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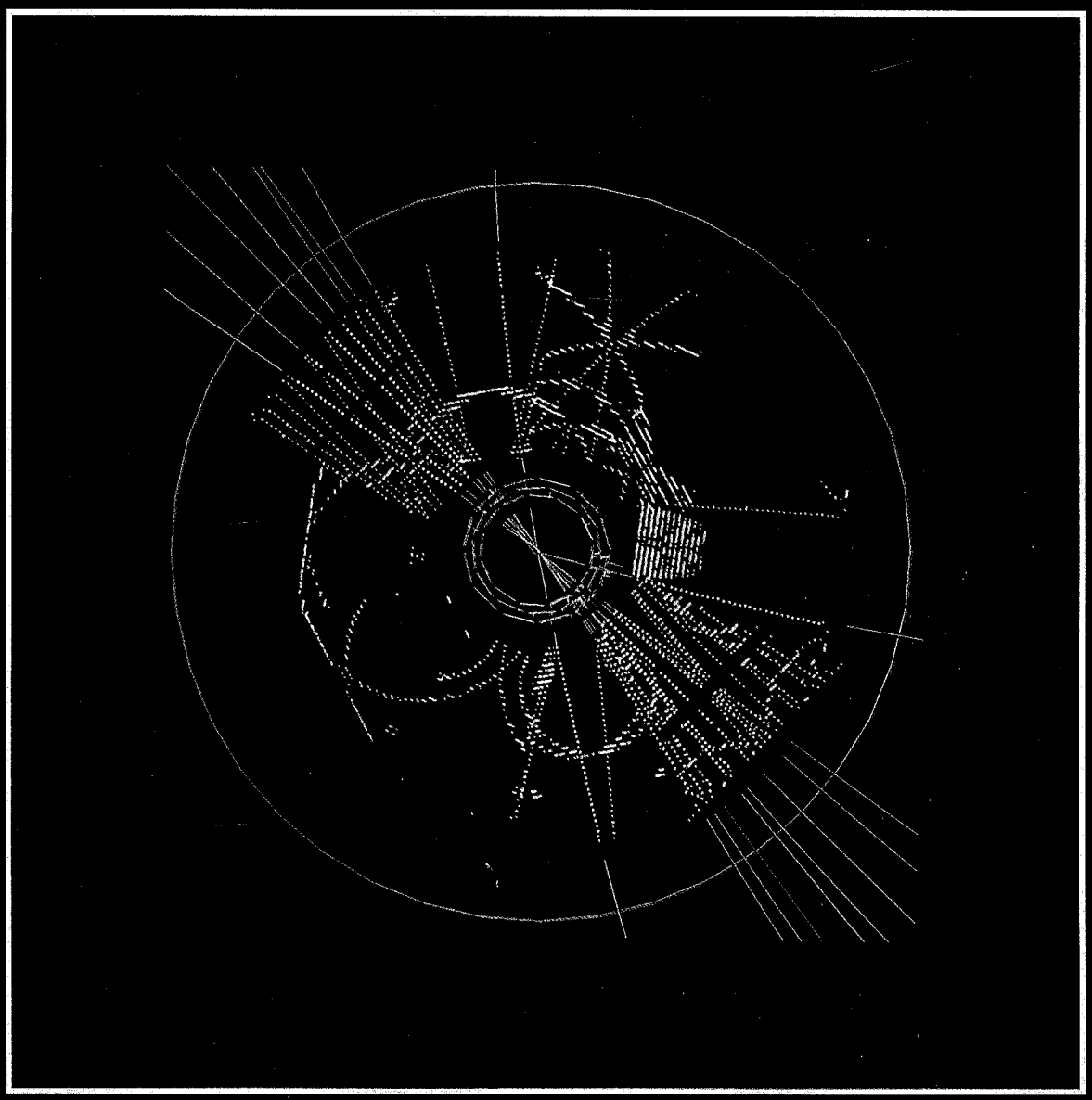

Beam Line

A PERIODICAL OF PARTICLE PHYSICS

SPRING 1990 VOLUME 20, NUMBER 1

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COVER: *A computer reconstruction of a Z decay, as observed with the Mark II Vertex Detector System (VDS) during the January 1990 run. In this event the Z particle disintegrated into what is believed to be a pair of B mesons plus other hadrons (shown as the red tracks). The decay products of the B's are the yellow and green tracks; the blue tracks represent low-energy background particles. For more information on the VDS, consult the article on page 8.*

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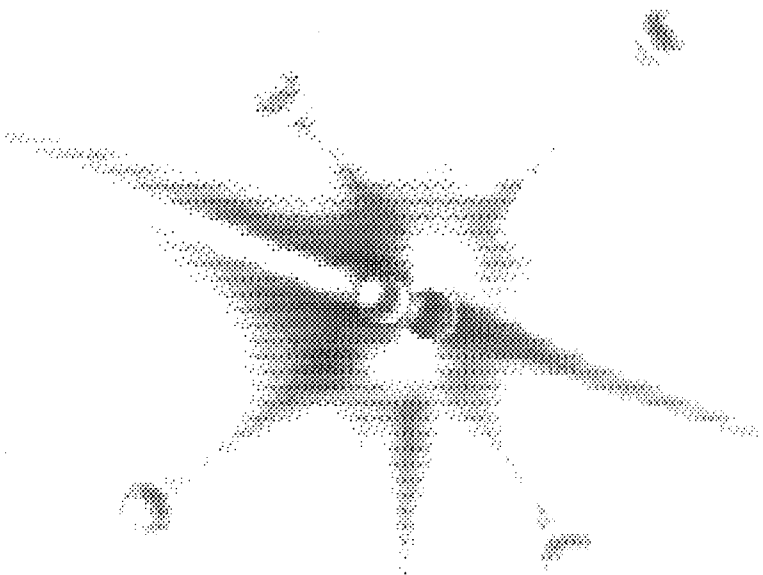


THE NEW PHYSICS
Where Is It?

by J. D. BJORKEN

The Standard Model will eventually break down, and any new particles discovered will be unlike those we know.

AT LAST THE FIRST returns from SLC and LEP are in. Nearly a decade of difficult, costly preparations have led to real results. The most important of these is the evidence for no more "ordinary" neutrinos beyond the three species now known. In addition, no new particles have been found and no new phenomena sighted. Everything seems

The Families of Matter Today

THE BUILDING BLOCKS of matter—the quarks and leptons— fall into a compact "periodic table":

Families	Neutral Leptons	Charged Leptons	Quarks
I	ν_e	e	u d
II	ν_μ	μ	c s
III	ν_τ	τ	(t) b

Only the top row is needed to make up all ordinary matter. The up (u) and down (d) quarks build up the protons (uud) and neutrons (ddu) of the atomic nucleus. The electrons (e) orbit about them to make atoms, molecules, and eventually us. The electron neutrino (ν_e), an electrically neutral lepton with feeble interactions, is an important by-product of the fusion reactions that power the sun. Although vast numbers of them spew out from the sun and flow through our bodies continuously, they pose no radiation hazard. Indeed the most sensitive detectors built to observe solar neutrinos have so far seen only a handful.

Proton accelerators have provided more useful neutrino beams and by now have revealed a wealth of information on not only the ν_e but also its close relative from the second row ("family") of particles, the muon neutrino (ν_μ). The ν_μ is a clone of the ν_e. They share the same feeble weak interaction involving exchanges of the W and Z particles. Neither has a detectable rest mass and they, like the photon, travel at the speed of light. Another clone of the ν_e, the tau neutrino (ν_τ), has not been directly observed yet, but there is a lot of indirect evidence for its existence.

The similarity of these three neutrinos with each other is nearly matched by the similarities of other members of our periodic table. The μ is a heavy version of the electron, and the tau (τ) (discovered at SLAC) a still heavier clone. The strange (s) and bottom (b) quarks are heavy versions of the down quark. The charm (c) quark is a heavy version of the up quark, and the as-yet-undiscovered top (t) quark is expected to be an even heavier version. However the fact that these family members have rest mass, with a most puzzling and non-understood pattern, provides a distinct difference from the neutrinos. To figure out that pattern is one of the the most urgent unresolved issues of Standard Model physics today.

to agree extremely well with expectations based on extrapolation from the observations at lower energies.

IT IS NOT CLEAR whether to rejoice or despair about this state of affairs. The increase in energy and sensitivity at SLC and LEP over electron-positron colliders is major: almost a factor of 3 in energy and (at LEP) a considerably more generous yield of events. The fact that the data agree extremely well with simulations made way in advance is impressive testimony to how well the strong and electroweak interactions are understood, from the arcane theoretical calculations of the basic reactions to the more phenomenological studies of how events really look and how detectors respond to them. The Standard Model really works.

On the other hand, it is the known deficiencies—the incompleteness of the Standard Model—that impel physicists and machine builders to undertake the extraordinary enterprises that the present generation of accelerators, storage rings, and detectors represent. There is bound to be growing impatience with the static state of affairs we seem to have encountered. To do good science, however, often demands plenty of patience.

