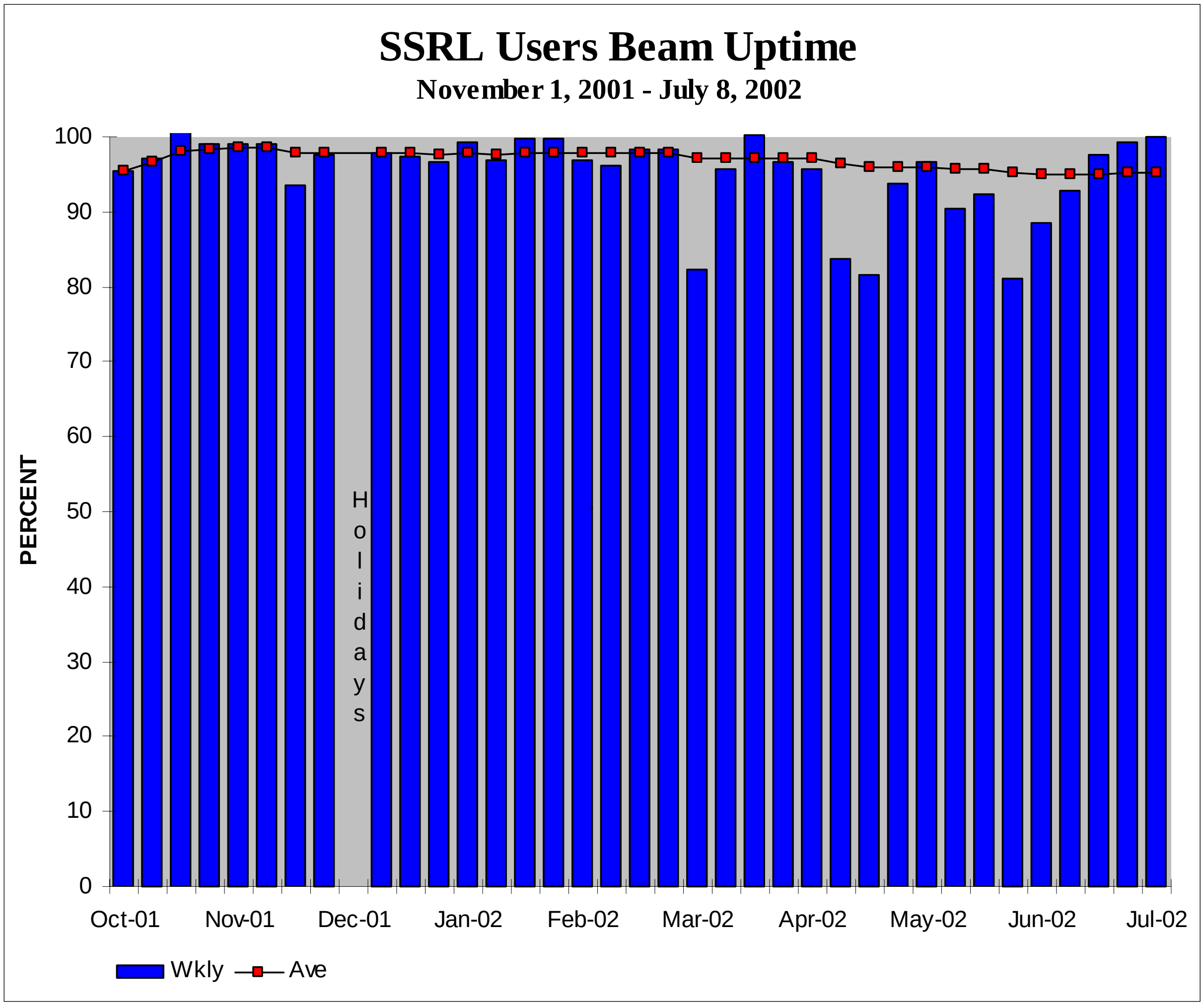
17. SSRL Overall Operations – FY02 User Experimental Run (Piero Pianetta)

FY2002 User Experimental Run

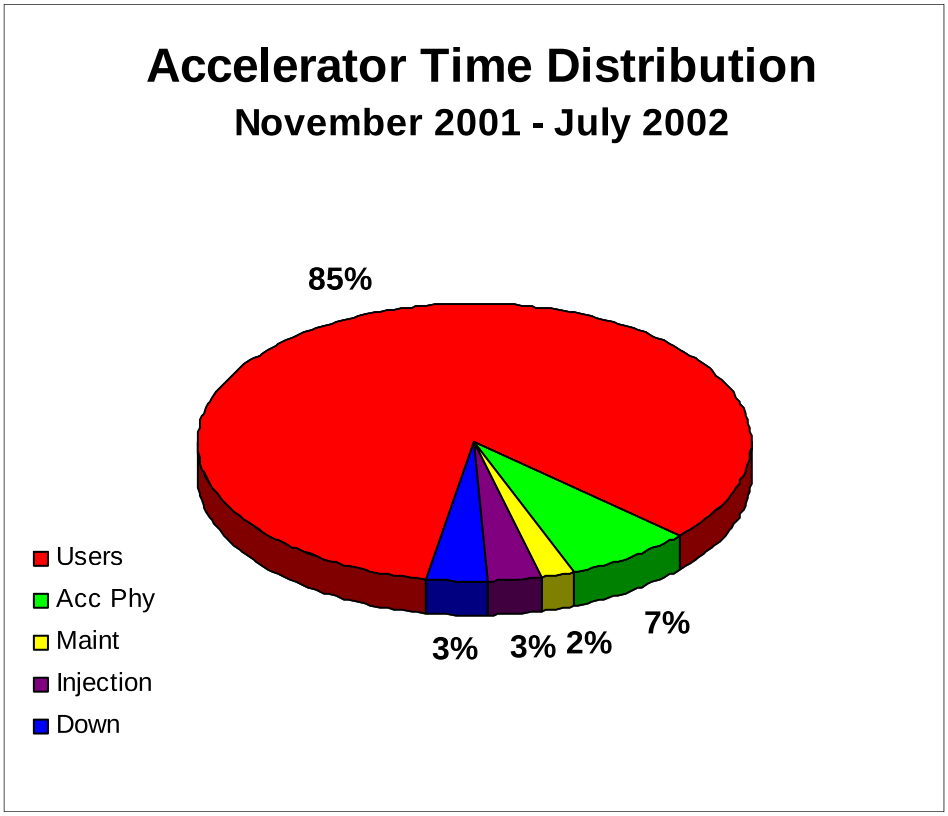
The FY2002 user run (November 1, 2001 – July 8, 2002) delivered 95.1% of scheduled user shifts, accommodating the beam-time needs of approximately 400 unique proposals. SSRL supported 1,011 experimental starts on 31 beam line stations that were open for users in FY2002. The User Research Administration office badged and processed 1,023 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 41% (user demand is 141% of available resources).

