TABLE OF CONTENTS

1. FY2001 PROGRESS FOR PEP-II...3

2. FY01 PROGRESS IN *BABAR* AT PEP-II.....................................7

3. FY01 PROGRESS IN SLAC LARGE DETECTOR (SLD)...........12

4. FY01 PROGRESS IN PARTICLE ASTROPHYSICS PROGRAM 15

5. FY01 PROGRESS IN E158 17

6. FY01 PROGRESS IN E159/E160/E161 AND ESA PHOTON BEAMLINE...20

7. FY01 PROGRESS FOR THE NEXT LINEAR COLLIDER RESEARCH AND DEVELOPMENT..21

The NLC Test Accelerator – NLCTA 24

8. FY01 PROGRESS IN ADVANCED ACCELERATOR RESEARCH...26

Advanced Accelerator Research A... 26
Advanced Accelerator Research B.. 38

9. FY01 PROGRESS IN ADVANCED COMPUTATIONS RESEARCH...41

10. FY01 HIGH POLARIZATION ELECTRON SOURCE DEVELOPMENT...43

11. FY01 PROGRESS IN FRACTIONAL CHARGE AND MASSIVE PARTICLE RESEARCH (MARTIN PERL).................................44

12. FY01 PROGRESS IN TEST BEAM PROGRAM.........................45

13. FY01 PROGRESS IN THEORETICAL PHYSICS 48

Physics at the Next Linear Collider 48
Physics at Bottom and Charm Factories 48
Quantum Chromodynamics at High Energy.. 48
Computational Quantum Field Theory.. 49
Space-Time Physics at Accelerators.. 49
Superstring Theory and M-Theory.. 49
New Theoretical Methods 50

14. FY01 PROGRESS IN RF POWER SOURCE DEVELOPMENT.51

15. FY01 PROGRESS IN RADIATION PHYSICS DEPARTMENT .52

Experimental Activities *52*
Linac Coherent Light Source (LCLS) R&D Activities: Systematic FLUKA-simulations were preformed in order to study the energy deposition by photons in micrometric volumes of the LCLS mirrors. Various combinations of mirror material, photon energy and incident (grazing) angles were investigated. For the calculations the unique feature of FLUKA to transport the particles in a single-scattering mode was employed. *52*
Development and Benchmarking Work in Radiation Transport Codes *53*
FLUKA: In collaboration with Siegan University and BRI Delaware work was done in preparation for the transition of DTUNUC-2 into DPMJET-III for eventual inclusion in FLUKA particle interaction and transport codes. Cross sections for giant dipole resonance interactions in FLUKA were updated. The cross sections are now based on detailed fits to data for elements up to copper. *53*

16. SSRL OVERALL OPERATIONS – FY01 USER EXPERIMENTAL RUN 54

FY2001 User Experimental Run *54*
Distribution of the 365 proposals receiving beam in FY2001 .... *57*
SPEAR Improvements and Accelerator Physics *57*
SPEAR3 Upgrade Project *59*
Fourth Generation Source Development *61*
New Beam Line Facilities and Beam Line Improvements *63*
Highlights of the Scientific Program *68*
Structural Molecular Biology *68*
Molecular Environmental Sciences (MES) *70*
Materials Science *71*

17. SCIENCE EDUCATION 75

Education *75*
Pre-College *75*
Undergraduate *75*
Graduate *76*
Professional *76*

18. FY01 PROGRESS ON SCIENTIFIC AND TECHNICAL INFORMATION MANAGEMENT 77

SLAC High Energy Physics Research Progress Report – FY01

1. FY2001 Progress for PEP-II (John Seeman)

The PEP-II run in 2001 started in February after a three-month installation period. After some time on issues and initial vacuum scrubbing for the LER, PEP-II started to deliver colliding beams to *BABAR* with machine studies interspersed. The early machine studies concentrated on reducing the beta x* in both rings and understanding the RF feedback and control systems. The results with PEP-II collisions showed that reducing both beta x*s from 50 cm to 35 cm was too large a step at one time and the beta changes were removed. The RF stability studies started to pay off allowing high currents to be stored. Starting in April, PEP-II went into an integration-only mode to provide as much data as possible to *BABAR* by the summer conferences. PEP-II delivered and integrated a total of about 38 fb^{-1} to *BABAR* by the end of June. Even without machine studies, the luminosity increased from February to June from 1.8 to 3.2 x $10^{33}/cm^2/s$. *BABAR* published in early July its" "sin2β " results on CP violation.
In July, weekly machine studies were resumed with the aim of increasing the currents and increasing the specific luminosity per bunch. 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. By the end of August, the luminosity was up to $3.6x10^{33}/cm^2/s$. In August, a simple knob on the beta x in the HER was developed to allow fine control. This knob was used several times over the next month to adjust the relative strength of the HER and LER during collisions. By the end of September, the horizontal beta x had been lowered from the measured 80 cm to about 65 cm. The HER and LER betatron tunes were carefully adjusted. The specific luminosity at low currents was above 3.8 x $10^{30}/cm^2/s/mA^2$. The luminosity reached 4.214x $10^{33}/cm^2/s$ on October 1, a record for PEP-II. 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.

PEP-II (and SLAC) had to watch the power budget during the summer but, in the end, ran remarkably well given the circumstances. Over that time, SLAC had no blackouts but had about five brownouts during which we were asked to reduce our load for several hours. During operation, PEP-II with *BABAR* has run very well with a mean time to failure of about 28 hours, a mean time to repair of 4 hours with PEP-II coasting through some of the repairs, a 92% uptime, and a peak of 13 pb^{-1}/hour delivered luminosity.

The various PEP-II performance levels as of October 3, 2001 are: The peak luminosity is $4.21x10^{33}/cm^2/s$ with *BABAR* taking data. At the peak luminosity, the HER current was 925 mA and the LER current 1620 mA in 728 bunches. The following integrated luminosity numbers are believed to be world records: The best integrated luminosity in an eight hour shift is 96.1 pb^{-1} delivered and 91.8 pb^{-1} recorded by *BABAR*. The peak integrated luminosity delivered in a rolling consecutive 8 hours is 100 pb^{-1}. The best integrated in three consecutive shifts is 281.6 pb^{-1} delivered of which *BABAR* logged

268.5 pb^{-1}. The best delivered luminosity in seven days is 1.68 fb^{-1}. In the month of September 2001, PEP-II delivered 5.08 fb^{-1} for its third month above 4 fb^{-1}. Overall, PEP-II has produced a total of 54 fb^{-1} since May 1999.

The plan for PEP-II is to run continuously until the end of June 2002 with a short break at the end of the calendar year for the holidays and a "one-week" maintenance down in early January. There is a planned three-month down in Summer 2002 to install two RF stations for PEP-II and to rework the end-cap IFR for *BABAR*.

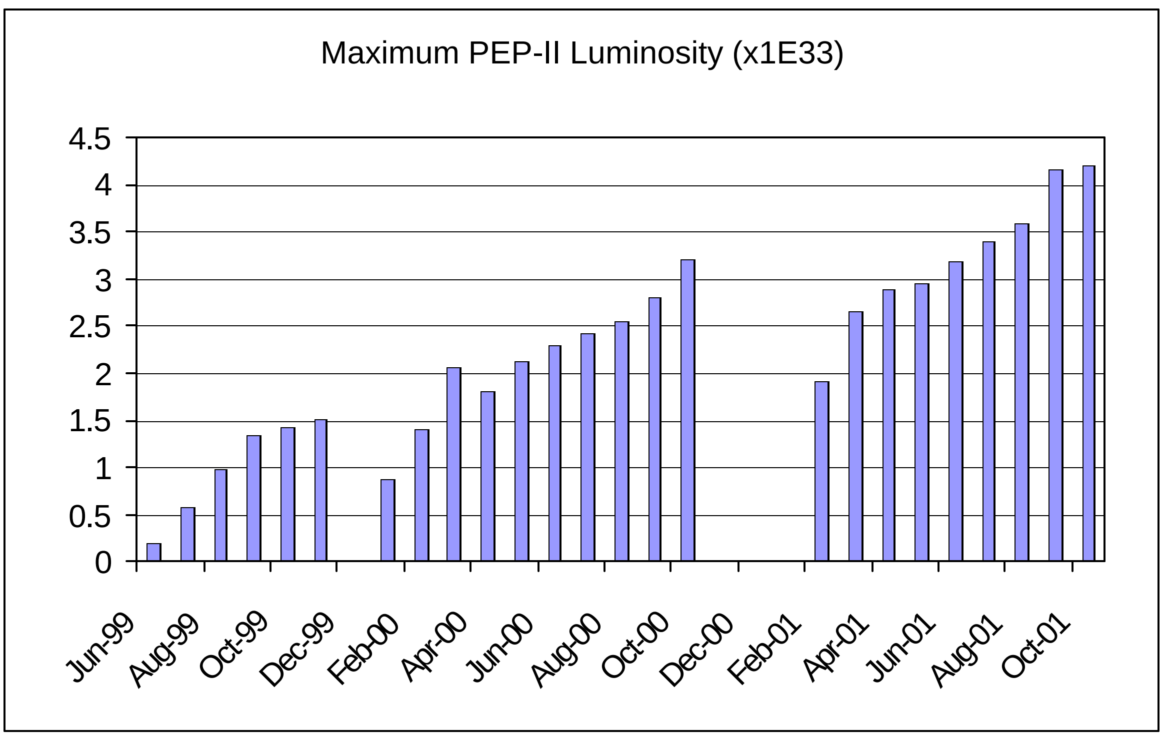


Figure 1. PEP-II Luminosity June 1999 – October 2001

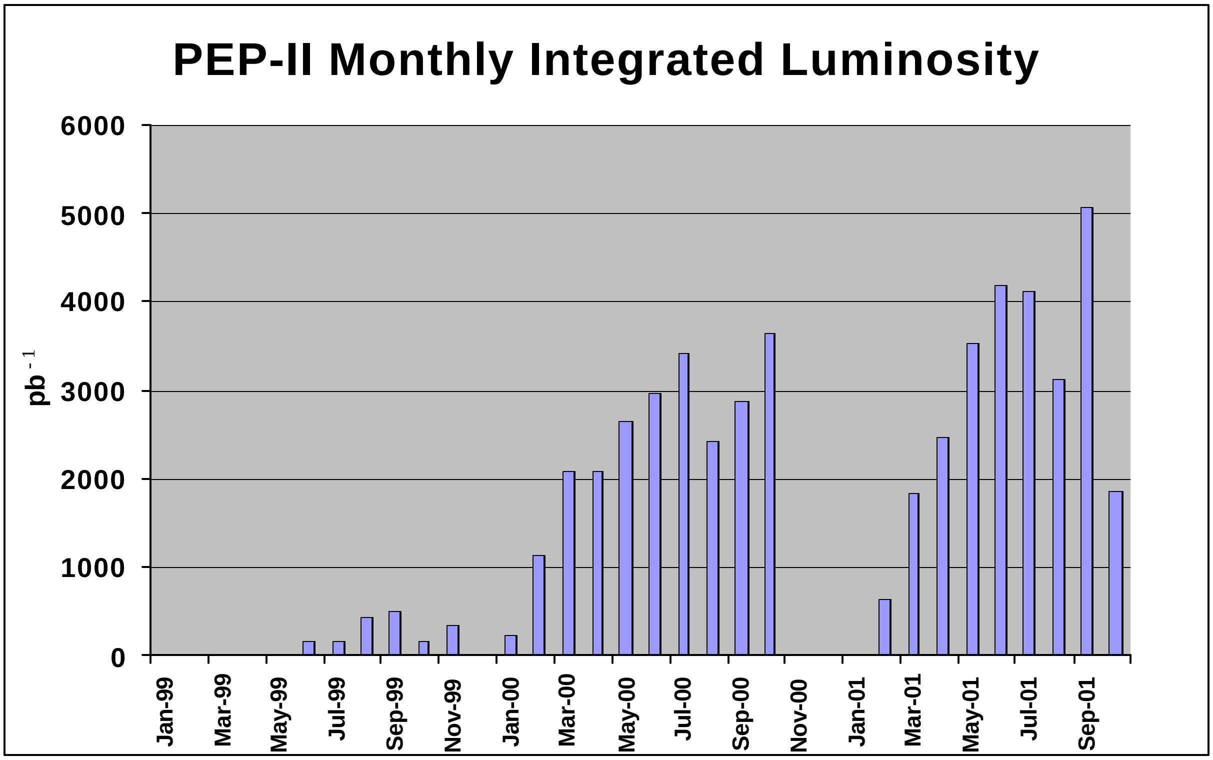


Figure 2. PEP-II Monthly Integrated Luminosity January 1999 – September 2001

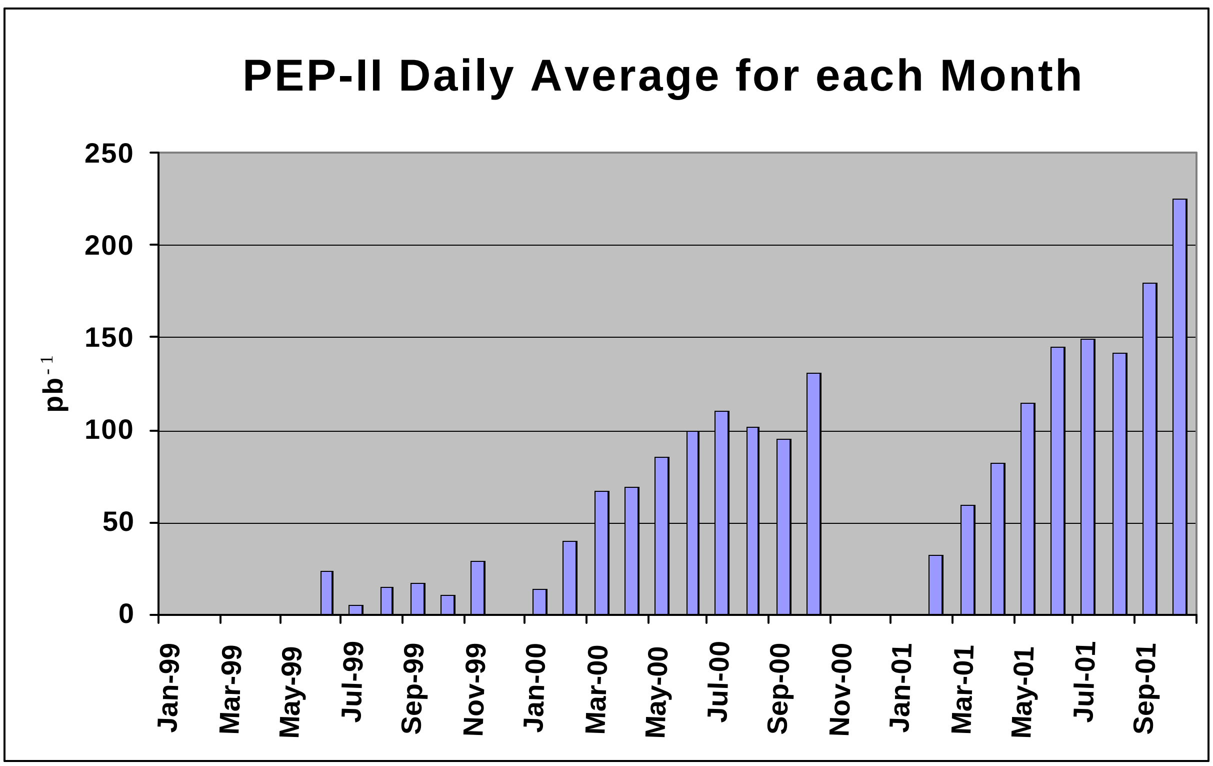


Figure 3. PEP Daily Average Monthly January 1999 – September 2001

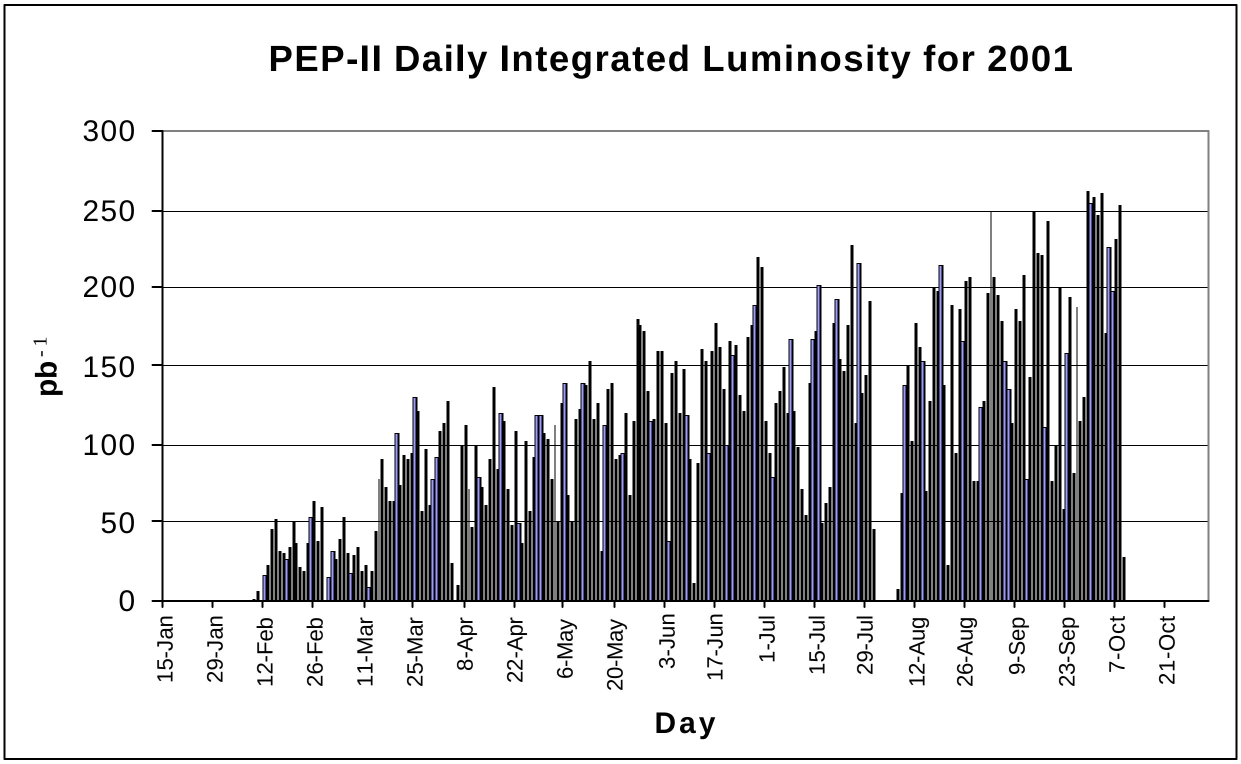


Figure 4. PEP-II Daily Integrated Luminosity 2001

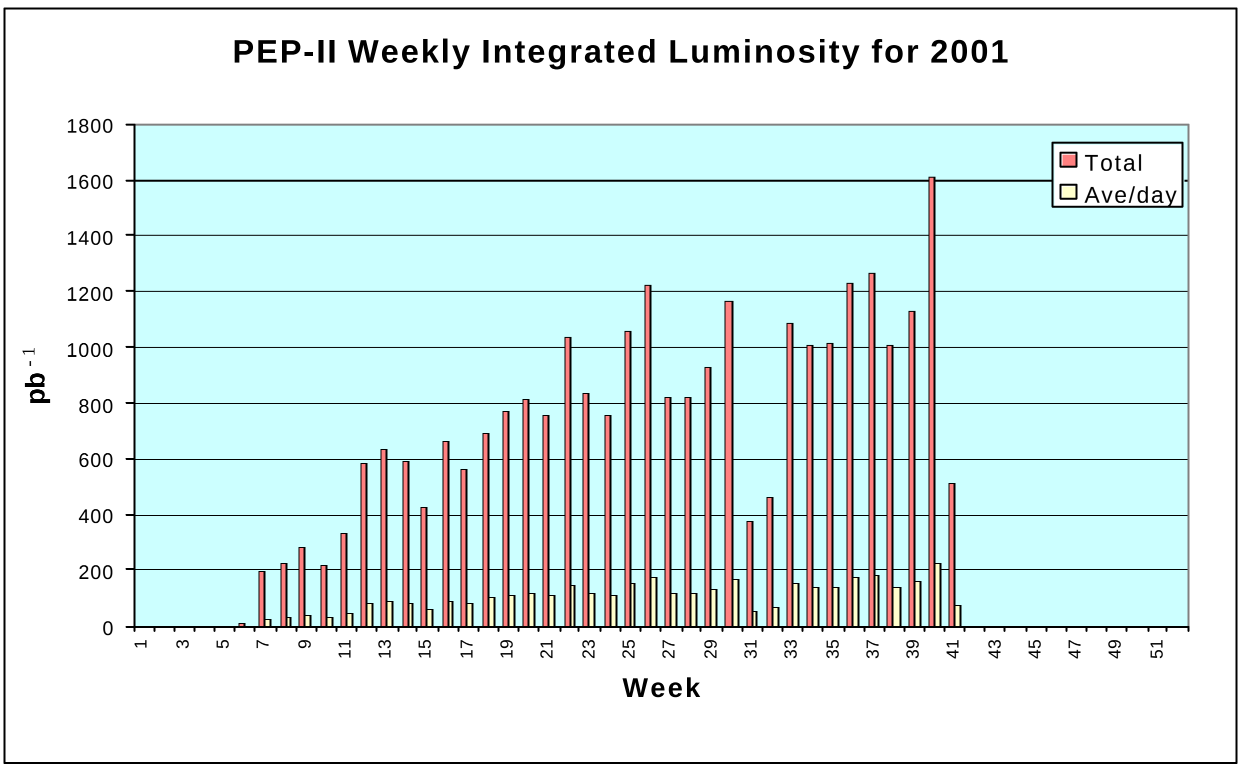


Figure 5. PEP-II Weekly Integrated Luminosity for 2001

2. FY01 Progress in *BABAR*: CP VIOLATION STUDIES AT THE PEPII B FACTORY (Stew Smith)

The BaBar detector in Interaction Region 2 of PEPII received its first beam in May 1999 and has been in full operation since November 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. With a 4π detector, excellent vertex detection and particle identification, and the asymmetric energies of the PEP II beams, BaBar is singularly well suited 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 50 million B events have been accumulated at the Y(4S), corresponding to an integrated luminosity of ~50 fb^{-1}. The highlight of the experiment so far took place this summer when BaBar published the first conclusive observation of CP violation outside the neutral kaon system, 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. Time-dependent asymmetry measurements are also underway in rare charmless decays, e.g. $B^0 \rightarrow pp, B^0 \rightarrow rp$, etc., to measure the phase α; measurements of asymmetries in even-rarer modes will be used in the future to infer the third phase γ.

