SLAC continues R & D on 100-GeV linear collider

SLAC is now using about ten percent of its operating budget for research and development on the SLAC Linear Collider, which would be the world's first linear collider. Unlike a storage ring, a linear collider eliminates the synchrotron radiation produced in circular devices by using an electron linac and a positron linac and then aiming the two beams at each other once (PHYSICS TODAY, January 1980, page 19); after the collision the remaining electrons and positrons are discarded.

Advocates of the linear collider, such as Burton Richter, argue that the cost of electron storage rings scales with the square of the center-of-mass energy. He doubts that a storage ring larger than LEP (to have 130-GeV electrons and 130-GeV positrons) will ever be built. The cost of a linear collider, on the other hand, scales linearly with energy; so at a few hundred GeV, the cost for a linear collider should be lower than for a storage ring. The SLC project has two major goals: the development of the technology to make much larger linear colliders practical in the future, and the experimental exploration of the physics of the Z^0.

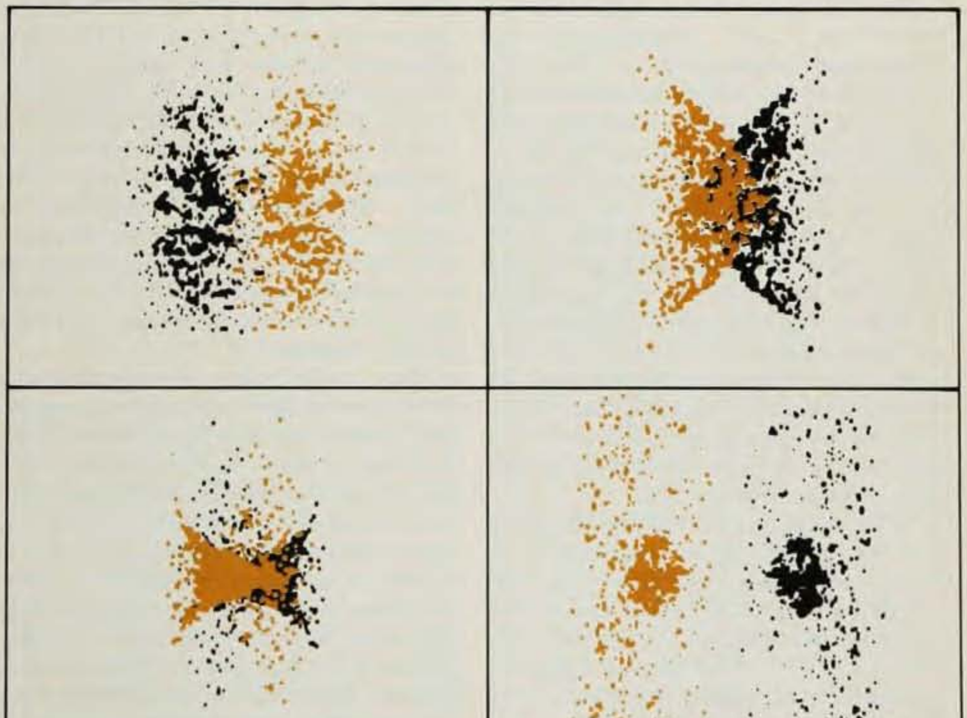
In March 1980, SLAC submitted a proposal to the Department of Energy to build a single-arm linear collider, using the existing two-mile linac, suitably modified, to produce 50-GeV electrons that would collide with 50-GeV positrons. After a HEPAP subpanel headed by Sam Treiman recommended postponing a decision on the SLC (PHYSICS TODAY, September 1980, page 121), SLAC continued its R&D and has again requested funds for the SLAC Linear Collider. If construction funds are approved at the requested rate for fiscal year 1983, the project could be completed by the end of 1985. In 1981 dollars, the total project would cost $77 million. If one includes an inflation rate of 1% per month, the estimated cost is $99 million.

The SLC would accelerate a single bunch of high-intensity electrons to 50 GeV, followed closely by a bunch of positrons, which would be accelerated by the opposite phase of the rf cycle. Then the two bunches are to be separated, transported in two collider arcs (shaped like question marks) and brought into a head-on collision.

