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SLC STATUS AND SLAC FUTURE PLANS*

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Abstract In this presentation, I shall discuss the linear collider program at the Stanford Linear Accelerator Center as it is now, and as we hope to see it evolve over the next few years. Of greatest interest to the high energy accelerator physics community gathered here is the development of the linear collider concept, and so I shall concentrate most of this paper on a discussion of the present status and future evolution of the SLC. I will also briefly discuss the research and development program that we are carrying out aimed at the realization of the next generation of higher-energy linear colliders. SLAC has a major colliding-beam storage-ring program as well, including present rings and design studies on future high-luminosity projects, but time constraints preclude a discussion of them.

INTRODUCTION

Linear colliders represent a new kind of colliding-beam machine. They were conceived of as being a way to overcome the scaling law for electron colliding-beam storage rings that, because of the emission of synchrotron radiation, have a size and cost which increase roughly as the square of the center-of-mass energy. The LEP storage ring at CERN, of which we will hear much at this conference, is the great culmination of more than 30 years work in electron storage rings, but it is 27 km in circumference. With the quadratic scaling law of storage rings, a machine of ten times the energy would be 2700 km in circumference, a size (and cost) to give even high energy physicists pause.

Linear colliders, on the other hand, have no synchrotron radiation emitted in the acceleration process, and so the size of these devices increases as the first power of energy. However, the solution of one problem almost always creates new problems, and this is the case in linear colliders. There are new problems in beam dynamics arising from their very high peak currents (1000 A in the SLC at full

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design intensity), and from the micron or submicron beam sizes required at the collision point.

The SLC is a beginning for this new technology. The project was conceived both to prove the linear collider technique and to carry out physics research at the Z^0. That the linear collider technique is viable and that one can do physics research with these machines were both demonstrated by the publication of the first physics paper to come from a linear collider in the August 14, 1989 issue of *Physical Review Letters.*

SLC

The SLC is shown schematically in Fig. 1. It uses a single linear accelerator to accelerate bunches of electrons and positrons of high intensity in the same

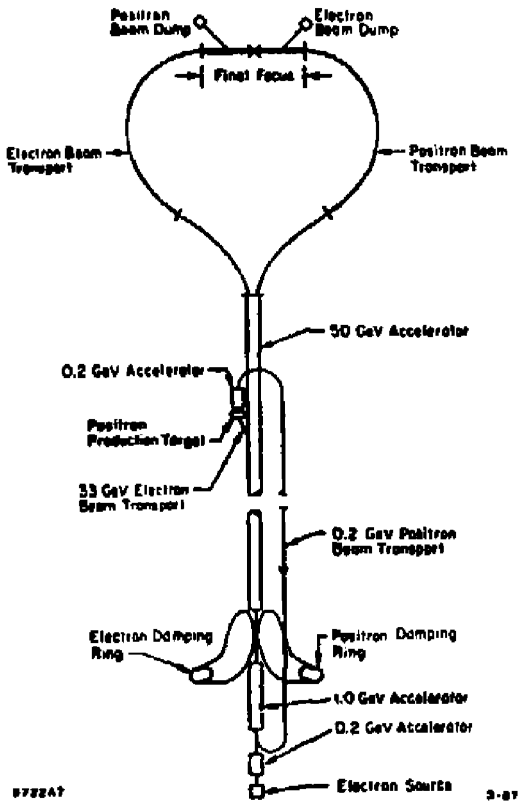

FIGURE 1 Schematic of the SLC.

machine pulse. The high-energy beams are then brought into collision by a small-aperture, very strong focusing, nonplanar beam transport system at the end of the linac.

The last component of the SLC was installed in April 1987, while the first Z^0 event was observed in the Mark II Detector in April 1989. During those two years, we learned a great deal about such things as beam dynamics in linear colliders, the optics of nonplanar beam transport systems, novel sources of background in particle detectors, etc. I shall not repeat all that, but in this talk shall rather give a status report on where we are, and describe where we hope to go in the next few years. More details can be found in other papers at this conference, and in the proceedings of the 1989 IEEE Conference on Accelerators held in Chicago.

Most of the elements of the machine work well, though some will have .o be upgraded to meet our performance goals of the next few years. The electron gun and one GeV booster work well and have been tested up to about 4.5×10^{10} electrons per pulse.

The damping rings which reduce the electron and positron emittance to approximately 1.5×10^{-5} rad-m perform nearly as expected. The vacuum chamber impedance is, however, somewhat larger than originally estimated, resulting in bunch-lengthening with a threshold of about 1.5×10^{10} electrons per pulse. Even with bunch-lengthening, the pulse compression system (phase rotation in the p-z plane) works well and can produce bunches as short as 0.5 mm for injection into the linac.