The BaBar Collaboration consists of approximately 600 physicists and engineers from 72 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. BaBar depends on, and provides advanced training for, a large number of postdoctoral physicists and graduate students around the world. A recent census is shown in the following Table.

POST DOC/GRAD STUDENT SUMMARY		
(BaBar Physicist Members, not including Associates)		*02/10/01*
Country	**Grad Students**	**Post-docs**
CANADA	4	4
CHINA	0	0
FRANCE	10	2
GERMANY	14	3
ITALY	21	12
NORWAY	1	0
RUSSIA	0	0
UK	25	19
USA	56	59
Totals	131	99

Note: In this census, the numbers of physicists having equivalent experience to US postdoctorals are significantly underestimated for France and Russia, where scientists quickly obtain permanent positions earlier in their careers than in the other countries.

Detector operations and computing issues. As FY2001 began, PEPII and BaBar had been smoothly operating for several months. The run continued until November 2000 when the facility shut down for repairs, maintenance, and installation of new vacuum chambers and additional pumping to improve PEPII performance. During this period the accelerator achieved its design peak and average luminosity. Operations resumed in February 2001 and have continued since then with only minor interruptions for maintenance. All PEPII design specifications have now been met or surpassed -- perhaps the most remarkable record is the delivery of 281 pb-1 in one day, more than double the design value! Approximately 30 fb^{-1} were delivered in FY 2001. To respond to the exciting prospect of steadily increasing PEP II luminosity – as much as 2.5 10^{34} $/cm^2/sec$ (8 times design) within a few years -- the BaBar collaboration has continued studies and has begun implementing improvements to the detector and to the computing system, following the plan approved by the BaBar International Finance Committee last winter.

Physics analysis and results. Enormous analysis activity and progress have taken place to extract physics from the data, including: improved tracking efficiency; better vertex resolution; better understanding and rejection of backgrounds; Geant-4 simulation of the detector. Approximately 12% of all data (~5.5 fb-1) were taken at a center of mass energy ~40 MeV below the *U*(4S) in order to understand the continuum events and subtract them from the sample of desired B decays. Twelve physics papers, most of which contain "world's-best" results, were submitted for journal publication in FY 2001, and over 20 additional results were presented at international conferences. Numerous other analyses are in progress, with results and publications expected in FY 2002.

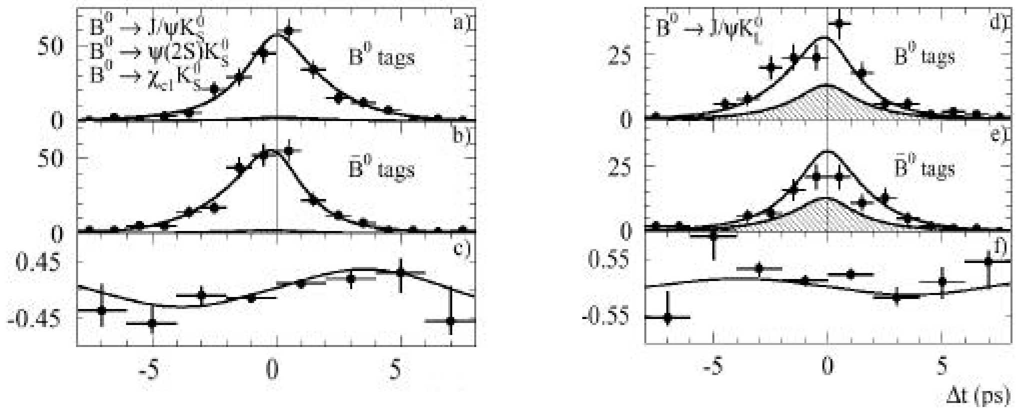
The most important result this year was the first observation of CP violation outside the neutral kaon system: measurement of the CP violating phase *sin2b*. Based on a sample of 29 fb^{-1} accumulated in FY 2000 and 2001, this result was submitted to Physical Review letters on July 5 and publicly presented shortly thereafter, first at the European Physical Society Meeting in Budapest and again two weeks later at the Lepton Photon Symposium in Rome. The quantity *sin2b* is determined by fitting the time spectra $\boldsymbol{f}_{CP}(Dt)$ for reconstructed events in which the flavour of one of the decaying B's is tagged at t=0, and in which the other B decays to a *CP* eigenstate at time *Dt*. In the fit, the measured quantities are convolved with the experimentally determined resolution function *R*. In the expression below, the mistag probability *w* is measured from much larger samples of events in which the reconstructed B decays to a state of flavour.

$$f_{CP,\pm}(\Delta t) = \left\{ \frac{e^{-|\Delta t|/\tau_{B_d}}}{2\tau_{B_d}} \times \left(1 \mp \eta_f .(1-2w).\sin 2\beta.\sin(\Delta m_{B_d} \Delta t) \right) \right\} \otimes R$$

$$"f_{CP,+}" \Leftrightarrow B^0_{tag} = B^0$$

$$"f_{CP,-}" \Leftrightarrow B^0_{tag} = \overline{B}^0$$

The fitted spectra are shown below. The final result is**: sin(2b) = 0.59 ± 0.14$_{stat}$ ± 0.05$_{syst}$**



The probability of obtaining the above result if CP is conserved is $<2 \times 10^{-4}$, so the presence of CP violation is therefore firmly established.

Other important results presented in FY 2001 included lifetime measurements of charged and neutral B's; $B^0 - \overline{B^0}$ mixing measurements; studies of radiative penguin decays to $K^{(*)0}\gamma$ and $K^{(*)0}$ ll; two-body and three-body charmless decays, charmonium decays, exclusive decays to charm. We have also made a first "proof-of-principle" measurement of sin2α from time-dependent asymmetry in the rare decay $B^0 \to p^+p^-$, based on a sample of 30 fb^{-1}:

$$\sin 2\alpha = 0.03 \ (+0.53-0.55_{\ stat}) \ \ (\pm 0.11_{\ syst})$$

Plans for FY2002

Operations: The data-taking run in progress at the end of FY 2001 will continue untill June 30, 2002, producing an additional ~50fb^{-1} and a grand total data sample of ~100 fb^{-1}. A 3-4 month shutdown will follow, during which PEPII and BaBar will install improvements to produce and accept higher luminosity. The performances of the Silicon Vertex Tracker, Drift Chamber, DIRC, and EMC have met or are approaching the specifications of the TDR. Studies of backgrounds indicate, in fact, that the detector should be able to handle instantaneous luminosities up to and above 10 nb/sec, as planned for FY 2003 and beyond.

However, the efficiencies of the resistive plate chambers (RPC's) continue to decrease. A task force studied the problem during Fall 2000 and Winter 2001, and recommended an upgrade of the forward endcap region to improve muon separation by adding approximately an interaction length of brass to the existing material of the flux return, and by replacing the existing RPC's with RPC's of new manufacture. This project is now under construction for installation in summer 2002. Continued deterioration of the "barrel" RPC's presents a very serious issue, which will have to be addressed by 2004 unless the system is stabilized. Remediation studies and other muon-detection R&D are being actively pursued by several institutions in the U.S. and Italy.

Improvement Plans to keep up with increasing luminosity: Plans for improvements to keep up with increasing luminosity were presented to the Director's Technical Review Committee at the beginning of FY 2001 and approved by the IFC in January 2001. The current scope and schedule are as follows:

Minor modifications to the Drift Chamber, DIRC, and EM Calorimeter

- A set of spare modules for the Silicon Vertex Tracker (SVT), comprising about ~30% of the original complement. Fortunately, recent radiation damage studies indicate that the SVT will withstand more than 4 Mrad (twice the design value) and therefore replacement will not be necessary till 2004.
- An upgrade to the Trigger system is under construction for installation in summer 2002. Information from the stereo layers of the drift chamber is used to improve rejection of tracks not originating at the IP, thereby reducing the Level-1 trigger rate by a factor of 2.
- The major and most expensive improvements needed to keep up with increasing luminosity are those to the data acquisition and computing systems. The needed DAQ performance will be achieved mainly by deploying faster electronics and CPU's. A detailed plan for storing, accessing, and processing of the increased amounts of data (~500 fb^{-1} by 2006) was approved in January 2001 and is being implemented in FY 2002. A remote "Tier-A" site (a facility capable of comprehensive production and analysis of >25% of the total BaBar data) has begun operations at CCIN2P3 in Lyon, France. Two more Tier A's will be established during FY 2002 and FY 2003 in Italy and the UK.

Physics analysis and results: For high-priority measurements that are statistics limited, we plan to produce new results in the summer of FY2002 based upon the entire ~100fb^{-1} data sample. Interim results will also be presented in March 2002 based on the data taken up to Christmas 2001, approximately 60fb^{-1}. In the case of $sin2b$, it should be possible to reach statistical precisions better than 0.10 by March, and 0.08 by summer. Meaningful comparisons of $sin2b$ among modes having different quark decay processes will become possible. This data will also yield the first significant measurement of sin2α, and precision measurements of direct CP violation in many different channels. New results will appear in semileptonic decays, including measurements of V_{ub} and V_{cb}. Greatly improved alignment of the SVT has opened the door to many interesting topics in charm and tau physics, and reduced systematic effects in many analyses. In all, BaBar expects to have published approximately 50 journal papers by the end of FY 2002.

Beyond 2002 we plan to continue running at the Y(4S) and to accumulate ~60 fb^{-1} in FY 2003, bringing the total sample to ~160 fb^{-1}.

Looking toward the long term, we shall be carrying out major R&D. Among the high-priority projects will be adding hermeticity for rare decay studies, and understanding possible new silicon and gas-chamber tracking systems able to withstand the backgrounds and radiation damage associated with luminosities as high as 30 nb/sec.

3. FY01 Progress in SLAC Large Detector (SLD) (Peter Rowson)

SLD completed its last scheduled run in June 1998, reaching the goal of 350 K Z's for the run. This run added 350 K Z's to the 50K Z's with the new vertex detector VXD3, and to the 150K Z's taken with the old vertex detector.

The past fiscal year has seen continuing demonstrations of the power of VXD3, particularly when combined with the polarized electrons of SLC and the particle identification of SLD. There has been continuing analysis progress and publications on many fronts. In addition, review papers describing the SLD program have been completed or are nearly complete. (An Annual Review of Nuclear and Particle Physics article is scheduled to appear in November, and is available now as SLAC-PUB-8985. A Physics Reports article written in collaboration with the LEP electroweak working group is in preparation.)

Since 1995, the SLD has provided the single most precise and reliable determination of the electroweak mixing angle, which in turn is the most sensitive probe of higher order corrections in the Standard Model. By testing the Standard Model to high precision, and including the present top quark mass data from FNAL, one is able to constrain the Standard Model Higgs mass and search for the effects of new physics. The measurement determines the left-right polarization cross section asymmetry in Z boson production (ALR), a method with inherently tiny detector systematic effects: using the entire 1992-1998 dataset the total error presently remains dominated by statistics (1.3% compared to a 0.65% systematic error).

The SLD analysis for ALR is now complete and is published [PRL,84,5945 (2000)]. The uncertainty of the running SLD average is 1.5%, which translates into a determination of $\sin^2\theta_{eff}$ = 0.23097+ - 0.00027. This result is combined with the SLD measurement of lepton left-right-forward-backward asymmetries, also a final result as of this writing was sent out for publication (to PRL), to yield our current overall average $\sin^2\theta_{eff}$ = 0.23098+ - 0.00026. This number is often compared to the global LEP result, which averages over leptonic and hadronic forward-backward asymmetry measurements and tau polarization results, with a present error of + - 0.00023. Interestingly, the assumption of fermion universality inherent in the LEP average has been brought into question by recent data from both sides of the Atlantic regarding the Z to b quark neutral current coupling, A_b, as mentioned below. The SLD result, by itself, provides an interesting upper bound on the mass of the Standard Model Higgs boson that is more stringent than the worldwide global fit result. The most conservative number is obtained using a particular choice for $\alpha(M_Z^2)$ (A. D. Martin et. al., hep-ph/0008078), and is 147 GeV/c^2 at 95% confidence – the more commonly used value (H. Burkhardt and B. Pietrzyk, LAPP-EXP-2001-03) leads to a limit of 133 GeV/c^2 .

By virtue of the SLC beam polarization and small and stable collision region, and the high precision and efficiency of the SLD vertex detector, the SLD collaboration is now providing several of the world's best heavy flavor electroweak measurements. These include measurements of A_b and A_c, the bottom and charm flavor analogs to ALR (which measures the parity violation of the electron neutral current, A_e). Only the SLD experiment directly measures these quantities. SLD also provides competitive measurements of R_b and R_c, respectively the bottom and the charm fractions of the hadronic cross-section. Both results confirm the LEP results that are in agreement with the Standard Model. However, as mentioned above, the precision A_b results from LEP, which are indirect, deviate from the Standard Model presently by about 2.5 sigma, while the direct results from SLD are consistent. R_b is mainly sensitive to the left-handed couplings, and A_b to the right-handed couplings, but there is little theoretical guidance to explain such an effect. It is perhaps more likely that these LEP deviations are due to some combination of statistical fluctuations and unknown systematic effects. The present situation is somewhat troubling, and indicates that purely leptonic data should probably be used to extract the weak mixing angle.

The large 1997-98 data set is also producing world-class results in B physics. Experiments around the world are trying to measure Δms, the oscillation frequency in B_s mixing, so far without success. SLD reported B_s mixing limits at the 2000 summer conferences. The experiment is currently sensitive up to ms about 14 ps^{-1}; this will be extended to $\Delta ms = 16\ ps^{-1}$ with some analysis improvements in the next few months, which will surpass LEP sensitivity. The ratio of B^+ to B^0 lifetimes were determined to be 1.06 + - 0.04, indicating that lifetime differences in the B sector are smaller than with charm, but that the B^+ may be the longer-lived, as expected. SLD is measuring the branching ratio BR (B-> DDbarX), which may help explain why the semi-leptonic branching ratio is anomalously low, a long-standing puzzle in B physics. Using a technique which exploits the decay vertex topology and kaon identification, we measure Br (B-> DDbarX)= .188 +.025 + .059. This measurement relies on the superb resolution afforded by VXD3, and will be improved with additional techniques to become the world's best.

SLD exploits its unique tool kit (polarization, precision vertexing, and particle identification) to test QCD and study hadronization. A new, precise measurement of the B hadron energy spectrum has produced the first clear indication that the shape of the spectrum disagrees with current Monte Carlo predictions. SLD has just published a comprehensive study of inclusive particle production of π, K, P, K^0, and Λ's. Gluon jets have been isolated in double-b-tagged b-bbar g events and their energy spectrum measured. This measurement allows limits to be set on anomalous couplings. The same events can be used to study parity violation in Z decays and detailed searches for CP and T violation in three-jet events. SLD's particle identification system has been put to good use studying charge and rapidity correlations between various hadron species in hadronic events. The superb vertexing capability of VXD3 has been exploited with a new measurement of the fragmentation of the gluon to bb pairs.

In summary, FY01 has seen the completion of several important SLD analyses, with significant progress on all fronts. SLD is contributing world class measurements to QCD, results in B-Physics that are both unique and the world's best, and an electroweak precision determination of the weak mixing angle that has set the standard in the field for several years and which indicates that the Standard Model Higgs boson should be relatively light. The results have made a significant contribution to particle physics.

4. FY01 Progress in Particle Astrophysics Program (Tsuneyoshi Kamae)

The GLAST group has been focusing on the design and development of the GLAST LAT detector.

Highlights of progress made in FY 2001 includes:

1) International collaboration has been strengthened: An INFN-Pisa group led by Dr. Ronaldo Bellazzini has joined the collaboration .The Italian space agent, ASI has also expressed its willingness to participate in the collaboration. Firm commitment have been made by the three French agents, CNES, IN2P3, and CEA. In addition, MOU's have been signed with the Japanese and Swedish GLAST collaboration.

2) Institutional responsibility and subsystem leadership have been identified. UCSC, SLAC, Italy, and Japan will take the responsibility of the Tracker subsystem. NRL, France, and Sweden will take the responsibility of the Calorimeter subsystem, and Goddard Space Flight Center will be responsible for the Anti-Coincidence Detector. SLAC will be in charge of the electronics, flight software, science analysis software, and mechanical subsystems. Integration and testing (calibration included) will be another important responsibility of SLAC, Stanford University and NRL.

3) The Beam Test Engineering Model was converted into a balloon flight instrument (Balloon Flight Engineering Model) and flown from the National Science Balloon Facility at Palestine, Texas on August 4 (see Figure 1). The instrument worked as expected and more than 100k cosmic ray events were recorded on the ground through telemetry (see Figure 2).

4) We expect a few hundred gamma rays in the BFEM data. Figure 3 shows one gamma ray sample. Four plastic scintillation counters (External Gamma Target) had been placed above the detector and registered hundreds of hadronic interactions. Figure 4 shows a clean gamma ray coming from such an interaction.

In February 2001, we went through a Pre-Baseline Review by DOE and NASA . Preliminary Design Review (PDR) and DOE Baseline Review ("Lehman Review") are now scheduled for January 2002.

Figure 1. The GLAST Balloon Flight Engineering Model (BFEM) during testing at National Scientific Balloon Facility, Palestine, Texas.

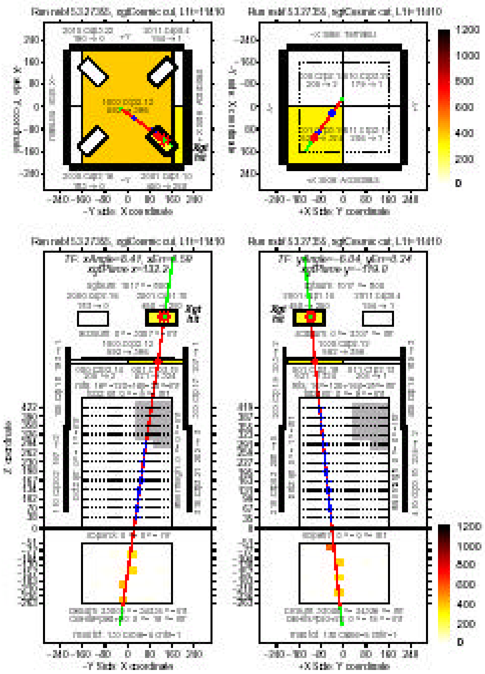


Figure 2. A real time display (four views) of a cosmic ray event in BFEM during the balloon flight.

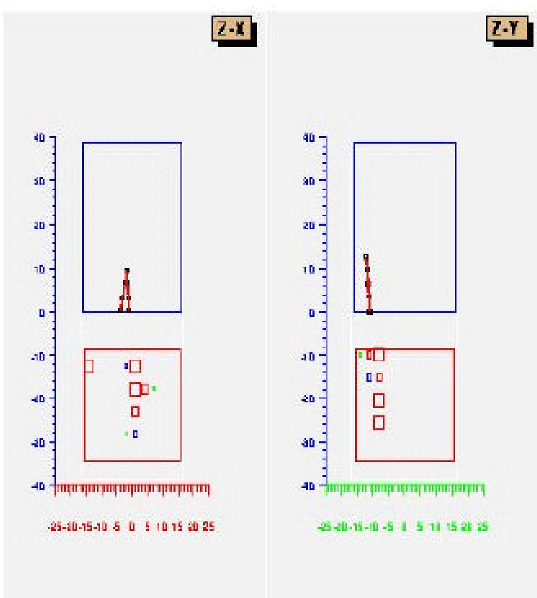


Figure 3 Orthogonal views of a pair production event in the BFEM. The lines are the tracks recognized by the reconstruction program.

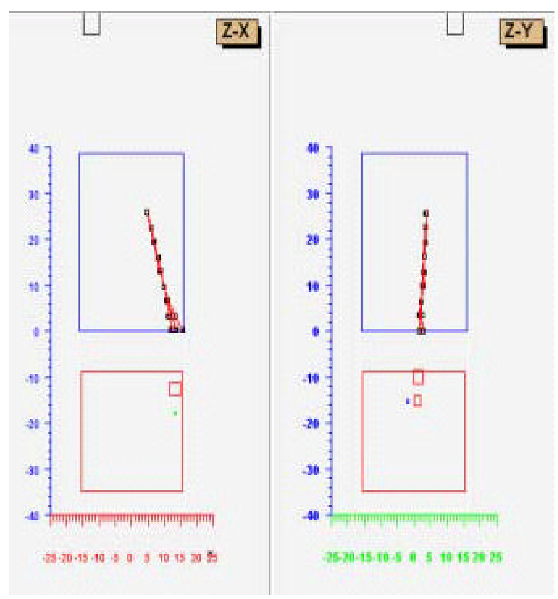


Figure 4. Orthogonal views of a shower generated by a gamma ray coming from an External Gamma Ray Target (XGT). The gamma ray is likely to come from a neutral pion produced by a proton in the XGT shown at the top.

5. FY01 Progress in E158 (Krishna Kumar)

During FY01, the E158 experiment progressed from a construction project to a running experiment. The E158 spectrometer system is one of the most ambitious design projects undertaken in the End Station A program. The system consists of three massive dipoles and four large quadrupoles placed precisely with a set of precision collimators interspersed between them. Hundreds of precision pieces have been fabricated in the SLAC machine shops. The last of these pieces were completed in time for the commissioning run in February 2001. The beamline assembly was completed and the system was ready for beam on February 13, 2001.

In parallel with the spectrometer construction, a great deal of progress was made in the commissioning of the polarized beam in FY01. The polarized gun with the capability of providing the very high charge necessary to run E158 was successfully installed on the linac in preparation for a test run in November 2000. A full-scale test of the laser and electron beam and the associated feedback systems to control helicity-correlations was carried out from November 2-9, 2000. A schematic diagram of the laser table layout for the E158 tests is shown in Figure 1.