It is not only the electron-positron colliders that have had a relatively quiet time. Since the discovery of the intermediate bosons W and Z in proton-antiproton collisions at CERN seven years ago, the search for new phenomena at such machines has advanced greatly in sensitivity. The W and Z production is now regarded as a nuisance background at the Tevatron collider in searches for the sixth, top quark and other new particles. It

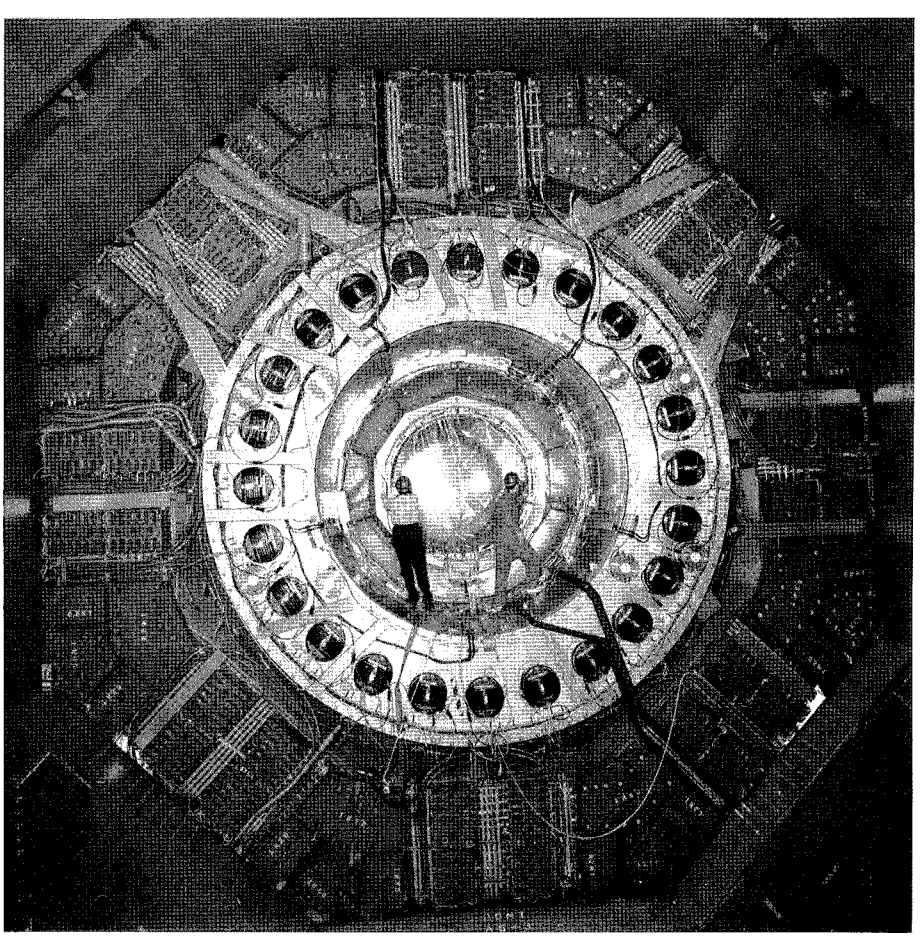
is Telegdi's maxim "Yesterday's sensation is today's calibration" all over again. There the scale of elementary quark-quark hard-collision energies reaches up to a TeV for the most common collision processes, and still the theory predicts quite well what is seen.

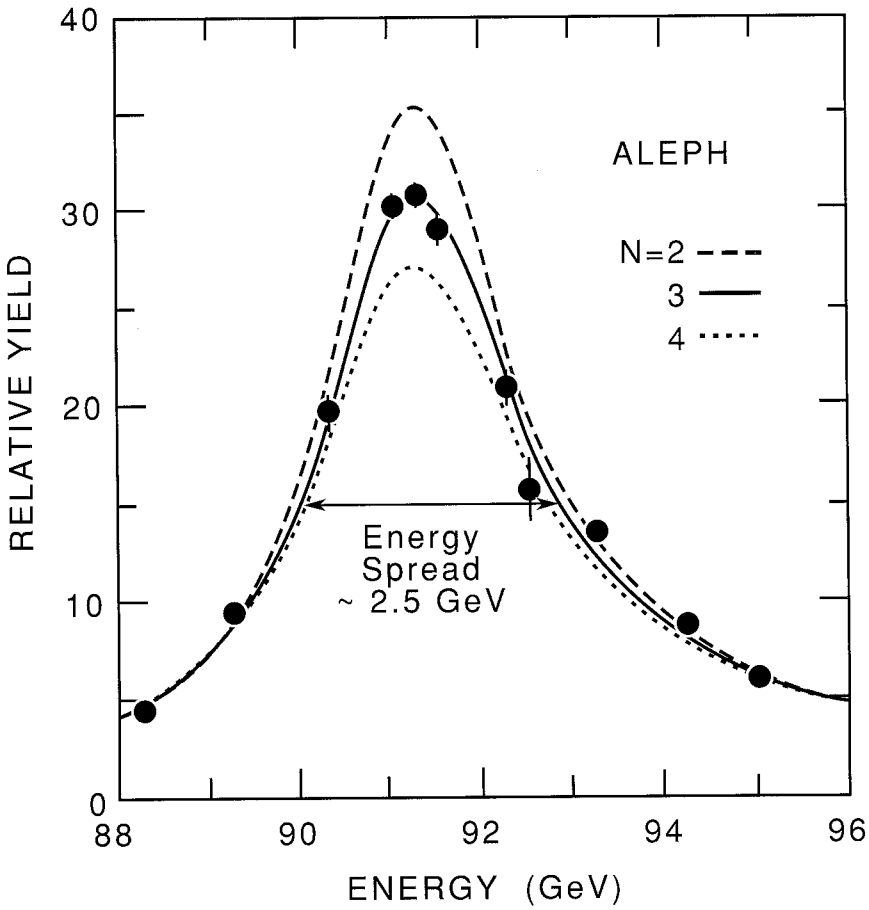
SO WHERE DO THINGS STAND? And what do these quiet, yet highly significant recent results suggest for the future? First of all there are no more "conventional" neutrinos. The absence of a fourth neutrino is very suggestive, but certainly no proof, that there will not be new clones of the electron or the quarks—or even more building blocks. We should remember that the bottom half of Mendeleev's Periodic Table of the elements doesn't look much like the top half, and that the richness of that bottom half is not readily inferred by staring at the top half. What the recent evidence indicates is that if there are more particles in our future, they are not going to be boring repetitions of what we already have in hand.

How was the limit on neutrino species obtained? Remarkably, it was reached without observing a single neutrino—by exploiting the properties of the Z particle as made at SLC and LEP. Once made, the Z particle doesn't last long; it soon disintegrates into a particle-antiparticle pair by the same kind of process that gave it birth. But it does not play favorites very much—it goes into up-antiup quarks or down-antidown quarks or $\nu_e \bar{\nu}_e$ at about the same rate as into an electron-positron pair. And it makes no family distinction; for example the decay rate into muon-antimuon pairs is identical to that into electron-positron pairs. From our new periodic table, it is easy to count up all the possible outcomes and get a rough estimate of 5 percent per type of particle. (To be more exact, it ranges from 3 to 13 percent.)

The decays of the Z into electrons, μ's, τ's, and the five kinds of quarks [the sixth, top, is too heavy] all leave distinctive signatures in particle detectors, while neutrinos interact too weakly to leave any kind of remnant. So the summed, "visible" decay rate, exclusive of the neutrino-antineutrino pairs, can be easily measured. What we then need is

A beam's-eye view of the SLAC Large Detector, or SLD, being readied for installation at the SLC interaction point later this year.





Left: Data measured in 1989 by the ALEPH collaboration at LEP that show how the yield of Z particles varies as the total energy is changed. The curve corresponding to three different kinds of neutrinos is the best fit to these data points.

some way of determining the *total* decay rate of the *Z*. Were that to be accomplished, then the total invisible decay rate could be determined by simple subtraction. The number of neutrinos then would follow by the assumption that the rate of decay per neutrino type is reliably known from theory. While one might worry a little about that point, it is not a problem. There is a lot of backup information from the many experiments that have used neutrino beams. In addition, the agreement between predictions and observations of the relative rates of *Z* decay into the visible species give confidence that this aspect of the problem is under control.

HOW DO WE DETERMINE the total rate of *Z* decay? This is accomplished by the wonders of quantum theory. In a very real sense the SLC and LEP tune in on the *Z*. The energies of the colliding beams are varied until one "hits resonance," an evocative phrase that carries with it the answer to our question. In the quantum theory energy and frequency are almost interchangeable concepts. To each energy is associated a frequency, their ratio being the basic parameter of the quantum world, Planck's constant *h*. The frequency to be associated with the *Z* will not be found on a radio dial; it is about 200 trillion gigahertz. But just as with any resonant system, be it a bell or an rf cavity, the *Z* resonance has a small frequency spread. The smaller the spread, the purer the resonance. The ratio of the resonant frequency to the frequency spread is a measure of the quality of the resonance. It is called the Q or quality factor. A high quality resonance, one with a big Q, will "ring" for a long time before dying away. The Q's of bells and pipes can be in the many thousands and Q's of rf cavities in the millions. In this respect the *Z* is a terrible resonator because its Q is only about 40. It dies very quickly, and how fast it dies is just what is needed to determine the number of neutrinos.

THE GRAPH ABOVE shows the distribution of *Z's* with energy (frequency), which clearly shows that its spread is about 3 percent. Accurate measurement of this shape provides a precise measure of the total decay rate and hence of the number of neutrinos. Because one extra neutrino represents only about a 6 percent increase in the spread, high precision is essential. And the experimental results are beautiful. Without going into the details, the latest bottom-line numbers from LEP,

N = 3.01±0.16 (ALEPH)
N = 2.97±0.26 (DELPHI)
N = 3.32±0.17 (L3)
N = 3.09±0.19 (OPAL),

greatly sharpen the early SLC value of N = 2.8±0.6.

Right: Aerial view of the Fermi National Accelerator Laboratory (Fermilab) in Batavia, Illinois. The ring, which is four miles in circumference, has been upgraded twice, and the newest machine, the Tevatron, now functions as a collider. With a total energy of 2 TeV, it is the world's most powerful collider. (Courtesy of Fermilab)

IN THE FUTURE the parameters of the resonance shape as well as many other precision measurements will provide redundant determinations of the most fundamental constant of the electroweak theory. This is its "fine structure constant," the analog of the famous number 1/137 that characterizes the intrinsic strength of electromagnetic processes in the quantum world. For the weak processes having to do with *W's* and *Z's*, the number is about 1/30 (It is often quoted as $\sin^2 \theta_W$, which is just 30/137.) This will be a major piece of business for both LEP and SLC over the next two or three years. Physicists at these machines will use different and complementary methods of determining this crucial number. Such precision measurements provide indirect indicators of what physics might (or might not) await us at energy scales not yet reached by present machines, as well as checking further that the electroweak theory really is correct.

