# SLAC BEAM LINE

*To make predictions is difficult,*
*especially when they concern the future.*
— *Victor Weisskopf*

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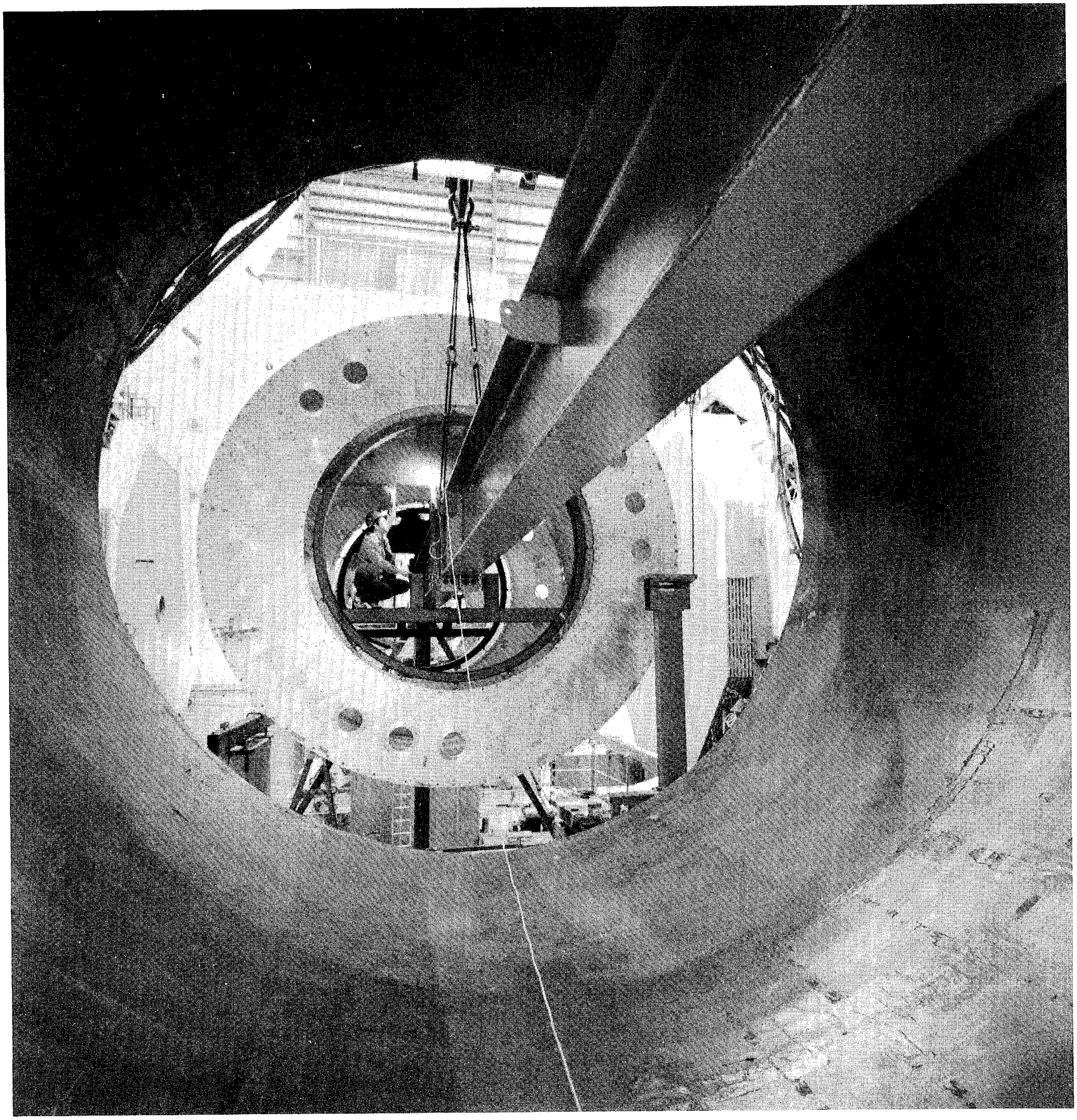

Final SLD Assembly Begins

*SLAC BEAM LINE*
*Mail Bin 80, (415) 926–2282*
*Bitnet Address:* BEAMLINE @ SLACVM

*Editor: Michael Riordan*
*Assistant Editors: Nina Adelman, Bill Kirk*
*Photography: Joe Faust, Elsi Stucki*
*Graphic Arts: Walter Zawojski*
*Production: Publications Department*

*IN THIS ISSUE:*



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# FROM THE DIRECTOR'S OFFICE

As you all know, our first operation of the new Stanford Linear Collider (SLC) proved to be a mixed success. On the one hand, we demonstrated to ourselves and to the world at large the feasibility of producing and colliding high-energy, micron-sized beams of electrons and positrons. Our demonstration of the basic linear collider idea is an important achievement. The significance of this new approach is confirmed by the fact that there are extensive programs aimed at developing very high-energy linear colliders in Europe, Japan and the Soviet Union.

On the other hand, we have not yet accomplished the second purpose for which the SLC was built — to study the properties and decay modes of the very important elementary particle called the $Z^{\circ}$. The initial commissioning run of the SLC and the first attempt to do physics with the machine occurred during the first eight months of 1988. During that time a number of problems caused the operating efficiency to be so low that no significant high-energy physics results could be obtained. This run was a disappointment but also an important learning period, during which we found out how the machine worked, what needed to be fixed, and how our instrumentation and control system would have to be improved.

Full-scale operation of the SLC is scheduled to resume this February. During this past four months we have resumed operating our two storage rings, PEP and SPEAR, both for high-energy physics research and for the synchrotron radiation research program of our sister laboratory, SSRL. There has also been a great deal of SLC activity going on, aimed at both hardware and software improvements in the machine's components, systems and controls. In addition, we are developing and implementing switching techniques that we hope will eventually allow us to operate all three of our major facilities (SLC, PEP and SPEAR) together. If we can switch from SLC operation to storage-ring filling and back again quickly and efficiently, then simultaneous operation of this three-machine complex should be possible.

These matters were discussed at length with SLAC's Experimental Program Advisory Committee, which met here on November 4–5, 1988. This Committee consists of a dozen prominent scientists from outside universities, research laboratories, and from SLAC itself who advise me on the laboratory program. During the November meeting, I specifically asked for the Committee's advice on the relative priority to be given the SLC program in comparison with the other high-energy physics programs.

In response, the consensus of the Committee members was that the most important activity for the future of SLAC was to have the SLC start producing physics results. I have accepted this advice, which in more detail can be summarized as follows:

1. Continue the present program of PEP and SPEAR operation mixed with occasional SLC tests until the end of the present running cycle. Complete SLC installation work by February 1989.

2. In February, resume the SLC program and concentrate exclusively on it. (During this period we will honor our commitment to SSRL of one fill per day of the SPEAR ring.) Continue this program until the SLC is operating satisfactorily for physics.

3. When it is running satisfactorily, joint operation of the SLC and storage ring programs will proceed, but only if the storage-ring program can be run jointly with the SLC while not imposing an "overhead" of more than 20 percent on its operations.

Here then is our planned program for 1989. We have already learned more about the SLC and will have completed its scheduled modifications and improvements by early February. At that time our program will focus almost exclusively on making it operate in an efficient and reliable manner, so that the Mark II collaboration can begin to collect $Z^{\circ}$ events and to study this important new energy region near 100 GeV. If all goes well, the storage-ring programs will be able to resume somewhat later in the year.

The upcoming run of the SLC will be critically important for everyone here at SLAC. Making it succeed will require careful, high-quality work by all of us. Let's do it.

— Burton Richter

# RESEARCH AT SSRL

## by Arthur Bienenstock

The Stanford Synchrotron Radiation Laboratory (SSRL) uses the SLAC storage rings to produce extremely intense beams of vacuum ultraviolet and X-ray radiation. These beams are used by scientists and engineers from all over the world for a variety of scientific and technological purposes. Some of these uses are discussed in this article, which provides a brief overview of the research performed at SSRL.

Synchrotron radiation is produced when charged particles traveling at relativistic speeds are accelerated. All current synchrotron radiation facilities use electrons or positrons circulating in storage rings like SPEAR and PEP. The acceleration of these particles occurs when their path is bent either by the ring's own bending magnets or by special arrays of magnets, known as "wigglers" and "undulators," which are inserted into its straight sections to produce the radiation deliberately.

A special beauty of synchrotron radiation is its characteristic spectrum, shown in Fig. 1. With SPEAR running at 3 GeV, for example, the spectrum emitted by electrons passing through a bending magnet varies smoothly, rising slowly to an energy of 1–2 keV and then dropping off sharply. The wavelength $\lambda$ of this radiation is related to the photon energy $E$ according to the formula

$$\lambda(angstroms) = \frac{12.4}{E(keV)},$$

where 1 angstrom equals ten billionths of a centimeter, or a ten-thousandth of a micron. Because there is still a small yield of photons with energies above 12 keV, we get appreciable intensities at wavelengths of 1 angstrom or less. Well into the X-ray region, such a wavelength is about equal to the spacing between atoms in solids and liquids. Synchrotron radiation therefore enables us to study structural features of this size.