As the beam leaves the linac it is expected to have a radius of 100 microns. Within the collider arcs, a series of magnets is to reduce the beam to a 30-micron radius. The SLC group has designed a collection of quadrupole, sextupole and correcting magnets that is expected to produce a final focus at the collision point of 1.4-micron radius. For the last quadrupoles on either side of the collision point, the SLC group may use permanent magnets made of a cobalt samarium alloy, which may be less expensive than conventional magnets.

When the two high-current beams penetrate each other, Helmut Wiedemann told us, a pinch effect is produced. If this self-focusing works, the crossing area would be reduced by a factor of three to six, thus raising the luminosity by a similar factor. Although such beam–beam interactions would enhance the SLC luminosity, they tend to reduce luminosity in an e^+e^- storage ring because the beam is recycled. The tighter the focus, the more rapidly the beam diverges from the focal point as a result of the interaction.

The SLC R&D program has three parts: The first was to construct a new front end for the two-mile linac. The first 100 meters of the linac will serve as injector for the SLC; it is expected to produce 5×10^{10} electrons per single S-band bunch, a factor of 100 higher than existing guns, according to Richter. After the electron gun was finished, the SLC team measured the interaction of the intense electron bunch with the linac; this effect tends to increase the beam phase space. The stronger the effect, the closer one must hold the



Beam–beam interaction in the SLAC Linear Collider from a three-dimensional Monte Carlo simulation. Top left shows electron and positron beams just before collision. Lower left is maximum overlap of beams. The large density enhancement at center is from pinch effect. Top right shows beams starting to separate. At lower right, beams are flung further apart than initially.

beam to the center of the linac structure to reduce divergence at the end of the beam's two-mile trip. The SLC designers calculated the required tolerance to be 0.1 mm, an alignment similar to that achieved in the CERN Super Proton Synchrotron. A rough analysis of the data shows the effect in agreement with the calculation within a factor of two.

The second part of the R&D program is to build a 1.2-GeV storage ring at the end of the linac's first sector (out of a total of 30 sectors). It will take a high-intensity bunch and shrink it by radiation damping or cooling. Then the radiation-damped bunch will be reinjected into the linac for continued studies of the beam-linac interaction. The storage ring is under construction: a 35-foot-deep hole has been dug, a vault and the magnets are being built. The entire ring is expected to be finished next summer.

The third part of the program is to design the tunnels and experimental halls. For this purpose DOE has given SLAC $500 000 to hire an architectural and engineering firm.

The SLC has a design luminosity of 6×10^{30} cm^{-2}sec^{-1} (including an enhancement factor of three from the pinch effect) at 100 GeV in the center of mass. At 90 GeV the luminosity would change slightly. As the energy is reduced to 60 GeV, the luminosity would be down by a factor of two, Richter said. However, he notes, SLC could easily have its center-of-mass energy raised to 140 GeV by adding more klystrons. At full luminosity and energy, Richter says the full width at half maximum energy spread would be 0.7 GeV, whereas the predicted total width of the Z^0 is even larger—2.6 GeV; the large width is expected because many decay modes are possible.

At Novosibirsk, Alexander Skrinsky and his collaborators are hoping to build a true linear collider. They are building a 30-cm-long accelerating section that is expected to produce 100 MV/meter (to be compared with the modified SLAC linac, which gets 17 MV/meter).

Meanwhile, Cornell University is also hoping to build an e^+e^- device with 100 GeV center of mass (PHYSICS TODAY, August 1981, page 20). The storage ring, CESR II, has a design luminosity of 3×10^{31} cm^{-2}sec^{-1}, a factor of five higher than that of SLC. Although CESR II is expected to cost more than twice as much as SLC, in addition to higher luminosity it would have four interaction regions operating simultaneously, whereas SLC could only operate one interaction region at a time.