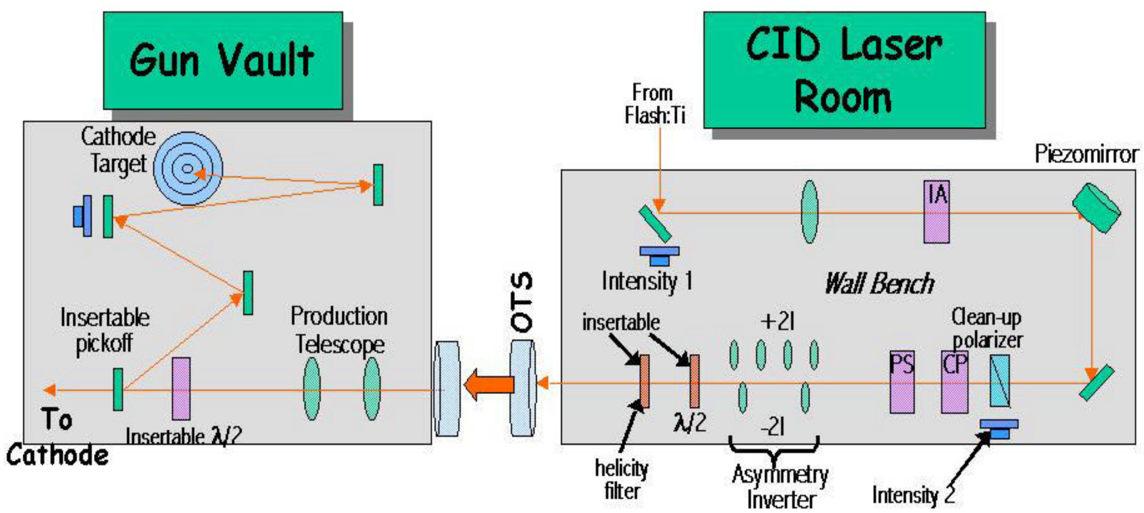


Figure 1: Schematic diagram of the optics transport system of the polarized source laser for E158.

During this test, the monitoring precision that is required for the measurement of beam intensity and position was demonstrated. Further, the feedback systems were commissioned and it was demonstrated that the helicity-correlations in the electron beam were controlled at the very precise levels required for the experimental run.

In January 2001, the high power beam was commissioned in the linac. Since E158 runs in parallel with the PEP-II storage ring, a linac lattice that is compatible for both programs had to be found. This was accomplished in a series of accelerator tests and high power beam was brought to the beam stopper at the entrance of End Station A.

In February 2001, the first beam was brought into End Station A after the spectrometer construction was completed. Figure 2 shows the spectrometer system as construction was being completed in February. The beam was tuned through the spectrometer and directed to the Beam dump with no significant beam losses. The spectrometer was commissioned and the primary physics signal was observed in specially designed calibration detectors from a calibration carbon target.

In March, the beam was shut down in order to enclose the entire spectrometer within a concrete shielding bunker. This shielding is required before high power beam can be brought into the End Station in order to limit the background radiation in neighboring areas.

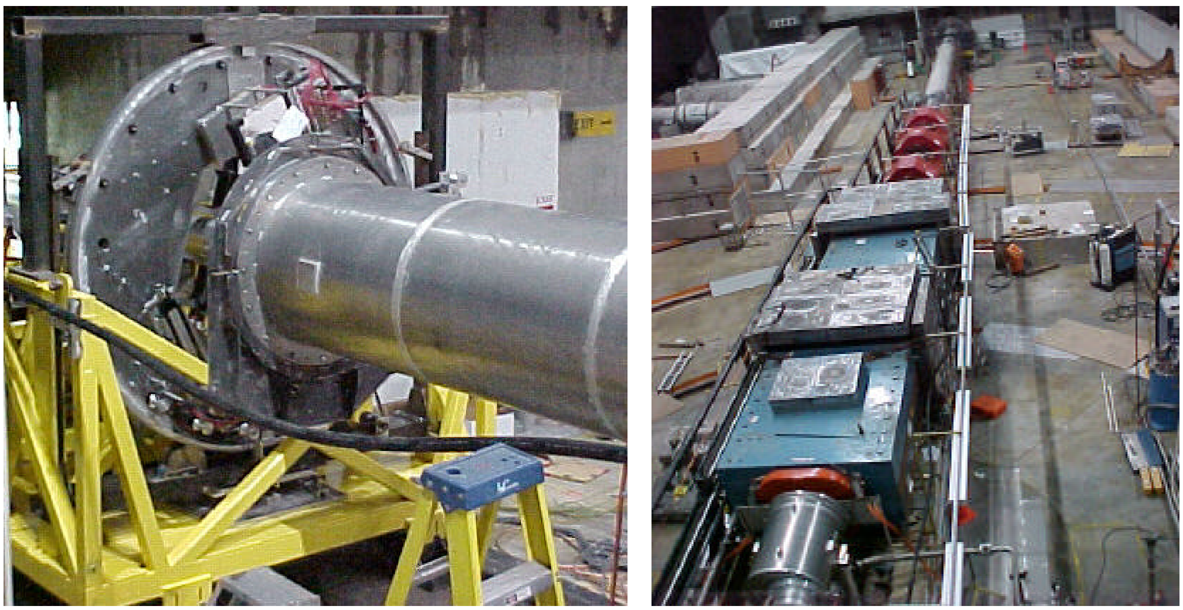


Figure 2: A view of the spectrometer magnets during installation is shown on the right. On the left is shown a closeup view of the detectors at the end of the spectrometer system.

In early April, pulsed magnet power supplies and chambers were installed in the vicinity of the linac damping rings. In the following week, these magnets were commissioned, which allowed for the simultaneous operation of the PEP and ESA beams for the first time. Subsequently, the main E158 quartz-tungsten calorimeter was installed and E158 commissioning began in earnest on April 24. The main physics signal was observed from the liquid Hydrogen target and the beam asymmetry control system was commissioned.

Over the month of May, all E158 subsystems were made operational and a detailed understanding of system performance was possible. This included extensive studies of beam asymmetries, physics backgrounds from photons, electrons and pions, radial distribution of the physics signals at the detector face, electronic noise and linearity measurements, polarimetry studies and target stability studies.

The E158 experiment has thus had a successful engineering run and is gearing up for the first physics run in spring 2002. The polarized beam is fully operational and the accelerator can simultaneously operate the beams for E158 and for Babar. The beam asymmetry controls have been demonstrated to be adequate for the final experimental measurement. The E158 target has been commissioned and it operates stably under normal beam conditions. The E158 detectors have been tested and debugged. Some problems with backgrounds were found which will be fixed during Fall 2001.

Once beam is established and the spectrometer is recommissioned in February 2002, it is anticipated that enough statistics will be collected to demonstrate parity violation in Moller scattering for the first time ever. This would measure the electroweak mixing angle to an accuracy of 1% and would be equivalent in precision to the best published low energy measurements of this fundamental parameter. It is worth noting that the E158 collaboration has been significantly strengthened in the past year with the addition of experienced young physicists. The collaboration now has three full-time postdoctoral research associates and eight graduate students. It is anticipated that five of these students will obtain their Ph.D. degrees on the experiment.

6. FY01 Progress in E159/E160/E161 and ESA Photon Beamline (Perry Anthony)

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. FY01 has seen 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 prepare for construction design reviews for the experiments. A successful conceptual design review for the beamline and E160 was held in August 2001.

Construction of the photon beamline has started with the refurbishment of the diamond Goniometer (photon source) and the removal of the electron dump magnets from the A-Line for repair and upgrading to 50 GeV capability. Detailed designs for all beamline components and support structures are in progress. The goal of SLAC and the RPC is to install this beamline in FY02, with commissioning in early FY03.

Two of the Coherent Bremsstrahlung experiments require the existing LASS Dipole to be used as the main spectrometer magnet. This magnet has been relocated to the ESA facility. All electrical and water connections to the magnet were replaced/refurbished, and the magnet successfully tested at the nominal running current. Further simulations and design studies are underway to determine final configuration.

The RPC has elected to order the experiments with E160 running first, followed by E161 and finally E159. This order follows naturally from the technical requirements of the individual experiments. E160 has completed its conceptual design review, and work to finalize all design components is now in progress. E160 construction activity is expected to start in FY02, with installation in late FY03. Both E161 and E159 use a polarized target with several long lead-time components, namely a high field super-conducting magnet and a high power microwave source. A conceptual design review for these components has been completed, and work is underway to finalize design requirements prior to ordering these components. Substantial progress has also been made in refurbishing the dilution refrigerator to be used with the polarized target.

7. FY01 Progress for the Next Linear Collider R&D (Albe Larsen)

In FY01 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) optimizing design of structures through which the positrons and electrons will travel, and extending studies of techniques to manufacture these structures; 3) development of cost-effective optics decks including beam-position monitors, magnets and magnet movers; 4) reexamination of final focus requirements; 5) 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; 6) industrialization of structures manufacture. Fermilab, now a year-plus into this collaboration, has more clearly defined its work scope and has initiated effort toward an Engineering Test Facility to be housed in a Fermilab tunnel. Work on permanent magnets is underway and site and conventional facilities work is now well integrated with the effort at SLAC. Work on structures manufacture on a commercial scale will also draw on Fermilab's expertise. Collaborative efforts continue in the US with the Lawrence Berkeley and Lawrence Livermore National Laboratories, internationally with the KEK National Laboratory for High Energy Physics in Japan, the University of British Columbia in Canada, and Brunel and Oxford Universities in Great Britain, 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 two 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. An updated *2001 Report on the Next Linear Collider*[2] was submitted to the Snowmass 2001 meeting in July. Both the beam parameters and the NLC collider layout have been modified to provide greater energy flexibility.

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 designed for precision measurements at lower energy, 90 to 500 GeV. This configuration was motivated by the recent breakthrough in the design of the final focus optics which made 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

[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.

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 compatibility with a possible ?? option. 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 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 x 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 a cathode with a thin doping layer indicate that the polarized electron source should be able to produce the full NLC bunch train with 80% polarization. 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 continuously restore the collimator surface. Experimental studies of collimator wakefields have begun using a 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. These studies are continuing with prototype carbon collimators from DESY to be tested next. Two different studies are underway 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 block in size dimensions, and extensions of these tests to more complex objects are planned. A parallel effort at the University of British Columbia is using an optical interferometer. Both of these are part of an extensive program of ground motion measurements and modeling to quantify site and equipment requirements. A study conducted in the SLAC linac last year revealed anomalous ground motion due to atmospheric pressure variations as well as amplified tidal motion due to ocean loading. Extensive ground motion measurements are planned this year at both SLAC and Fermilab using a hydrostatic leveling system developed with the Budker Institute in Russia.

Another potential cost reduction under study is the use of permanent magnets, where possible, throughout the NLC. This 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. R&D on permanent magnets for NLC, which began in 2000, is progressing. Prototype permanent magnets have been constructed at FNAL and measured there and at SLAC. A concern with the permanent magnets is the stability of the magnetic center when the strength is varied. Tight stability is required for present beam-based alignment techniques but alternative approaches are under study to relax this requirement.

Electrical systems work included continued advances in a solid-state modulator to achieve improved energy efficiency, higher reliability, smaller size and lower cost. A full-scale prototype was fabricated, assembled and tested to 75-kV output into a water load, the highest voltage attainable without introducing oil into the system. The components of the final element, a 1:3 step-up transformer, are manufactured and being assembled so that tests can be run to the full 500 kV. Costs of the IGBT power switches continue to drop and anticipated cost reductions are being realized. The design of a second prototype using higher voltage IGBTs has started, and IGBTs, Metglas and storage capacitors have been ordered and most were delivered. The 500-kW modulator power supply was ordered and is due to be shipped in October 2001.

Due to a diversion of effort to other NLC activities, including NLCTA, progress on Global and instrument systems slowed considerably. Progress was made in demonstrating sensitivity and noise performance of BPMS (tested at ATF in KEK), and in the benchtop prototype laser reflectometer timing system using thermally adjusted fiber optic tuning.

Some cost estimates were updated for modulator and DC power systems, and costing rules revisited.

Progress continued in obtaining industrial sources of supply for key NLC components. An SBIR recipient that has received and installed a two-spindle automatic machine tool that will perform both lathe and mill operations on both sides of the part without removing the part from the machine has been separately contracted to provide parts for prototype NLC structures. Another SBIR has resulted in a very low cost design for the microwave tube that provides the input rf signal to the klystron, and plans are in place to purchase some of these devices for the NLC Eight-Pack test in FY02. In order to better understand 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. 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. Extensive analytical work was performed in FY01 to arrive at the most viable design for the 75-MW PPM klystron that will provide the X-band power for the accelerator structures in the Main Linac. Cutting the number of required klystrons by a factor of two in FY00 resulted in a doubling of the average power that the klystron must deliver. Because this device is well beyond the state-of-the-art in the world, and because its permanent magnets are very sensitive to temperature, great attention was paid to the thermal design and cooling of the tube. A diode was fabricated to verify that the electron beam would be perfectly transmitted between electron gun and collector to minimize the thermal load on the magnets, and the diode performed flawlessly. Results on the first klystron with doubled average power will arrive early in FY02.

An initial Conventional Facilities design and construction schedule was completed in early FY99, and has been updated regularly. During FY 2000 and 2001, consultants prepared reports on various geologic conditions to be encountered during NLC tunnel construction for various tunnel configurations, based on available geologic information from multiple sources and some field reconnaissance. Using this information, tunnel configurations for some geological conditions might be better matched to a shallow bored tunnel configuration than to a cut and cover tunnel configuration. For the NLC cooling systems, a concept based on central chiller plants was explored. Although this concept substantially reduced the initial capital cost, it increased power demand and operating cost substantially, so hybrid concepts combining centralized and distributed layouts are now being explored. Cooling system studies have continued. A consultant has completed an estimate of the underground work based on a cut and cover configuration using the actual topography at a representative site. His reports thus far on Main Linac, Injectors and Beam Delivery indicate a slightly lower cost than earlier estimates. Work is continuing on estimates for the IR Halls.

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 MAC has now met three times, with its next meeting scheduled early in FY02. 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 second year of publication. An active preconceptual design R&D program will continue in FY02.

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 involves the concerted efforts of a number of departments at SLAC and the ongoing collaborative efforts with the KEK JLC group on structure development (LLNL is also involved in providing diamond-turned cells). The high gradient testing for this program continues at NLCTA, which now operates 24 hours a day, 7 days a week.

As part of this program, a series of structures with different lengths and group velocities were built to study the factors contributing to the damage. In addition, various improvements were made to the structure cleaning, handling and processing procedures to determine their impact on high gradient performance. A preprocessing procedure was adopted that includes ‘wet’ and ‘dry’ hydrogen firing at 950ºC, a two-week vacuum bake at 650ºC, and a one-week in-situ bake at 220ºC.

To date, six structures have been studied at NLCTA. The most recent test was of a pair of structures designated T53VG3 and T53VG5, denoting that they are traveling wave (‘T’), 53-cm long and have an initial group velocity (‘VG’) of 3%c and 5%c, respectively. In comparison, the earlier 1.8-m-long structures that were found to be damaged at low gradients (< 50 MV/m) have a 12%c initial group velocity. With 240 ns pulses, T53VG3 was processed to 86 MV/m and T53VG5 to 81 MV/m. The 5%c structure incurred a few-degree phase shift while the 3%c structure shows no discernable phase change (< 1 degrees). The structures were also operated for about 100 hours with 400-ns pulses, the NLC design value. For T53VG3 structure, the breakdown rate was about one per hour at 70 MV/m and one per 7 hours at 65 MV/m, which would be marginally acceptable for the NLC. These rates are dominated by breakdowns in the coupler cell. To reduce these events, an input coupler with lower fields and higher impedance has been built and will be tested next.

Another possible approach being explored for achieving higher gradients is to use short standing wave structures, which require much lower peak power than the traveling wave structures currently being studied. The first pair of traveling wave structures tested showed frequency shifts of about 500 kHz after operation for over 900 hours at the NLCTA. A gradient of 82 MV/m was achieved with a 100-ns flattop pulse and a gradient of 74 MV/m was achieved with a 270-ns flattop pulse, the NLC bunch train length. With the wider pulse, the breakdown rate was about two per hour in each of the 20-cm-long structures when the gradient was lowered to 55 MV/m, the NLC loaded gradient (unlike the traveling wave structures, the standing wave structures would not need to operate above the NLC loaded gradient). The breakdown in these structures appears to occur mainly in the input coupler cells. As a result, the next pair of structures to be tested has been tuned to have a lower field in the coupler region. Other improvements are planned in future tests, so it is still early in the development of these structures to access their viability for NLC/JLC.

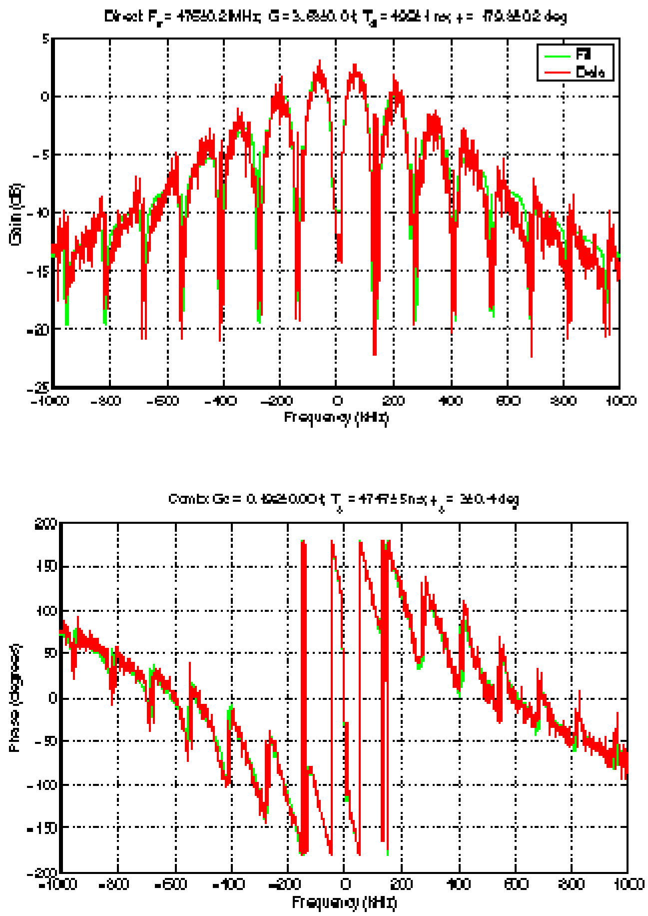
8. FY01 Progress in Advanced Accelerator Research (Ron Ruth and Bob Siemann)

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, LCLS 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.

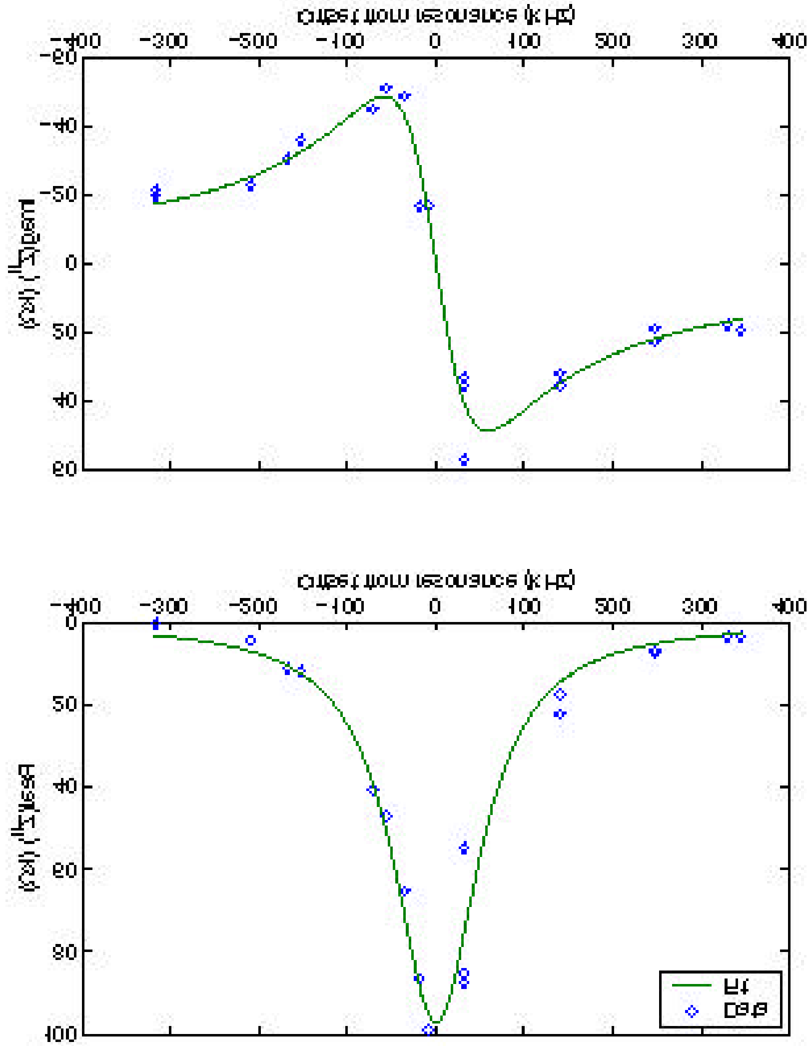
Electronics Research. The Electronics Research group in ARDA combines interests in particle beam dynamics with technology development of fast signal processing and feedback control systems. The group's pioneering hardware and software instability control systems have been implemented at PEP-II, the LBL 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 developing software tools 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 compares the measured transfer function of a PEP-II RF station through the RF cavities, and a software model of the system response is also presented. This software model is very important in configuring the RF system for optimal beam performance, and understanding the trade-off in RF configurations. This understanding will be of importance for future PEP-II upgrades.



Measured and modeled RF transfer functions in PEP-II

The measurement techniques based on transient-domain beam excitations have continued to be expanded. A technique for measuring frequency-resolved higher order mode (HOM) complex impedances has been developed. This technique allows the measurement of the complex impedances seen by the beams as a function of frequency (as opposed to convolutions with the beam distribution). The figure shows the measured complex impedance of a HOM in the ALS accelerating cavities. The data is different from that obtained from bench tests, and shows the impedance of the cavities physically installed in the ring with the actual couplers and vacuum structures.