As basic input the Standard Model has twenty seemingly arbitrary numbers, parameters like the fine structure constants 1/137 and 1/30, whose values remain to be understood. More than two thirds of them have to do with the baffling pattern of masses of the quarks and leptons. Nine are the masses themselves and four more have to do with "mixings" between the quarks. These four determine the relative rate of the decays of the *W* into the sundry species of quarks; the *W*, unlike the other gauge particles (photon, gluons, *Z*) makes no strict distinction between families when it decays. This phenomenon is believed to be linked to the mechanism that imparts rest mass to most of the known particles, as well as being behind the delicate but profound process underlying the violation of time reversal (or CP) invariance in decays involving the strange quark. The field has been stimulated a great deal recently by the prospects for observing more CP-violating decays involving particles made of the fifth, bottom quark. Bottom seems an especially useful member of the quark family, as the impressive results from Cornell and DESY attest. With this impetus, experimenters and machine builders throughout the world now are looking at ways of producing even greater numbers of bottom quarks, with an eye toward reaching enough sensitivity to search for CP violation.

But the absence of new phenomena in the present generation of experiments naturally focuses attention on still higher mass scales. The most specific focus is provided by the limits on the top quark mass from experiments at CERN and Fermilab. The top quark is probably heavier than the intermediate bosons *W* and *Z*, at 80 to 90 GeV. It then becomes more likely that this quark plays a significant role in the physics behind the origin of mass, because top itself has mass in such abundance. Some theorists now play with the notion that the top-antitop system is as important to this dynamics as the electron-hole Cooper pairs are to the theory of superconductivity. The origin of elementary particle mass, according to the Standard-Model picture, is believed to be closely analogous to phenomena that occur in superconducting materials.

From consistency arguments, the top quark is expected to weigh no more than 200 GeV, so sooner or later it should be discovered. This may happen at Fermilab in the next few years. The SSC should be a copious source, and future high energy electron-positron linear colliders should be able to provide especially clean samples. How much the top quark properties will teach us is hard to anticipate. It could be a very conventional object. But the opposite extreme is not out of the question.

Left: The 17-mile Large Electron Positron (LEP) collider at CERN straddles the Swiss-French border near Geneva, Switzerland. (Courtesy of CERN)

AND SOMEWHERE OUT there lie the Higgs particles. As the top quark mass increases, so do expectations for the Higgs boson mass. Discovery of, say, a 30 GeV Higgs boson and a 200 GeV top quark would cause a fair amount of consternation to the theorists, because the theory becomes unstable unless additional ad hoc particles and phenomena are thrown in. With top and perhaps the Higgs getting heavier than the W and Z, it becomes more and more natural to look at the whole picture from above, from high energy to low. The third generation of quarks may become first in fundamental importance. The masses of the W and Z may be regarded as small compared to the important mass scale for the dynamics, in the same way as the pion masses of the strong-interaction world are now regarded. In the 1930s, when Yukawa speculated on the existence of the pions, their mass scale was an enormous 100 million electron volts, something that took over a decade to attain. Now that energy is low even for nuclear physicists.

This is demanding news for the machine builders, not to mention taxpayers. But surely the high-energy scale of the SSC and a future generation of linear colliders are essential tools for breaking out from Standard Model phenomena now enveloping us. Because there could be surprises coming from low-energy observations and other machines, they must remain a vital component of our research program. And the returns from LEP, SLC, Tevatron, and other machines are still coming in with much to look forward to.

THE STANDARD MODEL is a provisional theory. It will break down eventually. We must be patient and never give up. ○

SLC Returns to Life

by MICHAEL RIORDAN

After a quick recovery from the October earthquake, the Stanford Linear Collider resumes producing Z particles.

DURING JANUARY, the Stanford Linear Collider (SLC) began producing Z particles again after the major disruptions due to the Loma Prieta Earthquake. What's more, the pulse repetition rate climbed smoothly from 60 to 120 Hz, part of the ongoing collider improvement program. Although the SLAC luminosity did not quite reach its best prequake levels, the collider managed to produce enough Z particles to permit Mark II physicists to test their newly installed Vertex Detection System (VDS).

The process of realigning more than three miles worth of accelerator components was completed by late November (see December 1989 *Beam Line*, p. 3). After that task was done, alignment crews began working on the Mark II vertex detectors, whose installation had begun during the October shutdown, just before the quake struck. With this project finished by mid-December, an attempt was made to restart the SLC, but no collisions were obtained before Christmas.

Fortunately, Director Burton Richter had extended the Mark II run an extra month to help compensate for the time lost due to the temblor. After a ten-day holiday shutdown, the SLC beams began colliding a few days into the new decade. By the middle of January a steady trickle of Z's began to appear inside the Mark II, enabling physicists to begin checking out the VDS (see related story, p. 8). Preliminary results from the January tests indicate the VDS is operating as designed and that the backgrounds are manageable.

Another important step forward on the SLC was the achievement of e^+e^- collisions at 120 Hz. This is twice the best pulse repetition rate attained in 1989. The transition went very smoothly, with no significant problems in beam monitoring or control, and the SLC began producing Z particles again about a day later.

By the end of January the peak luminosity had almost returned to its best prequake level, despite problems with the positron beam. The two beams approached their highest prior intensities, but physicists were unable to focus the positrons as well as before. Spot sizes of 4 microns (rms radii) were obtained at the SLC interaction point, whereas 3 microns were fairly typical at the end of the 1989 run.

This problem has been addressed during the recent three-month shutdown, and a new high-power positron target has just begun operating. Another set of collimators has been installed in linac sector 29 to help trim off tails of the beams that are responsible for backgrounds in the Mark II detector. SLC operations resumed in early May, with many other new features and equipment in place, including two of the three superconducting magnets needed to produce polarized electron beams at the interaction point. ○

A Closer Look at the Z

by

JOHN JAROS

and

ALAN LITKE

Two state-of-the-art vertex detectors have been added to the Mark II, enabling physicists to study short-lived decay products of the Z particle.

PHYSICISTS FROM THE MARK II collaboration successfully tested a new system in January that had been installed in their big detector the previous fall. This vertex detector system, or VDS, yields the sharpest pictures yet obtained of the Z particle and its progeny. It helps physicists to study the fine details of particle production and decay that occur within a few millimeters of the point where the Z was created by the annihilation of an electron and a positron.

With the VDS fully operational, Mark II physicists are able to take better advantage of one of the SLC's unique features, the extremely small sizes of the beams at the point where they clash, the interaction point or "IP." The SLC design allows experimenters to employ narrow pipes surrounding the beams and therefore place detectors much nearer to the IP than is possible at LEP. By getting closer to the action like this, we can better discern what happens when a Z breaks up into a pair of quarks or leptons.

A principal motivation for doing so at the SLC is to identify and study the extremely short-lived particles that can result from decays of the Z. Heavy particles such as the charmed and bottom hadrons or the tau lepton are generally very short lived, with lifetimes of about a picosecond (10^{-12}second). When they are produced in the decay of a Z, they travel only a couple of millimeters before disintegrating.

High-resolution detectors placed close to the IP can determine that a set of tracks emerge from a point, called the "secondary vertex," slightly offset from the

Physicists and technicians installing the Vertex Detector System into the core of the Mark II detector.

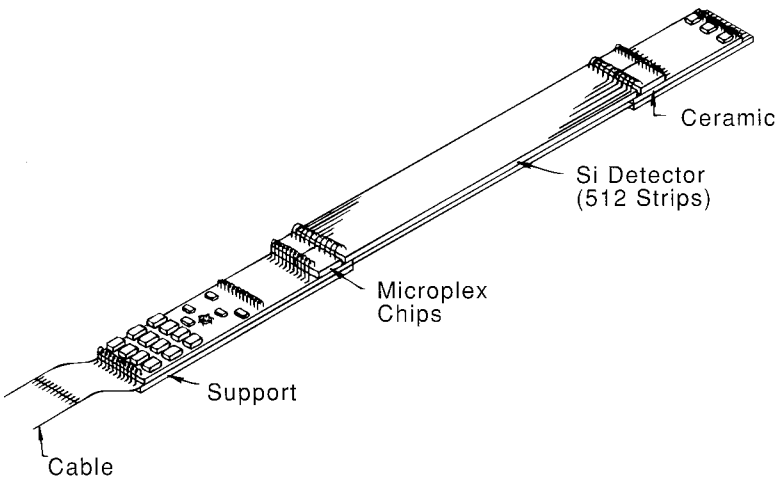
"primary vertex" where the Z itself disintegrated. As one unstable particle can decay into another—e.g., a bottom meson into a charmed meson—the decay chain may include tertiary (and even quaternary!) vertices too. By carefully reconstructing such decays with the help of vertex detectors, we can measure the lifetimes of the unstable particles and decipher what kinds were produced.

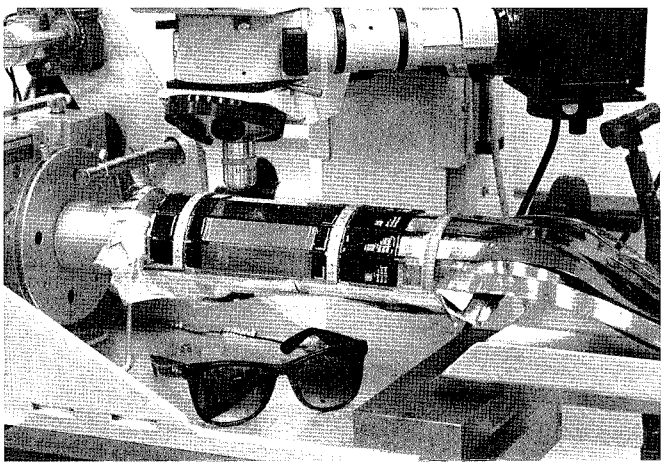
THE VDS IS DESIGNED to identify the secondary and other vertices that occur in a given event by precisely measuring the tracks of charged particles passing through it. Most tracks point back toward the IP, some more closely than others. Those that miss the primary vertex by a substantial distance (say a tenth of a millimeter, or a hundred microns) probably originated from a secondary vertex. If several such tracks are found, all emanating from the same general (offset) region, then the event has a secondary vertex. A heavy particle was produced and subsequently disintegrated!

To find such vertices, the VDS must be able to measure tracks with great precision and determine the distance by which they miss the primary vertex (called the "impact parameter") with high accuracy (better than 50 microns). A poorly measured track might appear to have a large impact parameter when it really came from the primary vertex.