*COVER PHOTO: The outer cylindrical shell of the liquid argon calorimeter (LAC) being inserted into the SLD magnet coil. This will be followed shortly by another, smaller shell and then by the LAC itself. See page 10 for a progress report on construction of SLAC's newest particle detector. (photo by Joe Faust)*

The radiation intensity available at SSRL is about 100,000 times that obtainable from a common X-ray tube. Moreover, an X-ray tube produces a spectrum peaked at only a few wavelengths characteristic of the tube's anode material and extremely weak elsewhere. The smoothly varying synchrotron radiation spectrum has opened the door to experiments that require other specific wavelengths, such as an angiography experiment (discussed below), or which require measurements at variable wavelengths, such as in structural studies of disordered materials. These wavelengths are obtained from the smooth spectrum with a device known as a "monochromator," which delivers only a narrow range of wavelengths to an experiment.

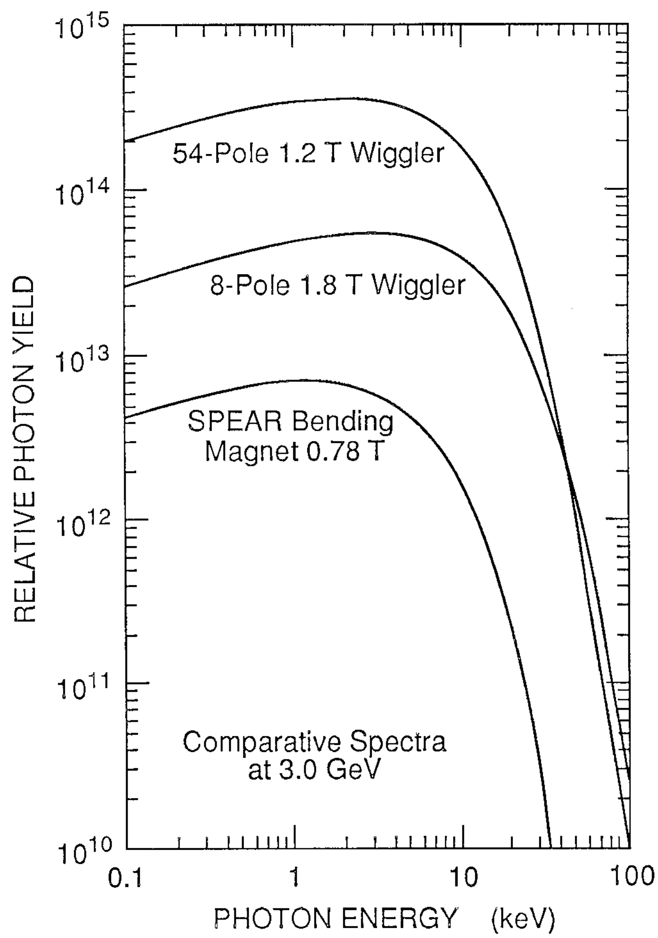



*FIGURE 1. Synchrotron radiation spectra developed by SPEAR bending magnets and two types of wiggler magnets inserted into the beam.*

## Wigglers and Undulators

Large enhancements of the synchrotron radiation intensity can be obtained through the use of wigglers. These arrays of multiple magnets are placed in the straight sections between the storage-ring bending magnets. They cause the particles to undergo a sinusoidal motion (or "wiggle") which generates radiation at each turn. At low photon energies the combined intensity is about the same as that produced by a single bending magnet multiplied by the total number of magnet poles in the wiggler. At high photon energies there can be a much greater enhancement because the magnetic fields of the wiggler magnet can be much stronger than the fields generated in normal ring bending magnets.

The high intensity X-rays produced by SPEAR's 8-pole wigglers have proved extremely valuable for an angiography experiment. Its 54-pole wiggler (see Figure 2), produced by a collaboration of Lawrence Berkeley Laboratory, Exxon and SSRL scientists, generates radiation so intense that it can melt or even vaporize a sheet of metal. Special techiques had to be developed in order to bring the radiation out to the experimental stations.

An undulator is a variant of the wiggler in which low magnetic fields are normally employed. At a few specific wavelengths, the radiation produced at each magnet pole is *in phase* with the radiation produced at the other poles; at other wavelengths, it is out of phase. The spectrum is therefore peaked at the specific wavelengths, rather than smooth, but it can be tuned by varying the magnetic fields. Because the fields used are generally weak, the achievable photon energies are limited, but extremely bright radiation is produced at selected wavelengths. Undulators at SPEAR produce peaks up to a few keV at most. Those at PEP yield photon energies in the 10–50 keV range, which is one reason for the excitement over its use as a synchrotron radiation source.

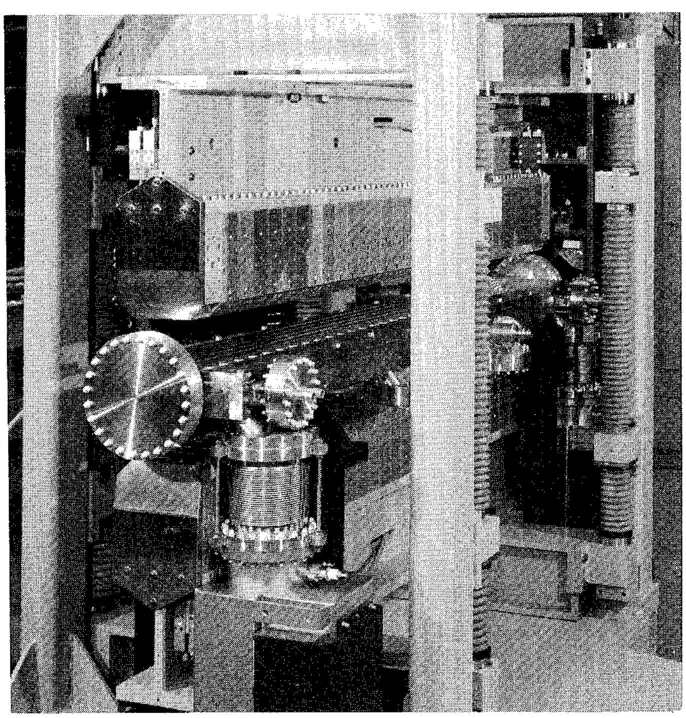


*FIGURE 2. The 54-pole wiggler magnet used to generate synchrotron radiation at SPEAR.*

## Research Applications

The principal use of synchrotron radiation is in determining how atoms are arranged in — and on the surfaces of — solids and liquids. Such knowledge is crucial for a modern atomistic understanding of the properties of materials. Any advance in such structural information usually brings a major new advance in understanding these properties. The quantum mechanical understanding of crystalline semiconductors, which followed our ability to determine their crystal structures, led to the development of transistors, integrated circuits and modern computers. Similarly, the revolution now underway in chemistry, biology, medicine and genetics is a result of our recent ability to determine the structures of proteins in crystalline forms.

In most materials, however, the atoms do not come in the periodic, three-dimensional arrangements characteristic of crystals. Instead, there are varying degrees of disorder ranging from atomic impurities in the crystalline structure to the almost chaotic atomic arrangements found in liquids, glasses and other amorphous materials.

Synchrotron radiation has allowed the development of techniques that help us obtain structural information when the atomic arrangement is very disordered. Consequently, we can determine the atomic rearrangements associated with the biological functions of protein. For example, we can examine how the atoms in the protein hemoglobin are rearranged when it is oxygenated, as occurs in the lungs, and then deoxygenated, as occurs when this molecule subsequently delivers the oxygen to various tissues in the body.

Other techniques based on synchrotron radiation can be used to determine the atomic arrangements near impurity or alloying elements, which are added to crystalline or amorphous systems to change their physical properties. Similar techniques are used to determine atomic arrangements at surfaces, allowing SSRL users to study how materials oxidize, corrode or interact chemically. Among the most interesting of these applications is the study of phase transitions (like freezing) at surfaces. With synchrotron radiation one can study how the transition changes as the sample is altered from a two-dimensional monolayer to a three-dimensional system.

Synchrotron radiation is also used to study the binding states of electrons in solids, liquids and gases. This electron binding is the "glue" that holds atoms together and determines almost all the properties of these materials. A large portion of the quantum mechanical studies of atoms and molecules in the past three decades have been aimed at determining these electronic states. The copious supply of photons provided by synchrotron radiation sources makes it possible to probe these states more carefully and to examine the unique electronic states associated with surfaces, interfaces and impurities.

Some of the most exciting studies of this type have been aimed at understanding the semiconductor-to-metal interface essential for solid state electronic devices. In the early days of semiconductor devices, when simple transistors dominated the field, this interface could be visualized readily as the junction of a block of semiconductor with a block of metal, producing the Schottky barrier. As integrated circuits have grown smaller and smaller, however, this simple picture has become less and less valid. As a result of key experiments by the Stanford groups of Professors Ingolf Lindau and William Spicer and a Xerox group led by Robert Bachrach, new atomistic models of the barrier have been developed.

Soft X-rays are also used in experimental programs on X-ray lithography for producing extremely dense integrated circuits. Present lithographic techniques based on visible light will soon be limited by the diffraction of this light at the edges of the masks used to form patterns on the silicon surface. At shorter wavelengths this diffraction effect is reduced, and features smaller than half a micron can be obtained. By contrast, optical lithography can only produce features that are larger than 1 micron across.

Conventional sources of soft X-rays, however, are not sufficiently intense to make X-ray lithography practical. Synchrotron radiation provides the required intensity. There are several efforts around the world to develop compact storage rings for this purpose. IBM has recently placed an order for its own storage ring for making synchrotron radiation, while Nippon Telephone and Telegraph already has one functioning. At SSRL, research in X-ray lithography has been performed by Professor Piero Pianetta and his students as well as scientists and engineers from Intel, IBM, Crystallume, Nanometrics and other companies. Their research has concentrated on the characterization of photoresists and radiation damage to the masks.