Because the SLC is a single-pass device, the beams would not develop the depolarizing resonances that occur in a storage ring. The SLAC linac can already produce highly polarized electron beams; so SLC would be capable of doing polarized-electron experiments similar to that done in 1978 by Vernon Hughes, Charles Prescott, Charles Sinclair, Richard Taylor and their collaborators; they showed the existence of parity nonconservation in a neutral-current interaction. —GBL

Gambling with a theory of quarks

The aim of the game recently in quantum chromodynamics has been to find a single theory that describes both the short-range and the long-range interaction of quarks (PHYSICS TODAY, July 1976, page 17). The principal obstacle is that the coupling of quarks changes with the size scale: Gauge theories applied to the short range have predicted that the quark coupling there is weak, going to zero logarithmically with quark spacing. In this phenomenon of asymptotic freedom, the quarks behave as nearly free particles. By contrast, gauge theories applied to the long range have indicated that strong coupling would confine the quarks to bound states. The challenge is to bridge the gap between these two regions and to demonstrate that the long-range, strong-coupling property of confinement persists even when the short-range couplings are weak. The application of Monte Carlo techniques to a lattice gauge theory has moved the players ahead one step in this direction. The game will be advanced by several more steps if theorists have luck in extending the same procedure to calculate the masses of the lowest lying quark bound states such as the pi or rho mesons.

Even before the recent successes with Monte Carlo techniques, theorists had noted the analogy between the particle theory and statistical systems. In particular, the strong- and weak-coupling regions correspond, respectively, to the disordered and ordered phases of a statistical system, with confinement being a property of the strong-coupling disordered phase. If the two regions constitute distinct phases, one would expect a phase transition, that is the nonanalyticity of a physical parameter, between these two regions. In that case, the weak coupling might extend to longer ranges, and the weak-coupling phase could support free quarks and gluons. Indeed, the Abelian gauge group of electrodynamics manifests such a phase transition, and free electrons and photons do exist. On the other hand, if no phase transition occurs, confinement must continue to characterize the long-range behavior even when the short-distance coupling is weak. This second possibility seems to hold for the non-Abelian gauge fields of quantum chromodynamics, and agrees with the apparent absence in Nature of free quarks.

The first evidence for a smooth functional matching between the strong- and weak-coupling regions in non-Abelian gauge fields came[1] actually not from Monte Carlo techniques but from a Hamiltonian formulation of SU(3) gauge theory. This work was done by John Kogut (University of Illinois) and Robert Pearson and Junko Shigemitsu (Institute for Advanced Study), who applied a method outlined earlier by Kogut and Leonard Susskind (Stanford). Nearly simultaneously, Michael Creutz (Brookhaven) reported[2] the results of a Monte Carlo calculation applied to SU(2) gauge fields in four and five dimensions. Creutz found that only the former did not experience a first-order phase transition. The Monte Carlo procedure had earlier been applied to Abelian systems by Creutz, Claudio Rebbi (Brookhaven) and Lawrence Jacobs (now at the Institute for Theoretical Physics in Santa Barbara). Kogut commented that, although the Hamiltonian and Monte Carlo approaches are complementary, the Monte Carlo method permits a more complex form of quark interaction and allows better control over the intermediate coupling regime.

Lattice gauge theories. Both these approaches follow the pioneering work by Kenneth Wilson[3] (Cornell) and Alexander Polyakov[4] (Landau Institute in Moscow) in formulating gauge theories on a discrete, four-dimensional space-time lattice. Franz Wegner (Heidelberg), working on a problem in statistical mechanics, was the first to put a locally invariant field on a lattice. Wilson and Polyakov proposed such a lattice in particle physics to remove in a natural way the ultraviolet divergences that arise in quantum field theory: Wavelengths are essentially cut off at twice the lattice spacing because any shorter wavelengths would have no meaning. The more conventional schemes for removing the divergences are based on Feynman expansions and are thus perturbative calculations. Such expansions would break down for large quark separation, where the coupling constant becomes large. In calculating any physical number from a lattice gauge theory, of course, one must take the lattice spacing to zero at the end.

On the finite space–time lattice, the gluon gauge field is translated into variables associated with the links join-