To measure tracks with such precision, the VDS uses two independent elements: the Silicon Strip Vertex Detector (SSVD) and the Drift Chamber Vertex Detector (DCVD). The SSVD is mounted directly on the narrow beam pipe and extends to a radius of about 4 cm. Surrounding it is the DCVD, which has an outer radius of 17 cm. The SSVD measures the position of the particle track with high precision, while the DCVD determines its angle very accurately. With both measurements we can extrapolate the track back to the IP and obtain the impact parameter to the required precision.

The beam pipe is a crucial part of this enterprise. It is made as small and as thin as we dare in order to minimize the myriad tiny scatterings that a charged particle undergoes in passing through it. But it also must be large enough to house the "wire flipper" mechanism used in SLC beam diagnostics and to avoid intercepting the swath of synchrotron radiation that accompanies both beams. The 2.5 cm radius used represents a compromise between these two factors. This is three times smaller than the beam pipe radius used in the LEP storage ring at CERN; this advantage means a factor of 3 better resolution for the Mark II VDS.





Above Left: One of the modules in the Silicon Strip Vertex Detector. The active area for particle detection has 512 parallel strips of silicon.

SMALLER THAN A CAN of soda, the SSVD contains more than 18 thousand individual detecting elements, each with its own electronic amplifier. It was fabricated using some of the techniques that have been developed for the manufacture of integrated circuit chips, which have revolutionized the electronics and computer industries and led to the phenomenal growth of Silicon Valley. As the SSVD vividly demonstrates, this technology is giving us new ways of making detectors and electronics for high energy physics.

The SSVD is built in three cylindrical layers, each containing 12 detector modules with 512 independent channels apiece. The heart of each module is the microstrip detector, a 0.30 mm thick piece of crystalline silicon up to 1.8 cm wide and 9.4 cm long, which is fabricated from a silicon wafer of extremely high purity (only one impurity atom for every 50 billion atoms of silicon). Using photolithography, ion implantation and other techniques developed by the semiconductor industry, a precise pattern of 512 parallel detecting strips is laid down on the wafer. Each strip is up to 9 cm long, with a strip-to-strip separation of 33 microns (accurate to a fraction of a micron). The strip is covered with a layer of aluminum that allows us to make electrical contact with it.

This strip is actually a diode, a common electronic device that permits an electric current to flow through it in one direction but not the other. A voltage (typically 60 volts) is applied to each strip with such a polarity that no current will flow under normal conditions. When a charged particle passes through the silicon, however, it deposits energy and generates an electrical signal on the one or two nearby strips. By amplifying and recording this signal, we can determine where the particle traversed the silicon. Because the strips are so closely spaced and so accurately positioned by photolithography, we can determine this position with very good accuracy, about 5 microns.

Amplifying the signal, which is less than a millivolt, is no mean feat. Conventional electronic amplifiers will just not do; each would be a significant fraction of the size of our entire detector, and we need more than 18,000 of them! There is simply not enough space available, the heat generated would be unmanageable, the cabling would be a nightmare, and they would be far too costly.

To solve this formidable problem, we turned once again to semiconductor technology. Terry Walker then of Stanford's Integrated Circuits Lab and Sherwood Parker of the University of Hawaii designed a custom VLSI chip dubbed the "Microplex" to amplify the signals. Smaller than a fingernail, the Microplex chip contains 128 amplifiers, plus circuitry for calibration and read-out. The cost of the chip is about five dollars, or four cents per channel! Four chips are sufficient to amplify and read out the 512 signals from a single module.

Each amplifier still must be connected to its corresponding microstrip. Here again, Silicon Valley came to the rescue. A standard technique used in the industry is wire-bonding: a sewing-machine-like instrument stitched together the chip and microstrips with aluminum wire 25 microns in diameter, about the width of human hair. Each wire was ultrasonically bonded to the appropriate electrode on the chip or detector module.

The 5 micron precision of the detector module is useless, however, unless we can hold it in a stable position (relative to the other modules) over long periods of time. In addition, we must be able to determine the relative position of the module to better than 5 microns. The 18 modules in each of two half cylinders are supported between two aluminum endplates that have carefully machined slots in them for positioning the modules. During assembly

Left: Exact positions of the SSVD modules were measured using a precision microscope. These measurements are accurate to better than 5 microns.

the relative positions of the modules were measured with a precision microscope. In the final assembly stage, a beryllium shell was placed around the detector, preventing any further optical measurements. There is no guarantee, however, that this last step did not move the modules a bit. It doesn't take much to move something a few microns!

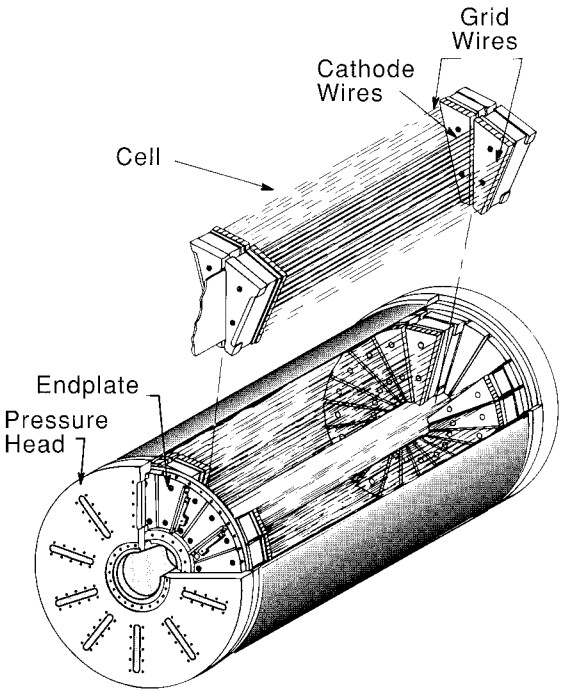
Here the versatility of silicon saved the day. Final alignment of the SSVD was accomplished by shooting a narrow beam of X rays through the detector, generating signals in the microstrips corresponding to where the beam intercepted each module. The X rays passed through the beryllium shell and each silicon layer with little absorption, allowing us to "see" each module in its final position.

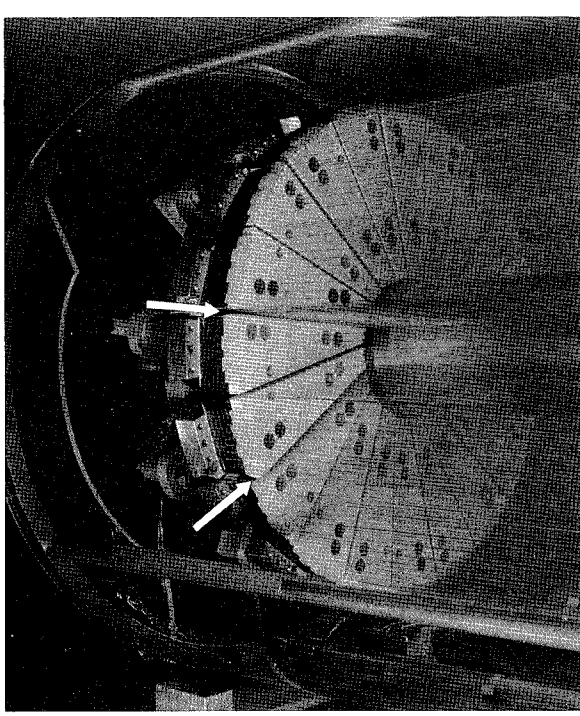
The SSVD was developed in a joint effort by groups of scientists from Johns Hopkins, SLAC, and the Universities of California (Santa Cruz) and Hawaii. It is a new kind of instrument that has required advances in silicon detectors, VLSI chips, precision mechanical assembly and precision alignment. It should point the way towards future particle detectors at new colliders, such as the SSC and the proposed Asymmetric *B* Factory.

THE DRIFT CHAMBER VERTEX detector (DCVD), a cylinder 14 inches in diameter and 2.5 feet long, uses a particle detection technique common to all drift chambers. As charged particles pass through the gas inside the chamber, a mixture of carbon dioxide and ethane at a pressure of two atmospheres (about 30 psi), they leave behind a trail of ionized gas molecules and electrons. Strong electric fields then pull these electrons onto 20-micron anode wires, where intense electric fields amplify the signal to a level that sensitive electronics can detect. Position information is extracted by determining the time interval between the electron-positron collision, which is known very precisely, and the arrival of a pulse on an anode wire. Using the velocity at which the electrons drift through the gas, we can work backward from this "drift time" and measure how near to the anode wire the particle passed.

A perspective drawing of the DCVD is shown at top right. Ten cells shaped like very thick slices of pie comprise the chamber. The electron-sensing anode wires are arranged along nearly radial planes, sandwiched between planes of grid wires that help in electron collection. Cathode wires, at potentials between 2 and 8 kV (from the innermost to outermost wires) demarcate the cells and generate the constant field throughout each cell. With 38 position measurments made along each track, the DCVD has considerable pattern recognition capability. Tracks from Z decays stand out unambiguously even in the presence of soft, looping tracks made by beam-related backgrounds (see cover photo).

The performance of the DCVD has already met its design goals; it may well be the world's most accurate drift chamber. Its position resolution depends in detail on the length of the drift path, but is typically 40 microns per wire. Its track-pair resolution, the ability to distinguish between two closely spaced particles in a hadron jet, is about 0.5 mm, which is adequate to resolve most of the individual particles in a jet.





Top: Drawing of the Drift Chamber Vertex Detector (DCVD), showing details of one cell.

Bottom: Close-up view of the DCVD. Planes of anode wires are indicated by arrows.

SUCH A HIGH PERFORMANCE level can be attained because the DCVD uses what is known as a "cool" gas as its detecting medium (one that slows down the drifting electrons and absorbs much of their energy). During the time the electrons are drifting toward the anode wires, they collide repeatedly with gas molecules, gradually spreading out in space. This process slows their arrival time, and the accuracy of the chamber consequently suffers. Such diffusion is minimized in a cool gas, such as CO_2, where highly inelastic collisions with the gas molecules rob energy from the electrons and keep the swarm of them well bunched. A factor 2 improvement in spatial resolution is thereby realized.