## Medical Applications

The commonest use of X-rays is for imaging human bodies as well as a variety of other objects. Here again, synchrotron radiation has led to major new developments. At SSRL a much safer procedure for the observation of heart arteries is being developed. The angiography procedure commonly used today requires passing a catheter a very long distance from the thigh to the heart through the arteries. This diagnostic procedure results in serious physical injury to approximately 1 in 200 patients and death to 1 in 500–1000 patients. The new approach to angiography being developed at SSRL is much safer and could, therefore, be used in routine follow-up examinations after heart surgery as well as for testing the effectiveness of drugs. In the last few years, the new procedure has been tested on two groups of three patients. We are hoping to test improvements early in 1989, with the aim of producing clinical quality images.

Synchrotron radiation tomography procedures are now being developed at SSRL. Tomography, which yields a two dimensional cross section of an object, is used in medicine (in the so-called CAT scanner) and for industrial purposes such as failure analysis. By using synchrotron radiation, it has become possible to obtain extremely high resolution (of the order of several microns) in tomography. One can also obtain cross-sections which provide maps of the distribution of individual atomic species.

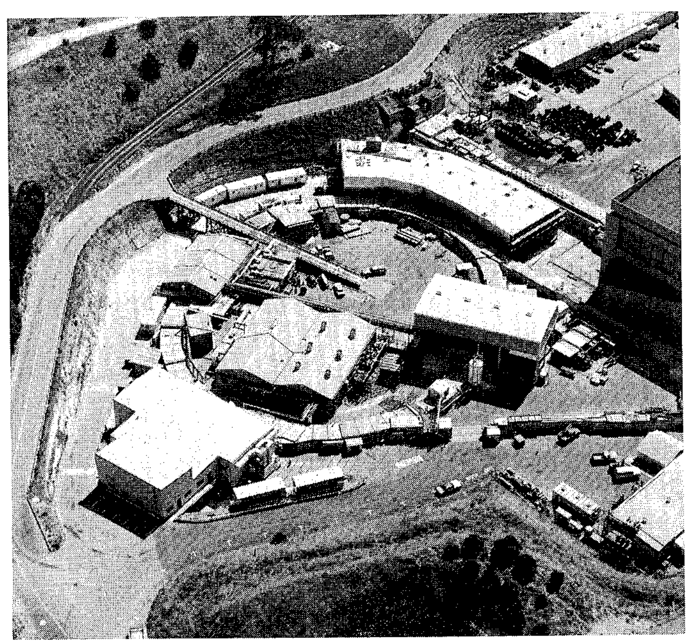


*FIGURE 3. Aerial View of the SPEAR storage ring. The SSRL beamlines are located in the two buildings at the upper right and lower left edges of the ring.*

## New Facilities

A major impediment to the scheduling of these and many other kinds of experiments has been the limited amount of SPEAR time available for synchrotron radiation production. This dedicated time has been limited by SSRL's finances, by our sharing of SPEAR with high-energy physics research and by the limited amount of time the SLAC linac has been available for injection during the initial phase of the SLC era. We expect the financial constraints to be eliminated soon, as there is increasing recognition in the Department of Energy and Congress of the importance of running synchrotron radiation facilities at optimal levels.

To eliminate problems associated with linac availability, SSRL is presently constructing a 3 GeV booster synchrotron that will serve as an additional injector for SPEAR. It should provide a major increase in running time dedicated to synchrotron radiation research by our users. When the high-energy physics program on SPEAR ends, we anticipate running SPEAR about 10 months per year for synchrotron radiation production.

Two synchrotron radiation beam lines built recently on PEP provide the world's brightest X-ray beams (by at least an order of magnitude) when used parasitically during high-energy physics experimentation. With dedicated operation at lower energy, that brightness could easily be increased by another two orders of magnitude and more (see box), opening up entirely new experimental fields. Such a brightness will allow the determination of atomic arrangements on the surfaces of liquids and other amorphous materials. It will make comprehensive studies of the nuclear resonance (Mossbauer) Bragg scattering possible. Crystallographers will be able to determine the structures of extremely small protein crystals and thus overcome limitations imposed by their inability to grow crystals large enough for application of normal X-ray techniques.

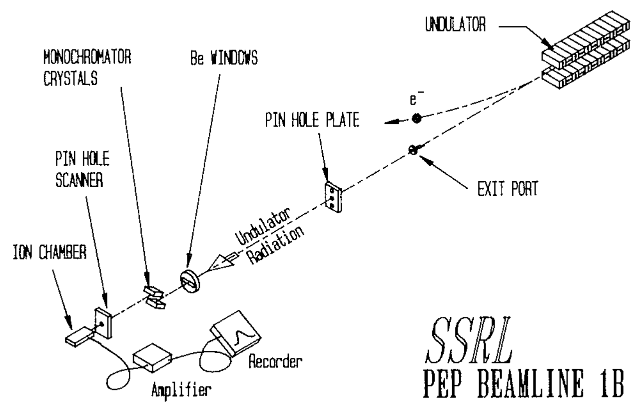
With additional hardware components known as "damping wigglers," SSRL plans to reduce PEP's emittance markedly, to obtain significant coherent radiation in the X-ray portion of the spectrum. This will allow for imaging at successively smaller wavelengths, yielding details of proteins and other small systems which have been unobtainable thus far. We do not yet know what other uses of this coherent X-ray radiation will emerge, but all experience with coherent sources at longer wavelengths indicates that dramatically new science will result from its being available.

*Arthur Bienenstock is Director of SSRL.*

### World's Brightest X-ray Source

*Scientists from SLAC and SSRL have generated an X-ray beam about a hundred times brighter than has ever been achieved elsewhere. In a dedicated run on the PEP storage ring, they passed narrow beams of 7.1 GeV electrons through an undulator magnet. The X-ray beam produced in these tests approached the intensities anticipated at new synchrotron radiation facilities now being designed or already under construction in Europe, Japan and the United States.*

*The key to this approach is operating PEP in a dedicated mode with only electrons circulating, which allows the beams to be focussed to an extremely narrow width as they pass through the undulator. The goal is to minimize the beam's "emittance" — a measure of its narrowness. The tighter the electron beam, the brighter the synchrotron radiation it produces.*




*During the recent PEP tests, an emittance of 6 nanometer-radians was achieved, as compared to a value of 450 usually realized on SPEAR. Levels of about 100 nanometer-radians are currently achieved at a dedicated Brookhaven facility, the NSLS. Previously the best emittance measured was about 25 nanometer-radians at a storage ring near Paris.*

*These high-brightness beams may open new vistas in synchrotron radiation research, according to SSRL Deputy Director Hermann Winick. Experiments currently under way can be expanded so that scientists can study smaller or more dilute samples — or processes with very short lifetimes. It would be possible, for example, to record complete X-ray diffraction patterns from protein crystals in less than a billionth of a second. "And every order-of-magnitude improvement in the qualities of a light source," noted Winick, "results in new, unanticipated science."*

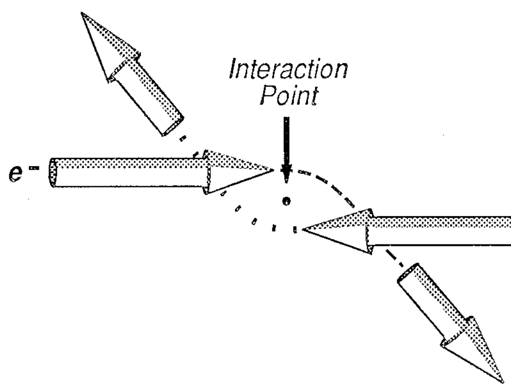
*— Michael Riordan*

# PROGRESS AT THE SLC

Although it produced no $Z^\circ$ particles, the Stanford Linear Collider (SLC) made major advances in accelerator physics during the recent summer run. Not only were micron-sized beams of electrons and positrons held in collision for hours at a stretch, but precision methods have also been developed to help aim the beams to a fraction of their diameters. And a new beam stabilization technique has allowed marked improvements in collider operations.

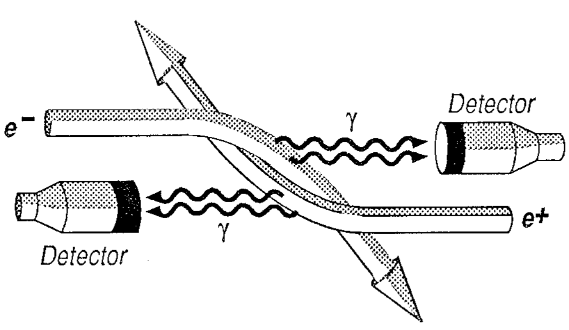
### Beam–Beam Deflections and Beamstrahlung

First witnessed in June, beam-beam deflections have been developed into a powerful beam steering aid. By measuring the slight deflection of one beam by the other (caused by their mutual attraction when they are not aimed exactly head-on), operators can monitor their relative alignment. The deflection reaches a maximum when the beams are about one diameter apart and falls to zero when they are exactly aligned.