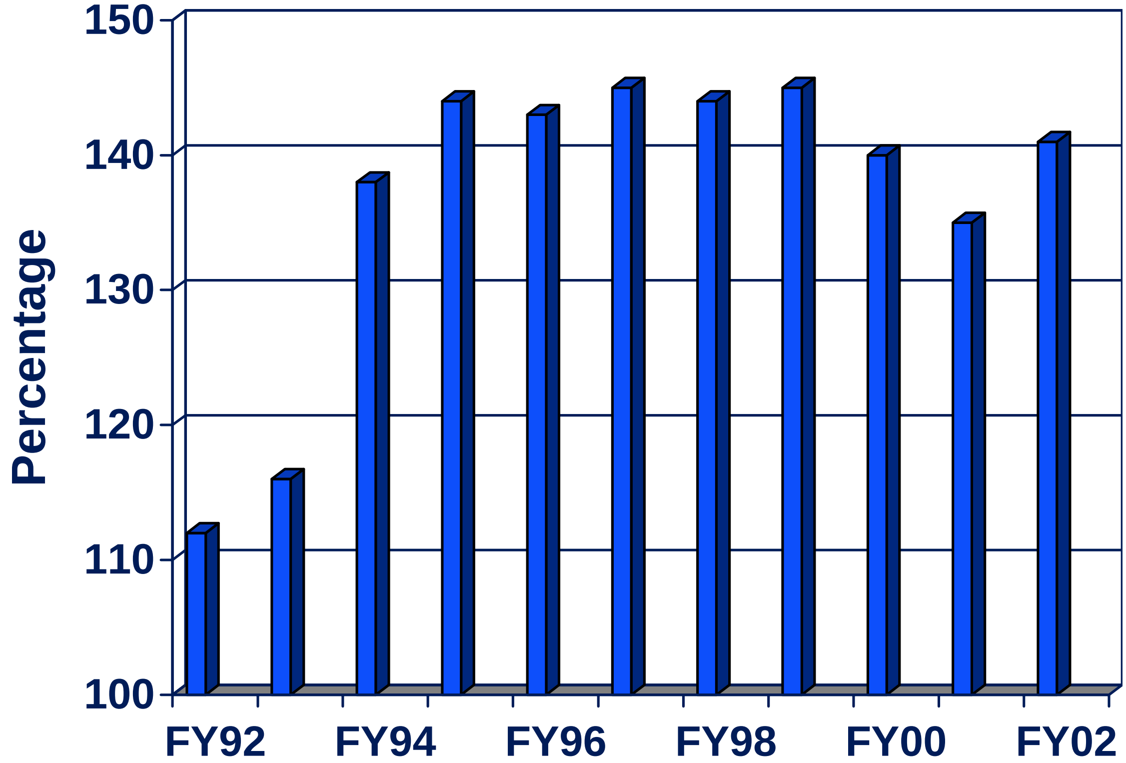
In FY2002, 1,767 SSRL users from over 20 countries received beam time. Of these users, approximately 84% were from the U.S., spanning 39 states and the District of Columbia. Users were predominantly from U.S. universities (58%) followed by U.S. laboratories (25%), U.S. businesses (7%), foreign universities (8%), and foreign laboratories (2%).



2002 SSRL Users Weekly Uptime



2002 Run Time Distribution



SSRL User Demand Graph (FY92 – 02)

Distribution of the 365 proposals receiving beam in FY2002

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

Improvements in the SPEAR Injector. In FY2002, work continued to improve the reliability, stability, and efficiency of the SPEAR injector. This work is particularly important given the increased injector performance requirements associated with SPEAR3. The booster beam position monitor BPM system was rejuvenated, and the closed orbit through the booster ramp was measured successfully. The BPM data were useful in understanding the booster survey and alignment. The Silicon-Controlled Rectifier-based radio-frequency soft-start was completed during the 2002 summer shutdown, and will be tested during the coming fall's accelerator start-up. The soft-start will reduce stress on the mechanical switches used to turn on and off the booster RF high voltage power supply. The six existing booster-to-storage-ring (BTS) steering magnets were replaced with stronger magnets for running the injector at 3 GeV. An additional steering magnet was installed at the front-end of the BTS, which will be used to improve the percentage of beam transferred along the BTS transport line.

Development of the Accelerator Toolbox Modeling Software Program. The Accelerator Toolbox (AT) is an accelerator modeling software tool. It implements computational methods for accelerator physics within the powerful MATLAB computational environment. Compared to other available codes using more traditional programming techniques, AT greatly increases the user productivity and flexibility in interactive accelerator modeling. The distribution version was completed in 2002 and was made available through the web to physicists at other laboratories. The return from this effort was a community of AT users that share code and experience in solving similar accelerator modeling problems. The AT-MATLAB environment is now used to implement the Linear Optics from Closed Orbit algorithm (LOCO). LOCO determines the accelerator model and linear optics parameters from a measured response matrix. The advantage of using AT-MATLAB versus the existing FORTRAN code is a shorter development time and more model-fitting options, which contribute to obtaining more rapid and accurate results.

Improvements to LOCO Accelerator Debugging Code: The MATLAB LOCO code was completed in FY2002. The program was used successfully to analyze the optics of both the Advanced Light Source at LBNL and the Aladdin storage ring at the University of Wisconsin SRC. The code was used in a new configuration to analyze the SRC data. The analysis should permit simultaneously correcting the beta functions and dispersion. The results will be tested at Aladdin in coming weeks.

Insertion Device (ID) Control System. The SPEAR ring has 4 variable gap wiggler magnets. Due to the 20-year time period over which these were built, they all have different, and in some cases obsolete, control components. A new, standardized, control system was designed and built. This was implemented on the Beam Line 11 ID, and will be tested in the coming user run. In the coming year the same system will be implemented on the two new IDs that will replace the Beam Lines 4 and 7 electro-magnet wigglers.

SPEAR3 Upgrade Project

FY2002, was the third full year of design and fabrication of SPEAR3 technical components following the project start of July 19, 1999. The SPEAR3 Upgrade project is classified as a major item of equipment (MIE) but is managed as a construction project because of the size and complexity. The total cost of the upgrade is $58M. The technical goals are: 1) 3 GeV at-energy injection, 2) less than 20 nanometer-radian beam emittance, and 3) 500 mA stored beam.

The project was reviewed by the DOE in February and July of this year. The executive summary of the July review noted that "The Review Committee found that adequate progress was being made to meet baseline objectives. The SPEAR3 installation plan can succeed, but is tight in both schedule and cost, and needs to be optimized. The pre-operations/commissioning plan is well defined for this stage of the project. Also, the ES&H aspects of the project are being adequately addressed. The total project cost estimate of $58 million and project completion milestone date of February 2004 appeared reasonable but without much margin for error."

At the end of this FY2002, the project is 75% complete in terms of accomplishments and overall progress. The status of each major technical system is summarized below.

Magnet System – A significant milestone was achieved late April with the final shipment of 20 corrector magnets from the Institute of High Energy Physics (IHEP) in Beijing. This marked the end of a very successful collaboration between SSRL and IHEP. A total of 294 Dipoles, Quadrupoles, Sextupoles, and Correctors were fabricated on schedule. All units met or exceeded the SPEAR3 magnetic field requirements. Four IHEP staff members arrived at SSRL in April and participated in the installation and alignment of the magnets on their support rafts. While all 46 support rafts for the 14 standard cells of the lattice are on-hand, the order for the remaining 8 rafts for the straight section matching cells was placed in June with expected delivery in October.