Drift velocities are also much lower in cool gases, making it easier to measure the drift time accurately. The drift velocity achieved in the DCVD is roughly a tenth of that in ordinary gases. This feature makes it easier to determine the arrival time to a given accuracy. What's more, it becomes possible to distinguish between two closely spaced pulses using standard waveform sampling techniques. With a system developed at SLAC, we can easily distinguish between two pulses separated by 100 ns, which corresponds to the 0.5 mm mentioned above.

These benefits of using cool gases do not come for free. The drift velocity in such gases, which must be known accurately to calibrate the chamber, is proportional to the electric field strength and inversely proportional to the gas density. Consequently, any electrical inhomogeneities in the drift cell, and any variations in gas composition, temperature and pressure, will adversely affect the calibration.

To make a device that could be reliably calibrated, novel techniques were developed to position wires with unprecedented accuracy and to insure cell-to-cell reproducibility. Voltages are applied with a corresponding level of accuracy, about 3 parts in 10,000, and the whole environment inside the DCVD is maintained very stably. The temperature throughout the chamber is kept constant to about 0.1°C and the pressure is held stable to 0.01 psi.

Initial calibrations of the DCVD using cosmic rays brought the device to within 30 percent of its ultimate performance limit. Charged particle tracks can be extrapolated back to the primary vertex with an accuracy of 30 microns. We expect this performance to improve substantially once we have a large sample of tracks from Z decays with which to perfect its calibration.

Scientists and technicians from the University of Colorado, Lawrence Berkeley Laboratory, and SLAC developed and built the DCVD. It is one of several cool-gas drift chambers currently being commissioned and the first to demonstrate the full accuracy of this promising new technique.

ON THE COVER OF THIS ISSUE of the *Beam Line* is a computer reconstruction of a Z event observed by the VDS during the January checkout run. In this event, the Z decayed into what is believed to be a pair of b quarks, $Z \rightarrow b\bar{b}$, which subsequently gave rise to a pair of B mesons plus other hadrons. These hadrons, which are shown as the red tracks, project back to the primary vertex, the point where the Z was created.

The tracks shown in yellow and green do *not* seem to point back to the primary vertex, but to secondary vertices offset from it. A likely interpretation of this event is that a pair of B mesons was created in the demise of a Z particle, each traveling a short ways from the IP before disintegrating in turn. What's more, one (and possibly both) of the B's decayed semileptonically, i.e., with the emission of a lepton—in this case a high-energy muon shown as the lone green track on the cover. All these tracks were readily distinguished from a fairly substantial background of low-energy particles, shown as the blue, looping tracks in the DCVD.

With the Vertex Detetor System checked out and found to be in good working order, the Mark II now has greatly enhanced ability to distinguish events involving heavy quarks and leptons. One of the primary goals of its forthcoming run, which begins this May, is to study these kinds of events in far greater detail than was ever possible before.

A *B* Factory at PEP

by

ANDREW HUTTON

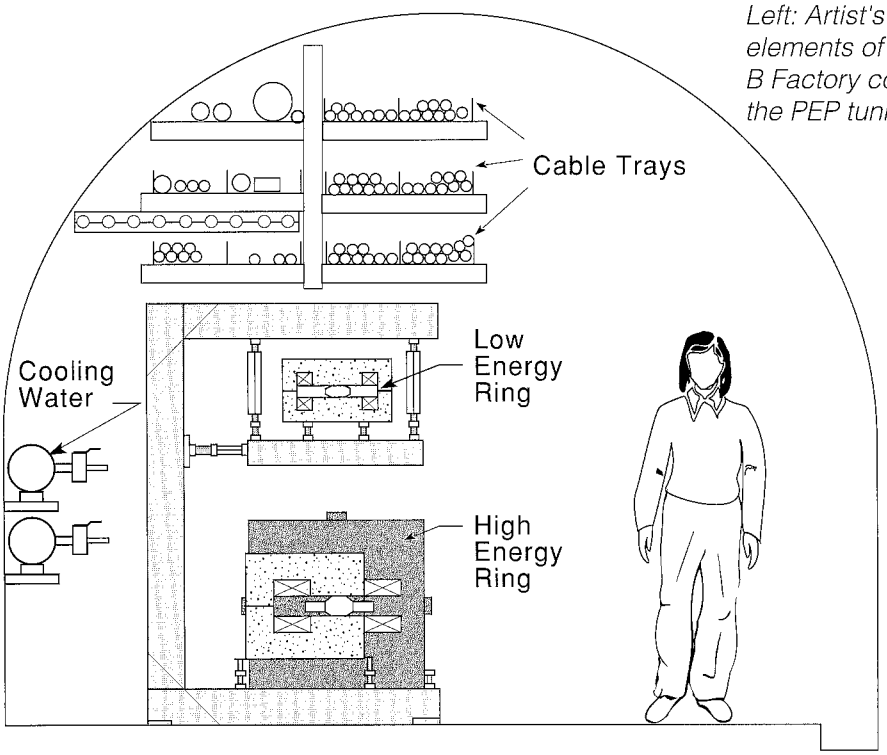
and

MICHAEL ZISMAN

There is growing confidence that a high-luminosity asymmetric collider can be built in the PEP tunnel.

IN RECENT MONTHS, work on the design of an Asymmetric *B* Factory has moved boldly forward. Once just a gleam in the eye of LBL's Pier Oddone, this idea is fast approaching the stage where concrete, realistic plans can be formulated.

Much of the excitement over such a factory stems from its possible use for studying CP violation in decays of *B* mesons. This task is greatly simplified at an electron-positron collider if the energies of the two beams are *unequal*, which is what is meant by an "asymmetric" collider. The best way to produce these *B* mesons is at the $\Upsilon(4S)$ resonance (see December 1989 *Beam Line*, p. 11), but because the cross sections for *B* decay to specific final states are tiny, a very high luminosity is required (10^{33} to 10^{34} $cm^{-2}s^{-1}$). Initially there



Left: Artist's conception of how elements of the High Luminosity B Factory could be positioned in the PEP tunnel.

was much skepticism about whether such a collider could ever be designed, but fairly substantial progress has been made recently in understanding this kind of machine. There is now a high degree of confidence that a suitable asymmetric collider can indeed be built with the required luminosity.

SLAC and LBL took an early lead on this new type of collider, studying a *B* Factory based on the PEP storage ring. In December 1989, the directors of SLAC and LBL established a new one-year study whose goal is to develop a conceptual design of a PEP-based machine with electron energies of 9.0 GeV and positrons at 3.1 GeV, operating at a luminosity of $3\times10^{33}cm^{-2}s^{-1}$. The design group includes nearly 60 scientists and engineers, with members from SLAC, LBL, Caltech, and LLNL.

Having a well-designed, flexible lattice with suitably long straight sections, the PEP storage ring is an ideal platform on which to base an asymmetric *B* factory. It also has a powerful injector—the SLAC linac—and a tunnel large enough to permit the addition of a second, low-energy ring without requiring extensive construction work. Most of the PEP hardware can be retained, as it will operate comfortably at the required 9 GeV level. The curved sections of the ring would remain essentially unchanged, except for lowering the present PEP magnets to install the low-energy ring above them. The estimated cost savings associated with employing the PEP tunnel and reusing PEP components is about $50 million.

Team members are also working on the design of an interaction region to bring unequal-energy beams into collision and then separate them, while keeping these beams as narrow as possible. The most significant issue yet to be resolved is that of obtaining the high luminosity required without generating unacceptable backgrounds in the surrounding detector. Various beam-crossing scenarios are being explored, including head-on collisions of round or flat beams, as well as collisions of flat beams at a non-zero crossing angle. These studies indicate that masking out synchrotron radiation is less a problem in the flat-beam scenarios; further work has begun to focus on this approach.

Other design challenges are associated with the operating requirements of very high beam currents (up to 3 amperes in each ring) and many circulating bunches (about 1000). Many of the PEP subsystems must be upgraded to handle such intensities, including the vacuum chamber, the rf system, and a powerful new feedback system, which all must be designed together to combat multi-bunch instabilities.

This past March over 60 scientists from all over the world gathered at LBL for a Workshop on Beam Dynamics Issues of High-Luminosity Asymmetric Collider Rings. Eight different projects were presented from the USA, Europe, Japan, and the USSR—indicative of the burgeoning worldwide interest in this new physics tool. In the summary to this Workshop, the organizers concluded that "there is no known reason to expect that such a facility cannot be built." A PEP-based asymmetric *B* Factory would enable CP violation to be studied in the second half of the 1990s using a facility optimally designed for this important research.

The Need for the NLC

by FRED GILMAN

HIGH-ENERGY PHYSICS is beset by the problem of too much success. The Standard Model of strong and electroweak interactions between quark and lepton constituents of matter is in excellent agreement with experiment up to the highest explored energies and at the highest precision presently available.

Along with the Standard Model come 18 or so parameters (masses, couplings, mixing angles) which are not fixed *a priori* by present theory. The known quarks and leptons seem to know about each other, as they can be neatly grouped into three generations or families. Why are there generations? Why are there three of them? How are the 18 parameters fixed or at least related to each other? Are the quarks and leptons composed of common constituents? Are they grouped together by some larger symmetry?

To these and many other questions we can only answer: *We don't know*. It is paradoxical that with all the success of the Standard Model comes its main problem: It can't be the whole story, but its very success means that we have precious little evidence on what larger theory encompasses it.

With this background, where do we go? What is the frontier?

WE NEED TO PIN DOWN THE PARAMETERS of the Standard Model. This is not necessarily just a process of making things neat and tidy, for we might find that once all the parameters are known precisely that some presently known phenomenon like CP violation would not agree with Standard Model expectations. The exquisite experiments in progress or planned on rare and/or CP violating K and B decays are prime examples of this work.