*Beam-beam deflections at the SLC.*

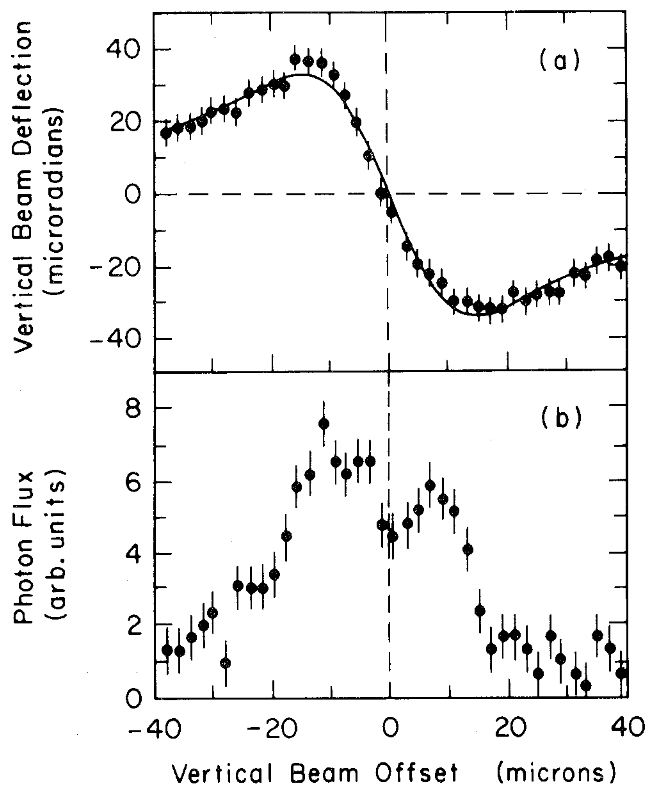
This technique is now employed routinely to align the two beams to an accuracy of 1 micron — or less than a ten-thousandth of an inch. Using computer-controlled scans, operators can accomplish this process and resteer the beams in less than a minute. Slow drifts of the beams, typically a few microns per hour, are easily corrected.




*Beamstrahlung due to beam-beam deflections.*

In early September, clear signals were observed for another phenomenon unique to linear colliders called "beamstrahlung." These brief bursts of gamma rays — high-energy photons — are emitted in the forward direction by compact electron and positron bunches when they clash or as they zoom past one another at close quarters. A small fraction of these photons is stopped in a thin metal plate about 35 meters further downstream, producing electron-positron pairs that are detected by a sensitive Cerenkov counter.

As one beam is scanned across the other, a characteristic peak emerges in the beamstrahlung signal (see graph below), with a dip at its center corresponding to exact alignment. The photon flux reaches its maximum when the beams deflect each other the most.




*Vertical deflection (a) of the SLC positron beam as it is scanned vertically across the electron beam at the interaction point. The beamstrahlung signal (b) witnessed during the same scan.*

This beamstrahlung signal, which will become much stronger as the beam size gets smaller, offers an excellent way to monitor the characteristics of the beams at the interaction point (IP) where they clash. SLC physicists plan to employ a combination of beam-beam deflections and beamstrahlung signals to optimize the beam sizes and alignment — and hence to maximize the number of $e^+e^-$ collisions — without interrupting the data-taking process.

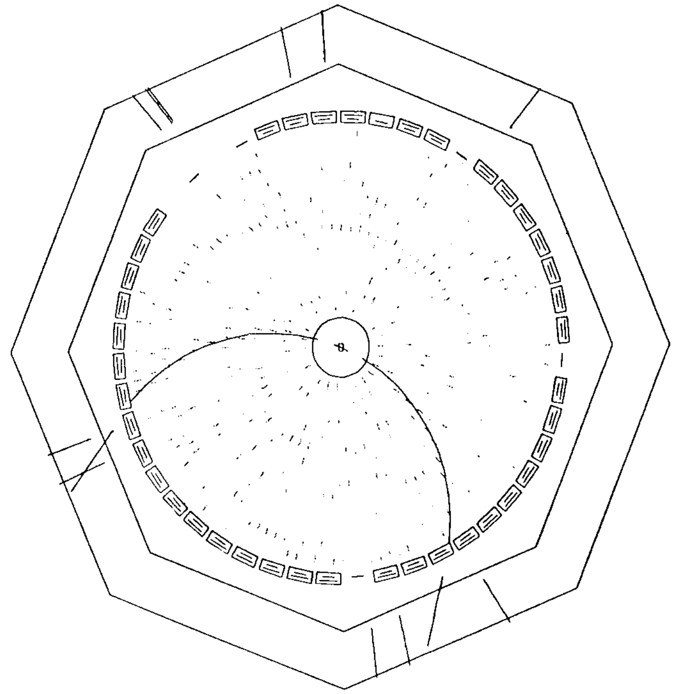
## BNS Damping

A major problem affecting SLC operations has been the growth of transverse "tails" on the electron and positron bunches as they are accelerated down the two mile linac. Ideally these particles come in cigar-shaped bunches a millimeter long and a few tenths of a millimeter wide. But because of the so-called "transverse wake-field effect," particles in the head of a bunch can impact those at its rear. If the bunch travels down the linac slightly off-axis, wispy tails can form on its trailing edge. These tails have been striking collimators in the final focus area, making life difficult for experimenters by generating large backgrounds of muons in the Mark II detector (see March 1988 *Beam Line*, p. 2).

The solution to this pressing problem seems to be a powerful new technique called "BNS damping," proposed in 1983 by V. E. Balakin, A. V. Novokhatsky and V. P. Smirnov of Novosibirsk. This technique was successfully implemented on the SLC during August — the first time it has ever been used in actual practice. By selectively rephasing the klystrons along the linac, the growth of tails can be markedly suppressed. Because of this rephasing, the rear portions of a bunch travel down the linac at a slightly lower energy than its head, and transverse wake-field effects on the trailing particles are cancelled by the effectively stronger focussing power of the quadrupole magnets. So instead of continually growing as a bunch hurtles down the linac, the troublesome tails are kept to a minimum.

The successful implementation of BNS damping has allowed marked improvements in SLC operations. Previously the tolerances on bunch injection from the damping rings into the linac needed to be very tight — else their off-axis oscillations would induce large tails. Maintaining such tight tolerances has been difficult because the "kicker" magnets that perform this injection have stability problems. With BNS damping in effect, however, the growth of tails can be controlled to a level where the present kicker magnets are satisfactory. BNS damping has also improved overall machine stability and has become a standard operating procedure.

There were other promising developments during the August tests. A technique was perfected that successfully reduces residual beam dispersion at the interaction point. It allows SLC operators to produce consistently smaller beam cross-sections that are routinely 3–5 microns in radius. And much-improved feedback loops were implemented that limit slow drifts in the beam positions at the IP to a few microns per hour. Well within tolerances, such drifts can be easily corrected by operator intervention.



*Computer reconstruction of a two-photon event witnessed by the Mark II detector at the SLC.*

On September 12 the SLC was shut down for modifications while preparations for high-energy physics research began at the PEP and SPEAR storage rings. In the last run before this shutdown, the Mark II detector recorded its first high-energy $e^+e^-$ collision — a "two-photon event" — on the SLC (see above). Surprisingly, the probability of such an event is thought to be about a *fifth* that of making a $Z^0$!

## PEP and SPEAR Begin Physics Runs

By mid-October electrons and positrons were routinely circulating in PEP and SPEAR. High-energy physics research on these storage rings resumed for the first time in more than two years. On PEP the goal was to achieve higher luminosity (a measure of the number of possible $e^+e^-$ collisions per second) than had ever been attained, while running at a combined energy of 27 GeV. This would produce the large quantities of B mesons and $\tau$ leptons needed to study their rare decay modes in detail. The initial running at SPEAR focussed on the $\psi'$ particle at 3.7 GeV.

A major goal of the fall runs was to implement a new set of operating techniques intended to allow rapid switching between the SLC and the storage rings. In normal operation, PEP and SPEAR need a new "fill" of electrons and positrons from the linac only every four hours or so. With the high beam intensities available in the SLC era, the actual filling process should take less than ten minutes.

### Record Luminosity Achieved at PEP

*Another aim of the fall cycle was to achieve higher luminosity on PEP than previously possible. By thus increasing the rate of $e^+e^-$ collisions, physicists working on this ring planned to accumulate the large quantities of $\tau$ leptons, B mesons, and two-photon events needed for their research.*

*This luminosity upgrade was achieved by squeezing the $e^+$ and $e^-$ beams to smaller diameters than had ever before been attempted on this ring. Such a feat was possible in the present running configuration because only one interaction region — IR2 with the TPC detector — is now being used for colliding-beam physics. There the quadrupole magnets used to focus the beams were moved much closer to the interaction point inside the TPC. To allow this change, some of the forward detectors on both sides of the TPC had to be removed. There were still 6 bunches (3 $e^+$ and 3 $e^-$) circulating in PEP, as before, but they were focussed to collide only in IR2.*

*In early December the PEP luminosity upgrade began to pay off. The peak luminosity reached $6 \times 10^{31}$ $cm^{-2}s^{-1}$, the first time this level had ever been achieved on PEP. Exceptionally smooth running during the weekend of December 14–15 allowed the integrated luminosity to reach 1.1 inverse picobarns on a single shift — a new PEP record (the old record was 0.61 inverse picobarns, set in 1983). The total luminosity accumulated over a single 24–hour period reached 2.5 inverse picobarns on December 15. Only the Cornell storage ring CESR has done better.*

*Although SPEAR was operating fairly well, problems were encountered filling it due to energy jitter in the linac and the large difference between SLC and SPEAR energies. Still, the ring often produced 10,000 $\psi'$ particles per day and totalled nearly 250,000 for the entire running cycle, which ended just before Christmas. A full report of all the recent PEP and SPEAR activities will be presented in a forthcoming issue.*

The rest of the time could be used for colliding-beam running on the SLC — *if* the process of switching between the two modes of operation can be achieved quickly. This is a big "if."