Vacuum System – There are 54 major vacuum chambers that must be integrated and aligned with the appropriate magnet rafts. At the end of this fiscal year, 32 units (59%) have been fabricated and a major fraction of these inserted within the magnet rafts. For the remaining units, the welding of main "boxes" for the 14 BM2 units is ~50% complete and the parts for the 8 transition section units are in production. The goal is for completion of all 54 rafts before April 1, 2003.

Other vacuum system components that are in procurement or fabrication include drift (straight section) chambers, bellows, DCCT, beam stoppers, injection and septum chambers, and isolation valves.

Magnet Power Supplies – All 200 power supply units, except for the bulk dipole unit, are released for fabrication and in various stages of assembly. All will be on site and bench tested by December 2002. Plans are underway for the removal of all existing SPEAR2 supplies, renovation of the existing power supply building with new reinforced concrete floor, and new AC distribution system. These activities together with installation of the new power supplies will take place during the major installation period scheduled for April-September of 2003.

RF System – Many system components (including waveguide, klystron power supply, low level RF controls and monitoring) together with RF Cavity accessories (coupling box, high order mode loads, tuners, etc) are complete. Cavity fabrication has been delayed by difficulties at the manufacturer. Fabrication methods similar to those used for the original PEP-II units are now underway with deliveries estimated between January and April 2003. The SPEAR3 purchased Klystron, which failed in tests will be repaired or replaced by March 2003.

Instrumentation and Controls – The design and specification of the computer control system topology, hardware and network components, and software tasks have progressed this year. Control system CPU boards were received and working EPICS IOCs have been configured. Corrector power supplies have been successfully tested using the new digital control daughter cards. Commercial BPM processing units have been received. The DCCT has been ordered. The injector RF and timing controller is under fabrication. Programmable Logic Controller and temperature monitoring components for the Machine Protection System have been received. Detailed design of the Orbit Interlock System is in progress. The I&C long-haul cable plant specification was completed and work on detailed interconnection diagrams is underway.

Cable Plant – The goal for the cabling systems (power, control, and monitoring) is to complete as much as possible, external to the shielding, before the major shutdown in FY2003. The cable external tray system is now complete. The tray systems for the East and West straight section areas and for the power supply building are complete. The design for the internal shielding tray system is 80% complete. The Electrical Safety, Seismic Safety, and ES&H committees have approved the planned installations. All cable has been ordered for the external installation, which will take place between August 2002 and March 2003.

Conventional Facilities – As in the case of the cable plant noted above, the goal here is to accomplish most tasks prior to the major system installation. Note that East & West straight sections with associated pits, shielding walls, and entry mazes were accomplished in the normal FY2000 shutdown. West straight section transition area walls and all new west area roof blocks were accomplished in FY2001. This year the Klystron building enclosure was completed in June. The contract for completing the East transition area walls and roof blocks was awarded in June with construction starting on July 12. This contract completes all planned shielding modifications and includes a new AC distribution system for tunnel power and tunnel lights as well as the required smoke detector system. Completion of this work is scheduled for October 2002.

Installation – As noted above, a detailed installation plan was presented to the DOE Lehman review. While it fits within the goal of 6-months duration, further work remains to optimize the plan within available resources and contract limitations. We plan to have the optimization complete by December 2002. Note that appropriate ES&H plans and procedures are also being finalized. Richard Boyce has been appointed to direct the installation effort.

Commissioning – James Safranek has been appointed to lead the commissioning effort, which follows the above installation activities. The Lehman Review found the preliminary commissioning plans adequate for this stage of the project. Further optimization of the plans and detailed procedures are being developed. Accelerator Physics issues that are important to the commissioning effort are being addressed.

Project Costs – The total project costs and commitments through September 2002 are $38.8M.

Fourth Generation Source Development

Since approval of Critical Decision 0 for the Linac Coherent Light Source (LCLS) Project proposal in June of 2001, effort was directed toward the preparation of a conceptual design report and cost estimate for the project. The LCLS Conceptual Design Report was completed in April 2002 [Linac Coherent Light Source Conceptual Design Report, SLAC-R-593, April 2002]. The LCLS design team also assembled a comprehensive project cost estimate. These documents and other aspects of the proposal were examined in a review organized by the Office of Science Construction Management Support Division. The review findings were supportive of the LCLS request for CD-1 approval and a start of Project Engineering Design activities in FY2003.

Research activities progressed satisfactorily in several areas in FY2002. Assembly of the prototype LCLS undulator was completed at Argonne National Laboratory. Field quality of this magnet has met LCLS specifications. Argonne is investigating revisions of the design to improve reliability and to simplify the magnet assembly process.

Much progress was made in the areas of numerical modeling and experimental verification of the performance of the LCLS photocathode gun design. Gun performance predictions using the computer code PARMELA were compared in detail with the results of other computer codes such as MAGIC3D and MAXWELL2D. It is known that the approximations made by PARMELA for computing space charge forces do not take into account the rapid change in velocity of the electrons within the first few millimeters of the cathode. Comparison with more accurate (but slower) computer codes demonstrated that PARMELA approximations do not lead to significant discrepancies in the predicted beam characteristics at the gun output.

A program of emittance measurements at the SSRL Gun Test Facility (GTF) has complemented the numerical simulations of gun performance. The best-projected emittances achieved to date at currents approaching LCLS requirements are in the vicinity of 1.4 millimeter-milliradian. These measurements are in good agreement with PARMELA predictions for GTF operating parameters, which are limited to lower accelerating gradients than LCLS targets. Most recently, GTF studies have been directed toward measurement of "slice" emittances, which are of more immediate relevance to LCLS and provide a much more stringent test of numerical predictions of gun performance. GTF personnel have participated in studies at the Brookhaven Source Development Laboratory, to observe the experiment techniques used there and to analyze data on "thermal" emittance of electrons from a copper photocathode.

Start-to-end simulations of LCLS performance made a significant breakthrough in the last year, as a result of vastly improved understanding of beam degradation due to coherent synchrotron radiation (CSR). SLAC and DESY organized a CSR workshop at the DESY-Zeuthen facility in January 2002. As a result of this workshop, three groups of theoreticians (at SLAC, ANL and DESY) developed theoretical treatments of CSR effects in LCLS and TESLA, which were incorporated into the computer codes used for design of the LCLS. Based on these improved codes, the LCLS bunch compression chicanes have been redesigned to minimize the deleterious effects of CSR.

SLAC scientists have begun experimental studies of diagnostic devices and techniques for measurement of ultrashort pulses. Short pulse diagnostics may be tested in the SLAC linac in the near future.

UCLA members of the LCLS Collaboration have continued to study methods for producing LCLS x-ray pulses of duration less than 100 fsec. Preliminary studies of "chirped-pulse" slicing with a germanium or diamond monochromator could produce pulses with instantaneous power unchanged from the LCLS design specification, and duration down to 10 fsec or even as low as 3 fsec.