Frequency-resolved complex impedance measurement of an HOM in the ALS main RF cavity 2

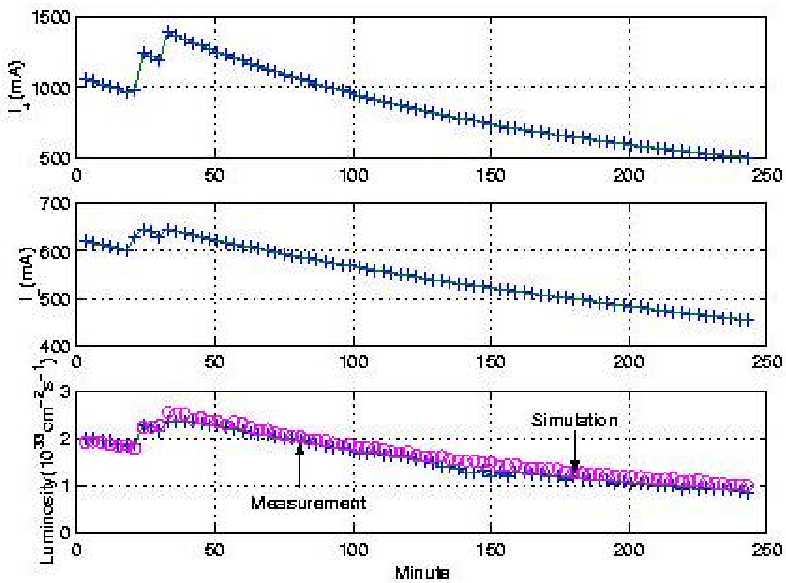
The group received several awards this year. Shyam Prabhakar, who finished his Applied Physics Ph.D. degree in 2000 won the 2000 - 2001 American Physical Society's Dissertation Prize in Beam Physics. John Fox won the Stanford Dean's Award for Distinguished Teaching. Dmitry Teytelman completed his Stanford Ph.D. thesis defense and accepted a permanent position at SLAC continuing in the Electronics Research group.

Collective Effects. The Collective Effects Group focuses on studies of instabilities and impedances in circular and linear accelerators, as well as general accelerator research. In addition, some members of the group perform extensive HEP and accelerator physics community service functions.

The most important studies carried out last year in the group include: (1) Calculation of the impedance for small-angle NLC-type collimators. The theory agrees reasonably well with the experimental data obtained in the collimator wake experiment at SLAC. It also gives necessary scaling for prediction of the wake generated by flat and round collimators envisioned for the NLC. (2) Study of the electron cloud effects in the positron ring of the PEP-II. In this study, using a computer code developed by Y. Cai, it was shown that the emittance blowup in the PEP-II could be related to microwave instability of the beam generated by the wake of the electron cloud. The threshold of the instability was found at an electron density of about 5×10^5 cm^{-3}. The electron cloud instability is also expected to be significant for the NLC damping ring. (3) Extension of the computer code that solves Vlasov-Fokker-Planck equation to include the wake field from shielded coherent synchrotron radiation. The code was applied to design of a compact storage ring with a laser cavity. A microwave instability driven by CSR was also simulated and a threshold, correlated with micro bunching was found. (4) In collaboration with colleagues from KEK, a study of intra-beam scattering (IBS) and impedance effects in the KEK ATF ring was performed. ATF is the first machine where the theory of IBS can be tested quantitatively; the first measurement imply that IBS is ~35% stronger than predicted. (5) A theory of microwave instability driven by coherent synchrotron radiation wake has been developed with the prediction of the instability threshold and the typical frequencies of the microwave radiation of the beam. The result qualitatively agrees with observations of the beam micro bunching at a number of photon sources. The latest development of the theory applies it to the micro bunching in bunch compressors — such as the one being designed for the LCLS. The results of the theory are used in optimization of the design of the LCLS bunch compressor with a goal to suppress the emittance growth of the beam due to the instability.

Lattice Dynamics. Over the past year, we worked extensively to improve the performance of the PEP-II. For optics, we started the investigation of possibility of running both the High Energy Ring and the Low Energy Ring closer to the half integer resonance so that the dynamic β effect from the beam-beam interaction is enhanced to further increase the luminosity. We designed new lattices for this purpose. These lattices were successfully implemented during the machine development. The closeness of the tune to the half integer resonance caused a significant increase of β beating in the machines. We upgraded the object-oriented library: LEGO to correct this β beating. Simulation of the correction has been carried out successfully. The simulated scheme will be used to correct the β beating in the machines soon.

Beam-Beam simulation. A highly accurate, self-consistent particle code to simulate the beam-beam collision in e^+e^- storage rings has been developed. It adopts a method of solving the Poisson equation with an open boundary. The method consists of two steps: assigning the potential on a finite boundary using the Green's function, and then solving the potential inside the boundary with a fast Poisson solver. Since the solution of the Poisson's equation is unique, our solution is exactly the same as the one obtained by simply using the Green's function. The method allows us to select much smaller region of mesh and therefore increase the resolution of the solver. The better resolution makes more accurate the calculation of the dynamics in the core of the beams. The luminosity simulated with this method agrees quantitatively with the measurement for the PEP-II B-factory ring in the linear and nonlinear beam current regimes. The comparison between the simulated luminosity and experimental measured one is shown in following figure. The measured luminosity was taken October 1, 2000.



In order to make more reliable prediction for a better working point for PEP-II, the two-dimensional code for the beam-beam simulation has been extended to a three-dimensional one on single-processor computer. To achieve the required accuracy of the calculation, we have to run the code on parallel supercomputers. Currently, the parallel version of the three-dimensional code is being developed.

We have simulated the additional beam-beam collision for the proposed PEP-N. The result of the simulation has quantified the degradation of the luminosity.

Model Independent Analysis (MIA) technique applied to PEP-II. The principal goal is to use these high-precision tools to measure and analyze the transverse orbits in storage rings so as to accurately estimate the linear machine parameters for checking the machine quality and guiding the machine correction. Currently, these techniques 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. The two pairs of the conjugate linear orbits allow for immediate calculation of the phase advancement and betatron motion amplitude at each BPM.

These two pairs of conjugate linear transverse orbits can also be used for calculating the Green's functions (R_{12}, R_{34}, R_{14}, R_{32}) between BPMs. Hence the actual machine optics can be compared with that of the ideal lattice model. Taking all BPM gains and couplings, quadrupole's normal and skew components, and sextupole misalignments as variables, we use SVD enhanced least square fitting to determine the difference between the machine and the model lattice. We can also obtain the actual machine linear map for calculating the betatron functions and the coupling parameters (global coupling angle for example) at each BPM. These fitted and calculated parameters are used for checking the accelerator machine quality and guiding the machine correction.

Two-Beam Linear Colliders. We have been examining two-beam upgrades to the NLC. If gradients can be increased with x-band above the nominal NLC operation gradient, the energy of the NLC could be increased to 1.7 TeV by adding a two-beam system that operates as a power source for 2/3 of the structures. The remaining 1/3 would receive power from the klystrons. Upgrades beyond this energy require changes in length or higher gradient acceleration at presumably higher frequency. In the case of the two beam part of the power source, most of the two beam system for 11.4 GHz acceleration is identical to that of a 22.8 GHz system and could be reused in an upgrade to 22.8 GHz. Thus one could envision a later upgrade of the NLC to about 2.5 TeV using the higher frequency RF system. All of these studies must be supported by high gradient studies to validate the gradients possible.

We are also collaborating on the CTF3. This is a system test of the two-beam idea at CERN. We have supplied the gun, and we are also designing the injector system. This test facility will be complete in the middle of the decade.

Studies of Miniature Rings. In the past we have been studying the application of relatively low energy electron rings for ultra-low emittance studies and also damping and subsequent X-ray production. This year we have focused on the study of the viability of a 25 MeV ring colliding with a laser pulse in a Fabry-Perot cavity. It appears that this ring can achieve a flux of X-rays useful for many applications. This study will be completed as the PhD dissertation of Rod Loewen who is a student in the Physics department.

Accelerator Structures. The work on accelerator structures consisted of theoretical and design studies, fabrication and experiments.

In order to develop X-band accelerator structures that reliably meet the NLC unloaded gradient goal, we have an aggressive R&D program underway. This program involves the collaborative efforts of a number of departments at SLAC, KEK and LLNL.

In the past year, we have designed and successfully completed **eleven (11)** high power test structures with different lengths and group velocities. Also, various improvements were made to the structure cleaning, handling, surface processing, vacuum bake and in-situ baking as well as RF processing procedures to determine their impact on high gradient performance.

DS2S is the first structure tested in this program, which is composed with the last 52 cells of 1.8m DS2 structure and newly added input coupler and five matched cells. Its group velocity varies from 5%c to 3%c. It was tested at 70 MV/m for nearly 750 hours with final breakdown rate of one per hour.

Name	L cm	Total Cells	v_g % c	2a mm	r MΩ/m	τ	Q_{ave}	T_f ns	E_p/E_a	P_{in} for E_a 50MV/m
T20VG5	20	23	5–4.4	8.9–8.5	82-86	0.071	6857	14.2	2.22–2.18	43.4
T53VG5	53	60	5–3.3	8.9–7.8	82-92	0.22	6843	42.3	2.22–2.13	42.1
T105VG5	105	120	5–1.6	8.9–6.3	82-107	0.61	6820	116.6	2.22–1.99	40.0
T53VG3	53	60	3.3–1.6	7.8–6.3	92-107	0.39	6797	74.3	2.13-1.99	24.5
SW20PI	20	15	π- Mode	9.5	68.3	β=1	8860	123	2.63	7.2

Table xx. Main Parameters of Newly Designed High Power Test Structures

Below is a brief description about the above structures. The suffixes refer to different technologies used in the various institutions. “N” refers to nesting accelerator cups, “F” to flat accelerator cups, “R” to accelerator cups made for SLAC by a private company called Robertson.

T20VG5N and T105VG5N were assembled at SLAC using KEK diamond turned cups with nesting feature and SLAC made input and output couplers. They were tested at 70 MV/m for 500 hours with small damage.

T53VG5R and T53VG3R are being made from conventional machined cups. They have been completed and processed with wet and dry H2 firing at 950ºC, a two-week vacuum bake at 650ºC, and a one-week in-situ bake at 220ºC. They were RF processed much more rapidly and reached above 80 MV/m.

T53VG5F has been fabricated in Japan. KEK and its collaborators machined all accelerator cells, couplers and the main structure body was diffusion bonded in Japan. SLAC finished the final assembly and surface processing. It will be tested in October 2001.

T53VG3RA The special designed input end has adaptive input waveguide to make the group velocity decrease to 1/6 of the speed of light using step-tapered width of input waveguide from 0.9 in. to 0.525 in. Also, in order to reduce the surface field, a racetrack shaped input cavity and the elliptical iris tip of first disk in coupler cavity side were adopted.

Standing Wave Option is one possible solution for high gradient operation because previous tests have indicated that standing wave structures go to higher field, and they need to be conditioned only to the loaded gradient. We have designed a 15-cavity π-mode structure as first test. Two SW20PI structures made from conventional machined cups have been completed and precisely tuned. The pair of structures is fed from a high power 3db hybrid with 90- degree phase difference in order to cancel the transient reflection back to power source. They were tested at 55 MV/m, the NLC loaded gradient.

We have completed two more standing wave sections **SW20PIL** with LLNL single diamond turned cells. They were specially tuned with 14% lower field in coupler cavities and will be high power tested in October 2001.

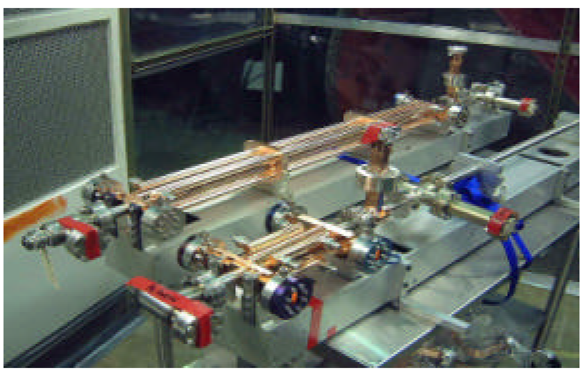


Figure xx. T20VG5N & T105VG5N.

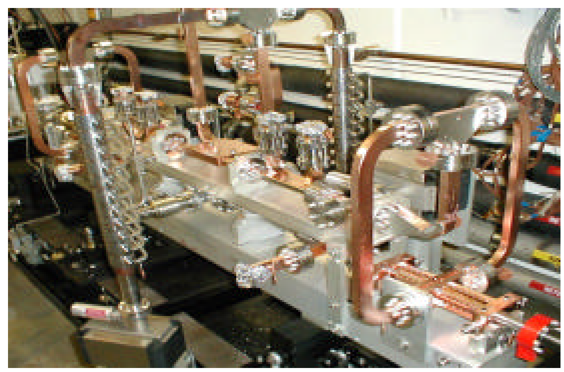


Figure xx. SW Structure Assembly

High Phase Advance Accelerator Structures

We have designed the structures with larger phase advance (for example, 150 degrees per cell) in order to reduce the group velocity. Designs for 0.9m structures with starting group velocity 5%c or 3%c and 0.6m structure with starting group velocity 3%c show that the large aperture and good RF efficiency still can be maintained. Both detuning and damping of deflecting modes are needed for multi-bunch short and long-range wakefield suppression. Three types of high phase advance structures H90VG5, H90VG3 and H60VG3 are being fabricated and they will be tested in February 2002.

More Standing Wave Structure Studies

In a parallel effort, we are studying detuned SW structure composed of eight 15-cavity sections. The preliminary simulation showed satisfactory dipole mode suppression if proper high order mode dampers are inserted between sections. We have designed and fabricated two types of high power test structures **SW20a565** and **SW20a375** with much lower ratio of surface field to accelerating field. A pair of **SW20a565** will be tested in February 2002.

Other Theoretical Studies:

1) Effort toward the NLC structure finalization. Design of new in-line tapered input couplers and new output couplers for further reduction of surface field.
2) We improved the equivalent circuit analysis to include lossy manifolds. It was shown that the wakefield could be significantly reduced near the recoherence region.
3) Work on some refined problems like tolerance required for specified emittance growth in multiple accelerator structures with or without interleaving.
4) Theoretical and simulation studies on breakdown mechanism and high gradient operation issues.
5) Development of advanced microwave measurement techniques for full structure dipole mode evaluation like wire measurement and others.

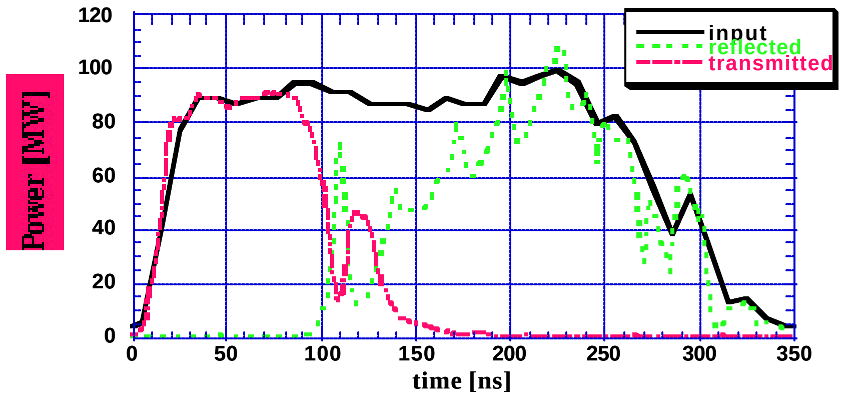
High Power RF. During this fiscal year, we continued development of the multi-moded RF systems and components. Ancillary components needed for the distribution system of RF power have been designed. These include high-power directional couplers with variable coupling coefficient. We also developed a theory for coupling and distributing power to several standing wave accelerator structures, while directing the reflected power to a set of loads.

To test our array of multi-moded component at high power we have designed a dual-moded SLED-II system capable of delivering approximately 400 ns pulses at power level above 600 MW at X-band. To get this pulse width with a reasonable length transmission line, we used two modes in this line. A compact and efficient reflective mode converter has been designed. This converter located at the end the transmission line converts the TE_{01} mode to the TE_{02} mode and vice versa. This has the effect of doubling the delay of the transmission line for a given length.

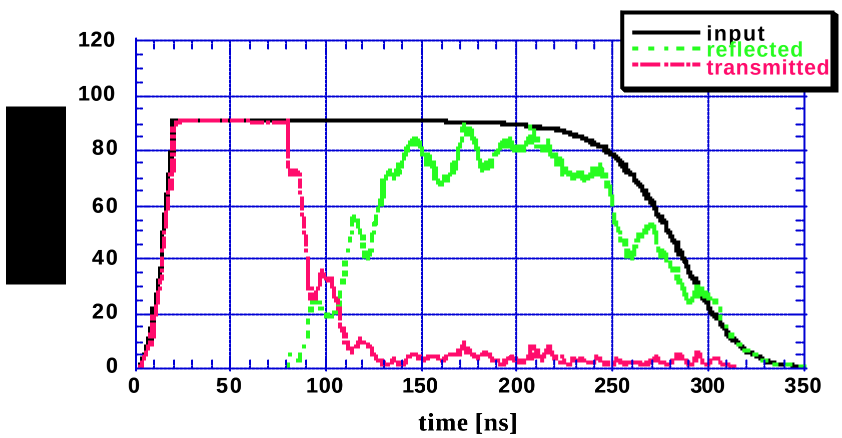
We also expanded our concepts for dual moded planar components to 4-moded planer components. A set of new devices that operates with four modes simultaneously has been developed. These include 16 port super hybrid (8 inputs and 8 outputs) and 4 mode planer launchers.

We are also developing non-reciprocal devices using ferrites and garnets in over-moded waveguides. Several theoretical designs have been proposed for these devices. Again, they use the circular mode TE_{01}. With these developments, we should be able to push the state of the art of RF circulators, electronic phase-shifters and switches to handle hundreds of MW power levels at X-band and higher frequencies. We will build most of the components for this device and expect to have a high power device within this fiscal year.

To understand the breakdown phenomenon in RF structures and components, we have constructed a geometrically simple experiment. This experiment makes it possible to make a direct comparison between experimental data and simulation. The experiment comprises a rectangular waveguide operating near cutoff, higher RF harmonics and finally precise measurements of transmitted and reflected powers. Based on these measurements we have been able to simulate the process of break down with a good agreement with experimental data; see Figure 1. To get this agreement we had to add ion injection to the simulation, and we needed to include electron collisions with neutral atoms. The presence of copper neutral atoms was a consequence of the light spectrum measurement. We are currently preparing for more waveguide experiments with different geometries and materials. We are using the information gained from these experiments to simulate and understand the complex RF breakdown phenomenon in accelerator structures.



Measurements, 24 April 2001,18:13:40, shot 45



3D PIC simulations, 4x4 mm emitting spot,
electron current 7kA, copper ion current 30A

Figure 1. Comparison between simulation and measurements for break down in rectangular waveguides.

Advanced Beam Concepts. One of the major activities in Advanced Beam Concepts during the past year has been the E-150 Plasma Lens Experiment at SLAC. Since the successful completion of the data taking process, we have concentrated our efforts on data analysis and the publication of results. At the same time, we have started turning our attention to applying our expertise in beams and accelerators to address issues related to astrophysics.

E-150 Plasma Lens Experiment. The plasma lens was proposed as a final-focusing mechanism to achieve high luminosity for future high-energy linear colliders. Previous experiments to test this concept were carried out with low energy density electron beams. The E-150 experiment was carried out at the SLAC Final Focus Test Beam facility (FFTB). The nominal beam energy was 28.5 GeV, with $1.5x10^{10}$ particles per beam pulse. The plasma lens was produced by laser and beam ionization of a neutral nitrogen gas jet injected into the plasma chamber through a fast-pulsing nozzle. The beam size was measured using a carbon-fiber wire-scanner system.

The E-150 collaboration has observed plasma focusing of high energy density electron and, for the first time, positron beams. The beam was focused by the plasma lens in both transverse dimensions simultaneously, with a reduction of the beam spot area by about a factor 2 at about 1cm downstream from the plasma lens. The focusing fields that produce such a strong focusing are equivalent to several MegaGauss/meter.

The results for the laser (and beam) ionization plasma focusing of positron beams are shown in Figure 4. The measured transverse beam size is shown as a function of the distance (Z) between the wire scanner and the plasma lens. The axis of the gas jet is at Z = 1.5 mm. The measured beam envelope without plasma is shown as squares. With laser (and beam) induced plasma focusing (filled circles), the beam envelope is shown converging towards a reduced waist and then diverging because of the strong focusing. Focusing is also observed for beam-induced plasma with the laser turned off (not shown here).

The collaboration submitted its first refereed paper ("Observation of Plasma Focusing of a 28.5 GeV Positron Beam") to the Physical Review Letters in September 2001. Data analysis efforts will continue, with further publications expected in the near future.

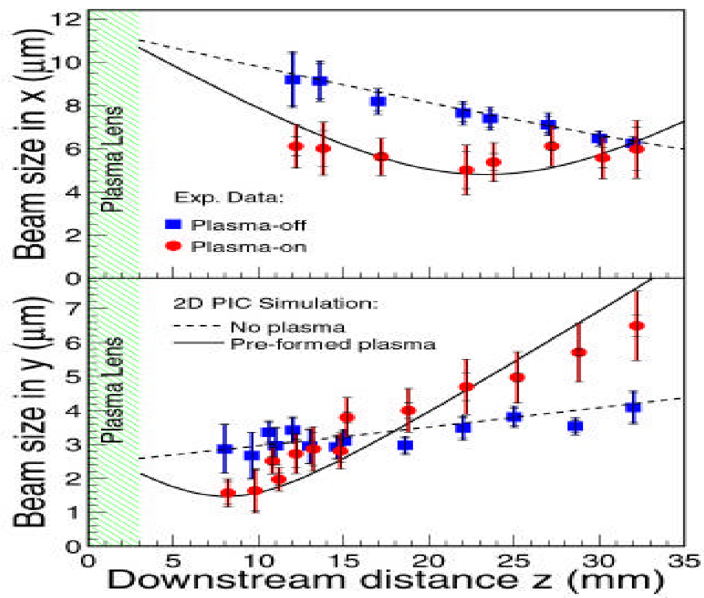


Figure 4. Horizontal and vertical plasma focusing of 28.5 GeV positron beams.