The challenge in making a quick switch occurs because of the great disparity in energies required by the three colliders: about 2 GeV per beam for SPEAR, 13.5 GeV for PEP and 46 GeV for SLC. That's more than an order of magnitude difference between the lowest and highest. Very different configurations of klystrons and magnet strengths (what accelerator physicists call the "lattices") are used for the two modes of operation. What's more, the detailed process by which the linac accelerates electrons and positrons for PEP and SPEAR is now extremely complex — much more than it was before the SLC was built.

By late October, operators had succeeded in switching from the SLC to storage-ring filling and back the to SLC in just over two hours. The goal is to achieve this full switching cycle in just over 50 minutes, starting from colliding SLC beams with small sizes (less than 5 microns in radius) and returning to that condition. In the October tests, the operators did not begin the switch with the SLC in a colliding-beam mode, nor did they try to return to colliding beams. This is one more "degree of difficulty" that will eventually have to be mastered. Though encouraging progress has been made on developing these switching techniques, there is still a ways to go.

### SLC Improvement Program

During September and October, several improvements were made to the SLC. Copper sleeves were inserted into sections of the north damping ring vacuum pipe in order to help control a phenomenon called "bunch lengthening," which limits the total number of electrons that can be packed into a single bunch. Another important SLC upgrade was the installation of "muon spoilers" in the north final focus. These consist of about 200 tons of toroidal (doughnut-shaped) iron magnets whose purpose is to deflect background muons away from the Mark II detector. The muons and other extraneous debris have seriously limited its ability to take good data.

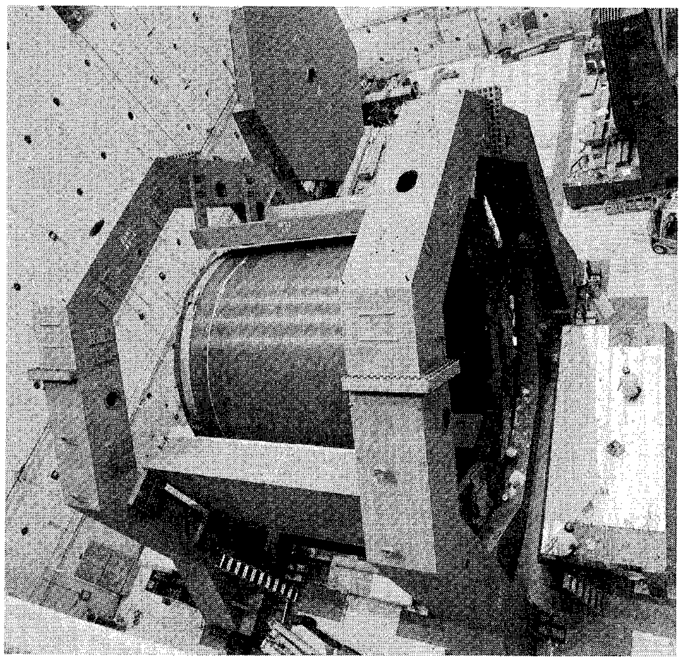
These improvements were tested in the first week of November during a dedicated SLC run. The damping ring upgrade worked moderately well. An encouraging new record of 33 billion electrons per bunch was delivered to the end of the linac, but bunch lengthening continues to be a problem (albeit not as severe). The muon spoilers worked extremely well, however, reducing the muon backgrounds by about a factor of ten. Other backgrounds can be reduced, too, and the Mark II can now take data with little extraneous debris clouding the picture.

Following further SLC tests just before Thanksgiving, the linac resumed filling PEP and SPEAR. Work began simultaneously on the installation of similar muon spoilers in the south (positron) final focus. In January, extensive modifications will begin at the front end of the SLC — particularly on the damping rings and early linac sectors. Current plans call for a February resumption of full-scale colliding-beam research.

— *Michael Riordan*

# SLD BEGINS FINAL ASSEMBLY

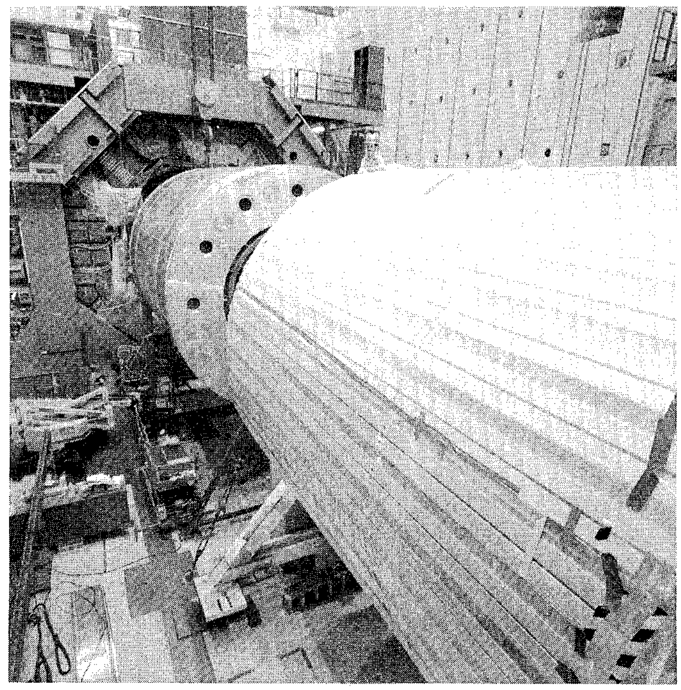
Almost two years ago, 2500 tons of prefabricated steel pieces quietly entered San Francisco Bay aboard the good ship *Ruth Lykes*, bound for SLAC. About six months later, a 100-ton aluminum coil 20 feet in diameter came trundling down Palo Alto's El Camino Real on a special truck, with its own police escort and utility servicemen leading the way to raise power lines. By early 1988 the coil and hundreds of steel parts had been assembled into two arches, a barrel and two endcaps — making an enormous detector shell that filled more than half the west pit of the Collider Experimental Hall.



*The detector shell of the SLD being assembled September 1987. The large cylinder between the two arches is the magnet coil; the two endcaps stand to the rear.*

Now the SLD, a new, state-of-the-art detector being built for the SLC, has begun the final assembly of its separate components inside this shell. The SLD collaboration, composed of over 200 scientists and engineers from SLAC and 30 universities and laboratories in the United States, Italy, Canada, England, and Japan, expects to complete the detector by the end of 1989.

On the cover of this *Beam Line* is a photo taken down the barrel of the SLD as workmen inserted the external shell for the liquid argon calorimeter (LAC) last November. This big aluminum cylinder will serve as the outer jacket of a huge vacuum "thermos bottle" that surrounds the LAC and helps keep its argon cold and liquid. The LAC itself is a 600-ton cylinder that will soon be inserted into the detector. This 3-foot thick sandwich of lead plates immersed in liquid argon converts electrons, photons and hadrons into particle showers whose total ionization is related to the energy of the original particle. Surrounding the LAC and its thermal jacket are the foot-thick coil that produces the solenoidal magnetic field, the 2000-ton steel exoskeleton of the barrel, and the two 500-ton steel endcaps.

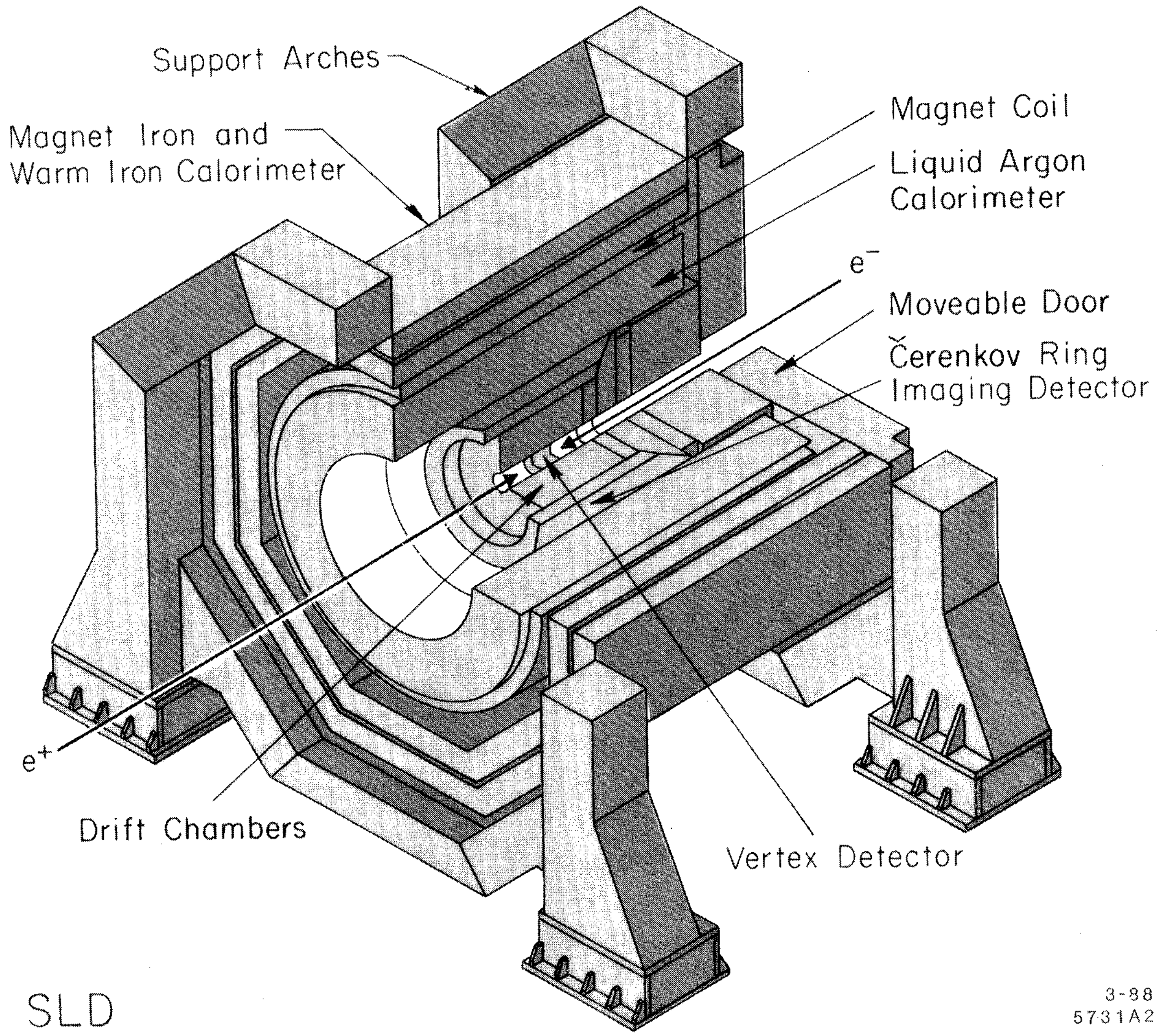


*The liquid argon calorimeter (foreground) and its outer jacket about to be inserted inside the magnet coil of the SLD (rear).*