New Beam Line Facilities and Beam Line Improvements

Beam Line Front-Ends. The replacement of the beam line front ends for compatibility with the power and exit port relocation of SPEAR3 is the highest priority of the beam line upgrade program. At the close of FY2002, all bend magnet beam line front-end components were undergoing final vacuum assembly. Masking for the higher power insertion device (ID) front ends has proved a significant challenge. In particular, corner stress concentrations in the fixed mask required considerable engineering modeling before a satisfactory design concept was established. At this time, five of the seven ID fixed masks are in fabrication while the remaining two are in design. All seven ID moveable masks are in fabrication or final vacuum assembly. Though not strictly part of the front ends, the system of Bremsstrahlung shadow walls, collimators, and stoppers required for beam line radiation safety have been subject of extensive radiation safety analysis during FY2002. Final approval of the system design is anticipated in early fall.

Beam Line 1. The complete renovation of the BL1-5 hutch components and instrument control system was completed in FY2002, bringing the station to the SSRL standard configuration for macromolecular crystallography. The changes include a hutch extension, implementation of new electronics and control system, a new hutch table, kappa goniometer and detector positioning system, and a significant redesign of the user area as well as new computer hardware. The beam line has been fully commissioned and is operating in a full production mode. A robot based on a prototype developed on BL11-1 has been installed for the automated mounting of up to 280 samples. During the next run period the robot will be fully commissioned. It should be noted that the support for the Structural Molecular Biology efforts described in this report has come from a combination of DOE, NIH and PRT resources.

The machine protection system for BL 1 and 2 is being replaced with the SSRL standard Allen-Bradley based system as well as being moved from the former beam line control room to the BL1-2 mezzanine. This move will allow the SPEAR3 synchrotron light monitor to be located in the former beam line control room and enable more sophisticated measurements to be done on the SPEAR3 electron beam. Finally, BL1-2 was decommissioned in FY2002 since this branch line could not operate in the SPEAR3 era and it was possible to shift its users to BL8-1.

SPEAR3 Related Upgrades for Bend Magnet Beam Lines 1, 2, 3, 8. For the initial startup phase of SPEAR3 the bend magnet beam lines will not have benefited from the planned upgrade program as limited resources are directed to the higher priority front end and ID beam line upgrade programs. In FY2002, the SPEAR3 upgrade related activities on the bend beam lines have been limited to front-end replacement as discussed above and a recently initiated program of detailed analysis of beam line fan reallocation and realignment. Once the fan reallocation and realignment analysis is complete, the effort will shift to identifying minimal cost beam line performance enhancements including options for raising the power tolerance of the beam line components.

Beam Line 4. The 20-pole hybrid wiggler for the SPEAR3 upgrade of BL4 has been received and accepted. The design of the associated vacuum chamber was completed and its fabrication commenced. Modification of the SPEAR concrete shielding housing to accommodate the wiggler and increase the shielding at the location of the BL4 rolling block door was completed at the end of FY 2002. Design of the three different versions of the LN monochromators required for the three branch lines is complete and fabrication of two of the three monochromators is progressing. The design of the monochromator entrance slits and graphite filter modules is scheduled for completion within the next few weeks.

Beam Line 5. The modification of the SPEAR concrete shielding housing discussed under BL4 above included the relocation of the BL5 alcove wall to accommodate the inclusion of a new bend magnet beam line alcove. The new BL5 alcove wall thickness was increased 50% to three feet thick to provide enhanced radiation shielding. This relocation and modification of the BL5 alcove required a reconfiguration of the BL5 optics and beam transport system that is scheduled for completion by early November. BesTech's detailed design of the new spherical grating monochromator (SGM) for BL5-1/2 is complete and has been approved by SSRL. Fabrication of this monochromator is proceeding with delivery anticipated early in calendar 2003. Engineering analysis of thermal deformation of the BL5-1/2 M_0 mirror has just finished with external procurement anticipated to commence shortly. Conceptual design of the associated mirror bender and cradle system is well along.

Beam Line 6. During FY2002, it was decided to replace the BL6 variable gap ID vacuum chamber owing to concerns regarding its compatibility with the SPEAR3 beam. The detailed design of the new vacuum chamber is scheduled for review in the next month with fabrication expected to commence shortly thereafter. The BL6 LN monochromator was assembled, installed, and commissioned successfully during FY2002. Unfortunately, the full potential of the monochromator was not realized as the vendor responsible for preparing the multilayer substrates defaulted on its contract. Thus the monochromator was installed with Si(111) crystals rather than both Si(111) crystals and multilayers. A new vendor for multilayer substrates was identified and the completed multilayers are scheduled for delivery in early November. Progress on other aspects of the beam line upgrade such as misc. slits, masks, and the M_0 mirror system continues.

Beam Line 7. The 20-pole hybrid wiggler for the SPEAR3 upgrade of BL7 has been received and accepted. The design of the associated vacuum chamber was completed and its fabrication commenced. The specification for the white beam M_0 mirrors for all three BL7 branch lines has been completed and fabrication contracted with an outside vendor. The BL7-3 LN monochromator is in vacuum assembly while design of the BL7-2 sagittal focusing LN monochromator has begun. The conceptual design of the BL7-1/9-1 side scattering monochromator is complete and detailed design work scheduled to start shortly. The design of the monochromator entrance slits and graphite filter modules is scheduled for completion within the next few weeks. The BL7-2 diffractometer was upgraded to provide a precisely controllable alpha motion. Plans are underway for additional upgrades of the diffractometer system to provide for a high-energy powder diffraction station by the time SPEAR3 is operational.

Beam Line 9. BL9-1 and BL9-2 were in full production during FY2002. The entire mechanism for tracking the beam on the side-station, BL9-1, was upgraded and improved which allows for rapid and reproducible changes in energy or wavelength. A fluorescence detector system (originally implemented on our standard MAD line, BL9-2) was installed on BL9-1 and allows for SAD and MAD experiments to be conducted. A 2nd state-of-the-art large-area matrix CCD detector (Quantum-315) was installed on BL9-2, which was fully characterized and commissioned for normal user operation. This detector has the largest active surface area of any CCD detector used for macromolecular crystallography worldwide, and it can be read out in less than one second, producing excellent quality diffraction data. Funds were secured for an additional Quantum-315 detector system for BL9-1, which is scheduled to be installed in January 2003. Both BL9-1 and BL9-2 are also outfitted with robots (based on a prototype system originally developed on BL11-1), which allow for automated sample mounting. During the next run period the robots will be commissioned and will operate in full user mode.

The damaged BL9-3 M_0 mirror was successfully repolished last summer and reinstalled and commissioned at the beginning of the fiscal year. A LN monochromator was installed and commissioned on BL9-3. The BL9-2 LN monochromator design has just been released for fabrication. The conceptual design of the BL7-1/9-1 side scattering monochromator is complete and detailed design work scheduled to start shortly. Various 500 mA rated masks and slit systems are in final vacuum assembly. The design of the monochromator entrance slits and graphite filter modules is scheduled for completion within the next few weeks.