WE NEED TO CHECK THE STANDARD MODEL up to quantum corrections. With the mass of the Z known with high precision, the parameters associated with the electroweak gauge boson part of the Standard Model are fixed to a degree that one can now compare with the mass of the W or with coupling strengths, e.g., using the polarization asymmetry at the SLC, and check the quantum corrections that enter in graphical terms at one-loop order. Depending on how one views it, this is either a check on the consistency and correctness of the theory or a telescope to get a first glimpse of particles at still higher mass that affect the observable results through their presence as virtual states.

WE NEED TO FIND THE TOP QUARK. It already appears that its mass is at least as great as that of the Z. It could well be out of the range of LEP II. Then, of present or near-term accelerators, only the Tevatron collider has a chance of finding it. Here is the place where the next linear collider could play a key role. While top might be discovered at the Tevatron and produced in abundance (or even discovered?) at the SSC, detailed studies of the properties and decays of a very heavy top quark are likely the province of an electron-positron machine. The next linear collider will operate in a regime where Quantum Chromodynamics (QCD) is truly capable of perturbative application; incisive tests of this theory of strong interactions become possible in the top-antitop system produced (near threshold and in a well-defined state) in e^+e^- annihilation.

WE NEED TO SEARCH for extensions and additions to the Standard Model in a "modest" form—for example, new quarks and new leptons—but also in the dramatic form of whole new classes of particles such as occur in theories with supersymmetry. Such searches have turned up nothing up to now; the torch will be passed to the next generation of electron-positron and hadron-hadron colliders.

WE NEED TO CHECK on the gauge structure of the electroweak theory. This entails especially checking the correctness of the W^+W^-Z triple gauge boson vertex. This can be done especially cleanly at an e^+e^- collider, and will be a prime focus of LEP II. Further, more sensitive probes of the W^+W^-Z and $W^+W^-\gamma$ vertices await the still higher energies available at the next linear collider.

BARRING TOTAL SURPRISES, however, the prime task facing high energy physicists over the next decade or so is that of uncovering the nature of electroweak symmetry breaking, the mechanism by which mass is given to the W and Z, as well as quarks and leptons.

The gauge theory with massless bosons is beautiful and rather well behaved. At first glance, it appears that masses can be inserted in the crudest way by simply writing mass terms into the Lagrangian. However, with such a "hard" mass term the theory becomes sick—infinities arise and cross sections become divergent at high energy. A particularly salient example is provided by considering the scattering of two W bosons with longitudinal polarization, i.e., $W_L W_L \rightarrow W_L W_L$. This sounds like a theorist's gedanken experiment at best; it is not. In electron-positron or hadron-hadron collisions the leptons or quarks (in the hadrons) can emit (virtual) W's which then collide with each other. Such would be the case at a linear collider operating in the TeV range. Calculations of this process with just gauge bosons alone give answers that blow up as the energy of the W bosons becomes infinite.

The Standard Model solves this by a "soft" mechanism for giving masses to particles. In picturesque terms, the originally massless W and Z bosons of the weak interactions "eat" spinless bosons put in the theory to be available for just this purpose, and acquire mass. In addition to the three (2 charged and 1 neutral) spinless bosons which disappear into the stomachs of the $W^\pm$ and Z, a fourth, neutral, spinless boson is left behind as a physical particle and witness to the feast; this is the Higgs boson. With this particle present, cross sections no longer blow up, the worst infinities disappear, and the theory is better behaved.

There are many variants on the same basic theme of breaking electroweak symmetry—"soft" ways of introducing mass into the theory so as to keep it well behaved. There could be many Higgs particles, composite Higgs bosons, technicolor theories, or it could be that the nature of the symmetry breaking is to be found in W's and Z's undergoing strong interactions at high energies, with a rich dynamics at energies in the TeV region.

WHERE IS THE HIGGS? Or more generally, at what mass scale does the electroweak symmetry breaking mechanism become manifest physically? The Higgs boson could in principle be found at masses anywhere from the experimental lower limit of about 25 GeV to of order a TeV or so. We cannot presently pinpoint the scale of symmetry breaking better than this.

For a Higgs boson at the "low" end of possible masses, $e^+e^- \rightarrow ZH^0$ at LEP or the next linear collider is a powerful method to discover it. More generally, electroweak symmetry breaking can be studied in electron-positron collisions in the process already noted above: $e^+e^- \rightarrow \nu\bar{\nu}W^+W^-$ with the W^+ and W^- scattering off each other. The prime issue is the nature of the interaction of the longitudinal bosons. In the simplest case, if a resonance (Higgs or other) is present, it will form a bump in the WW cross section. For such a discovery a linear collider with a total energy that is a few times that of the potential resonance would be needed.

It may be necessary to study the scattering of longitudinal W bosons up to center-of-mass energies of a few TeV in order to be sure of being able to understand the nature of electroweak symmetry breaking. This drives the choice of energy and luminosity of the SSC. Clearly then, the pursuit of this key sector of the Standard Model requires pushing the frontier of accelerator physics and detector capabilities at both hadron-hadron colliders such as the SSC and at the next electron-positron linear collider. ○

HISTORY NOTES
DATES TO REMEMBER

DATES TO REMEMBER

Jun 3–29	TASI-90: Theoretical Advanced Study Institute in Elementary Particle Physics, Boulder, Colorado (fur further information contact Linda Frueh, University of Colorado, Physics Department, Campus Box 390, Boulder, CO 80309, or BITNET TASI90@COLOPHYS)
Jun 4–8	Workshop on Physics and Detector Issues for a High-Luminosity Asymmetric *B* Factory, SLAC [for further information contact Sharon Lankford, SLAC, (415) 926-2706 or BITNET SKL@SLACVM]
Jun 11	REXX Symposium for Developers and Users, SLAC [for further information contact Cathie Dager (415) 926-2904 or BITNET CATHIE@SLACVM]
Jun 25–Jul 13	DPF Summer Study on High Energy Physics: Research Directions for the Decade, Snowmass, Colorado [for further information contact Robin Craven, University of Wisconsin, Madison, Wisconsin, or BITNET WI SNOWMASS@WISHEP]
Jul 16–27	18th Annual SLAC Summer Institute on Particle Physics [for information and application forms contact Nina Adelman Stolar, SLAC, (415) 926-2877 or BITNET SSI@SLACVM]
Jul 27–28	Annual Meeting of SLAC Users' Organization, SLAC Auditorium [for further information contact Margaret Helton, SLAC, (415) 926-4505 or BITNET ROSES@SLACVM]
Aug 2–8	XXV International Conference on High Energy Physics [contact K. K. Phua, National University of Singapore, BITNET PHYPKK@NUSVN]
Oct 15–18	Symposium on Detector Research and Development for the SSC, Fort Worth, Texas (contact Phyllis Hale, Users Office, SSC Laboratory, MS-2080, 2550 Beckleymeade Avenue, Dallas, TX 75237, BITNET DETRD@SSCVX1)
May 6–9, 1991	Particle Accelerator Conference, Sheraton Palace Hotel, San Francisco [for further information contact Rene Donaldson, SLAC, (415) 926-2585 or BITNET RENED@SLACVM]

History Notes

MARCH 1937. Collaboration begins between the brothers Russell and Sigurd Varian and Stanford Prof. William W. Hansen that leads to the invention of the klystron microwave tube, a device for generating high power microwaves. The University provides space and $100 to finance the Varians' work and within a year proceeds from a licensing agreement begin providing substantial income that contributes to building up Stanford's science and engineering programs.

—*Stanford: A Centennial Chronology*, 1985

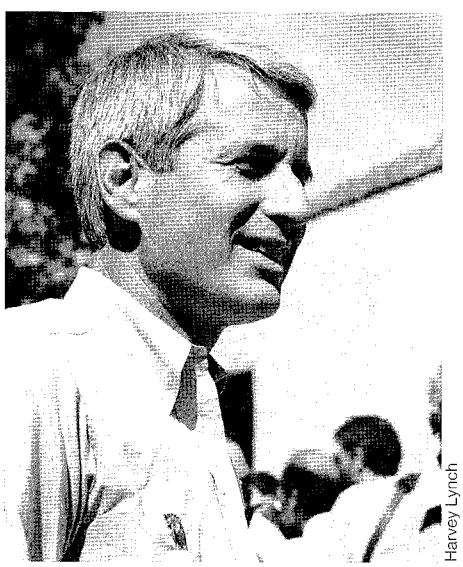
DOWN THE LOWER SIDE OF a cigar-shaped radio beam, an airplane flown by Capt. Milton M. Murphy and Jack Haynes, Civil Aeronautics inspector, glided repeatedly to safe landings on East Boston airport in Massachusetts recently. These flights demonstrated for the first time an application of the klystron. . .

—*Scientific American*, January 1940

LATER, THE KLYSTRON TUBE becomes a cornerstone for microwave research and an important device for the construction of a variety of high-energy particle accelerators useful in medicine and nuclear physics, including the two-mile accelerator at the Stanford Linear Accelerator Center.

—*Stanford: A Centennial Chronology*, 1985

PEOPLE AND EVENTS


Harvey Lynch

Gilman to Head SSC Research Division

ANOTHER OFFICE ON THE THIRD FLOOR OF THE CENTRAL LAB is soon to be vacant. Fred Gilman, who has busily paced the SLAC corridors for more than twenty years (and usually at an extremely rapid clip), is hurrying on to the SSC Laboratory in Texas, where he has recently been appointed Associate Director, Physics Research Division. There he will oversee perhaps the most ambitious research program ever conceived, the attempt to find the elusive Higgs particle and other extremely massive particles thought to exist at the tremendous energies the SSC will generate.

Fred came to SLAC in 1967 from Caltech, working as a postdoc in the Theory Group until he was named Assistant Professor two years later. As the kind of theorist best described as a phenomenologist, one who evaluates the experimental consequences of particle theories, he played a major role in shaping and guiding the SLAC program during its exciting early years, when the deep inelastic electron scattering experiments provided the first solid evidence for quarks. Made full Professor in 1973, he continued in this role as colliding-beam experiments became the dominant research method here.

For many of his years at SLAC, Fred served as one of the Directors of the popular SLAC Summer Institute. In 1989, he was Chairman of the Division of Particles and Fields in the American Physical Society and served as Program Chairman for the 1989 Lepton-Photon Symposium. His organizational talents and broad understanding of particle physics should come in handy at the SSC, where approximately a billion dollars will be spent under his watchful eye just to design and build its enormous detectors.