Early this year, these endcaps were closed on the barrel to complete the iron yoke for the magnet. During ensuing tests, the 6-kilogauss field inside the cavernous coil was mapped over the central region and found to be more uniform than predicted. The aluminum coil, which takes 6600 amps and uses 5 megawatts of power, was built large enough to surround all the inner components of the detector. Its material will not interfere with their detection of the particles produced in $e^+e^-$ collisions.

Each section of the octagonal steel barrel is a weld-up of fourteen 2-inch-thick steel plates with 1-inch gaps between them. The gaps are filled with flat limited-streamer chambers that detect the penetrating muons produced in $e^+e^-$ collisions as well as measure the remnants of showers from the inner calorimeter. This system, called WIC for warm iron calorimeter, together with analogous components in the two endcaps has already been installed. It is now being checked out using cosmic rays.

Once the LAC is completely installed, the cylindrical shell of the Cerenkov Ring Imaging Detector



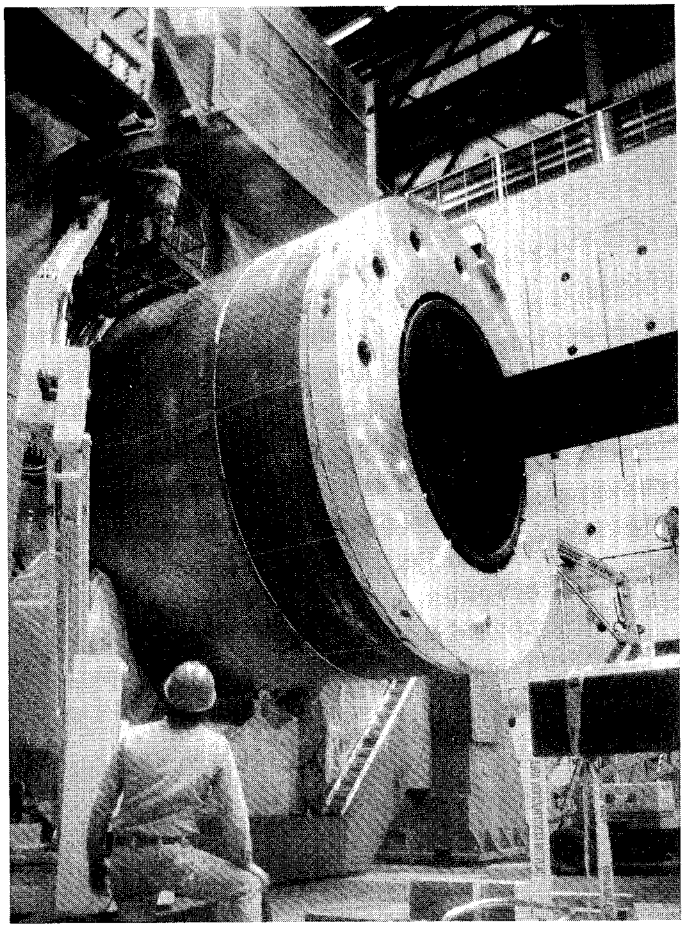

*Cut-away view of the SLD with one endcap removed.*

(CRID) slides in. The light emitted by charged particles traveling through the liquid and gas volumes of this two-foot thick segment is collected and converted to electrons in a series of wire planes. The circular pattern of the light emitted by a particle traversing the CRID will be reconstructed using the signals from these wires to identify the type of particle, such as a pion or kaon.

The next layer in is the 6-foot diameter central drift chamber (CDC), which contains about 50,000 thin wires strung through precision-drilled holes in aluminum endplates. This gas-filled chamber detects the passage of charged particles, which ionize the gas molecules. Ions drift to sense wires, leaving particle tracks that are reconstructed by computer. The pattern of these tracks is the standard 'picture' of a collision. About one-third strung as of December, the CDC will be installed this summer.

The innermost system is the vertex detector, two cylindrical sheets of silicon chips about the size of a tin can that record the position of passing charged particles to better than a thousandth of an inch. The combination of this ultra-high precision with the extremely small size of the SLC beams will allow the detection of particles that decay less than a trillionth of a second after they are produced.

The SLD endcaps are penetrated by the collider beampipe and final focusing quadrupoles. The beampipe contains special shielding to intercept background particles produced by the beams upstream of the interaction point. It is surrounded by small calorimeters that complete the coverage at very small angles and also monitor the machine luminosity — the rate of $e^+e^-$ collisions that are occurring. Since the large magnetic field of the detector prevents the use of conventional iron magnets,



*Workmen inserting the LAC thermal jacket.*

a superconducting final focus system is being built using quadrupoles manufactured by Fermilab.

The amount and the detail of information collected from all these detector elements is staggering. Nearly 100,000 channels of the CDC, LAC, and CRID are not only read, but their waveforms are analyzed as well. Another 100,000 channels sense hits in the WIC. Quite apart from the cost, conventional electronics and cabling simply would not fit into even as large a detector as the SLD. The solution has been to use large-scale integrated electronics in hybrid chips, digitizing the raw signals right at the detector elements, and to send the processed signals on fiber optics to the surface of the detector. This process happens so quickly that a computer can decide whether to read out the event in detail.

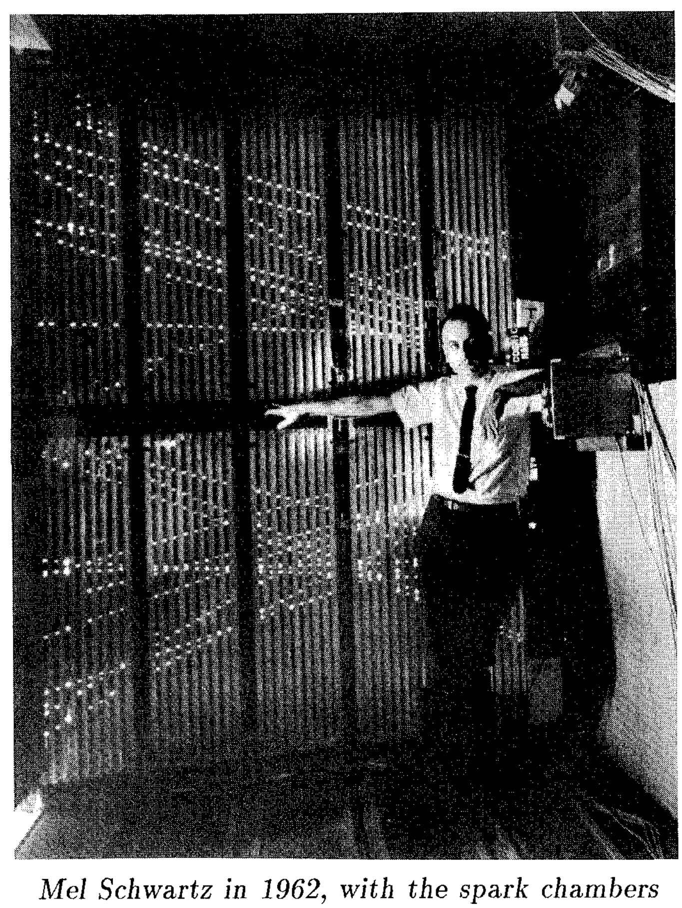
Except for the vertex detector, all the detector components have comparable systems that fit into the endcaps. Thus, the final detector surrounds the collision point and every event is completely analyzed. This combination of full coverage with complementary methods of particle measurement will allow the SLD to take full advantage of the Stanford Linear Collider.

— *The SLD Collaboration*

## *SLAC* ALUMNI IN THE NEWS

On October 19 the Royal Swedish Academy of Science announced that a trio of physicists would share the 1988 Nobel Prize in Physics for their 1962 discovery of the muon neutrino. Among the winners was Stanford/SLAC physicist **Melvin Schwartz**, who conceived the idea for this experiment while an assistant professor at Columbia University. The others are Leon Lederman, currently Director of Fermilab, and Jack Steinberger, spokesman of the ALEPH collaboration at CERN's new LEP collider. The three men, who made their discovery on Brookhaven's Alternating Gradient Synchrotron (AGS) while faculty members at Columbia, received the Prize last month in Stockholm.