Our new klystrons perform beyond design specifications. They were originally designed to produce 50 MW of peak power in a 3.5-μsec pulse and have a 15,000-hour lifetime. They actually produce 65 MW peak power, and have a lifetime of approximately 35,000 hours.

The positron production system has a net yield (positrons out of the damping ring, re-injected into the linac, divided by electrons on the production target) of 0.9. There is still more to be gained here, for theory indicates we should be able to make this yield as large as two. The present positron production target cannot stand the full design average power, and a new target is in preparation that should be ready for installation around the beginning of 1990. The present target is limited to an intensity of 2.5×10^{10} at 60 Hz.

The collider arcs consist of a collection of achromatic sections in planes tilted with respect to each other to accomplish the combined vertical and horizontal bending. The coupling that came from the sensitivity of this system to small systematic errors has been overcome by smoothing the transitions between the rotated planar sections and installing a distributed correction system near the ends of the arcs.

The *Final Focus System* is the most complicated transport section in the machine. In this system, the arc optics are first matched to the rest of the system, the first demagnification of approximately five is made, a system of sextupoles and bending magnets next corrects chromatic aberrations, and a final demagnification of another factor of five to the interaction point is accomplished. All this works about as designed.

One of the new problems that must be faced in a linear collider is the effect of longitudinal and transverse "wake fields." These are fields generated by the interaction of the accelerated bunch with the accelerating structure which, in turn, interacts back on the bunch that produced the fields. This becomes a problem for linear colliders because the typical charge per accelerated bunch is two or three orders-of-magnitude larger than is usual in electron linacs. The longitudinal wake produces an energy spread in the beam that can be compensated for by accelerating the bunch off the crest of the RF wave, and is not a serious problem in the SLC or in the high energy linear colliders that are now under discussion.

The effect of the transverse wake is, however, potentially quite serious and has to be dealt with. The transverse wake field strength is proportional to the distance of the bunch from the axis of the accelerator, and the fields are always such as to push the tail of the bunch farther away from the axis. Looked at in the r–z plane, a bunch which, in the absence of wakes, would be traveling parallel to the accelerator axis, can be turned into a banana-shaped object with the tail much farther from the axis than from the head. The practical consequence of this is to increase the projected area in the x–y plane, and thus reduce the luminosity of the machine. In addition, these tails can generate serious backgrounds which compromise the ability of the detector to do the physics research for which it was intended. In a perfectly aligned machine, with no orbit distortions caused by misaligned focusing elements, the beam would travel on the accelerator axis and the strength of the wake field would be zero. However, no machine is like that and the roughly 250-μm rms orbit distortion existing in the SLC would lead at high intensity to unacceptable transverse emittance growth in the absence of another method of control.

In addition to orbit control, at the SLC we use the method known as BNS damping ring (named for Balikin, Novotsky and Smirnoff of Novosibirsk) to control the process. In BNS damping, an artificial energy spread is introduced in the bunch early in the accelerating process, and then removed at the end of the accelerator so that the beam emerges with its natural energy spread. If the energy at the tail of the bunch is reduced, the effective kick from the quadrupole focusing elements on the machine increases toward the tail of the bunch, and thus, can counteract the effect of the wake fields. Figure 2 shows the energy spread induced in the SLC as a function of distance along the accelerator. The maximum energy spread required to control the emittance growth is a function of the intensity of the bunch and the configuration shown in the figure is used for intensity up to 2.5×10^{10} particles per bunch.

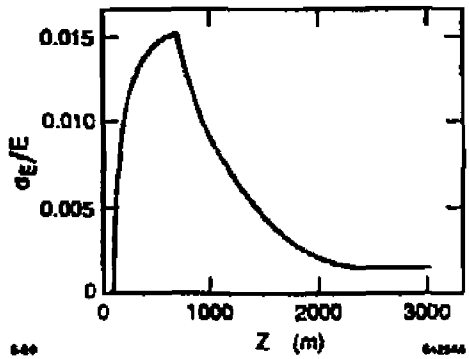

FIGURE 2 Induced energy spread profile along the linear accelerator for BNS damping at intensities up to 2.5×10^{10} per bunch.

Figure 3 shows a computer simulation of the effect of BNS damping on wakefield driven emittance growth. The left two frames show the effect on the emittance at the end of the linac in x–x' phase space while the right two frames show the effect in x–z configuration space. The effect of BNS damping is dramatically apparent and this system is routinely used at the SLC.