High Energy Astrophysics. Although there has been much progress in astrophysics in recent years, many outstanding problems remain. We believe our expertise in beam physics could contribute to the advance of this exciting field. The origin of ultra-high energy cosmic rays, with energies extending beyond 10^{20} eV and unknown acceleration mechanism, is one of the major puzzles. The nature of gamma-ray bursts, where intense radiation with energy output 10^{51} – 10^{54} ergs in a second, remains a mystery. Another phenomenon of interest is the relativistic jets of matter ejected from the center of active galactic nuclei (AGN). We are currently investigating the possibility of using the high energy and high intensity particle and photon beams that can be made available at SLAC to study these high-energy astrophysical phenomena in a laboratory setting. For this purpose, we are organizing a Workshop on Laboratory Astrophysics in October 2001 to explore experimental ideas and to build a strong science case for what will be a facility for laboratory astrophysics at SLAC.

Advanced Accelerator Research B

The advanced accelerator research in Accelerator Research Department B (ARDB) has concentrated in four areas: mm-wave accelerators, laser driven structures, plasma wakefield acceleration, and a facility for advanced accelerator research.

Rf breakdown and dark current trapping limit acceleration gradient. These limits are more favorable at short wavelengths, and this has motivated research in mm-wave (W-band) accelerations. The major accomplishments this year have been a relativistic klystron experiment and a pulsed heating experiment.

The relativistic klystron experiment was the first high gradient study of a millimeter-wave accelerator. It employed a planar dielectric accelerator powered by means of a 0.5-A, 300-MeV, 11.424-GHz drive electron beam from the NLCTA. This beam was synchronous at the 8th harmonic, 91.392 GHz. There was a ring resonator circuit that enabled the structure to be operated with a gradient of 20 MeV and a circulating power of 200 kW. The structure was operated in this way for 2×10^5 pulses, with no sign of breakdown, dielectric charging, or other deleterious high-gradient phenomena. The experiment was Marc Hill's PhD thesis and the results have been published in Physical Review Letters (M. E. Hill *et al*, PRL **87**, 094801 (2001)).

Pulsed heating could become the physical mechanism limiting gradient at short wavelength. In this phenomenon, a few micron thick layer of the cavity surface is repeatedly cycled to high temperatures, and this could induce fatigue and metal failure. An experiment exploring this phenomenon using an X-band standing wave cavity has been completed with a second and final run. In the first run, reported last year, a cavity exposed to 56 million pulses with a pulsed temperature rise of 120 K showed substantial damage. Therefore, the second run was at a lower temperature rise. A cavity was exposed to an 82 K temperature rise for 86 million pulses. Q-degradation, slip bands and some cracks induced by fatigue were seen after this exposure indicating that the pulsed temperature rise would have to be even lower for conservative operation. This presents a severe limit for the gradient at W-band and structures at lower frequencies such as X-band. The experiment was David Pritzkau's PhD thesis, and a manuscript describing the experiment and results is being prepared.

ARDB is collaborating on an experiment to study acceleration with a laser driven structure. The experiment is being performed at the Hansen Experimental Physics Laboratory (HEPL) at Stanford University in collaboration with Stanford physicists. The structure is an open structure a fraction of a mm long driven by a synchronized Titanium Sapphire laser. Gradients close to 1 GeV/m are possible. The experiment was installed, and the electron beam transport, laser beam transport, energy spectrometer, and data acquisition system were commissioned some time ago. Work this year has concentrated on improving instrumentation, the accelerator cell design, and taking data. Despite these improvements, we still have not observed laser acceleration. However, we remain optimistic because of the number of experimental problems that have been solved.

Laser acceleration has enormous potential because of the intrinsically high gradients that are possible, the recent developments in laser efficiency and in optical phase locking of lasers, and the tremendous investment in laser development being made by the telecommunications and laser machining industries. Our experiments are designed to exploit that potential, but scarce beam time at HEPL, a few days per year, has become a significant factor limiting progress. For that reason, experiment E163 has been proposed to move the experiment to the NLCTA at SLAC.

A major activity during the past year has been E-157 and E-162. These are experiments on wakefield acceleration and focusing in plasmas. They are performed by a collaboration of USC, UCLA, and SLAC physicists. Analysis of the data from earlier runs has been completed and published. The published results are:

- P. Muggli *et al*, "Collective Refraction of a Beam of Electrons at a Plasma-Gas Interface", Nature **411**, 43 (3 May 2001)
- P. Catravas *et al*, "Measurements of Radiation near an Atomic Spectral Line from the Interaction of a 30 GeV Electron Beam and a Long Plasma", Physical Review E **64** 046502 (2001).
- P. Muggli *et al*, "Collective Refraction of a Beam of Electrons at a Plasma-Gas Interface", Physical Review Special Topics - Accelerators and Beams **4**, 091301 (2001).

In addition, results from the earlier runs on transverse focusing and x-ray production have been submitted for publication.

There have been two data taking runs this year. A run in March concentrated on plasma focusing of positrons. The results include measurements of the overall focusing of a positron beam and the time evolution of that focusing within the 5 psec long bunch. The data are of very high quality, and a final analysis prior to publication is in progress.

A major change to the apparatus was made after the March run. The plasma chamber was moved 14 m upstream from its previous location. This brought two major benefits. First, the new location permits the beam to be properly focused into the plasma, and, second, the additional space allowed construction of a focusing spectrometer. These two changes significantly improved the ability to separate focusing and acceleration effects. Data were taken in this new configuration in June and July using an electron beam. The data are being analyzed now. There are some dramatic results including the evolution of focusing within the bunch, and energy loss by the electron beam that goes into exciting the plasma wave that will accelerate particles. There are tantalizing signs of acceleration, and extracting this result with high confidence is now a major analysis activity.

A final E162 run is expected later this year. The experiment will concentrate on acceleration of positrons in a plasma. It relies heavily on the improvements described above.

A proposal to continue plasma acceleration experiments by making measurements with a 100 micron long electron bunch has been submitted to the laboratory. This experiment, E164, is the next step needed to access the potential of plasma accelerators for extending the energy frontier of particle physics.

ARDB has been leading the design, and hopefully construction of a facility dedicated to advanced accelerator research. This facility, called ORION, would be a user facility that would welcome faculty and students with wide ranging interests in acceleration techniques. ORION would be based on the NLCTA; facilities and space would be added for experiments. An ORION workshop was held in February 2000, and there was an enthusiastic response from the potential user community.

A proposal was prepared for the NSF Frontiers of Physics solicitation that would have funded the construction of the ORION facility and provided support for a core group of users. It was not successful despite glowing reviews. Alternate possibilities for funding ORION are being explored.

The ARDB research has an important educational component. Our two senior students completed their thesis work last year on the W-band power production and pulsed heating experiments. We have two ARDB students doing thesis projects on the laser acceleration experiment, a student doing thesis work on the plasma acceleration experiment, and a beginning student working on W-band measurements. In addition, we are working closely with students from other groups or universities in the klystron development, laser acceleration, and E-162 experiments.

9. FY01 Progress in Advanced Computations Research (Kwok Ko)

The Advanced Computations Department (ACD) was formed in April of 2001 for the purpose of expanding the R&D efforts in high performance computing to benefit accelerator and other scientific applications. It has assumed a leading role on the "Advanced Computing for 21st Century Accelerator Science and Technology" project, a multi-lab and university collaboration recently funded by SciDAC, whose goal is to build a terascale simulation capability for the US accelerator community. Previously with the Numerical Modeling Group in ARDA, members of the ACD have participated in the highly successful Computational Accelerator Physics Grand Challenge that led to the development of Omega3P and Tau3P, a set of new parallel electromagnetics codes for modeling large, complex accelerator cavities. Under SciDAC, this work will be continued on a much large scale to involve additional national labs and academic institutions to improve the efficiency of these codes, and to apply them to present and future accelerators of national importance.

The new department consists of three groups: Accelerator Modeling, Computational Mathematics, and Computing Technologies, although members from all three groups work together on most projects. Such a multi-disciplinary team approach has become increasingly necessary in complex, large-scale simulation efforts. FY01 progress in each group is summarized below.

Accelerator Modeling. This group uses standard packages and SLAC codes to support research activities in ARDA, ARDB, the Klystron Department, and lab projects such as the NLC, PEP-II, and the LCLS. Modeling highlights in FY01 include the NLC structure design, the PEP-II IR, and the LCLS injector. For the NLC structure, simulations were performed with Tau3P for the matching of the input coupler and with Omega2, MAFIA and Omega3P for the cell optimization of various designs to reduce surface fields, minimize RF breakdown, and suppress wakefields, while maintaining structure efficiency. Omega3p calculations were also carried out for finding localized dipole modes in a RDDS accelerating section that consists of 47 cells. The actual field pattern of a dipole mode in such a long complex structure was obtained showing, for the first time, the self-consistent fields in the damping manifold and the cavities. Modeling of longer structures is in progress. During beam operation of the PEP-II, anomalous heating was observed around the interaction region (IR) so that plans are underway to rebuild the vacuum chamber to remedy this situation. Wall loss distributions have been computed with Omega3P for the entire IR geometry from crotch to crotch to identify modes with high contributions and to help evaluate new designs. In preparation for the full-scale LCLS injector simulation, the 2D PIC code Maxwell-T was benchmarked against PARMELA and MAGIC3D on a test problem. It was determined from the simulation results that Maxwell-T would be used in the initial stage of the gun for better accuracy while its results could be imported into PARMELA for modeling the later stage with faster speed. Simulation with the real gun geometry is underway. Other modeling activities include a cavity BPM and the linac collimator for the NLC, 3D gun design for a multi-beam klystron, and the SPEAR 3 vacuum chamber.

Computational Mathematics. This group is concerned with the numerical solutions to Maxwell's equations in the context of very large problem sizes. Members of this group are PhD students from the Scientific Computing and Computational Mathematics (SCCM) program at Stanford who are carrying out their thesis research under Prof. Gene Golub of the Computer Science Department. The main research focus is on parallel algorithms and the associated numerical analysis. One thesis topic is devoted to the parallel eigensolver in Omega3P and significant progress has been made in the past year towards improving its performance and efficiency. A filtering algorithm that consists of an inexact shift-invert Lanczos step followed by a JOCC refinement step has been implemented for faster convergence. The solver also added the capability to find clusters of closely spaced eigenvalues. As a result, cavity meshes with millions of degrees of freedom are now routinely being solved with speed and accuracy previously deemed not possible. A second thesis topic is dedicated to the development of a new parallel static solver Phi3P that is based on a hybrid field-based finite element formulation for superior accuracy. Implementation following the Omega3P framework has been completed while testing of solver algorithms has just begun.

Computing Technologies. This group deals with the many aspects of high performance computing essential to large-scale simulations, ranging from parallel programming to code optimization, to mesh generation and visualization. There have been considerable efforts in the past year in porting Omega3P and Tau3p to parallel platforms such as the IBM SP2 and SGI/Cray T3E at NERSC as well as the VA Linux cluster at SLAC, and in optimizing their performance through improved software engineering and more efficient numerical linear algebra. In addition, parallelization of the wakefield calculation in Tau3P is complete while that of the particle tracking in Omega3p is in progress. Working with Sandia Lab, the CUBIT mesh generation package has been enhanced to better treat cavity geometries of complex shapes such as the PEP-II IR. Progress has also been made in implementing an adaptive refinement strategy to improve on wall loss calculations. Finally, a new graphics package is under development for visualizing particles and fields in 3D structures more effectively via novel illumination techniques. This is continuing thesis research by a PhD student from UC Davis working with the ACD as part of the SciDAC collaboration.

10.FY01 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 (SLAC experiment E-150, Plasma Lens and picosecond electron beam magnetic field switching in magnetic materials).

Cooperative research with SSRL is in progress at the FFTB on Experiment T456, the response of magnetic matter to the ultrashort picosecond magnetic field pulses generated by the passage of the SLAC Linac 28.5 GeV electron bunch. Previous experiments in this PEL series showed that previously magnetized domains are demagnetized by passage of the e-beam's magnetic field but that nearby domains influenced the demagnetization details. Future experiments will probe the temperature dependence of this effect.

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. To overcome the charge limit phenomenon, we have explored a high-gradient-doping technique. 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. We have completed a series of measurements at the SLAC Gun Test Lab for a high-gradient-doped strained-GaAsP sample. No charge limit was observed up to the maximum laser energy, and the maximum measured polarization was 78%. A charge output as high as $2.2x10^{12}$ e^-/pulse was measured from a 14-mm diameter area illuminated by a 270 nsec-long laser pulse. This is the first demonstration that an NLC-compatible beam with polarization approaching 80% is achievable.

An alternate to the high-gradient-doping technique is the addition of a direct lateral surface charge sink in the form of a metallic grid overlaid on a GaAs photocathode surface. Tungsten grids have been successfully deposited using standard semiconductor photolithography techniques at the Stanford Nanofabrication Facility. Charge measurements are in progress at the Gun Test Lab.

11. FY01 Progress in Fractional Charge and Massive Particle Research (Martin Perl)

We have just completed a very sensitive search in about 0.1 grams of silicone oil for elementary particles with fractional electric charge using our own drop-on-demand technology in a highly automated version of the Millikan method. No evidence for fractional charge particles was found. This search was about 20 times more sensitive than bulk matter searches by other experimenters and was about six times more sensitive then our own previous search.

Our research is now concentrated on searching for fractional charge particles in meteoritic material. This material that comes from asteroids formed about 5 billion years ago is one of the least processed material in the solar system, and is one of the best candidates for containing fractional charge particles. A moderate data rate search has been started and we are now testing concepts for a high data rate version.

Engineering studies of methods for searching for charged, stable, very massive elementary particles were continued but no experimental work was started because of our emphasis on searches for fractional charge particles in meteoritic material.

Our drop-on-demand technology, now protected by a Stanford University patent, was licensed for testing to a commercial maker of micro-array plates. We also applied for a patent, via Stanford University, for a document security system. The concept came from our research and development work on small drop technology.

12.FY01 Progress in Test Beam Program (Ted Fieguth)

Included in the SLAC Test Beam Program during FY01 were two studies in support of the experimental program for the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory. One study was in support of the Solenoid Tracker at RHIC (STAR) collaboration and another was for PHENIX, the second of the two major RHIC detectors. A third very significant use of SLAC's test beams were represented by an international collaboration between SLAC and Tohuku University of Japan that performed an important measurement of the neutron spectra. In addition, a test of the spin dependences of the beam for experiment E158 and several materials testing experiments in support of the NLC and LCLS programs were performed.

In November 2000, test T437 "E158 Source Commissioning" was conducted using the Polarized Gun and instrumentation in Sector 2. This study sought to precisely measure and minimize the spin dependence for beam intensity and position at Sector 2. The experimenters achieved a resolution of 10 parts per billion for intensity and 1 nanometer for position, close to the stated goals and limited only by statistics.

Test T452 represented the second visit to SLAC of a group testing the Endcap Electromagnetic Calorimeter and Shower Maximum Detector for STAR. The prototype Endcap EMC module was exposed to beams of 5, 10 and 20 GeV electrons in the Final Focus Test Beam (FFTB). Measurements were made that determined linearity of the PMTs up to 160 GeV and the average transverse shower profile was found to be in good agreement with simulations. This agreement suggests that the design of the STAR Endcap EMC will be able to accurately characterize the longitudinal shower profile, thereby aiding in the discrimination between $e^{\pm}$ and charged hadrons. It is expected that the detector will be capable of making the first measurement of a spin asymmetry in a polarized proton collider.

A second test, T455, was conducted for the PHENIX detector at RHIC. This tested the design of a small PbW glass calorimeter, which will be used to measure the asymmetry in the inclusive π° channel to monitor the beam polarization during proton-proton running at RHIC.

Test, T454, "Measurements of High-Energy Neutron Spectra Outside the FFTB Dump Shield" recorded data with sufficient statistics to establish a set of benchmark data for comparison with FLUKA and other Monte Carlo codes. FLUKA calculations were also performed to determine the neutron and photon time-of-flight distributions for this experiment. Results from this experiment will be part of the thesis for one of the Tohuku University students and are expected to be published.

An experimental test, T456, "Magnetization Dynamics" aimed at understanding the ultra-fast dynamics of magnetic switching in magnetic thin films was conducted in September 2001. It involved scientists from institutes: SLAC/SSRL and Stanford and from industry: IBM Komag and Seagate. A very small beam of about 4 microns sigma in transverse size was passed through samples of deposited thin magnetic film (tens of nanometers thick) and the resulting response of the material to the picosecond circular high intensity magnetic field is measured afterward with an electron microscope.

In addition, SLAC continued a program in support of other experimental needs and the testing of beam damage in various materials for possible use in applications for NLC and LCLS (these are represented by T446, T447, T448, T450 & T453).

SLAC continues to encourage and support Research and Development in High Energy Physics through an active program of providing beams for the purpose of testing detector prototypes and other beam related activities.

During FY01 ten test beam experiments were conducted:

T437 E-158 Source Commissioning, M. Woods, SLAC (ASSET, Sector 2); Commission Position and Charge Asymmetry Control and Monitoring for E-158. Ran November 2000.

T446 & T447
Single Pulse Damage in Materials, M. Ross , SLAC (FFTB); Damage test materials (10 coupons) for NLC positron target and RF structures. Ran September - October 2000.

T448 Magnified Optical Transition Radiation Test, M. Hogan, SLAC, (FFTB); Test new optical setup magnifying electron beam images for E157, Quantify Resolution Limits. Ran October 2000.

T450 Damage Test in Diamond, for LCLS, P. Krejcik, SLAC, (FFTB); Determine single pulse damage threshold in diamond used for x-ray diagnostics. Ran October 2000.

T451 High Energy Neutron Spectra Measurements, T. Nakamura, Tohuku U. (Japan), S. Rokni, SLAC, (FFTB); Study feasibility of measuring neutron radiation field near FFTB. Ran March 2001.

T452 STAR Endcap Calorimeter + Shower-Maximum Detector, L. Bland, IUCF, (FFTB); Compare transverse profile of EM shower measured by scintillator shower maximum detector to GEANT simulations, for STAR/RHIC. Ran January 2001.

T453 Damage Test in Diamond for LCLS, P. Krejcik, SLAC, (FFTB); Determine damage to diamond crystal structure from single pulse. Ran April 2001.

T454 Measurement of Neutron energy Spectra, T. Nakamura, Tohuku U. (Japan), S. Rokni, SLAC, (FFTB); Measure neutron energy spectra at FFTB dump shield and compare with FLUKA results. Ran June 2001.

T455 Calorimeter for Local Polarimeter at PHENIX/RHIC, B. Fox & A. Deshpande, RIKEN-BNL, (FFTB); Calibrate the energy and position measurements of the calorimeter for the local polarimeter at PHENIX/RHIC. Ran August 2001.

T456 Magnetization Dynamics, J. Stohr & H. Siegmann, SSRL, (FFTB); Research on response of magnetic matter to the ultrashort magnetic field pulses generated by electron bunch. Ran September 2001.

13. FY01 Progress in Theoretical Physics (Michael Peskin)

The research of the Theoretical Physics Group ranges from the development of fundamental theories such as supersymmetric unified theories and M-theory to detailed calculations directly relevant to current high-energy physics experiments. Here are some topics which members of the theory group have been working on in the past year:

Physics at the Next Linear Collider

For many years, the SLAC Theory Group has been one of the most active centers in the world in exploring the potential physics opportunities of next-generation electron-positron colliders. Through studies of a wide variety of processes within and beyond the Standard Model, we have clarified how precision measurement and special features such as beam polarization and heavy-quark tagging can test novel aspects of physics at very high energies. In the past year, members of the Theory Group participated in the writing of a `Sourcebook' on linear collider physics to assist the community in assessing this option at the Snowmass 2001 summer study. We have also done studies which demonstrate new capabilities of this collider, including the ability to make supersymmetry mass measurements at the part-per-mil level, the ability to study the chirality of b quark decays using large samples of polarized b baryons, and the ability, in certain models, to observe resonant production of gravitons. Complementing these theoretical studies, we have been constructing a general-purpose event generator to aid the experimental community in making detailed studies of the linear collider capabilities.

Physics at Bottom and Charm Factories

The Theory Group is intensely involved in all aspects of heavy-quark physics and in the physics associated with the BaBar experiment. In the past year, members of the Theory Group have introduced new experimental strategies to test factorization in 2-body B meson decays and, more specifically, to discriminate different approaches to understanding these decays in QCD. We have continued studies of effects of new physics on penguin processes such as b-> s gamma, b-> s l+l-, and b-> s gluon, and of methods for resolving the sign ambiguities in CP angle determinations at B factories. We continue to discuss methods to exploit the increasing samples of B meson decays from the B factories to sharpen the tests of the standard picture of CP violation.

Quantum Chromodynamics at High Energy

For many years, members of the Theory Group have emphasized that a wide variety of strong interaction reactions at high energy can be understood in terms of hadron light-cone wavefunctions. In the past year, we have continued our efforts to determine the light-cone wavefunctions and develop new theoretical methods for analyzing them. These include studies of diffractive hadron production using light-cone wavefunctions and fundamental studies of theoretical methods for light-cone quantum field theory. We have also studied the use of light-cone wavefunctions to make predictions about B meson exclusive decays.

Computational Quantum Field Theory

To extract precise information from high-energy experiments, it is necessary to have available precise predictions from Quantum Electrodynamics and Quantum Chromodynamics. Many interesting measurements must be compared to Feynman diagrams calculations carried to two-loop and even three-loop and higher order. A few years ago, such calculations were thought to be insuperably difficult. However, we have been developing new methods for Feynman diagram calculations that bring many of these desired predictions within reach. In the past year, members of the Theory Group have completed the two-loop QED correction to Bhabha scattering and the two-loop correction to threshold production of top quark pairs in gamma-gamma collisions. Both of these projects illustrated new theoretical methods that will be widely applicable in two-loop QED and QCD analyses. We have also clarified the theoretical understanding of hadronic corrections to the muon (g-2), hopefully allowing future experimental data to give a precise theoretical prediction for this quantity.

Space-Time Physics at Accelerators

In the past few years, a number of new models of elementary particle physics have been introduced, which involve new space dimensions or strongly-coupled quantum gravity at the TeV energy scale. Members of the Theory Group have been involved both in the construction of these models and in exploring methods for testing these models at accelerators. These studies have included investigations of string theory at the TeV scale, non-commutative generalizations of the Standard Model gauge theory, strong quantum gravity effects and graviton resonances, and studies of the interaction of these ideas with models of supersymmetry in particle physics.