Beam Line 10. A wiggler failure in FY2001 resulted in BL10 being down for approximately half of the last run cycle. The wiggler was repaired and reinstalled during the FY2001 summer shutdown and then the wiggler, beam line and the new mirror were successfully re-commissioned at the beginning of the FY2002 run and turned over to users. Subsequently, the chin guard mask of the old BL10-2 M_0 mirror system failed during the FY2002 run resulting in the venting of water into the beam line UHV beam transport system. The damaged mirror system was removed and the beam line recommenced operations after an intensive recovery effort. The M_0 mirror system scheduled for installation in the summer of 2003 as part of the SPEAR3 beam line upgrade was accelerated. This mirror system is currently in final vacuum assembly with installation anticipated for mid-October. A new LN monochromator was successfully installed and commissioned on BL10-2 during the FY2002 run. The BL10-1 M_0 mirror, which experiences extremely high power deposition in SPEAR3, is the subject of an ongoing engineering analysis. SPEAR3 replacement entrance slits for the BL10-1 SGM were specified and outside procurement initiated.

Beam Line 11. The PRT side-station BL11-1 was in full production in FY2002 (PRT members are The Scripps Research Institute, Stanford University and SSRL). The first state-of-the-art large-area matrix CCD detector (Quantum-315) was installed and tested on this line. The detector was initially characterized by staff and suggested improvements were implemented before the vendor, ADSC, delivered the 2nd Qunatum-315 detector (installed on BL9-2). The original detector has been shipped back to ADSC for the upgrade and will be installed and commissioned during the beginning of the next running period. The hardware required for energy tracking was upgraded for rapid and reproducible energy changes. A similar detection system to BL9-1 was installed for conducting SAD and MAD experiments. The crystal monochromator has been replaced with a crystal with a new cut to increase the energy resolution at the selenium K-edge, thereby enhancing Se MAD experiments. The first prototype robot was installed on this beam line during FY2002 for high throughput crystallography. The robot system is capable of mounting up to 280 crystals from 3 cassettes without human intervention. The system was thoroughly tested and successfully used by staff members that are part of the Joint Center for Structural Genomics effort at SSRL as well as several test user groups. The robot system has since been improved and will become the standard setup for all of the macromolecular crystallography beam lines.

The BL11-3 fixed energy branch line was scheduled for installation and commissioning during the FY2002 run. Monochromator, mirror, and other beam transport systems were designed and assembled accordingly. Unfortunately, a crucial white beam mask developed a leak during the final braze/weld assembly operation. Since the leak was not repairable, the installation of this new branch line was delayed. The replacement mask is in final vacuum assembly and the branch line is scheduled for installation prior to the start of the FY2003 run. Construction of the end station instrumentation for the BL11-3 side station began in FY2001 with completion anticipated in late 2002. This side station will deliver high-intensity x-rays at a wavelength of 0.98 Å and will be equipped with a slightly modified version of the standard SSRL macromolecular crystallography instrumentation allowing it to be shared between materials diffraction experiments and macromolecular crystallography. The fabrication of the M_0 mirror cradle and bender, monochromator, masks, filters, vacuum systems, hutch, hutch table and hutch stoppers are complete. The hutch instrumentation and instrument control is currently being fabricated, assembled and installed. Full production mode is anticipated in early 2003.

BL 11-2 was in full production during FY2002, with approximately twice as much beam delivered to users than in the previous year (at which time it was in commissioning mode). User commissioning commenced on a spectrometer for grazing-angle XAS, x-ray reflectivity, and x-ray standing-wave measurements. This instrument provides 7 axes of motion (including theta/2-theta scan capability) and motorized slits designed in-house, which, as a system, provide sub-micron control over beam size and sample position. An ion chamber and a gas proportional counter with analyzer are available for detecting intensity data. Two LHe cryostat systems for XAS measurements on environmental materials were commissioned at BL11-2 during the past year.

Commissioning activities continued on a micro-XAS and chemically-specific imaging system for analyzing chemical reactions, contaminant speciation, and microstructures in environmental samples. The system is based on elliptically-figured tapered metal capillary optics, which produce focused spots as small as 2 to 5 μm. These optics are well suited to use at wiggler beam lines. They can accept relatively large convergent beams, such as produced by wiggler beam line focusing optics, and produce a round spot, regardless of the source dimensions. This aspect makes the optics optimal for wiggler side stations, which have large asymmetric photon source dimensions. Metal capillaries have much higher reflectivity than glass capillaries and virtually no halo effects. Three such metal capillaries were procured to cover the energy range 5 – 20 keV. A positioning stage was designed in-house and tested. The optics were used to measure uranium speciation and distributions in soil samples removed from under high level waste storage tanks at Hanford, Washington.

SSRL Instrumentation and Control Software.
One of the major problems with the current system is the availability of stable OpenVMS driver software for the specialized hardware that the SSRL beam lines presently use. However, better vendor support for other operating systems, such as Microsoft Windows is available. As part of the new control software, a CAMAC command list processor was developed using the Operating System Independent (OSI) library and tested on the Microsoft NT operating system. This software can be used by programs that run on the same computer, or can be combined with a network-based server for remote access. In order to gain real-life experience of the network component, this CAMAC list processing software was integrated with the existing SSRL control software. This enables the existing SSRL data acquisition programs (such as XAS-Collect and Super) to take data using the new network based system without any modifications. In FY2002, the new CAMAC command list processor system was installed on Beam Line 2-3. In this phase, only the CAMAC list processor software was moved from the OpenVMS computer, all other components remained on the OpenVMS system. At present, this system is under extensive testing; to date no significant problems have been encountered.

Blu-Ice/DCS: The graphical user interface for macromolecular crystallography beam line control and experimentation (Blu-Ice), developed primarily on BL9-2, to interface with the distributed control system (DCS) was implemented on BL11-1, BL9-1, and BL1-5. The distributed nature of the software allows many processes to run simultaneously anywhere on the network. This gives staff remote access from their office or home to the user's experiment increasing the efficiency of user support. It also allows for user groups to monitor their experiments remotely in a collaborative mode. New features developed in FY2002 include live video of the experimental equipment and sample crystal, an automated centering routine for sample crystals, and a new tab for high throughput crystal screening. Screening is accomplished by uploading an excel spreadsheet containing information for up to 280 crystals. A series of actions can be selected that is repeated for each sample including automated mounting of a crystal from a sample cassette, crystal centering, exposing a crystal with x-rays, data readout of the diffraction image, crystal rotation, video snap shot of the crystal, etc. The software has been tested and will be commissioned with several test user groups during the next running period. The Blu-Ice/DCS software is freely available through a version control software suite (VCS), which also documents all new features for each new version of the software. A recent version of Blu-Ice/DCS is implemented on Beam Line 8.3.1 at the Advanced Light Source in Berkeley and the GM/CA CAT at the Advanced Photon Source plans to implement the entire package for their new beam lines currently under construction.

