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LINEAR COLLIDERS

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The SLAC Linear Collider (SLC) is the first of a new type of electron-positron colliding-beam device. It is designed to be both a research tool for elementary particle physics experiments and a facility in which this new technique can be further developed and tested.

A true linear collider would consist of two linear accelerators firing intense bunches of electrons and positrons at each other. During the collision, the beams in such a machine would be disrupted by the very strong electromagnetic fields in the collision region, and would thereafter be disposed of and not used again. Since the beams would not have to be deflected into a circular path (as they are in the storage-ring technique that has been used up to now for electron-positron colliding-beam experiments), no synchrotron radiation would be produced in the true linear collider. This makes the scaling laws for the size and cost of linear colliders as a function of energy much more favorable for extension to considerably higher energies than are the scaling laws for storage rings. Since the beams in linear colliders only interact once, the disruptive effect of the collision of the two beams can be much stronger than could be allowed in a storage ring, where the beams must be kept circulating in the magnetic aperture of the ring for periods of hours (billions of collisions).

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A schematic of the SLC is shown in Figure 1. This machine is not a true linear collider, since it uses one linac rather than two, and the beams coming out of the linac are magnetically deflected through curved arcs to reach the collision point. The linac is the existing SLAC two-mile-long machine, and in this variation of the linear collider technique intense bunches of electrons and of positrons are both accelerated in a single pulse of the linac, are separated by a magnet at the end of the machine, and are then injected into two beam-transport systems that guide the beams to the collision point. At the design energy of the SLC, the synchrotron radiation emitted in this transport system is comparatively unimportant, although at much higher energies it would become so severe as to make this one-linac variant impractical.

The main design goals of the SLC are as follows. The center-of-mass energy at the collision point is to be 100 GeV, and the luminosity (reaction rate per unit cross section) at this energy is to be $6 \times 10^{30}\ cm^{-2}s^{-1}$ at a repetition rate of 180 pulses per second. To reach these goals the linac must be upgraded in energy; a positron- production facility must be built to produce the 5×10^{10} positrons required for each pulse; a beam-conditioning system (damping rings) must be built to produce the low emittance beams required for operation; tunnels must be bored to house the beam transport magnets required to bring the particles from the end of the linac to the final focus system; a highly corrected magneto-optical system must be built to focus the beam down to the 1.4 micron radius required at the collision point; and an experimental hall must be built to house the experimental apparatus. Construction of this facility began in October of 1983, and the expected startup date is October of 1986.

To discuss the operation cycle, assume that the machine is running in equilibrium. The two damping rings near the front of the linac (one for electrons and one for positrons) are each filled with two bunches of particles. At the start of the cycle, one positron and two electron bunches are extracted from the damping rings and injected into the linac. At injection each bunch has an energy of 1.2 GeV, is two millimeters long, and has an emittance (radius times angular divergence) of 1.3×10^{-8} radian-meters. The bunches travel down the linac about 17 meters apart, gaining 17.5 MeV for each meter traveled.

At the 2/3 point of the linac, the positron and the first electron bunch pass the positron source. The second electron bunch is diverted from the linac to the positron source. The first two bunches continue down the linac, reaching 51 GeV at the end of the machine with an energy spread of $\pm 0.4\%$. The bunches have a cross-sectional radius of approximately ninety microns at this point. A magnet separates the electron and positron bunches and directs them into the two transport systems. In these transport systems (the collider arcs), the beams lose about 1 GeV of energy by synchrotron radiation. The focusing must be very strong to prevent quantum fluctuations in synchrotron radiation from increasing the emittance, which is 3×10^{-10} radian-meters at this point. The bunch radii are about 30 microns in the arcs.

The final focus is a complex system that must reduce the beam size at the collision point to a radius of 1.4 microns and must also correct for both chromatic and geometric aberrations. During the actual collision of the two bunches, the extremely strong fields within the bunches, equivalent to about a megagauss, reduce the mean beam cross sectional area during the collision by about a factor of three (a "pinch" effect). After the collision the non-linear part of these intense fields has so badly distorted the phase space of the beams that it is impossible to refocus them to a small size again; thus they are disposed of and not used further.

Meanwhile, the bunch that was extracted at the positron target has struck the target, producing about 10^{11} positrons within the acceptance of the positron production system . The average energy of these positrons at the production target is only 2 MeV. This intense low-energy bunch is boosted to 200 MeV by a small linac, then turned around and brought back to the front of the linac by a transport system built in the existing linac housing. It is then turned around again and injected into the first section of the existing linac, boosted to 1.2 GeV, and injected into the positron damping ring. Two electron bunches are produced and injected into the electron damping ring. In the damping rings the transverse beam sizes decrease through synchrotron radiation. The positron bunch, which is initially much larger than the electron bunches, must remain in the damping ring for a longer time than the electron bunch. Then in the next cycle, which starts about 5 milliseconds later, the "old" positron bunch and the two electron bunches are extracted to begin the cycle all over again.

At the present time (October 1984), considerable progress has been made on the project. The tunnels for the arcs are nearly complete, and construction of the experimental hall has begun. Production of the small strong focusing magnets (8mm aperture) required for the arcs has also begun. The electron injector and one of the damping rings are complete and have been in use for research and development for more than six months. The positron return line is partly installed, and fabrication of all other components has started.

The energy upgrade of the SLAC linac requires the development of a new 50-megawatt (peak power) S-band klystron to replace the existing 36 megawatt tube. These new tubes must operate at a higher voltage and have twice the pulse length of the old tubes. A pulse compression scheme is used at the output of the klystron to raise the effective peak power of the new tubes at the linear accelerator by a factor of 2.5 over that provided by the old tubes. Successful prototypes of these new tubes have been tested, and full-scale production has begun.

Testing of the front end of the machine with the required two electron bunches has successfully demonstrated the full cycle of electron production, acceleration, damping, reinjection and acceleration to the 1/3 point of the linac. The electron bunches meet the emittance specification at this point. The full SLC should begin tests in the last quarter of 1986, and the experimental physics program should begin early in 1987.

The experimental program is aimed at the study of the production and decay of the Z^0 boson, the transmitter of the weak force. The Z^0 production rate of 800 per hour expected at full luminosity should give much new information on the unification of the electromagnetic and the weak interactions and on the structure of the basic building blocks of matter.

In parallel with the construction of the SLC, work is proceeding in the U.S., the Soviet Union, Europe, and Japan on the technology and optimization procedures required for the construction of a practical and economical large linear collider in the TeV (1000 GeV) energy range. These studies have already demonstrated accelerating gradients in conventional structures of more than 100 MeV per meter. New types of high-efficiency, high-power rf sources are under development. Novel accelerating schemes capable of still higher accelerating gradients are also under investigation. A key element in progress toward these large machines will be the demonstration by the SLC that the dynamics of the acceleration and beam-beam interaction process are understood as well as we now believe we understand them.

BIBLIOGRAPHY

The Physics of High Energy Particle Accelerators, The American Institute of Physics Conference Series, to be published