Superstring Theory and M-Theory

For many years, superstring theory has been studied as a candidate for the `theory of everything', since it consistently incorporates quantum gauge theories together with gravity. Recently, string theory and the more general theory, M-theory, in which it is embedded have been found to have a large number of unexpected and interesting classical solutions. These include particle-like solutions, solutions in the form of domain walls, and complete cosmological solutions. These objects can be used to study the fundamental aspects of quantum gravity in string theory, and as starting points for the construction of realistic models of elementary particle physics. In the past year, members of the theory group have studied a variety of classical solutions of string theory in anti-de Sitter space with both of these goals in mind. We have shown how the study of unstable string objects can illuminate the general structure of the space of these classical solutions. We have also shown how almost-singular limits of string geometries can lead to new methods for breaking supersymmetry and generating fermion masses in realistic elementary particle models.

New Theoretical Methods

Members of the Theory Group have for some time been studying the use of direct Hamiltonian methods to address a variety of problems in quantum field theory. In the past year, we have demonstrated a new renormalization group method for one-dimensional spin models. We have also presented an illuminating new derivation of Hawking radiation-based Hamiltonian treatment that respects unitary time evolution.

14. FY01 Progress in RF Power Source Development (George Caryotakis)

One of the ten XL-4 solenoid-focused klystrons that power the NLCTA failed during the past fiscal year. The failure was a leak in a vacuum gasket, a failure that does not relate to the soundness of the basic engineering design. An eleventh XL-4 has been completed and is being prepared for test. The X-75 P2, a beam-tester version of the periodic permanent magnet, 75MW X-75 P1, was successfully tested to the full 3 µSec pulse length and repetition rate. This is the beam-tester version of the X-75 P1 that was described in last year's report. The value-engineered, low-cost DFM version of the X-75 P1, the XP-3 has been fabricated and awaits processing. This klystron has a unique clamshell type of removable periodic permanent magnet focusing structure that is designed to greatly reduce the labor required for dressing the production klystrons.

The development of a six-beam, multiple-beam klystron that is being carried out through a CRADA with a small business partner, under SBIR auspices, remains on schedule. A beam-tester was operated at full beam voltage using two different types of focusing structures; 1) a solenoid-driven periodic magnetic field, and 2) a permanent magnet long period radial magnet focused structure. Fabrication and testing of the klystron (one beam 12.5MW peak power) is scheduled for FY2002.

Work has begun on the design of a new type of klystron, the sheet beam klystron (SBK) that has the low power density advantages of a multiple beam klystron but at much lower production cost (very low part count with a low-cost periodic permanent magnet focusing circuit). The cost and average power advantages of this new kind of klystron has been recognized for some time, but it is only recently that the 3-D simulation codes required for producing and focusing a sheet beam and managing the additional RF complexities (cavity designs and control of unwanted RF modes) have made possible carrying out a full design with a high probability of success.

15.FY01 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.

Experimental Activities

Induced Activity Measurements: The data analysis and the calculations for the Test Beam Request T-439 were completed in FY01. In this experiment, samples of soil, water, aluminum, copper and iron had been 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. In addition, the isotope production in the samples was calculated with detailed Monte Carlo simulations using the FLUKA code. The comparison of measured and calculated activities showed that the isotope yields are underestimated by the calculations, in most cases by about a factor of two.

Neutron Energy Spectra Measurements: A SLAC-Tohuku University collaboration completed measurements of High-Energy neutron spectra outside the FFTB dump shield in experiments T-451 and T-454. In these experiments a combined pulse-shape discrimination and Time-Of-Flight technique with a NE-213 liquid scintillator was used to measure the neutrons generated in the interaction of the 28.5 GeV beam on the main FFTB dump. The experiments successfully established the feasibility of using this method of measuring neutrons in electron facilities. Sufficient statistics were recoded to establish a set of benchmark data for FLUKA and other Monte Carlo particle interaction and transport codes.

Neutron Dosimetry Measurements: A series of passive and active neutron measurements were performed at the Mt. Zion Hospital of the UCSF. Data were taken for neutron doses at the maze door and along the patient couch for conventional and IMRT treatment.

Linac Coherent Light Source (LCLS) R&D Activities: Systematic FLUKA-simulations were performed in order to study the energy deposition by photons in micrometric volumes of the LCLS mirrors. Various combinations of mirror material, photon energy and incident (grazing) angles were investigated. For the calculations the unique feature of FLUKA to transport the particles in a single-scattering mode was employed.

Next Linear Collider (NLC)-related R&D activities: Defect production in tungsten-rhenium targets due to electron irradiation was studied using FLUKA in collaboration with LLNL. In particular, the production of recoil nuclei and nuclear fragments by high-energy interactions and the production of low-energy neutrons was calculated for different target sizes and beam energies. Based on this information the effect of the recoil momenta of residual nuclei and nuclear fragments, as limiting factors for the lifetime of such targets, could be estimated.

Development and Benchmarking Work in Radiation Transport Codes

EGS: A two-year DOE Small Business Innovative Research (SBIR) collaboration, to develop a new version of the EGS code (EGS5), together with a Visual User Interface (VUI), is in the final stages of completion. A new electron transport algorithm in EGS5 allows for, among other things, accurate transport of electrons across material interfaces (e.g., bone-tissue, tissue-lung) and the latest low-energy photon enhancements are now included in a self-consistent manner. Also, the user no longer has to be concerned with creating cross section data by means of the preprocessor code, PEGS, since this task has been automated in EGS5. A primary feature of the new VUI method allows the user to *point*, *click and drag* objects (e.g., cylinders, cones, etc.) on the screen to form complex geometries, which eliminates, for the first time, the very difficult task of writing geometry-descriptive code. Both the EGS5 and VUI codes are currently being beta tested and benchmarked for accuracy prior to official public release of the system.

FLUKA: In collaboration with Siegan University and BRI Delaware work was done in preparation for the transition of DTUNUC-2 into DPMJET-III for eventual inclusion in FLUKA particle interaction and transport codes. Cross sections for giant dipole resonance interactions in FLUKA were updated. The cross sections are now based on detailed fits to data for elements up to copper.

Detailed FLUKA-simulations of the cosmic ray cascade in the atmosphere were performed for a set of parameters covering all possible environmental conditions, i.e. geographic location and solar modulation. The study involved comprehensive benchmark-calculations for neutron and charged particle dosimetry measurements performed aboard of aircrafts and on ground. The results serve as basis for the European Computer Program Package for the Calculation of Aviation Route Doses (EPCARD), which will be used by the European Airlines for dose estimates and risk assessments.

16. SSRL Overall Operations – FY01 User Experimental Run
(Piero Pianetta)

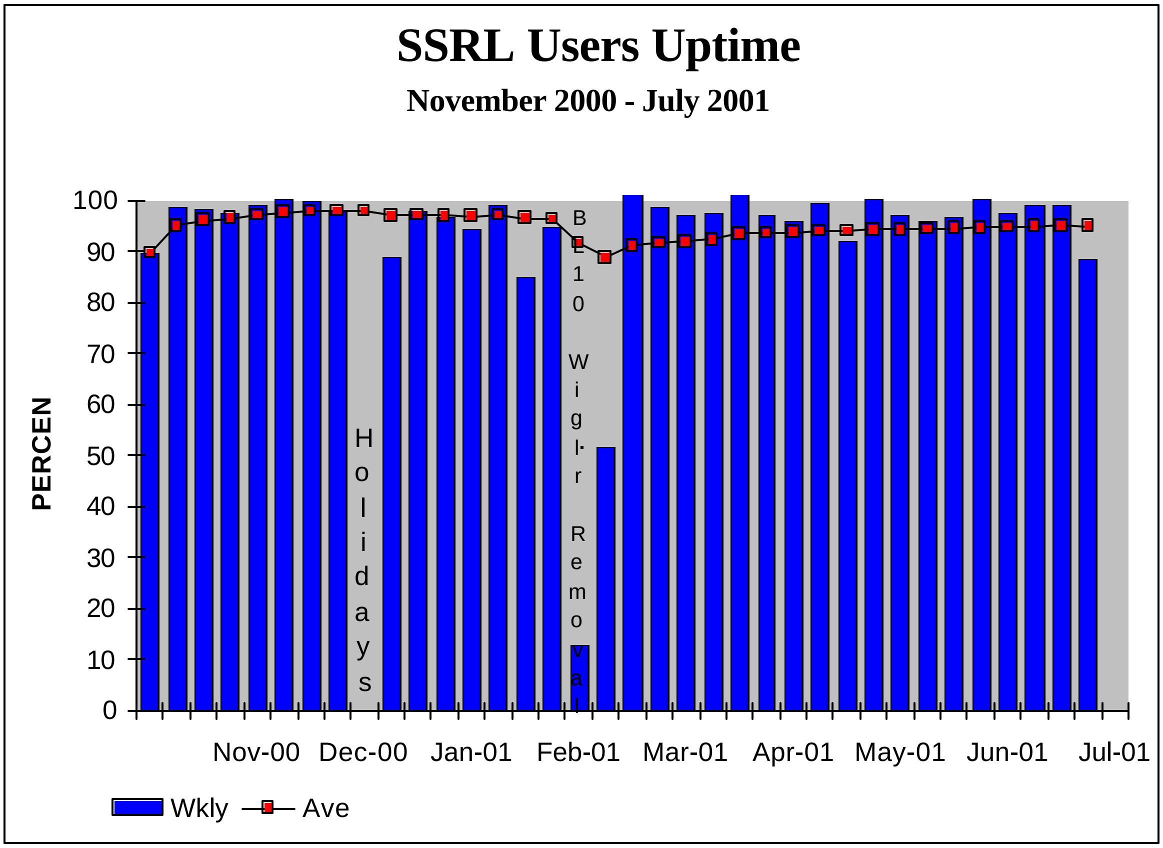
FY2001 User Experimental Run

The FY2001 user run (November 1, 2000 – July 3, 2001) delivered 94.9% of scheduled user shifts, accommodating the beam-time needs of over 365 unique proposals. SSRL supported 776 experimental starts on 31 beam line stations that were open for users in FY2001. The User Research Administration office badged and processed 900 users who came on-site to perform experiments.

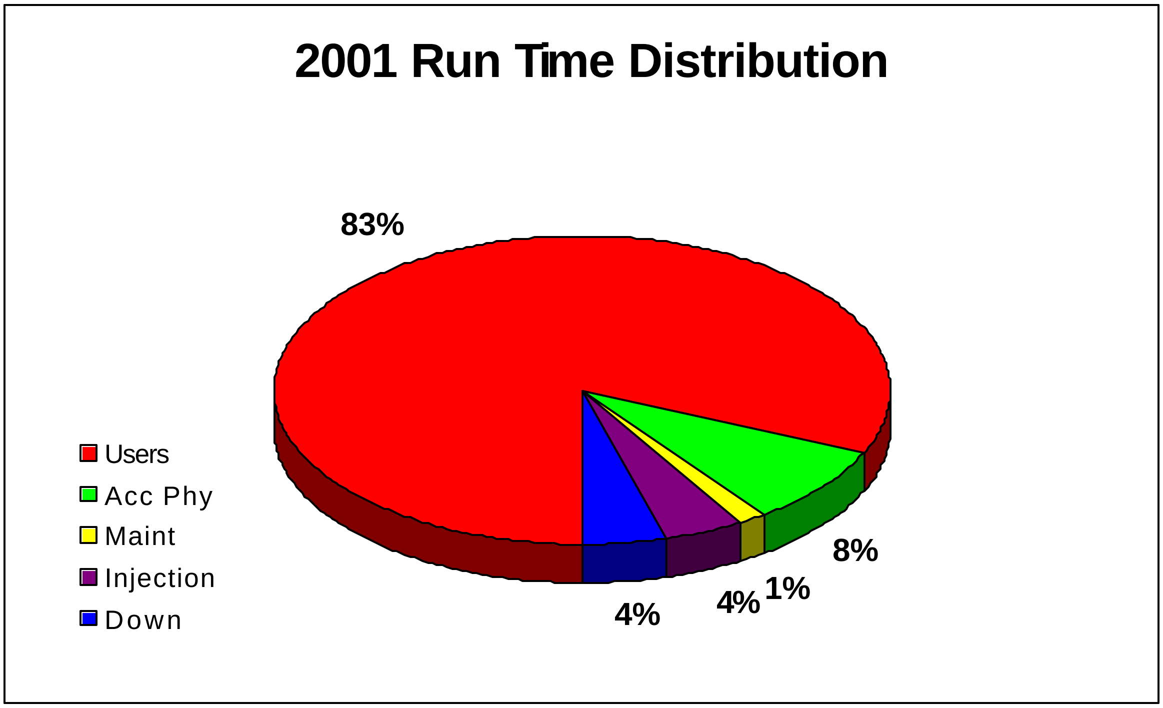
It should be noted that this year's statistics have been negatively impacted by the failure of the BL10 wiggler in February 2001. A pole piece of the magnet became separated damaging the vacuum chamber and resulting in a quadrant of SPEAR being vented. Although the recovery was quite rapid (approximately 5 days of user beam were lost as a result of this failure) both BL10-1 and BL10-2 were down for the remainder of the run. The wiggler has since been repaired and reinstalled into the ring.

Competition for beam-time assignments remains extremely high. When averaged across all beam lines, the over-subscription rate was 35% (user demand is 135% of available resources).

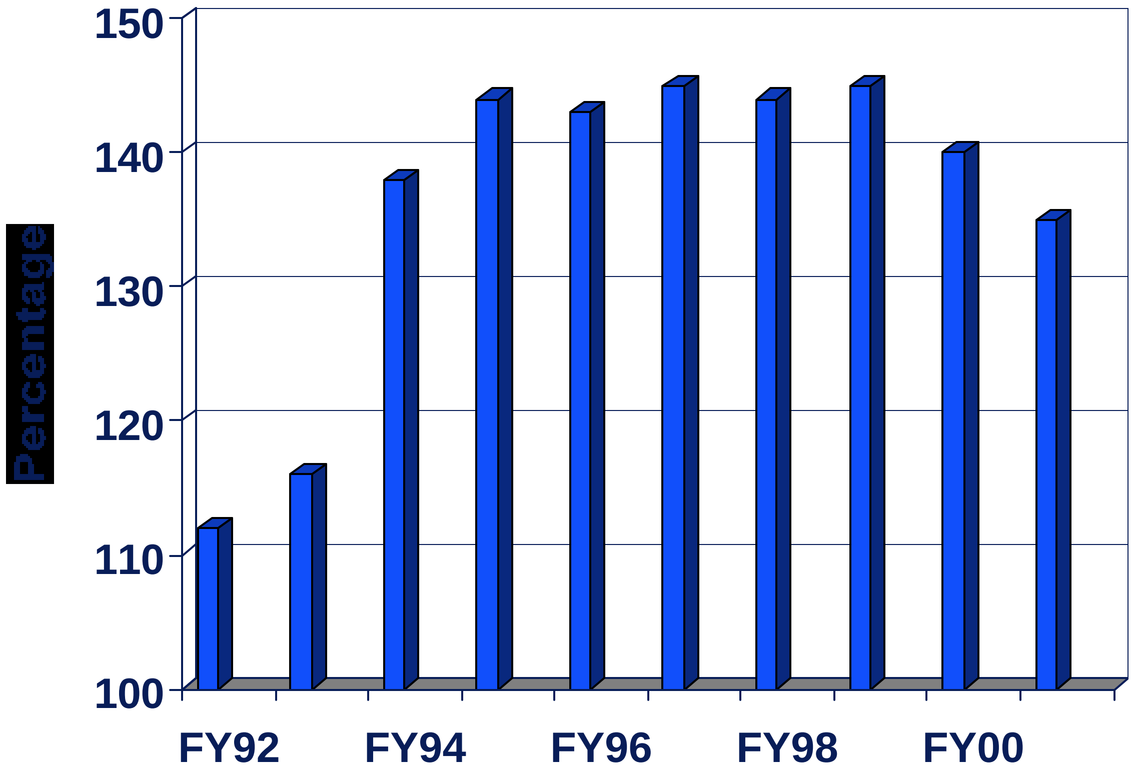
In FY2001, 1634 SSRL users from over 20 countries received beam time. Of these users, 84% were from the U.S., spanning 39 states and the District of Columbia. Users were predominantly from American universities (58%) followed by American laboratories (25%), American businesses (7%), foreign universities (8%), and foreign laboratories (2%).



2001 SSRL Users Weekly Uptime



2001 Run Time Distribution



SSRL User Demand Graph (FY92 – FY2001

Distribution of the 365 proposals receiving beam in FY2001

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

BL11 "Magic Fingers" Successful. The "magic fingers" installed to correct the nonlinear fields from the BL11 wiggler were successful in restoring the SPEAR dynamic aperture. Prior to the installation of the magic fingers, closing the BL11 gap to its design 16 mm gap reduced the electron beam lifetime by 30% at 3 GeV and made it impossible to store electrons at 2.25 GeV. The problems arose from nonlinear fields seen along the direction of the electron-wiggling trajectory and associated with the relatively narrow pole width in BL11. The nonlinear fields reduced the dynamic aperture, which is the maximum stable oscillation amplitude of a stored electron about the center of the electron bunch. Once these nonlinear fields were understood, magnets were designed and installed at either end of the wiggler to best cancel these nonlinearities. With the magic fingers we can now store and inject beam at 2.25 GeV, and we see no measurable decrease in lifetime at 3 GeV. During standard operations, the gap is still opened to 25 mm for fills, because this makes tuning for maximum injection rate easier.

RF Waveguide Dampers/Improved Lifetime. RF waveguide dampers improve beam stability and lifetime. Dampers were installed in the two RF waveguides during the 2000 shutdown in order to damp higher order mode oscillations excited by the electron beam in the RF cavity/waveguide system. These higher order modes had been occasionally causing multibunch instabilities in the stored beam during operations. The RF dampers eliminated the instabilities. They also enabled us to switch to a fill pattern with more bunches filled, reducing the stored current in each bunch, increasing the Touschek lifetime and giving a 20% improvement in the total electron beam lifetime.

Successful 3GeV Injector Test. On July 3, 2001, the SPEAR injector was successfully run at 3 GeV, proving that the injector is ready to provide at-energy injection for SPEAR3. The 3 GeV beam was ramped in the booster and ejected down most of the Booster-to-SPEAR (BTS) transport line to the BTS Faraday cup. Actual 3 GeV injection into SPEAR will have to wait until the SPEAR3 project, when the last two dipoles and the injection septum magnet at the end of the BTS will be replaced. The injector now routinely operates at 2.25 GeV, while the SPEAR storage ring delivers beam at 3 GeV, so the storage ring magnets must be ramped at each fill. At-energy injection will improve SPEAR3 performance by reducing fill times and, more importantly, providing better fill to fill orbit reproducibility and reducing mechanical motions associated with thermal transients from injection. At-energy injection also opens the possibility of top-up injection, which would provide yet another significant increase in thermal stability of storage ring and beam line components. The 3 GeV test came toward the end of the two-year Injector Upgrade Accelerator Improvement Project, in which power supplies, magnets, and diagnostics were upgraded to insure reliable 3 GeV operation.

Bunch Motion Monitor System. The Bunch Motion Monitor is a diagnostics system that excites transverse bunch oscillations with a fast kicker and then records them with turn-by-turn beam position monitors (BPMs). In FY2001, the new power supply for the horizontal kicker was installed and tested to allow computer control of the kick amplitude. This upgrade permits faster and more accurate measurements of machine parameters such as the tune shifts with amplitude.

Orbit Control Application Program in MATLAB. SPEAR3 will require a new electron beam orbit control program with graphical interface. During the period FY2001, prototype software for this task was written and tested. Online tests were made during machine development periods for SPEAR2 and simulation studies were made for SPEAR3. Most of the mathematical algorithms and main features of the interface are now in place. In particular, response matrices were measured (online mode) and computed (simulation mode) where possible. Several 8-hour orbit feedback tests were made on SPEAR2 using the measured response matrix to demonstrate online control and code stability. The database access routines use EPICS-compatible Channel Access calls to be consistent with SPEAR2, SPEAR3 and many other DOE facilities. The MATLAB Accelerator Toolbox (AT) is used to simulate accelerator performance. Work remains on input-output file handling.

Insertion Device (ID) Trim Tables. A new robust and user-friendly software interface was written for controlling insertion device gaps and generating ID trim tables. ID trim magnet corrector tables keep the closed orbit constant when the ID gap is changed. The software for generating the tables uses the measured closed orbit response to the trim magnet and the measured orbit to minimize the rms orbit error as the insertion device gap is changed.

Longitudinal Beam Instability Suppressed. The SPEAR ring has two accelerating cavities, but needs to power only one for normal operation. However, the klystron for the idle cavity must be powered to maintain stable beam operation. During the "energy crisis" of last year the importance of eliminating this extra power consumption increased. The origin of the instability caused by the idle system was the waveguide connecting the klystron to the cavity. Ambient temperature changes caused the waveguide to resonate with the fundamental frequency of the beam and drive it unstable. By controlling the air pressure inside of the waveguide and setting it to the correct value, we were able to perturb the waveguide shape enough to move the resonance away from the beam frequency at all temperatures. The cavity was able to operate with the klystron unpowered for the entire run.

RF Modes in ID Chambers. SPEAR3 will require greater orbit stability than SPEAR2. In preparation for the new ring, we are commissioning the SPEAR3 orbit feedback system on SPEAR2. Early results have shown that we can also use this commissioning as an important tool in the design of proper ID chambers for the new ring. IDs have transverse cross-sections that vary greatly from that of the rest of the ring. The devices need small gaps and large antechambers. The transitions from the standard chamber to the ID chamber can generate stray electromagnetic fields. Although these fields are not large enough to generate beam instability, they are large enough to introduce errors in the electronics used to measure the beam position for the orbit feedback system. We have identified certain IDs whose transitions generate these fields and from continued study in FY2002 run will develop ID design rules that will eliminate these problems for SPEAR3.

SPEAR3 Upgrade Project

FY2001 was the second full year for the final 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 of the upgrade. The total estimated cost of the MIE upgrade is $58M. The goals of the SPEAR3 Upgrade are: 1) 3 GeV at-energy injection, 2) less than 20 nanometer-radian beam emittance, and 3) 500 mA stored beam.

On February 9, 2001, the Department of Energy (DOE), Office of Science (SC) conducted the fourth technical review of the project. The review concluded that “the technical systems have continued to make good progress in system design and procurement. The Review Committee did not find any major issues and believe the project is working aggressively in making timely decisions to correct concerns on design, schedule and resources.”