Facilities and Infrastructure. The West Beam Line Enclosure, WBLE, and the Bldg. 131 electrical substation, both of which were started in FY2001, have been completed. In addition, the Bldg. 118 roof was upgraded. The WBLE with associated alcoves will provide space for three additional beam lines including a beam line utilizing a 4 m long straight section. In addition, the WBLE provides an unfinished second floor that can be used in the future for laboratory space for materials science activities.

The SLAC visitor network (which is more open than the internal SLAC network and allows easy access to the Internet to non SLAC/SSRL managed computers) was made available in beam line and conference room areas. It also allows wireless access. A central SSRL file server and backup infrastructure was installed.

Highlights of the Scientific Program

Structural Molecular Biology

3D X-ray Diffraction Microscope Provides a First Deep View**.** The successful effort of an international collaborative team from SSRL, SPring-8/RIKEN, APS and LBNL in the development of a high resolution 3D microscope by combining coherent x-ray diffraction with the over-sampling phasing method earned the cover story of the August 19, 2002 issue of PRL. Using an undulator beam line at SPring-8, this microscope was used to image buried 2D and 3D nanostructures at 8 nm and 50 nm resolution, respectively. The imaging resolution is currently limited by the exposure time and the computing power, while the ultimate resolution is limited by the x-ray wavelengths. These results will pave the way for the development of atomic resolution 3D x-ray diffraction microscopy, which can image thick materials not accessible to scanning probe microscopy and transmission electron microscopy. In combination with the planned x-ray free electron lasers, this form of microscopy could be applied to image single biomolecules at near atomic resolution. See J. Miao, T. Ishikawa, B. Johnson, E. H. Anderson, B. Lai and K. O. Hodgson, *Phys. Rev. Lett.* **89**, 088303 (2002). News articles published in FY2002 include: JR Minkel, "X Rays Stack Up", *Physical Review Focus*, August 6 (Story 6), 2002; Philip Ball, "X-rays scratch below the surface", *Nature Science Update*, August, 14, 2002; and "3D X-ray vision", *Nature Physics Portal*, August, 2002

Enabling New Science with Advanced Beamline Control and the Quantum-315 CCD Detector: The Ultra-High Resolution Structure of Nitrogenase MoFe-Protein.
The Research group of Douglas Rees at the California Institute of Technology collected macromolecular X-ray crystallographic data to a resolution of 1.16 Å at SSRL Beam Line 9-2 using the new Quantum-315 CCD detector from crystals of nitrogenase MoFe-Protein, an extremely efficient enzyme found in bacteria that catalyzes the production of ammonia from dinitrogen. Bacteria produce about half of the world's bio-nitrogen available for agriculture; the rest comes from nitrogenous fertilizer produced chemically at extreme temperature and pressure, consuming about 1% of the world's total annual energy supply. The high-resolution analysis [*Science* **297**, 1696-1700, (2002)] revealed a previously unrecognizable ligand coordinated to six iron atoms in the FeMo-cofactor catalytic site of nitrogenase. The electron density for this ligand, which is masked in structures with resolutions lower than 1.5 Å, is consistent with being a light element, most likely nitrogen. The presence of a nitrogen atom in the cofactor would have important

implications for the mechanism of dinitrogen reduction which may in turn help chemists to design a more efficient method for producing ammonia from atmospheric nitrogen.

This work was made possible with the availability of a large-area Quantum-315 CCD detector funded by the NIH-NIGMS, installed on the high-intensity wiggler end station, BL9-2 using an advanced data collection environment developed at the SSRL structural biology resource. The detector has a large active area of 315 x 315 mm^2 and a rapid readout speed of ~1 second in full resolution mode (51 x 51 μm^2 pixels) – ideal for collecting ultra-high resolution data in a single data collection pass. Nitrogenase data were collected at a wavelength of 0.998 Å; the ultra-high resolution data set used 0.2° rotations with a relatively long exposure of 60 s per image and a quick low-resolution pass used 0.5° rotations with short 10 s exposures. In all, 2 x 180° of data (1260 images total) were collected in less than 17 hrs with no added time for detector readout or for additional ultra-high data sets with the detector in offset positions. Beam Line 9-2 is currently being outfitted with a standard 284-sample changing system originally developed at BL11-1, which will automate and optimize the screening process for identifying the highest quality crystals for future ultra-high resolution experiments.

Time Resolved Protein Folding. The advent of structural genomics era parallels the unprecedented high rate and quality of structural determination carried out at protein crystallography facilities at synchrotrons. Many very difficult structures such as RNA polymerase and ribosomes have recently been conquered. These, in turn, shed light into the importance of RNA as another structural/functional element in biology. Physicochemical properties of RNA, lesser known compared to those of proteins, enable it to form certain structural features that are a key to the enzymatic and structural function of RNA. Russell *et al.* used time-resolved solution x-ray scattering to study thermodynamics of the *Tetrahymena* group I RNA folding [*Proc. Natl. Acad. Sci.* **99**, 155 (2002)]. Combined with single molecule fluorescence results, the scattering data revealed the energy landscape that has discrete folding pathways separated by large free-energy barriers that prevent interconversion between them, indicating the multiple folding pathways lying in deep potential channel. Another publication [Russell *et al.*, . *Natl. Acad. Sci.* **99**, 4266 (2002)] reports the time-resolved studies encompassing a time window of more than five orders of magnitudes to examine global structural events. They conclude that RNA forms a non-specifically collapsed intermediate, which is similar to those in protein folding, in the low millisecond time scale and that it then searches for its tertiary contacts within a highly restricted subset of conformation space. These studies have brought structural studies of RNA into the level comparable to proteins.

Molecular Environmental Sciences (MES)

Toxic Metal Partitioning at Buried Biofilm/Mineral/Solution Interfaces.
Sorption reactions on mineral surfaces dramatically affect the speciation, biogeochemical cycling and bioavailability of essential micronutrients (*e.g.*, PO_4^{3-}, Cu, Mn, Zn) and toxic metals and metalloids (Pb, Hg, Se, As) in the environment. Considerable attention has

been focused on understanding structural molecular chemistry of metal adsorption reactions at surfaces of common mineral phases such as Fe-, Mn- and Al-(hydr)oxides and clays minerals. Relatively little attention has been paid to microbial organisms that extensively colonize mineral surfaces in the subsurface. Soil microbial colonies frequently produce extensive films of hydrated exopolysaccharide polymers (so called *biofilms*), which insulate mineral surfaces from the bulk solution. Microenvironments are created within biofilms that have substantially different redox, pH, and solute concentration conditions than exist in the bulk solution. Furthermore, reactive functional groups such as carboxyl, hydroxyl, amino and phosphoryl moieties are present in the biofilm and on bacterial surfaces, providing a wealth of binding sites for metals. In some cases, bacterial activity may catalyze the transformation of toxic metals into less (or more) toxic species or enhance the dissolution of the underlying mineral substrate. These reactions can strongly affect the contaminant-attenuating properties of subsurface media.