Since January, Fred has been commuting between Palo Alto and Dallas, but he and his family will make a permanent move this summer. SLAC will miss Fred's ready good humor and eager interest in virtually everything that has to do with particle physics.

University of Chicago to Honor Perl

CONGRATULATIONS ARE IN ORDER FOR MARTIN PERL, leader of Experimental Group E, who this June will receive an honorary degree of Doctor of Science from the University of Chicago. Past recipients of this award have included such noteworthy figures as Clifford Geertz and Mary Leakey in Anthropology, and Stephen Hawking and Leon Lederman in Physics. In April Martin traveled to the University of Michigan, where as Distinguished Senior Visiting Professor he delivered three lectures on the status of particle physics, including a public lecture titled "The Discoveries of the Electron, Muon and Tau: Motives and Methods."

Burke to Lead Experimental Group I

BEGINNING IN MARCH, A NEW EXPERIMENTAL GROUP I has been established with David Burke at the helm. This group will play a leading role in the construction and instrumentation of the Final Focus Test Beam, which will soon replace the C-line in the Research Yard; members of Group I will also do high-energy physics as part of the SLD collaboration. Dave arrived at SLAC in 1978 as a Research Associate in Experimental Group E, after completing his Ph.D. at the University of Michigan. Named Associate Professor in 1988, he has distinguished himself in the commissioning of the SLC and as a key member of the Mark II Collaboration.

Klystron Department Gets New Head

JOINING SLAC THIS PAST FEBRUARY AS THE NEW HEAD of the Klystron and Microwave Department in the Technical Division is George Caryotakis. He has spent most of his professional career at Varian, where he served as the President of the Electron Device Group and Managing Director of European Operations. Having received his M.S.E.E. and Ph.D. at Stanford, George is pleased to be back on campus.

B Factory Workshop

IN PARALLEL WITH THE GROWING ACTIVITY devoted to the conceptual design of a high-luminosity *B* factory at PEP (see story on p. 13), there has been an ongoing series of meetings to assess the related physics questions and detector design issues. Called the Workshop on Physics and Detector Issues for a High-Luminosity *B* Factory at SLAC (whatta mouthful!), it has met three times so far, at SLAC and Columbia University. Nine working groups have formed that meet regularly to hash out the various questions.

This Workshop will culminate in a week-long session at SLAC that begins on June 4. Group leaders will report on their progress, and there will be general talks on measurements of CP violation in the *B*-meson system. Interested parties should contact Jonathan Dorfan (SLAC) or David Hitlin (Caltech) for further information. Invitations and registration material can be obtained from Sharon Lankford (SKL@SLACVM).

— Michael Riordan

SLAC PUBLICATIONS

Experimental High-Energy Physics

This list of SLAC publications issued during the period from November 1, 1989, through March 31, 1990, was prepared by the staff of the SLAC Library. It is organized according to five categories: Experimental High Energy Physics, Theoretical Physics, Accelerator Physics, Instrumentation and Techniques, and Other Topics.

To obtain copies of these publications, write to the Publications Department, SLAC Bin 68, P. O. Box 4349, Stanford, CA 94309. Please be sure to specify author and publication number in your request.

MARK II Collaboration: G.S. Abrams, et al., ***First Measurements of Hadronic Decays of the Z Boson***, (SLAC-PUB-5045, Jul 1989; Published in Phys. Rev. Lett. **63**:1558, 1989).

MARK II Collaboration: G.S. Abrams, et al., ***Searches for New Quarks and Leptons Produced in Z Boson Decay***, (SLAC-PUB-5106, Oct 1989; Published in Phys. Rev. Lett. **63**:2447, 1989).

MARK II Collaboration: G.S. Abrams, et al., ***Measurement of Z Decays Into Lepton Pairs***, (SLAC-PUB-5124, Dec 1989; Published in Phys. Rev. Lett. **63**:2780, 1989).

MARK II Collaboration: G.S. Abrams, et al., ***Measurements of Charged Particle Inclusive Distributions in Hadronic Decays of the Z Boson***, (SLAC-PUB-5092, Dec 1989; Submitted to Phys. Rev. Lett.).

MARK III Collaboration: J. Adler, et al., ***Resonant Substructure in $K^-\pi^+\pi^+\pi^-$ Decays of D^0 Mesons***, (SLAC-PUB-5130, Dec 1989; Submitted to Phys. Rev. Lett.).

D. Aston, et al., ***Strangeonia and Kin: New Results from Kaon Hadroproduction with LASS***, (SLAC-PUB-5150, Dec 1989; Invited talk given at Hadron '89: 3rd Int. Conf. on Hadron Spectroscopy, Ajaccio, France, Sep 23–27, 1989).

D. Aston, et al., ***Update on K^* Studies at SLAC***, (SLAC-PUB-5151, Dec 1989; Invited talk given at Hadron '89: 3rd Int. Conf. on Hadron Spectroscopy, Ajaccio, France, Sep 23–27, 1989).

D. Aston, et al., ***$s\bar{s}$ Spectroscopy from the LASS Spectrometer***, (SLAC-PUB-5145, Dec 1989; Invited talk given at 9th European Symp. on Antiproton-Proton Interactions, Mainz, Germany, Sep 5–10, 1988. Submitted to Nucl. Phys. B, Supp.).

MARK III Collaboration: Z. Bai, et al., ***Observation of a Pseudoscalar State in $J/\psi \rightarrow \gamma\phi\phi$ Near $\phi\phi$ Threshold***, (SLAC-PUB-5159, Feb 1990; Submitted to Phys. Rev. Lett.).

MARK III Collaboration: Z. Bai, et al., ***Measurement of the Absolute Inclusive Leptonic Decay Branching Fraction of the D_s^+ Meson***, (SLAC-PUB-5191, Mar 1990; Submitted to Phys. Rev. Lett.).

MARK II Collaboration: T. Barklow, et al., ***Searches for Supersymmetric Particles Produced in Z Boson Decay***, (SLAC-PUB-5196, Mar 1990; Submitted to Phys. Rev. Lett.).

P. Bosted, et al., ***Measurements of the Deuteron and Proton Magnetic Form-Factors at Large Momentum Transfers***, (SLAC-PUB-5131, Dec 1989; Submitted to Phys. Rev. C).

MARK II Collaboration: P. Burchat, et al., ***A Search for Decays of the Z to Unstable Neutral Leptons with Mass Between 2.5 GeV and 22 GeV***, (SLAC-PUB-5172, Feb 1990; Submitted to Phys. Rev. Lett.).

C. Edwards, et al., ***Hadron Production in e^+e^- Annihilation from $\sqrt{s}$ = 5.0 to 7.4-GeV***, (SLAC-PUB-5160, Jan 1990; Submitted to Phys. Rev. D).

G.J. Feldman, ***Production and Decay of Z Bosons at the SLC***, (SLAC-PUB-5152, Dec 1989; Invited talk given at 1989 Cargese Summer Inst. in Particle Physics, Cargese, France, Jul 18–Aug 4, 1989).

G.J. Feldman, ***Measurement of the Z Boson Resonance Parameters***, (SLAC-PUB-5143, Nov 1989; Invited talk given at 14th Int. Symp. on Lepton and Photon Interactions, Stanford, CA, Aug 7–12, 1989).

D. Hitlin, Ed., ***The Physics Program of a High Luminosity Asymmetric B Factory at SLAC***, (SLAC-0353, Oct 1989).

W.R. Innes, ***A Search for New Particles in Z Decay***, (SLAC-PUB-5115, Oct 1989; Presented at Int. Europhysics Conf. on High Energy Physics, Madrid, Spain, Sep 6–9, 1989).

MARK II Collaboration: C. Jung, et al., ***Search for Long-Lived Massive Neutrinos in Z Decays***, (SLAC-PUB-5136, Nov 1989; Submitted to Phys. Rev. Lett.).

MARK II Collaboration: S. Komamiya, et al., ***Determination of α_s from a Differential Jet Multiplicity Distribution at SLC and PEP***, (SLAC-PUB-5137, Nov 1989; Submitted to Phys. Rev. Lett.).

S. Komamiya, ***Study of Hadronic Final States of Z Boson Decays***, (SLAC-

PUB-5154, Oct 1989; Presented at Int. Europhysics Conf. on High Energy Physics, Madrid, Spain, Sep 6–13, 1989).

MARK II Collaboration: S. Komamiya, et al., ***Search for Nonminimal Higgs Bosons from Z Boson Decay***, (SLAC-PUB-5175, Feb 1990; Submitted to Phys. Rev. Lett.).

MARK II Collaboration: J.F. Kral, et al., ***Measurement of the $b\bar{b}$ Fraction in Hadronic Z Decays***, (SLAC-PUB-5147, Dec 1989; Submitted to Phys. Rev. Lett.).

MARK III Collaboration: W.S. Lockman, ***Production of the $f_0(975)$ Meson in J/ψ Decays***, (SLAC-PUB-5139, Nov 1989; Presented at 3rd Int. Conf. on Hadron Spectroscopy, Ajaccio, France, Sep 23–27, 1989).

Crystal Ball Collaboration: H. Marsiske, et al., ***A Measurement of $\pi^0\pi^0$ Production in Two Photon Collisions***, (SLAC-PUB-5163, Jan 1990; Submitted to Phys. Rev. D).

Crystal Ball Collaboration: W. Maschmann, et al., ***Inclusive J/ψ Production in Decays of B Mesons***, (SLAC-PUB-5133, Nov 1989).

MARK III Collaboration: R. Mir, ***Recent ψ' Results from MARK-III***, (SLAC-PUB-5114, Oct 1989; Presented at Int. Europhysics Conf. on High Energy Physics, Madrid, Spain, Sep 6–13, 1989).

J. Nash, ***A Measurement of the Z Boson Resonance Parameters at the SLC***, (SLAC-PUB-5141, Nov 1989; Presented at Int. Europhysics Conf. on High Energy Physics, Madrid, Spain, Sep 6–13, 1989).