The next DOE review was held July 24, 2001. The review summary report noted that “the SPEAR3 project is within cost, on schedule, and is meeting the technical scope objectives.” Due to an accident in which a dipole magnet in transport fell from a truck, the committee recommended that “management needs to continue its leadership in making staff aware the importance of ES&H and hold each project member responsible for ensuring that activities are safely accomplished.”

At the end of this fiscal year, the project is near the halfway mark in terms of costs, schedule and technical accomplishments. The status of each major technical system is summarized below.

Magnets. The project has received six shipments (nearly 80%) of the 218 dipole, quadrupole, and sextupole magnets from the Institute of High Energy Physics (IHEP). All main magnets will arrive by December. The additional mechanical and electrical checks of the magnets at SSRL have been successful. Only minor mechanical problems were found and corrected.

The prototype corrector magnet was assembled at IHEP and delivered in September. Measurements at SLAC confirmed IHEP results that all measurements, excitation, transfer function and integrated field quality distribution within the required good field region compare favorably with each other and satisfy all requirements.

Assembly of the QFC prototype raft with magnets and vacuum chamber has been completed. The raft is located in building 750, where the assembly of all rafts will take place. Procedures were developed for mounting each magnet, splitting the magnets to install the vacuum chamber and sliding in the dipole magnet. The assembly process went smoothly and the procurement for the production rafts is underway.

Vacuum System. The prototype BM-2 chamber was completed and installed with magnets on its prototype raft. Welding of the chamber was delayed due to the overhaul and cleaning of the e-beam welder in order to improve performance and reliability. The chamber design tolerances were met except for the horizontal curvature. The welding parameters will be modified and additional welding passes will be used to reduce the distortion during the production phase. All QFC machined chamber plates were received in April and QFC production started in June with completion scheduled in October. The production plan is to complete 1.5 chambers per week using multiple shifts as necessary. The BM-1 prototype chamber will be welded after the QFC production.

RF System. The four cavities being fabricated are experiencing delays because of resource conflicts at the manufacturer. The machining and e-beam welding delay has caused a two-month slip in the delivery schedule. The manufacturer has contracted out some of the work to make up the schedule. The first cavity will be delivered in December.

The klystron received in April was loaned to the B-factory for testing and operation. After about 800 hours of operation, the klystron failed. It was sent back to the manufacturer for repair. Another klystron is being delivered in July and will be tested. The klystron failure is a concern for both the B-factory and SPEAR3. Several options are being evaluated to address this problem. The installation of these components is nearly two years away.

Power Supply. The dipole magnet power supply transformer was factory-tested and delivered in early June. Engineering analysis continued on the suitability of the B-factory style power supply for SPEAR3. The power supply will be tested in the SPEAR booster building during the current shutdown to determine needed upgrades to satisfy SPEAR3 requirements. Many of the remaining power supplies are in various stages of the procurement cycle.

Facilities. The annual shutdown started on July 5 and several SPEAR3 construction activities were accomplished on schedule. The West Pit shielding work was awarded in June. This work completed the straight section shielding walls and the associated concrete roof shielding. The contract for cable tray structural supports, concrete footings, trench work for the HV RF cables, and cable tray installation was also awarded and completed.

Instrumentation and Controls. Progress in design and implementation of instrumentation and control systems for the SPEAR3 project continued. Most effort was devoted to specifying and scheduling Computer Control System software tasks, designing Control System hardware components, deciding on the BPM processing system plan, and beginning the detailed design of the Machine Protection System. The design effort for the Injection Timing System was renewed, and the design of the Quadrupole Modulation System commenced.

Accelerator Physics. The accelerator physics group conducted a complete review of the Synchrotron Light Monitor. In parallel, software developments were made to provide timing features with MATLAB. SPEAR2 accelerator physics shifts successfully demonstrated the software on-line. Also, as a test for SPEAR3, beam was successfully accelerated in the Booster to 3 GeV.

ES&H. Efforts have focused on shutdown activities including shielding modifications and Personnel Protection System changes. The Earthquake Safety Committee and Electrical Safety Committee have approved cable tray supports and the general plan for cable plant installation.

Project Costs. The total project costs and commitments through September 2001 are $24.5M. For the estimated total project costs at completion (58M$), approximately $6.5M of contingency funds remains.

Fourth Generation Source Development

A major step was taken toward realization of the Linac Coherent Light Source (LCLS) with the approval of Critical Decision 0 in June of 2001. CD-0 approval was the culmination of a thorough evaluation of the scientific potential of the LCLS. The evaluation process included peer review of five experiments described in “LCLS – the First Experiments” www-ssrl.slac.Stanford.edu/LCLS/papers/LCLS_Experiments_2.pdf, presentations to the Basic Energy Sciences Advisory Committee 10-11 October 2000 and 26-27 February 2001, and the BES Workshop on Scientific Applications of Ultra fast, Intense Coherent X-Rays held in Washington, D.C. 4-5 May 2001. The workshop underscored the importance of producing short x-ray pulses, in the realm of tens of femtoseconds. Several techniques for producing such short pulses with the LCLS were presented and discussed. A UCLA-SLAC proposal for slicing a 10 fsec pulse out of a longer LCLS pulse, presented to the workshop, will be published in the proceedings of the 2001 Free Electron Laser Conference, held in Darmstadt, Germany. The proposal involves the controlled variation of the energy of electrons as a linear function of position in the bunch. This energy variation produces a position-dependent correlated variation in the wavelength of x-rays emitted by the bunch; longer-wavelength x-rays are produced by the front of the electron bunch, and shorter-wavelength x-rays are produced by electrons in the back. This kind of correlated modulation of wavelength is termed a "chirp". The x-ray wavelength can be varied by more than 2% from the front to the back of the 230-fsec LCLS pulse. An x-ray monochromator can select a 0.1% - 0.2% bandwidth from the light pulse. The correlation between time of emission and wavelength means that x-rays of the wavelength selected by the monochromator are produced for an interval of only 10 - 20 fsec. The x-ray pulse exiting the monochromator will have this very short duration, and can be used as the input signal for a SASE x-ray amplifier located downstream. The amplified 10 - 20 fsec input pulse will dominate the output of the amplifier. Workshop attendees emphasized the importance of precise synchronization of the LCLS x-ray pulse with that of a pump laser.

The LCLS collaboration successfully completed the Visible-to-Infrared SASE Amplifier (VISA) experiment at the Brookhaven National Laboratory Accelerator Test Facility (ATF). The collaboration reached "saturation", the theoretical maximum power output, given the properties of the ATF electron beam. Measured results are in excellent agreement with UCLA's comprehensive "start-to-end" computer model of the electron beam produced by the ATF. This strengthens confidence in the use of the same modeling techniques that have been applied to the LCLS. VISA experimenters also observed the expected production of intense, coherent radiation at a harmonic of the wavelength amplified by the SASE process.

Experiments continued at the SLAC Gun Test Facility (GTF). Short (2-4 psec) electron pulses have been produced with peak currents at LCLS – specified levels and normalized emittances as low as 1.2 mm-mrad, very close to LCLS requirements. Upgrades of the GTF are planned for FY2002. These upgrades will make it possible to explore operating configurations predicted to produce an electron beam suitable for LCLS. A major effort has been made to compare GTF results (and indeed to guide GTF experimental strategy) with computer simulations using PARMELA, the code most commonly used for gun modeling. Several researchers from SSRL and the Advanced Accelerator R&D Groups at SLAC have conducted an investigation of the performance of computer codes that predict RF gun characteristics. Particular emphasis was placed on the performance of PARMELA. This code makes certain simplifying approximations concerning electrostatic and wake field forces that are appropriate for high-velocity beams but questionable when applied to electrons subject to rapid acceleration from rest. Preliminary results suggest that PARMELA is a satisfactory tool for optimizing gun design, and certain "particle-in-cell" (PIC) codes, which make fewer approximations (but which consume more computing time), may be used for checking results of the optimization process.

Research at the LCLS partner laboratories has made significant progress as well. Los Alamos has begun fabrication of a high-efficiency semiconductor cathode for use in the LCLS photocathode gun. Brookhaven National Lab has made progress on the design of a gun modified to operate at 120 Hz, the maximum repetition rate of the SLAC linac. Lawrence Livermore has developed and tested prototype optics for the extremely intense LCLS beam. Argonne National Laboratory has constructed a prototype LCLS undulator, investigated the SASE process and harmonic generation at wavelengths down to 260 nm. ANL has also performed start-to-end simulation of the LCLS to determine tolerances on steering and acceleration in the SLAC linac. ANL has also pursued important numerical simulations and experimental studies of the detrimental effects of coherent synchrotron radiation produced as a byproduct of the bunch compression process.

Work on design of the first LCLS experiments has made significant progress. Contact persons for each of the six initial experiments have been identified. LLNL collaborators have prepared requirement lists for each experiment, to guide the design of the experiment enclosures, x-ray optics and apparatus.

The LCLS Conceptual Design Report is being assembled for DOE review and preparation for Critical Decision 1 early in CY2002. Cost estimates are at an advanced stage for the linac and conventional facilities. Good progress has been made on the cost estimates for the experiments.

New Beam Line Facilities and Beam Line Improvements

The beam line related activities in FY2001 were a combination of upgrades for SPEAR3, maintenance activities, as well as general upgrades that enhance the scientific capabilities of the ongoing scientific program.

One overall component of the SPEAR3 beam line upgrade project that must be done for all the beam lines prior to the commissioning of SPEAR3 is the upgrade of the front ends. To that end, the detailed design of SPEAR3 500mA front end masking (fixed and moveable) for bending magnet lines is complete with fabrication expected to start in early FY2002. Similarly, the detailed design of the new SPEAR3 injection stoppers is complete with fabrication to start in early FY2002. The SPEAR3 500 mA moveable masks for the insertion device (ID) beam lines (BL4, 7, 9, & 10) are in various design stages while the masks are in fabrication or assembly for BL6 and BL11. The fixed masks for the ID beam lines are still in the analysis phase.

In what follows, the SPEAR3 beam line upgrades, along with the more general upgrades, will be listed on a beam line per beam line basis.

Beam Line 1. A major portion of the BL1-5 upgrade to bring the station to the SSRL standard configuration for protein crystallography took place in FY2001. The changes include a hutch extension, implementation of new electronics and control system, a new hutch table, and a significant redesign of the user area as well as new computer hardware.

Beam Line 2. The pinhole camera system that is used to monitor the electron beam size in SPEAR was upgraded to include motorized horizontal motion capability of the pinhole itself.

Beam Line 3. The BL3-3 M_0 mirror control system was upgraded to the SSRL standard instrumentation control system (ICS) including a commercial E500 stepping motor indexer as well as new stepper motor drivers/cables. This system now controls the four-axis mirror mover, M_0 bender, and M_0 vertical aperture.

Beam Line 4. The 20-pole hybrid wiggler for the SPEAR3 upgrade of BL4 is in construction with delivery from the vendor anticipated in early calendar 2002. The detailed design of the associated vacuum chamber is approximately 90% complete. Long lead-time raw materials (such as the 316L stainless steel plate) for the chamber have been received. The liquid nitrogen (LN) cooled monochromator for BL4-3 is in fabrication. Delivery of the LN chiller system is anticipated in October. The conceptual design for the BL4-2/6-2 LN mono featuring both Si crystals and multilayers is complete.

The BL4-2 SAXS system has also seen significant activity in 2001. The motion control system that is used to align essential components of the SAXS setup was upgraded to incorporate the SSRL standard ICS system, with all 24 of the SAXS-specific motors now controlled via three 8-channel E500 motor controllers, providing more sophisticated ways of controlling motion speed via ICS. These features, in addition to the use of the SSRL SUPER software package for general experimental control, allow alignment of the instrument and data collection far more efficiently. A new linear gas proportional chamber detector was acquired, which has an improved feature for rapid replacement of the anode wire. It also has a new delay line speed that is more compatible with the existing data collection electronics. An interline CCD camera head was purchased to upgrade the image-intensified CCD x-ray detector. A 5-ms resolution, time-resolved solution x-ray scattering experiment conducted in February 2001 demonstrated that a single stopped-flow mixing event is typically sufficient to obtain satisfactory data statistics in studying conformational changes in proteins using this detector. A rapid mixer/flow-cell has been developed based on a pair of motorized micro-syringes, to be used for biological samples that cannot be prepared in large quantities required for the use of a standard stopped-flow mixer.

Beam Line 5. The conceptual design of the SPEAR3 upgrade for BL5-2/5-3 is complete. This includes replacement of the BL5-2/5-3 monochromator with a new spherical grating monochromator (SGM) for which the procurement is in process. The control system for the existing monochromator has been replaced with SSRL standard ICS system including an E500 indexer as well as new stepper motor drivers/cables for the entrance apertures, coddling mirror, and exit slit. These upgrades will be transferable to the new monochromator.

Beam Line 6. As noted above, the conceptual design of the BL6-2 LN monochromator featuring both Si crystal and multilayers is complete. Fabrication of the components common to the standard LN mono is largely complete. Delivery of the LN chiller system is anticipated in October. Installation of this monochromator is scheduled for March 2002. Fabrication and assembly of miscellaneous masks and slits required for SPEAR3 are in process. In addition, a new fused silica M_0 mirror was installed and a vacuum leak on the photon beam position monitor was repaired.

Beam Line 7. The fabrication of the new BL7 20-pole hybrid wiggler fabrication is almost complete with final magnetic inspection scheduled to start in October 2001. The detailed design of the associated vacuum chamber is approximately 90% complete. Long lead-time raw materials (e.g., 316L stainless steel plate) for the chamber have been received. The BL7-3 LN monochromator is in fabrication. Delivery of the LN monochromator chiller is anticipated in October. In preparation for the stringent beam stability requirements of SPEAR3, a prototype M_0 mirror pitch feedback system was installed and commissioned on BL7-2. The photon beam detector which is at the heart of the system consists of a pair of Be blades. One blade extends completely through the beam and the other half way through the beam. The wide-angle x-ray scattering from each Be blade is observed by a photodiode. The signal from each photodiode is locally amplified, digitized (20 bits), and transmitted by fiber optic link to a control unit. The control unit provides arithmetic signal processing and feedback loop control with error and hutch stopper beam interruption handling for actuation of a piezoelectric pitch adjuster on the mirror pitch plate. This system has been able to stabilize vertical beam motion to the ±1.5 µm level and therefore shows promise for use with SPEAR3 beam lines.

BL7-1 was in full production throughout FY2001. This beam line will undergo a major upgrade within the framework of the SPEAR3 project with a new wiggler insertion device and optimized optics. This upgrade will also include the implementation of the standard SSRL macromolecular crystallography instrumentation and instrument control. The design for this upgrade was completed in 2001 and will be executed over the next 18 months.

A new 30-element Ge detector array for x-ray absorption spectroscopy fluorescence measurements, including new electronics, was commissioned and put into production for general users on BL7-3. The electronic adjustments are under computer control, and an improved interface, GE30^{plus}, was written and implemented.

Beam Line 8. BL8-1 M_0 and M_1 mirror control systems and BL8-2 M_0 mirror control system have been replaced with the standard SSRL ICS system that includes E500 indexers and new stepper motor drivers/cables.

Beam Line 9. BL9-1 and BL9-2 were in full production during FY2001. The SSRL macromolecular crystallography standard detector positioning system and associated instrumentation and instrument control system were installed on BL9-1. The detector positioning system can be used for all available detectors (currently a MAR345 imaging plate system; a CCD detector will be installed in FY2002). An upgrade plan was developed to improve the entire mechanism for changing wavelengths on BL9-1 for MAD and SAD experiments, which require rapid and reproducible changes in energies. This upgrade will be completed by the end of 2001. On BL9-2, a new detector positioning system was installed that can carry and position the new 3x3 matrix CCD detector, which is scheduled for delivery in late 2001. BL9-1 and BL9-2 were also equipped with a full suite of Co-laboratory tools that include pan-tilt and zoom cameras that can be remotely controlled for interactive participation in the experiment by remote users.

On BL9-3, dedicated for biological x-ray absorption spectroscopy, a video camera system was installed, which significantly improves the capability to monitor the adjustment of the focusing of the x-ray beam, as well as the alignment and homogeneity inspection of frozen protein samples. The cryostat stage was upgraded to give faster-motion capability. This reduces the radiation exposure time for sensitive samples during alignment without compromising the accuracy in the alignment. A photodiode detector to monitor the intensity of the x-ray beam before the monochromator crystals was fabricated and installed inside the monochromator housing. This device has greatly simplified the optimization of the pre-monochromator M_0 mirror for any given optical configuration.

Work on BL9-3 to carry out micro-x-ray absorption spectroscopy and chemically-specific imaging measurements on biological samples continued in FY2001. A tapered metal capillary optic has been developed externally that focuses the beam down to a spot size in the order of <5 microns in diameter. The advantages of such an optic are that it is more reflective, stable and robust than corresponding glass optics, and that it can be simply added into the beam line at the experimental hutch. A prototype motorized optic alignment stage was developed and implemented and preliminary results obtained. An apparatus for rapid alignment of the optics was built and specialized alignment and data acquisition software was developed for the x-ray absorption spectroscopy imaging experiments.

The BL9-3 M_0 mirror was re-polished. The BL9-2 and 9-3 M_0 mirror Compton shields have been replaced. SPEAR3 compatible masks and slits for BL9-2 and 9-3 have been fabricated. Installation of these mirrors, Compton shields, masks, and slits is scheduled for October 2001. The BL9-3 LN monochromator has been fabricated. Installation is scheduled for October 2001 with the crystal installation scheduled for early December 2001. Delivery of the LN chiller system is also anticipated for October 2001. An improved, lab standard version of the LN monochromator controller is in fabrication. The BL9-3 M_1 mirror pitch feedback system was installed and commissioned.

Beam Line 10. The BL10-2 LN monochromator is in fabrication with installation scheduled for January 2002. Delivery of the LN chiller system is anticipated for October

2001. The BL10 wiggler magnetic modules damaged in the accident last year were repaired and stainless steel bands were added to the magnet to prevent a reoccurrence of the problem. The damage to the wiggler vacuum chamber was repaired. The wiggler has been reinstalled into SPEAR and will be available for the FY2002 run. BL10-1 M_0 and M_1 mirror control systems have been replaced with the SSRL standard ICS system with an E500 indexer and new stepper motor drivers/cables. A new fused silica M_0 mirror was installed on BL10-2 as was improved alpha motion capability on the BL10-2 rear hutch diffractometer.

Beam Line 11: Final commissioning and start of the user program on the BL11-1 PRT line took place in FY2001 (PRT members: The Scripps Research Institute, Stanford University and SSRL). A new 3x3 CCD detector (the first to be delivered) was tested on BL11-1 toward the end of the FY2001 run cycle. Final commissioning is anticipated for November 2001, at which point it will go into full user production. This detector has the largest active surface area of any CCD detector used for macromolecular crystallography worldwide and also features a very rapid readout (~1 sec). The beam line is undergoing the same upgrade program as BL9-1 for rapid and reproducible change of the beam energy.

More specifically, the BL11-1 side scattering monochromator crystal bend fixture was redesigned and reconstructed for improved performance. The BL11-2 M_1 mirror pitch feedback system was installed and commissioned. The BL11-1 and 11-2 M_0 mirrors were removed and the side clamp cooling system modified for improved stability. The Compton shields associated with these mirror systems were also modified for improved performance. The BL11-2 LN monochromator crystal translation slide was removed and returned to the vendor to correct a lead screw problem.

Construction of the BL11-3 side station began in FY2001 with completion anticipated in early 2002. This side station will deliver high-intensity x-rays at a fixed 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 M_0 mirror for this station has been received. Detailed design of the mirror cradle, bender, and vacuum systems are complete and fabrication is in process. The detailed design of the BL11-3 side scattering monochromator and the associated mask/filter is approximately 85% complete. The long lead I-beam geometry crystal is in fabrication. Fabrication and assembly of the BL11-3 hutch, hutch stoppers, and hutch table is complete. Procurement of in-hutch experimental equipment and associated control hardware is in process. Installation of this side station is scheduled for February 2002.

Blu-Ice/DCS: The graphical user interface for macromolecular crystalography 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 and will be implemented on BL1-5 in FY2002 and BL7-1 thereafter. The software was successfully refined during the FY2001 run with input from our user groups. 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. Blu-Ice/DCS is currently being implemented at various synchrotrons including the ALS/Berkeley and APS/Argonne.

Detectors for X-ray Absorption Spectroscopy: The electronic systems that control two existing 13-element Ge array detectors used for x-ray absorption spectroscopy have been redesigned, built and tested. The upgrade allows for complete computer control of the electronic adjustment of the data acquisition settings. A new computer-to-detector interface, GE13^{plus}, was written to operate these systems, enabling the selection and display of a detector element's spectrum completely at the computer. GE13^{plus} also enables a new paradigm for windowing the detector that should prove easier and more efficient to the user: by controlling the gating levels for each element independently, the User will be able to window a feature simply by selecting it from a supplied library.

Microfocus Optics System for X-ray Micro-spectroscopy: X-ray micro-spectroscopy is an increasingly used new technique in which micron-scale x-ray beams combined with high monochromator resolution are used to interrogate the spatial distribution of various chemical forms of a particular element. The recent development of tapered metal capillary micro-focus x-ray optics combines high-gain, ease of alignment, and a relative insensitivity to x-ray energy. In addition, the use of metal capillaries provides higher power handling capabilities as compared to the more standard glass capillaries. A modular apparatus has been developed for rapid alignment of the metal capillary in the x-ray beam, with full computer control over all motions. The apparatus is also portable allowing experiments to be conducted on different beam lines. Specialized data acquisition software has also been developed for x-ray absorption spectroscopy (XAS) imaging experiments. In these experiments a chemically specific image is built up by raster scanning the sample in the x-ray beam at several different x-ray energies. This new capability has already been used to perform x-ray micro-spectroscopy and XAS imaging experiments to follow selenium biochemistry in plants, to investigate the chemical forms of sulfur in intact plant cells, to probe the chemical forms of arsenic in plant roots and to study the crystallization of amorphous silicon islands for semiconductor applications.