Gordon Brown's group at Stanford University has focused on using synchrotron-based x-ray spectroscopic techniques to study lead and selenium (both common and pernicious environmental contaminants) sorption reactions at biofilm-mineral-solution interfaces under *in situ* conditions. Model systems were constructed using *Burkholderia cepacia* biofilms grown on single-crystal surfaces of α-Al_2O_3 and α-Fe_2O_3. Metal-ion distributions within the biofilms were probed using under hydrated *in-situ* conditions using long-period x-ray standing-wave (XSW) measurements [Templeton *et al*., *Proc. Natl. Acad. Sci.* **98** 11897, (2001)]. A range of metal ion concentrations were employed to probe for mass-action effects. Lead(II) ions were found to preferentially bind to highly reactive sites on the oxide surfaces, with the lead(II)-surface affinity decreasing the order: α-Fe_2O_3 (0001) > α-Al_2O_3(1-102) > α-Al_2O_3(0001). These results demonstrate that, in spite of its metal binding capability, the thick biofilm has not passivated these underlying mineral surfaces.

Materials Science

Anomalous Electronic Structure and Pseudogap Effects in Electron-doped, High-Tc Superconductors – Fermi Surface "Hot Spot" Revealed.

In order to develop an understanding of high-T_c superconductivity, it is necessary to understand the behavior of the electrons at the Fermi surface. To this end, the electron-doped cuprate superconductors, such as $Nd_{2-x}Ce_xCuO_{4\pm\delta}$, provide a unique opportunity to study the physics of doped Mott insulators and high-T_c superconductors. The *n*-type materials, with their different normal state properties and phase diagram, also offer an alternative venue to test various theories of high-T_c superconductivity. Through the use of high-resolution angle-resolved photoemission spectroscopy, significant differences are found between the *n*-type and *p*-type materials that shed light on a number of important topics in the high-T_c superconductors. It has been found that the Luttinger volumed Fermi surface is truncated into several pieces with a high-energy "pseudogap"-like suppression that occurs <u>not</u> at the maximum of the *d*-wave functional form as in the underdoped *p*-type materials, but near the intersections of the Fermi surface with the antiferromagnetic Brillouin zone boundary. This work has thus provided a positive identification of the psuedogap effect with the Fermi surface "hot spot" phenomenon associated with antiferromagnetic (π, π) scattering. Furthermore, a systematic doping dependence study reveals important information on the doping evolution of the electronic structure from half-filled Mott insulator to high-T_c superconductor, one of the most fundamental issues towards understanding the mechanism of high-T_c superconductivity. It has been found that, at very low carrier concentrations, electrons are doped into regions close to (π, 0), forming a small electron-pocket; while at higher doping level, more electronic states are created in the nodal region, constituting a large hole-like Fermi surface. This evolution provides a natural explanation for the confusing transport data from electron-doped materials.

Dimensionality of the Ordered Phase of the Layered Manganite La0.5Sr1.5MnO4 .
The Ruddleson and Popper series of transition-metal oxides is an important class of materials for the study of correlated electron physics. Such a material can be viewed as a slab of perovskite separated by a rock-salt-structure layer of alkaline-earth-doped rare-earth oxide. The perovskite slabs, containing the transition-metal atoms, are thought to be the "active" regions of the structure and the doped rock-salt-type layers play a passive role, generating and transferring excess charge to the active layers. Ruddleson and Popper manganites with nominal Mn valence in the vicinity of +3.5 undergo a second-order structural phase transition that is thought to be driven by charge and orbital ordering on the Mn site. Viewing the structure as active perovskite slabs separated by passive rock-salt layers, the dimensionality of the charge-ordered phase should be determined by the dimensionality of the active layers of the compound. In the first member of this series, the active perovskite slab is only one unit cell thick and hence nearly two-dimensional. X-ray diffraction was used to determine whether the dimensionality of the phase transition in the single-layer manganite $La_{0.5}Sr_{1.5}MnO_4$ is in fact 2-D. By carefully measuring the intensity and the width of the superlattice peak associated with the ordered phase, the three critical exponents for the transition were determined to be β= 0.17(2), γ= 1.90(20), and ν= 1.10(15). They compare well with the values expected for a 2-D Ising system (0.125, 1.75, and 1), but poorly with those expected for a 3-D Ising arrangement (0.326, 1.238, and 0.631). This supports the view that the properties of the single-layer manganite are determined by the highly two-dimensional perovskite layer.

Short and Medium Range Order in Bulk Metallic Glasses**.**
Over the past decade, there has been renewed interest in the properties of metallic glasses, prompted largely by the development of multicomponent bulk glass-forming alloys which can be made in sufficiently large sizes to allow their use in structural applications. In particular, the widespread availability of bulk specimens (as opposed to ribbons produced by rapid solidification) has made possible a wide range of studies of the mechanical behavior of amorphous alloys, which has lead to a dramatic improvement in our understanding of fundamental aspects of deformation and fracture.

The understanding of the structure of amorphous alloys, however, has not advanced nearly so rapidly. There are several reasons for this. First, the microstructure of amorphous alloys (which one can loosely define as structure with characteristic length scales of 2~nm to 0.1~mm), such as phase separation into compositionally distinct amorphous phases, is much more subtle than that of crystalline alloys which have easily observable features such as grain boundaries and second-phase particles. Second, characterizing the short-range order (0-0.5~nm) of an amorphous alloy is quite difficult with present techniques, particularly for multicomponent alloys which have $n(n+1)/2$ independent pair correlations (where n is the number of components). Third, structure over intermediate length scales (0.5-2~nm), commonly called "medium-range order," is also difficult to adequately characterize with scattering techniques (which are only sensitive to pair correlations).

Hufnagel and Brennan have used x-ray scattering to examine short-range and medium-range order in $(Zr_{70}Cu_{20}Ni_{10})_{90-x}Ta_xAl_{10}$ amorphous alloys. Analysis of the radial distribution functions (RDFs) shows that the addition of four atomic percent Ta enhances the average short-range topological order, as the nearest-neighbor peak in the RDF becomes more sharply defined. The enhanced order due to the Ta addition persists beyond the first few atomic shells, however, out to distances of at least 15 Å. From resonant x-ray scattering near the Zr *K* absorption edge, they were able to extract differential radial distribution functions (DRDFs) which show the atomic environment around Zr atoms only. The DRDFs show that Ta has little effect on the nearest neighbors of Zr atoms, but does significantly enhance the medium-range order (over distances of 5-15 Å from an average Zr atom). To explain these observations, it was proposed that topologically ordered atomic clusters are a significant feature of the structure of Zr-based amorphous alloys, and that the influence of Ta is to enhance the order associated with packing of these clusters. This work has been submitted for publication in *Physical Review B.*

18. Science Education by Helen Quinn

Education

Pre-College Education

SLAC continues to support local schools through its surplus equipment donation program, through tours for students in physics or physical science classes, and through involvement in the leadership of an ongoing eight school district project (Bay Area Schools for Excellence in Education) to improve science teaching in grades K-6. 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.

This summer, four high school teachers (two chemistry teachers and two physics teachers) spent eight weeks at SLAC working on research-related projects. They are the lead teachers for the SLAC and Stanford Quarknet projects and will return next summer to assist SLAC staff in presenting a workshop for a larger group of teachers. Quarknet lead teachers from Vanderbilt University and from University of Cincinnati also visited SLAC for shorter periods during the summer.