Schwartz was the first to recognize that they could use the AGS proton beam to produce a beam of neutrinos. By stopping the protons in a metal target, the Brookhaven-Columbia team produced a plethora of pions, which subsequently decayed into muons and neutrinos. The muons were filtered out by 10 meters of armor plate that came from the decommissioned U.S. battleship *Missouri*, leaving only the billions of neutrinos that easily penetrated this iron shield.



*Mel Schwartz in 1962, with the spark chambers used to discover the muon neutrino. (Life photo)*

A few of these neutrinos were detected using a 10-ton spark chamber (shown in photo) made of inch-thick aluminum plates. A neutrino that interacted in the plates generated trails of sparks in the gaps between them, corresponding to charged particles leaving the collision. All forty-odd events collected in eight months of running had a penetrating muon track emerging from the point of collision, while none showed an electron track. This fact proved there were two different kinds of neutrinos, an electron neutrino and a muon neutrino.

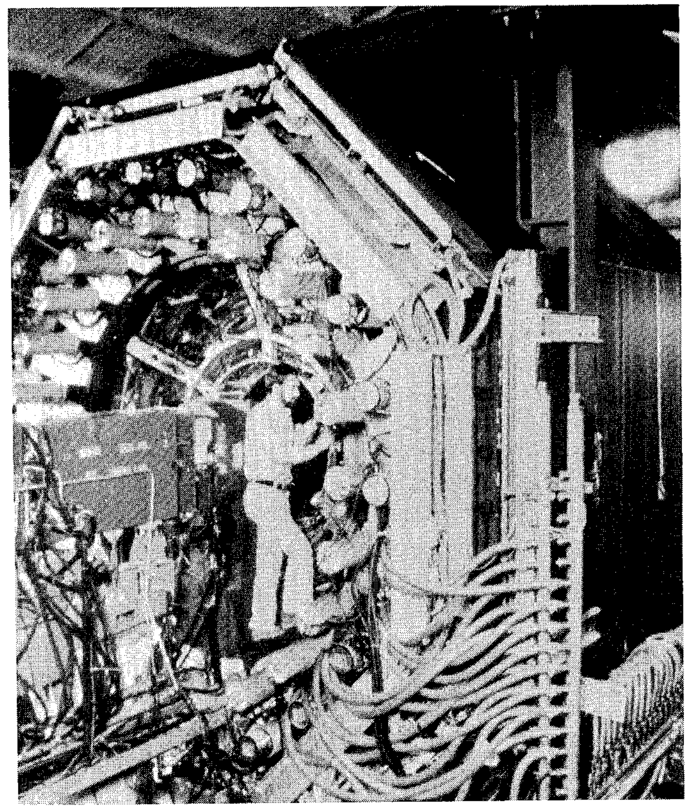
In 1966 Schwartz came to Stanford as professor of physics, starting SLAC Experimental Group G. Among other things, Group G performed a long series of kaon-decay experiments in End Station B and a famous 1970 beam-dump experiment behind End Station A (ESA). Dubbed the "Black Hole" experiment ("schwartz" is the German word for "black"), it consisted of digging a deep hole into the hill behind ESA and installing in it the same aluminum spark chambers used to discover the muon neutrino. Schwartz's team witnessed a few curious events that appeared to be neutrino-nucleon collisions, but they had neither muons or electrons among the debris. When the same kind of events began turning up in a CERN bubble chamber two years later, they were taken as clear evidence for unified gauge theories of weak and electromagnetic interactions.

Frustrated by the growing bureaucracy of high-energy physics, Mel left Stanford in the early 1980s to devote full time to Digital Pathways, of which he is chairman and chief executive. The thriving Mountain View company produces systems that protect computers against tampering. "I had grown uncomfortable with the way high-energy physics was going," the *New York Times* quotes the outspoken Schwartz as saying. "Teams were big and everything was highly bureaucratic. I wanted to go out and run my own show."

* * *

Another SLAC alumnus, **Roy Schwitters** was recently named Director-designate by the Universities Research Association (URA) in its official proposal to manage and operate the Superconducting Super Collider (SSC). URA is the organization of 58 U.S. and Canadian universities formed to operate Fermilab under contract with the Department of Energy (DOE). If the DOE approves the URA proposal and Congress authorizes the SSC, Schwitters would become its first Director.

Roy arrived at SLAC as an MIT graduate student working on an ESA photoproduction experiment in 1970. The very next year he took a job here as a post-doc in Experimental Group C, becoming a key member of the team that designed and built the famed Mark I detector at SPEAR. Roy was instrumental in



*Roy Schwitters and the Mark I detector.*

the research that led to the discovery of the $\psi$ particles in 1974. He rose to associate professor at SLAC before departing for Harvard in 1979.

Roy steps down from his post as spokesman of Fermilab's CDF collaboration to assume the SSC responsibilities. We expect to see him moving to Waxahatchie, Texas, soon and setting up offices in a trailer surrounded by cotton fields. Good luck, Roy!

* * *

Finally, we hear from the DOE that **Sam Berman** has won its 1988 Sadi Carnot Award, one of two awards it presents annually for "significant scientific and technological achievements in the area of energy conservation and renewable energy." He was given the award in honor of "his pioneering and creative contributions to the application of scientific methods in the area of heat and light transfers in window materials and the conversion of electricity to visible light." In a ceremony November 30 at the DOE, Secretary of Energy John Herrington presented Berman with a citation, a gold medal and a check for $10,000.

Sam served as a professor in the SLAC Theory Group from 1967 to 1977, when he left for more practical work at the Lawrence Berkeley Laboratory. At LBL he became leader of the Lighting Systems Research group, doing most of his award-winning work in that capacity.

— *Michael Riordan*

# SENATORS VISIT *SLAC*

On Wednesday, October 16, SLAC hosted a group of illustrious visitors from the United States Senate, including then Democratic Party candidate for Vice President, Lloyd Bentsen of Texas. Joining him were Barbara Mikulski (D-Maryland) and J. Bennett Johnston (D-Louisiana), the Chairman of the Senate Committee on Energy and Natural Resources.

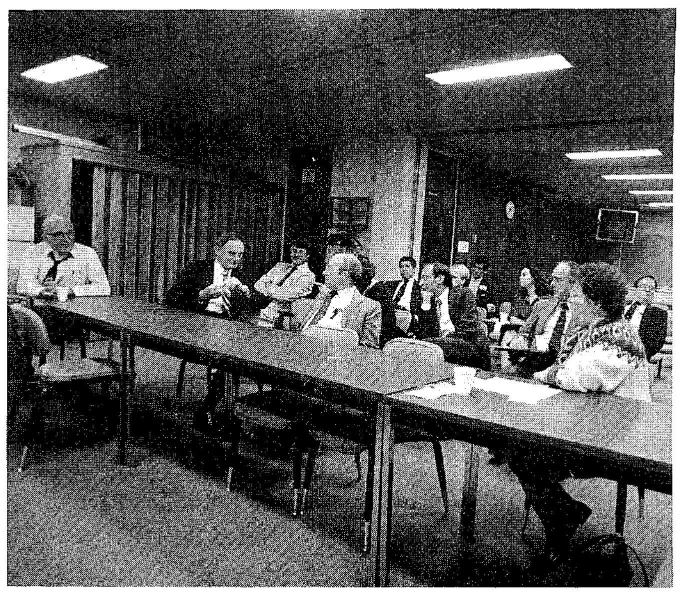
After the SLC Collider Experimental Hall had been thoroughly combed and swept the previous day by Secret Service agents and Bentsen's advance men, the Senators and other guests began arriving at about 9:00 a.m. Following them were busloads of journalists and cameramen, who swarmed into the pit for a photo session with Director Burt Richter, Deputy Director Sid Drell and former astronaut Sally Ride in front of the huge SLD magnet yoke. In reply to a question from Bentsen about foreign physicists using the SLAC facilities, which are funded by U.S. taxpayers, Burt noted that SLAC has cooperative agreements with these countries, like Italy and Japan, whereby they contribute money or equipment in return for access to our laboratory facilities.

*Burt Richter talking with Lloyd Bentsen in front of the SLD magnet yoke, as Barbara Mikulski (far left) listens. Others standing (l. to r.) are Kathleen Kennedy Townsend, Sally Ride, Sid Drell, and J. Bennett Johnston. Note wary Secret Service agent sneaking around behind them.*

After the Bentsen motorcade sped away to its next destination, Senators Mikulski and Johnston returned with Sid, Burt and Sally to the Orange Room. There they were joined by Pief for coffee, doughnuts and an hour-long discussion of topics ranging from particle physics to cosmology to the Strategic Defense Initiative and U.S. science education.

Johnston seemed particularly well-informed about high-energy physics and its ramifications for cosmology. "How do we know there is more than one universe?" he asked his learned hosts.

"We don't," Sid answered. "That's just a mathematical speculation of theorists who need to clean up things they don't like in their theories — things like infinities."



*Drell, Johnston, Panofsky and Mikulski discussing science and politics in the Orange Room. (Both photos on this page by Ed Souza)*

Mikulski was unimpressed with all the expensive machines used in high-energy physics. "Everyone is always mesmerized by the technology," she observed, "but where are we going to get the scientists for new facilities like the SSC?" Money for science education was clearly high on her list of priorities.

At about 11 o'clock, the Senators and their staff members left SLAC for a noon-hour speaking engagement down on the Stanford campus. It had been an excellent opportunity for the SLAC management to speak directly with them, listen to their concerns and interests, and talk about a few of its own.

— *Michael Riordan*

# AN ETHNOGRAPHY OF *SLAC*

Here's a curious success story. A former Public Information Officer from SLAC writes a Ph.D. thesis in anthropology about the "culture" of high-energy physics. Years later she accepts an academic position at Rice, and Harvard University Press publishes her thesis as a book!