J. Nash, ***A Measurement of the Resonance Parameters of the Neutral Intermediate Vector Boson***, (SLAC-0356, Jan 1990; Ph.D. Thesis).

W.K.H. Panofsky, ***A Perspective on Lepton-Photon Physics***, (SLAC-PUB-5055, Sep 1989; Invited talk given at 14th Int. Symp. on Lepton and Photon Interactions, Stanford, CA, Aug 7–12, 1989).

M. L. Perl, ***Properties of Leptons***, (SLAC-PUB-5132, Dec 1989; Presented at Int. Symp. on Lepton and Photon Interactions at High Energies, Stanford, CA, Aug 7–12, 1989).

M. Petradza, et al., ***Study of Four Lepton Final States in e^+e^- Interactions at $\sqrt{s}$ = 29 GeV***, (SLAC-PUB-4981, Mar 1990; Submitted to Phys. Rev. D).

MARK II Collaboration: F. Porter, ***Measurement of B^0-$\bar{B}^0$ Mixing Using the MARK-II at PEP***, (SLAC-PUB-5148, Dec 1989; Presented at Int. Europhysics Conf. on High Energy Physics, Madrid, Spain, Sep 6–13, 1989).

R.H. Schindler, ***Status of the Tau Charm Facility and Highlights of Its Physics Program***, (SLAC-PUB-5202, Feb 1990; Presented at 1990 Lake Louise Winter Inst.: The Standard Model and Beyond, Lake Louise, Canada, Feb 18–24, 1990).

SLD Collaboraton: ***SLD Physics Studies: Proceedings of the SLD Physics Week, Kirkwood, CA, July 31–August 4, 1989***, (SLAC-0354, Oct 1989; Proc. of SLD Physics Week, Kirkwood, CA, Jul 31–Aug 4, 1989).

M.L. Swartz, ***A Search for Doubly Charged Higgs Scalars in Z Decay***, (SLAC-PUB-5176, Feb 1990; Submitted to Phys. Rev. Lett.)

W. Toki, ***Note on D_s Decays***, (SLAC-PUB-5208, Feb 1990; Submitted to Rev. Particle Properties)

S.R. Wagner, et al., ***Measurement of the B^0 Meson Lifetime***, (SLAC-PUB-5107, Nov 1989; Submitted to Phys. Rev. Lett.).

A. Weir, et al., ***A Reanalysis of B^0-$\bar{B}^0$ Mixing in e^+e^- Annihilation at 29-GeV***, (SLAC-PUB-5146, Dec 1989; Submitted to Phys. Lett.).

D.Y. Wu, et al., ***Radiative Tau Production and Decay***, (SLAC-PUB-5128, Nov 1989; Submitted to Phys. Rev. Lett.).

Theoretical Physics

A. Aurilia and E. Spallucci, ***A New Look at the Riemann-Cartan Theory***, (SLAC-PUB-5140, Nov 1989; Submitted to Phys. Rev. Lett.).

J.D. Bjorken, ***Two Topics in Quantum Chromodynamics***, (SLAC-PUB-5103, Nov 1989; Invited lectures given at 1989 Cargese Summer Inst. in Particle Physics, Cargese, France, Jul 18–Aug 4, 1989).

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THE SLAC BOOKSHELF

MONTE CARLO TRANSPORT OF ELECTRONS AND PHOTONS
Edited by Theodore M. Jenkins, Walter R. Nelson, and Allesandro Rindi
Plenum Press, 638 pp., $115.00

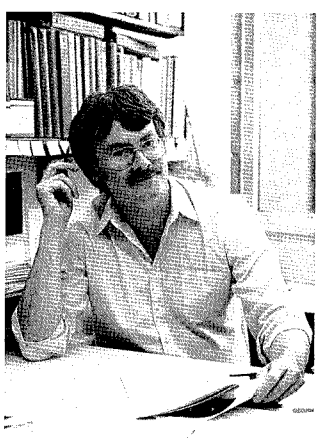
There is hardly a physicist at SLAC who has not, at one time or another, used or encountered the Monte Carlo program known as EGS, which has proved to be invaluable in the simulation of electron-photon showers. What they probably did not realize, however, is that the very same program finds extensive use in radiation dosimetry and medical physics—to simulate radiation doses absorbed by living tissues. The original EGS code, which was developed during the 1970s by W. Ralph Nelson of SLAC together with R. L. Ford at Stanford's High-Energy Physics Lab, has gone through several versions and is now used throughout the world.

In 1987, Monte Carlo simulation of electron and photon showers was the subject of a ten-day gathering at the Ettore Majorana Center for Scientific Culture located in Erice, a restored medieval town at the western tip of Sicily. A group of 75 scientists from 21 countries met to assess the current state of their craft and to compare notes on the various programs currently in use—ITS, ETRAN, and EGS4. The proceedings of that meeting are now available in this pricey volume, edited by Nelson and Ted Jenkins of the SLAC Health Physics group together with Alessandro Rindi of Sincrotrone Trieste.

Just about anything one could want to know about these simulations is contained in the pages of this book—including the fundamental assumptions, formulas and cross sections used in the programs, their comparisons with experimental benchmarks, and practical applications in medicine and high-energy physics. The editors are to be commended for gathering all this valuable information into a single volume that should be sitting on the shelves of serious physics libraries around the globe.

— Michael Riordan

FROM THE EDITOR'S DESK



THE PRESENT ISSUE REPRESENTS A GREAT LEAP FORWARD for the *SLAC Beam Line*. Not only has the interior been completely redesigned by Rene Donaldson into a far more exciting and attractive format, but she and Terry Anderson have also developed our first color cover. What's more, and this gives me great pleasure, we have several very solid and thoughtful articles contributed by individuals working at the frontiers of high-energy physics. They help put activities at SLAC into the broader perspective of trends in the field at large. No more just the world of SLAC according to yours truly.

With this issue we also begin a new column that will appear regularly in the *Beam Line*. Toward the Next Linear Collider is intended to serve as a forum where physicists can discuss the great promise of a full-fledged linear collider and delve into the gritty problems of making it a reality. This column begins with a piece by the new SSCL Physics Research Director Fred Gilman; it will be coordinated by Ron Ruth, who heads the Accelerator Theory and Special Projects Department at SLAC. In this column we plan to present these kinds of issues to a broad audience of scientists, engineers and others interested in extending the linear collider technology pioneered by the SLC. We encourage contributions from inside and outside the SLAC community.

The new *Beam Line* cannot long survive, however, without a continuing stream of articles from working physicists, and we are actively soliciting them for upcoming issues. They should be written in a fashion to communicate what is done here—and elsewhere in high-energy physics but particularly in electron scattering—to an audience of interested readers who may not understand the jargon and assumptions of a given specialty. We hope that theorists will use this forum to communicate their enthusiasms to accelerator physicists, for example, and that experimenters will want to write about their recent exciting results for the graduate student who happens to glance through the *Beam Line* at his or her local physics library. So please contact me if you would like to contribute.

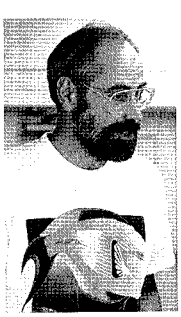
It is an auspicious beginning indeed for the new decade. We plan to continue publishing the *Beam Line* on a quarterly basis, and hope the stream of contributions eventually allows us to make it bimonthly. Please help us make this leap forward great.

Michael Riordan

CONTRIBUTORS

JAMES (BJ) BJORKEN returned to SLAC last year as a member of the Theoretical Physics Department after a 10 year hiatus at Fermi National Accelerator Laboratory where he was Associate Director of Physics and did much to encourage graduate students pursuing a career in physics. While at SLAC from 1963 to 1979, he played a central role in the development of the quark-parton model. More recently, Bj completed a sabbatical at the University of Pisa where he gave at least three to four lectures a week and took many photographs.

FRED GILMAN has been at SLAC since 1967 and is currently on a leave of absence (see article on page 18) to assume the position as Associate Director, Physics Research Division at the Superconducting Super Collider Laboratory. Before coming to SLAC, Fred was at the California Institute of Technology. He has served on the SLAC, Fermilab, and Cornell Program Advisory Committees and was Chairman of the American Physical Society Division of Particles & Fields Steering Committee for Snowmass '88 and served as Chairman of the APS Division of Particles & Fields in 1989.



ANDREW HUTTON was born and schooled in England and then spent five years in Italy installing a high current Linac for Radiation Chemistry followed by seven years at CERN where he worked on the design of LEP. He came to SLAC in January 1984 to work on the SLC and has been successively in charge of the Damping Rings, the Arcs, and the Beam Delivery Section. Since October 1989, he has been leading the Machine Design Group for the *B* Factory based at PEP.

JOHN JAROS came to SLAC in 1975 as a postdoc in Group E and has worked on the Mark I, Lead Glass Wall, and Mark II experiments. John joined the SLAC faculty in 1979. He and his colleagues built the first vertex detector for the Mark II at PEP and used it to measure heavy quark and lepton lifetimes. Since then he has concentrated on building an improved detector for studies of the *Z*. John is currently serving as one of the spokesmen of the Mark II collaboration.

ALAN LITKE has been engaged in e^+e^- colliding beam experiments since his late-1960s graduate work at Harvard on the CEA Bypass. His involvement with SLAC dates from 1973, when he worked on the Mark I experiment at SPEAR as a member of the famed SLAC-LBL collaboration that discovered the ψ particles. Since 1984 Alan has been at the University of California, Santa Cruz, currently as Adjunct Professor of Physics.

While developing the Silicon Strip Vertex Detector for the Mark II experiment, he became convinced that this silicon technology can have important applications to many scientific fields. He is collaborating with neurophysiologists at Stanford Medical School on applying VLSI techniques to the study of information processing in the retina.

MICHAEL ZISMAN has been at Lawrence Berkeley Laboratory since 1974, first in the Nuclear Science Division and more recently as Senior Scientist in the Exploratory Studies Group of the Accelerator and Fusion Research Division. He participated in the design of the Advanced Light Source, a 1–2 GeV synchrotron radiation source now under construction at LBL, and for the past half-year has coordinated LBL design activities for the proposed *B* Factory at SLAC.

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