Undergraduate students

SLAC invites 25 students for summer research internships under DOE's Energy Research Undergraduate laboratory Fellowships 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. This summer, the communication office began a 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 second year and held on the Stanford University campus. The Stanford-Berkeley Summer Schools are jointly organized by Stanford University, University of California 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 in the Physical and Life 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 stimulated through dedicated problem solving sessions and round table discussions.

The Summer Schools 2002 attracted 68 students from various parts of the world. This year's program in the Life Sciences focused on structure determination methods in macromolecular crystallography, from crystal screening to structure interpretation with special emphasis on computational methods. The Physical Sciences program provided a comprehensive overview of the synchrotron radiation process and its applications related to spectroscopy and diffraction. Particular emphasis was given to examples from physics, chemistry, and material science.

In addition, in conjunction with the 28th SSRL Annual Users' Meeting in October 2001, three workshops covering a broad range of applications of synchrotron radiation were held. On the Wednesday preceding the meeting, the three workshops titled "Thin Film Scattering," "Metrology with Sub-Picosecond X-ray Pulses," and "On the Roles of XAS and SAXS in Structural Genomics/Proteomics" engaged about 90-100 participants.

19. Scientific and Technical Information Management – 2002 DOE Assessment (Pat Kreitz)

SLAC continues to integrate STI into program and project management by funding the publications, access and STI management functions as a core part of the Research Division. Announcement records for all appropriate scientific and technical information products were submitted in electronic form to DOE's Office of Scientific and Technical Information. Full text versions of SLAC publications are available via the Web. In fact, this year we have over 10,000 electronic versions of SLAC preprints, reports, and other documents on the SLAC Publications Web server. Bibliographic records are included in the SPIRES-High Energy Physics Database, which is the core literature database of the worldwide particle physics community to make SLAC's research even more accessible. . In these three ways -- through OSTI, through Web-accessible electronic full text, and through the HEP database -- SLAC STI publications are made broadly available in electronic form.

SLAC Preprints	FY99	FY00	FY01	FY02*
Pubs	272	310	314	484
Reports	19	14	12	21
AP-Notes		8	3	4
Tech Notes				1
Working Papers				2
Total Submitted to OSTI	291	332	329	512

**The increase in papers reported in FY01 and FY02 is due to increased scientific output and a project to improve identification of SLAC papers that 'escape' the document control process.*

Reprints	FY99	FY00	FY01	FY02*
SSRL Reprints	10	14	325	166
SLAC-HEP Reprints	111	128	47	16
Total	121	142	372	182

** In FY02, SLAC began submitting announcement records for SLAC-HEP and SSRL reprinted papers. Most of the SSRL STI products will be reported this way since most are not reported to SLAC Technical Publications until after the papers are published in a journal or proceedings.*

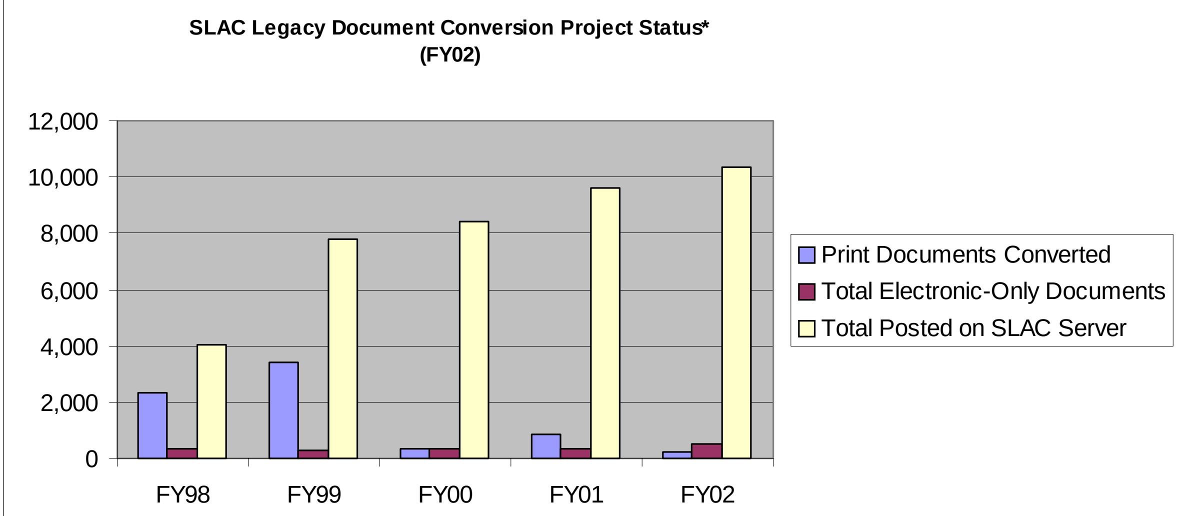
This year's data shows some interesting trends. First, there is an increase in total items reported to OSTI. This is partly due to the addition of reprint announcement records from the SLAC Synchrotron Radiation Laboratory). 2001 marked the first year OSTI required reports on reprints, particularly from synchrotron research. SLAC was unable to report SSRL reprints in 2001 but caught up with the past two years in its 2002 reporting process. Another reason for the increase in items reported is an expected rise in the number of SLAC papers being written. BaBar, the main high-energy physics experiment at SLAC, has been taking data in 2001-2002 and its significant scientific findings translate into more papers published. It is particularly interesting that not only is the experiment producing more papers, but also the importance of those papers is readily apparent through an analysis of citation rates. Four of their published papers from 2001 and 2002 have already received over 50 citations each from other researchers referring to their findings.

A final reason why the reporting rate increased this year is that the Technical Publications Department and the Library collaborated in a project to improve the software used to check for authors who do not get SLAC preprint numbers before they submit publications to either the E-print Archive or to a journal for publication. They reviewed the journal literature and the Archives for items published in 2001 and 2002. This is why the percentage 'published' without first obtaining a SLAC Pub/Report number increased for these two years. All of those publications and reports have subsequently been given numbers and reported to OSTI. Technical Publications is going to take an active role in communicating with the authors of those 'leaked' papers so that they follow the standard process in the future. To improve author compliance, Technical Publications has implemented a Web-based system for authors to report publications and obtain SLAC numbers. This has been received very positively and will be even better publicized to our authoring community in the next year.

Leaks	FY99	FY00	FY01	FY02*
Total pubs/reports submitted to OSTI	291	332	329	512
Subset that 'leaked' out without first obtaining SLAC Pub/Report Numbers	23	19	69	207
Percentage of Leaks per Year	8%	6%	21%	40%

** In FY02, the jump in the number of leaked papers processed is due to improved scripts for finding these errant papers, and a concentration of efforts in assessing and processing these papers.*

SLAC's legacy conversion project is all but about 2% complete. The chart below shows the number of print documents converted, the number of fully electronic submissions not requiring conversion, and the total number of electronically Web-accessible documents on the SLAC server.



**Announcement records for legacy documents were submitted to OSTI in prior years.*