*Beamtimes and Lifetimes*, by Sharon Traweek (published in November, 1988, 187 pages, $20.00 cloth) is a professional ethnographer's revelation of the rites and rituals practiced by physicists who seek to accumulate information about the subatomic world. *Us*, that is. The coin of this realm is beamtime, hence her title. The focus is upon SLAC, where Traweek did her major "fieldwork" during the 1970's. Our assumptions and practices are analyzed and contrasted with those in force at Japan's National Laboratory for High-Energy Physics, or KEK, which she finds to be a much less competitive culture.

But wait a minute. If we're being studied by an anthropologist, that makes us the *natives*, doesn't it? And although our dauntless Director may occasionally think of donning warpaint and feathers to chant midnight incantations over the SLC, I doubt if many of us consider our work to be "ritualistic" in nature. Our product is science, not myth. Not necessarily, claims Traweek, who proceeds to dissect the SLAC culture in support of her arguments.

Rather than attempt to evaluate her claims, I will just quote from the book, to let you sample its flavor. From the publisher's jacket copy:

> *Through their detectors scientists express their diverse styles of doing research. They must convince their colleagues that the information produced by these devices is a passive recording of nature's signals, but at the same time they feel their own detector is a product and representation of the group that built it — its signature, so to speak. With vivid descriptions of the great machines and how they work, the author shows how these beliefs coexist with the images of scientists as male and of nature as female, the detectors being the site of their coupling.*

Though I can't say too much about that last zinger, Traweek indeed develops some powerful metaphors for the SLAC facilities, among them the following:

> *The pervasive grey of the concrete at End Station A (or ESA) and the large, lumbering detector boxes, with their supporting equipment reaching toward the pivot pit, always look to me like great mechanical elephants with their trunks plumbing a watering hole.*

On individual group styles of doing physics and building detectors:

> *The group at SPEAR... sees itself as having designed its detector architecturally rather than analytically. This group regards its detector and its physics interests as changing rapidly. The detector is designed so that it can be quickly altered: 'We're too stupid to build it right from the beginning, but we can build it so that it can be fixed easily.... If the detector's architecture is good, new parts will fit in.'*

Contrasting this detector with the ESA spectrometers, Traweek quotes a SPEAR physicist:

> *'Our detector was built on much less money, and we are better off for it: we built it with much more thought and ingenuity. Their machine was built in fat times, and you can still see it in their cupboards. If you wanted three of something, the leader said to order a hundred; we will use them eventually.'*

Finally, on the subject of oral communication in physics, Traweek observes:

> *Acquiring the capacity to gossip and to gain access to gossip about physicists, data, detectors and ideas is the final and necessary stage in the training of a high-energy physicist. Losing access to that gossip as punishment for violating certain moral codes effectively prevents the physicist from practicing physics.*

I'm not sure what to make of all these observations, but of one thing I'm fairly certain. In the future, we'd better be more careful who we hire for the Public Information Office!

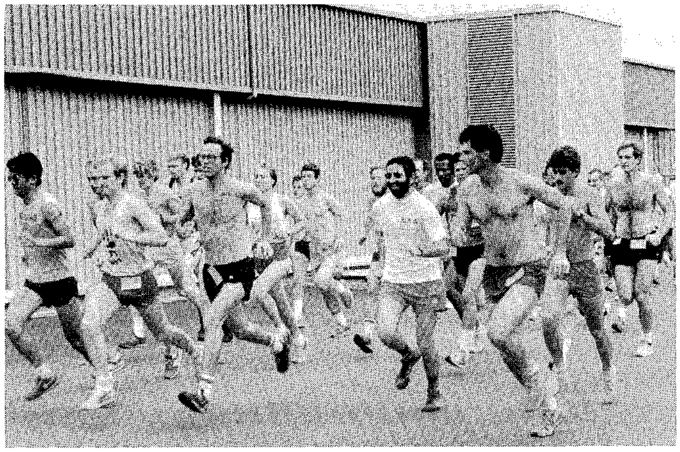
— *Michael Riordan*

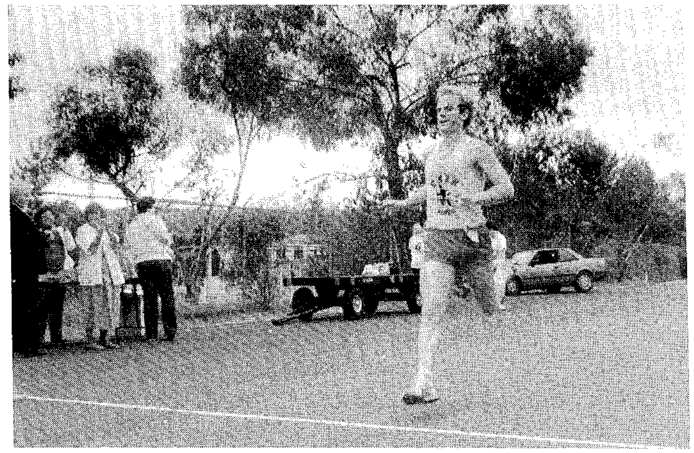
## Conferences and Workshops

*From November 28 through December 9, SLAC hosted the* **International Workshop on Next-Generation Linear Colliders**. *Over 100 scientists registered for the gathering, including 29 from overseas. A large Soviet delegation headed by Alexander Skrinsky and groups from CERN, KEK and Orsay made this workshop a truly international affair bringing together the world's experts on linear colliders. A complete report on this workshop will be presented in the next* **Beamline** *issue.*

*For nuclear physicists, there's the* **Topical Conference on Electronuclear Physics with Internal Targets**, *to be held here this January 9–12. Contact Ray Arnold (415-926-2755 or ARNOLD @ SLACVM) for further information.*

*And, of course, mark down August 6–13 for the* **International Symposium on Lepton and Photon Interactions**, *to be hosted by SLAC and held in Stanford's Kresge Auditorium.*





*Fero finishes well ahead of the pack.*

# FERO WINS 17th *SLAC* RACE

Just before noon on November 3, a colorful mob of runners, walkers, race officials and spectators gathered at sector 30 for the seventeenth running of the annual SLAC race. Wandering through the crowd there was even an SLC "centipede," consisting of three linked runners masquerading as bunches of positrons and electrons. The skies had been grey and threatening all morning, but the weather fortunately remained cool, calm and dry right up to the starting signal.

At the word "Go!" from Race Director Dave Bostic, 75 runners and 4 walkers surged across the starting line to begin the 3.8 mile run. Among them were 16 women. The pack soon spread out as it continued west along the south side of the klystron gallery.

On the return leg, the race turned into a duel between Mike Fero and Per Lindberg. But Fero pulled ahead steadily in the last mile, crossing the finish line in a blistering 19 minutes and 45 seconds — the first time since 1981 that anybody has broken the 20-minute barrier. Finishing second with an excellent time of 20:33, Lindberg took the medal for the men's under-30 age group.

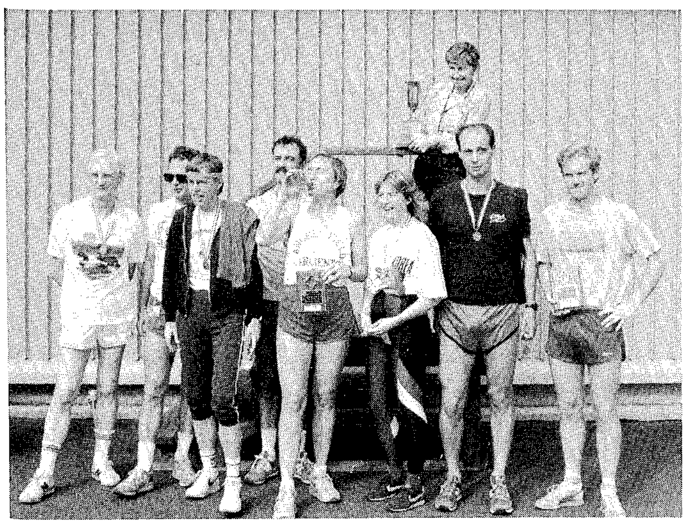
Eleventh overall, John De Larios won the men's over-40 title with a good effort of 24:06, edging out Steve Rock by a mere second. The first woman to cross the finish line was Dale Pitman at 25:07. Winning the women's title has become a habit for Dale — this is her fourth consecutive win.

The first walker, Alan Nuttall, finished in 47:52, and a minute later it was all over but the award ceremony. Adele Panofsky once again presented the prizes to the 8 winners in the various race categories.

Before, during and after the run, Race Committee members did a brisk business in T-shirt sales. They disposed of most of this year's models, whose design was contributed by Elsi Stucki, as well as many of the left-overs from previous years. The proceeds will go to the SLAC recreation fund.

We wish to thank the many people who assisted in the preparations, the events, the ceremonies and the clean-up. It was an enjoyable outing.

— *SLAC Race Committee*



*The winners (l. to r.): Alan Nuttall, Al Lisin, Evelin Sullivan, John De Larios, Dale Pitman, DeAnn Mata, Per Lindberg, Mike Fero. Adele Panofsky (above) awarded the prizes.*

**SLAC Race Winners**

| *Age Group* | *Men* | *Women* |
|---|---|---|
| *0–29* | *Per Lindberg* | *DeAnn Mata* |
| *30–39* | *Mike Fero** | *Dale Pitman** |
| *40–49* | *John De Larios* | *Evelin Sullivan* |
| *50+* | *Al Lisin* | |

**Overall Winners*