Highlights of the Scientific Program

Structural Molecular Biology

A New Approach to 3D Structures of Biomolecules Utilizing Single Molecule Diffraction Images. Protein crystallography can routinely determine the 3D structure of protein molecules at near atomic or atomic resolution. The bottleneck of this methodology is to obtain sizable and good quality protein crystals. An approach to overcome this obstacle under rapid development is single molecule imaging using cryo electron microscopy (cryo-EM). The highest resolution currently achievable by this technique is ~7 Å for highly symmetrical viruses and 11.5 Å for the asymmetrical ribosome. The main limitations to achieving better resolution by cryo-EM is radiation damage, specimen movement and low contrast. Radiation damage is one of the problems using an analogous x-ray based approach. Due to the much weaker interaction between matter with X-rays than with electrons, it requires much higher radiation dose to achieve the same resolution by X-rays than by electrons. Another is the difficulty of focusing X-rays. By using zone plates, the best focus currently achievable is ~ 30 nm for soft X-rays and ~ 100 nm for hard X-rays.

With the prospects of X-ray free electron lasers (X-FEL), the radiation damage problem could in principle be circumvented. Theoretical simulations by Hajdu and collaborators [*Nature* **406**, 752 (2000)] show that, within about 10 femtoseconds, biomolecules can withstand an X-ray intensity of ~ 3.8 x 10^6 photons/$Å^2$ with minimal structural changes. A 2D diffraction pattern can hence be obtained from a single exposure of a biomolecule before the radiation manifests itself. From a set of such diffraction patterns covering 3D reciprocal space, the structure of the molecule can be obtained if phase information is available. The phase problem can be solved by using the oversampling method, which was first demonstrated by successfully converting an experimental diffraction pattern from a non-crystalline specimen (an array of sub-micron size dots) to the structure of the specimen [Miao, *et al.*, *Nature* **400**, 342 (1999)]. By combining the oversampling method with a simulated X-FEL, computer modeling studies of imaging single biomolecules in 3-dimensions have been carried out. An X-FEL was simulated with a wavelength of 1.5 Å, pulse flux of 2 x 10^{12} photons and a pulse length of 10 femtoseconds. The X-FEL was then focused down to a 100 nm diameter spot. A 3D diffraction pattern was then processed by utilizing the simulated X-FEL exposures and a large number of identical copies of single protein rubisco molecules. The 3D diffraction pattern extends to a resolution of 2.5 Å, which requires 10^6 identical copies of the molecules. Poisson noise was then added to the diffraction pattern and 3x3x3 pixel intensity at the center was removed to simulate a beam stop. By employing the oversampling method, it was possible to successfully reconstruct the 3D electron density map of the molecule directly from the noisy 3D diffraction pattern [Miao, *et al. PNAS* **98**, 6641 (2001)]. The quality of the 3D electron map is comparable to that achieved from a conventional method. The promise of such experiments indeed offers one compelling motivation for the expedient construction of a next generation X-ray light source.

Cooperativity in Protein Function Regulation. The combined use of x-ray crystallography and solution small angle x-ray scattering has enabled a research collaboration involving scientists from Boston College and SSRL to provide structural evidence supporting a 30-year old model accounting for the cooperative binding of ligands to allosteric proteins and enzymes - a function central to physiology and cellular processes.

Over 30 years ago, two major models were developed to account for the cooperativity observed in oligomeric allosteric proteins such as hemoglobin, the oxygen carrier protein in blood: the concerted model, in which a protein has only two "all-or-none" global states, *vs.* the sequential model that allows a number of different global conformational/energy states. Both, however, are based on just two local states of building blocks (subunits) in close analogy to magnetic spin states. In either model, a transition of one or more protein subunits leads to the global transition, in the case of hemoglobin, from the oxygen-releasing form to the oxygen-binding form, depending on the oxygen level in the blood stream. The concerted model, based on highly positive cooperativity, resembles the ferromagnetic phase transition, in which only two spin states account for the sharp phase transition between two global states. The sequential model, on the other hand, permits mixture of active and inactive subunits. Macol *et al.* [Nature Struct. Biol. 8, 423 (2001)] constructed a version of an allosteric enzyme *E. coli* aspartate transcarbamoylase, which is composed of six equivalent catalytic monomers and six equivalent regulatory monomers in its native form, in such a way that only one of the six catalytic monomers could bind a substrate analog. Using solution x-ray scattering data recorded at BL4-2 to monitor the global structural state, they provided the first structural evidence that the transition of only one catalytic monomer is sufficient to transform the entire enzyme into the highly active state, lending strong support to the concerted model.

Molecular Environmental Sciences (MES)

The seminal MES programmatic achievement during FY2001 was user commissioning on BL11-2, a new state-of-the-art facility dedicated to MES. A total of two months of beam time were delivered to 8 different user groups at BL11-2. XAS measurements were performed on elements with binding energies ranging from 5 to 33 keV, including U, Np, Pu, As, Se, Pb, Hg, Cr, Fe, Ce, and I. BL11-2 features a radiologic sample handling facility, which was commissioned with help from LANL scientists and technical teams in January 2001. In aggregate, MES experiments were carried out on 14 SSRL beam lines, with total MES beam time increasing 13% relative to the previous year. Other program achievements include: demonstration of a 15 micron micro-spectroscopy capability at BL11-2 (to be implemented for routine use in FY2002), testing of an experimental transmission Laue analyzer for XAS measurements, and continued progress on the following other projects: assembly of a grazing incidence spectrometer system, commissioning of liquid He sample cryostat systems redesigned to handle high x-ray power densities, assembly of a muli-element Ge detector azimuthal positioning system, and installation of a new sample preparation laboratory.

The radiologic sample handling facility provides continuous air monitoring in a lined, HEPA filtered hutch, permitting analysis of radioactive samples. The facility was used to measure Cr speciation in radioactive sediment samples removed from beneath high level waste storage tanks at the Hanford site tank farm in Richland, Washington. Chromium is a key concern in these sediments, where it occurs at concentrations up to 37,000 parts per million owing to effluent leakage from the tanks. When in the 6+ form, chromium is highly toxic and mobile in groundwater. In contrast, chromium 3+ is non-toxic and forms insoluble, immobile solids. XAS spectroscopy shows three of the sediment samples to contain about 50% Cr(VI), whereas one sample contained about 20% Cr(VI). These results indicate that reduction of Cr(VI) to Cr(III) is incomplete; hence Cr(VI) migration in groundwater is expected to be a continuing problem.

Materials Science

Technological Impact of Synchrotron Radiation Research on IBM's New Flat Panel Displays. Today's laptop computers utilize flat panel displays where the light transmission from the back to the front of the display is modulated by orientation changes in liquid crystal (LC) molecules. One of the key steps in the manufacture of the displays is the alignment of the LC molecules in the display. Today this is done by mechanical rubbing of two polymer surfaces and then sandwiching the LC between two such surfaces with orthogonal rubbing directions. Over the past years a great challenge of this $20 billion/year industry has been to devise an alternative method of liquid crystal alignment. The rubbing process is plagued with contamination issues and the polymer film is deposited by a wet process that is incompatible with high-tech manufacturing techniques. Also, the rubbing process does not lend itself to the manufacture of multidomain alignment layers that are necessary to increase the limited viewing angle in present displays. The development of a new alignment technology, however, has been impeded by the fact that the origin of LC alignment has remained a mystery since its discovery in 1907.

Polarization and surface sensitive NEXAFS spectroscopy measurements at SSRL have been used to solve this puzzle. The understanding of the molecular alignment mechanism for rubbed polymer surfaces has directly led to a proposal for the development of alternative alignment materials and processes and has resulted in three IBM patents. The work has only recently been cleared for publication by IBM [J. Stohr *et al., Science* **292**, 2299 (2001)]. The new proposed alignment material is an amorphous carbon film that can conveniently be deposited in a dry deposition process. Hydrogen is added in the deposition process to make it more transparent. Irradiation by a directional ion beam is used to create orientational order at the surface of the carbon film. The understanding of the alignment mechanism based on the creation of preferential molecular orientation in any carbonaceous material, including rubbing of polymer films or ion beam irradiation of carbon films, and the easy manufacturability of thin amorphous carbon layers by CVD or sputtering methods, convinced IBM to develop this process for manufacturing. The process has now cleared all development checkpoints and full flat panels have been reliably manufactured. The process is especially well suited for large displays and IBM has used it to build the highest resolution flat panels available today [P. Chaudhari *et al., Nature* **411**, 56 (2001)].

Nature of Charge Order in the Layered Manganite $La_{1-x}Sr_{1+x}MnO_4$. The strong electron correlations in transition metal oxides give rise to such phenomena as high-temperature superconductivity in layered cuprates and to stripe-like order in layered cuprates and nickelates. In the case of the manganites, an additional strong electron-lattice interaction leads to a very rich phase diagram in which structural, magnetic, and transport properties are intimately related. Colossal magnetoresistance (CMR) has been observed in the perovskite and double-layer manganites, but not in the single-layer system $La_{1-x}Sr_{1+x}MnO_4$ (Mn214). Nevertheless, there are signs that the physics of Mn214 is similar to that of the perovskites. Information about the low-temperature structural phases of Mn214 can be expected to provide valuable insight into the role of dimensionality on the properties of the manganites, and also to contribute to a deeper understanding of single-layer transition metal oxides in general.

Simon Larochelle and co-workers have grown single crystals at Stanford's new Laboratory for Advanced Materials and carried out x-ray scattering studies at SSRL BL7-2 to establish the low-temperature structural phase diagram of Mn214 [S. Larochelle *et al., Phys. Rev. Lett.* **87**, 095502 (2001)]. For x = 1/2, this study provides a more complete picture than previous neutron and x-ray scattering experiments. An investigation of the effects of varying the e_g electron concentration ($n_e = 1 - x$) in the MnO_2 layers revealed three distinct regions: disordered ($x < 0.4$), mixed-phase ($0.4 < x < 0.5$), and charge-ordered ($x > 0.5$). Above $x = 0.5$, the ordering of e_g electrons is found to result in a structural distortion whose modulation period only depends on n_e. Even though Mn214 does not exhibit CMR, this trend resembles findings for $La_{1-x}Ca_xMnO_3$, which is a CMR material. This behavior furthermore is reminiscent of the charge- and spin-density wave order tendencies in the hole-doped layered cuprates and nickelates. The results of this study thus provide valuable quantitative information for tests of theories for CMR materials and layered transition metal oxides.

Complex Materials Research by Angle-Resolved Photoemission Spectroscopy to Probe the Detailed physics of High T_c Superconductivity. Extensive research efforts to study the novel electronic properties of high-T_c superconductors and their related materials by angle-resolved photoemission spectroscopy at a recently commissioned BL5-4 (led by Z.-X. Shen) continue to be successful, producing many important results. These results, which are highlighted by five articles recently published in Physical Review Letters and one in Science, brought our understanding steps closer to solving the mystery of the high-T_c superconductivity.

With the development of the latest generation of ultra-high resolution electron spectrometers in the past few years, the technique of angle resolved photoemission spectroscopy (ARPES) has recently experienced a renaissance. Nowhere is this revolution more evident than in the study of the high-temperature superconductors, which more than a decade after their discovery, continue to defy theoretical explanation. Recent ARPES experiments performed at BL5-4 have led to critical new discoveries about the fundamental nature of these mysterious superconductors and are now changing the way that the physics community views these materials. An excellent benchmark for the huge leap in detector resolution and technology is the recent work on Sr_2RuO_4. Although it belongs to a slightly different family than the high temperature superconductors, its exotic superconducting mechanism (T_c = 1K) and complex electronic structure make it in itself a fascinating material. In the past, due to poor resolutions, ARPES studies on this material were in disagreement with theory and other experimental techniques. However, with the use of the new spectrometer on BL5-4, this longstanding controversy has finally been resolved by studying the electronic states as a function of momentum and energy with unprecedented resolution. As a result, the subtle issues that plagued the earlier studies have been clarified, demonstrating both the reliability and unique sensitivity of ARPES as a technique for studying complex materials [A. Damascelli *et al., Physical Review Letters* **85**, 5194 (2000)].

Moving to the high-temperature superconductors, a recent work at SSRL on the compound $Bi_2Sr_2CaCu_2O_{8+\delta}$ [D.L.Feng *et al.*, *Science* **289**, 277 (2000)] has shown that the photoemission spectra exhibits unexpected sensitivity to the superconductivity. In particular, the intensity of the (p,0) peak in the photoemission spectrum exhibits striking resemblance to the density of paired electrons participating in the superconducting state, as measured by other techniques. This surprising manifestation of collective quantum effects in single-particle excitation spectrum may indicate that the pairing of electrons in the superconducting state cannot be reconciled with more conventional theories, but rather, point to more exotic pairing mechanisms.

Although $Bi_2Sr_2CaCu_2O_{8+\delta}$ is, by far, the most studied superconductor by ARPES, a long-standing mystery has been the absence of a so-called bilayer splitting in the electronic structure. It has been theoretically predicted that the interaction between the two adjacent CuO_2 layers in $Bi_2Sr_2CaCu_2O_{8+\delta}$ would result in a doubling in the number of bands. However, such a splitting has never been observed in previous ARPES studies, and hence deemed nonexistent and unimportant. Recent experimental confirmation of this long-sought bilayer splitting [D.L. Feng *et al.*, *Physical Review Letters* **86**, 5550 (2001)] unambiguously demonstrated that the interaction between neighboring CuO_2 planes strongly affects the electronic structure, and that theories must be once again revisited to include the bilayer interaction in any accurate description of $Bi_2Sr_2CaCu_2O_{8+\delta}$.

$YBa_2Cu_3O_{7-\delta}$ is one of the most extensively studied high temperature superconductors not only because it is one of the first true "high" T_c superconductors, but also due to its enormous application potential. All previous photoemission experiments on this material had been plagued by unfortunate surface effects which have obfuscated the measurements. Recently, there was a breakthrough in this challenging problem, made possible by significantly improved sample quality and instrumental resolution. The article in Physical Review Letters by D.H. Lu *et al.* [*Physical Review Letters* **86**, 4370 (2001)] reports the first observation of the so called "peak-dip-hump" structure on a system other than $Bi_2Sr_2CaCu_2O_{8+\delta}$, finding key similarities in the spectra from $YBa_2Cu_3O_{7-\delta}$ and the more well-understood $Bi_2Sr_2CaCu_2O_{8+\delta}$, as well as some notable differences which may arise from their slightly different crystal structures.

From $YBa_2Cu_3O_{7-\delta}$, the most popular, we move to $Nd_{2-x}Ce_xCuO_4$, the "black sheep" in the family of high-temperature superconductors. Because the doped charge carriers in $Nd_{2-x}Ce_xCuO_4$ are electrons, as opposed to holes for $YBa_2Cu_3O_{7-\delta}$, $Bi_2Sr_2CaCu_2O_{8+\delta}$, and the vast majority of high-T_c's, the properties of $Nd_{2-x}Ce_xCuO_4$ are significantly different from its hole-doped cousins. This disparity, along with the dearth of experimental data, has made the few electron-doped high-T_c superconductors rather poorly understood. In particular, while it is now widely accepted that the superconducting pairing in the hole-doped materials is strongly dependent on the momentum of the electrons (a *d*-wave symmetry), it has been long believed that the pairing in the electron-doped materials had no such momentum dependence (an *s*-wave symmetry). However, new photoemission data [N.P. Armitage *et al.*, *Physical Review Letters* **86**, 1126 (2001)] has challenged that long-standing notion by detecting a small but clear momentum asymmetry by utilizing the extremely high-energy resolution of the new electron spectrometer on BL5-4. The detection of this momentum dependence in the superconducting pairing demonstrates that the electron and hole doped materials may not be as disparate as originally believed, moving us closer towards a unified picture of the high-temperature superconductors. Some of the work on $Nd_{2-x}Ce_xCuO_4$ appeared on the cover page of February 2000 issue of Physics World.

Collaboration with a group at University of Tokyo in Japan produced an important result in a more fundamental problem. Spin-charge separation is an exotic phenomenon in which the charge and spin of an electron are separated and behave like independent particles. This phenomenon occurs only in one dimensional (1D) systems and was first confirmed by an experiment in insulating $SrCuO_2$, performed at SSRL. Observation of such phenomenon in a metallic system would be important and there have been steady efforts to observe spin-charge separation in metallic 1D systems. These efforts, however, have been hindered by materials issues. $PrBa_2Cu_3O_7$ is one of the rare systems that provide possibility of studying doped Cu-O chains. The work by T. Mizokawa *et al.* [*Physical Review Letters* **85**, 4779 (2000)] shows two dispersive features, corresponding to the spinon and holon edges. It is the first convincing experimental evidence of spin-charge separation in a doped Cu-O chain.

17.Science Education

Education

SLAC continues to be a major education resource at all levels. The following gives a brief summary of such activities.

Pre-College

In 2001, SLAC continued as an ongoing support for local public schools. Elements include activities such as donations of used equipment to schools, access to SLAC tours for school groups (several thousand students each year come on such visits), an information network for high school physics teachers, and participation in the advisory board of a Local Systemic Science Project, which is an NSF funded collaboration of eight local school districts known as Bay Area Schools for Excellence in Education (BASEE). Many SLAC scientists also contribute science education in their local schools via talks and classroom visits.

Two one-day programs provided an educational opportunity for the children of SLAC employees or their friends: These were Take our Daughters to Work Day and Take our Sons to SLAC day, which together bought over 150 youngsters between the ages of 9 and 16 to the site for a day of science activities and tours.

Another form of outreach that impacts both high school and college level classrooms is the educational component of the SLAC website, which is known as the Virtual Visitor Center (http://www2.slac.stanford.edu/vvc/). In 2001, two new interactive components to this site were developed. One gives access to the cosmic ray data collected by the detector in our real visitor center and suggests student activities to interpret this data. The second, to be launched in early October, gives access to a simulation tool based on the EGS (Electron Gamma Shower code), allowing students to select conditions, run a simulation, and view the results in pictorial form.

Undergraduate

SLAC participated in the DOE Energy Research Undergraduate Laboratory Fellowship Program with a summer program that brought 25 undergraduates (many of them from groups traditionally under-represented in physical science careers) to SLAC in 2001 for an eight-week research experience internship. Students were placed in all segments of the laboratory. In addition, a number of undergraduate students made arrangements to work in a research group through their home university faculty members who are SLAC HEP or SSRL users.

This year a very unfortunate incident occurred. While bicycling to work, one of the students was killed in a collision with a car right outside the entrance to SLAC.

Many additional students come to SLAC as direct summer hires. In 2001 students did work that ranged from clerical to computer programming.

Graduate

All aspects of the SLAC research program involve graduate students, many of whom complete their thesis work here. SLAC faculty members serve as advisors for Stanford Ph.D students. In addition there are over 100 students each year working in HEP, at GLAST, and at SSRL, who came to SLAC for thesis research as part of a user group. SSRL also plays host to a number of Masters thesis students each year.

Professional

For scientists, education does not end with a Ph.D. degree. There is an ongoing need for specialized training in many areas. SLAC contributes notably to such training. In 2001 150 physicists attended the two-week long school and topical conference known as the SLAC Summer Institute. SLAC physicists also once again played a lead role in the US Accelerator Physics School.

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. A joint Stanford-Berkeley one week Summer School on Synchrotron Radiation and its applications was introduced this year and is planned to be an annual event. The thirty-six selected students came from a diverse range of scientific fields including atomic and molecular physics, condensed matter physics, surface science, polymer chemistry, environmental science and biophysics. In addition, SSRL hosted 26 students in a summer school on Structural Molecular Biology RL (September 19–23, 2000), including an intensive series of lectures, complemented by hands-on tutorial sessions. A broad cross-section of state-of-the-art macromolecular crystallography techniques and methods were covered. A second such school is planned for the fall of 2001.

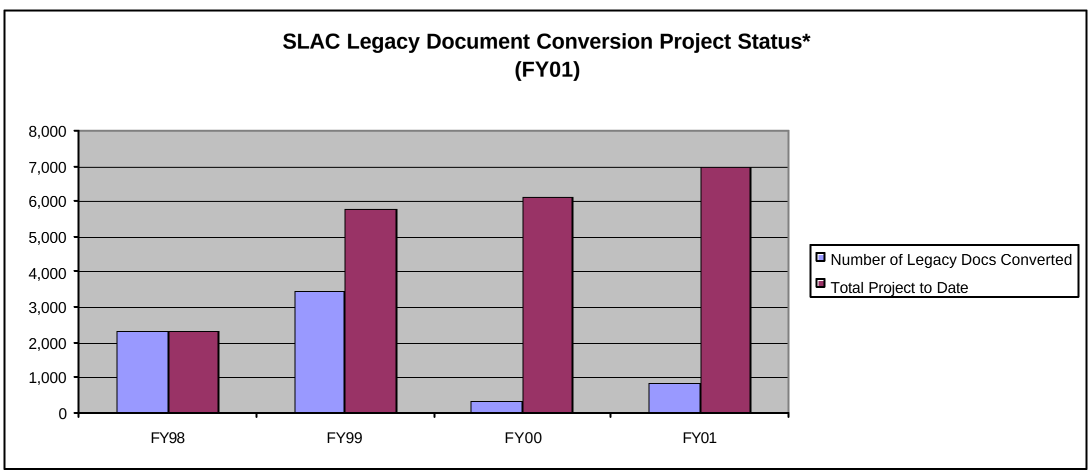
In addition, in conjunction with the SSRL annual users meeting, five workshops covering a broad range of applications of synchrotron radiation were held. On the Wednesday preceding the meeting, three onsite workshops titled "Application of Synchrotron Techniques to Materials Issues in Art and Archeology," Sulfur K-edge X-ray Absorption Spectroscopy: Applications, Opportunities and Future Directions in the Biological, Environmental and Chemical Sciences" and "Soft X-ray Speckles: Nanoscale Dynamics in Liquids and Solids" engaged about 100 participants. A joint ALS-SSRL workshop titled "X-ray Microdiffraction and Its Application to Problems in Materials Science" was also held on Wednesday at the ALS. On the Saturday after the meeting, another 45 scientists learned about "New Scientific Opportunities in Ultra-high Resolution Spectroscopies: from Nanomaterials to Complex Quantum Systems."

18. FY01 Progress on Scientific and Technical Information Management (Patricia 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 as required by contract and the performance measure. Full text versions of all SLAC publications are available via the Web and bibliographic records are included in the SPIRES-High Energy Physics Database, which is the core literature database of the worldwide particle physics community. 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.

Scientific/Technical Information Products	FY01	FY00	FY99
Pubs	314	310	272
Reports	12	14	19
AP-Notes	3	8	
Total Submitted to OSTI	329	332	291

As staffing is available, SLAC continues to convert the remaining legacy documents to electronic form.



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