The SLC, in a sense, is like a modern airliner—it requires continuous active control to keep flying. Not only must the wake fields be controlled by accurate steering, but the energy and energy spread must be controlled as well, so that low-intensity tails on the beams do not appear that can generate intolerable backgrounds

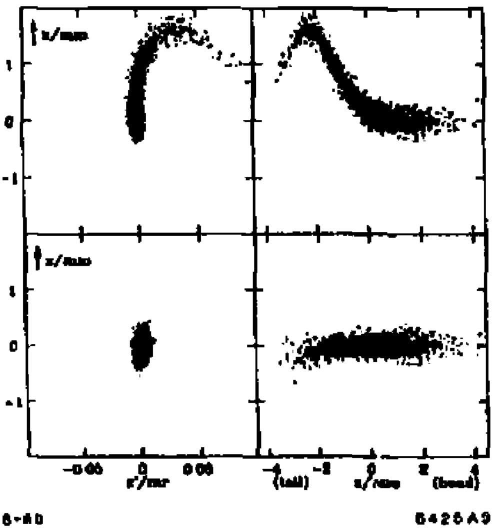

FIGURE 3 The effect of wake field driven emittance growth without (upper two boxes) and with (lower two boxes) BNS damping. The left-hand boxes show the projection in transverse phase space, while the right-hand boxes show the transverse projection along the bunch.

in the detector. We control these tails by both collimation and feedback. Collimation systems exist at the end of the linac, in the arcs, and in the Final Focus System. All three sets of collimators are required to remove halo particles from the beam.

The feedback systems we use are of two types. The first type is a "slow" system that can get its information from any of the 100 or so microcomputers distributed along the machine. These local computers communicate with the main control computer, which does any necessary calculations and can tell any of the microcomputers what action to take. This system has a minimum update time of about 20 sec. There are many such systems; the two that are most important for operational purposes are: (1) the "linac launch system," which controls x and x' for both electrons and positrons at the injection point into the linac from the damping rings to about 2 μrad and 20-μm tolerances, and (2) the Final Focus launch system, which controls the beams as they exit the arcs and enter the Final Focus to about the same tolerances.

Fast feedback systems use dedicated microprocessors that receive information directly from various sensors and directly control various functions. The two most important of these are the linac energy control and the arc launch control. The linac energy is controlled to about 20 MeV with a system that varies the phases of certain accelerating elements along the accelerator. The time constant of this system is approximately five accelerator pulses. The arc launch system holds both the electron and positron beam centered in the collimators at the end of the linac. It also has a five-pulse time constant and controls to about 10 μm and 1 μrad.

TABLE I Measured emittance of the SLC beams; $N \approx 10^{10}$ particles per bunch.

Location	$\gamma\epsilon_x$ (10^{-5} mrad)	$\gamma\epsilon_y$ (10^{-5} mrad)
Damping ring	1.5	1.5
Linac, begin	2–3	2
Linac, end	4–6	3–4
IP	4–6	4

Table I shows the measured emittance of the SLC beams at various points. The invariant emittance in the damping ring is as calculated. There seems to be a small emittance growth between the exit of the damping ring and the injection point of the linac that is not really understood. The emittance grows as the beam travels down the linear accelerator, and we believe this to be caused by chromatic effects and filamentation as the beam travels through the 3 km of accelerator. There is no evidence of any further emittance growth between the end of the linac and the interaction point.

Probably the most complex of the set-up tasks at the SLC is that which tunes the Final Focus to produce the desired beam spot. Here we have to match the beam coming from the arcs, make chromatic corrections, set the coupling to zero, and set the interaction-region β-function to the desired value. The most important of our diagnostic tools are those that allow us to measure the beam size at the interaction point and to minimize that beam size as a function of all of the Final Focus variables.

The initial system that we used consisted of fine horizontal and vertical carbon fibers that could be inserted at the collision point. The smallest of these fibers was 4 μm in diameter and the beam was scanned across the fiber by a small upstream steering magnet. The signal from the wire could be read out either by looking at the secondary emission from the wire itself or by detecting the bremsstrahlung from the interaction of the beam with the wire in a downstream photomultiplier system.

This system works quite well at low beam intensities, but cannot be used at intensities above approximately 1×10^{10} particles per bunch because of wire heating. Since the wire cannot survive at operational beam intensities, an alternative system was developed.

The new standard method of beam tuning uses a system known as "beam deflection." The two beams are scanned across each other and, as they are scanned, the macroscopic electromagnetic field of each beam deflects the other beam. The deflection angle is measured on each pulse of the machine as the scan proceeds, and the measurements are digested and analyzed by the control computer. Figure 4 shows a typical beam deflection scan. The position of the zero crossing of the scan data shows how well the beams are centered and is used to adjust the relative position of the two beams. In addition, the slope at the zero crossing and the separation of the two peaks are both related to the rms sum of the sizes of the two beams, and to the current in the other beam. The beam deflection scans are run entirely by the computer and each one takes about 8 sec for both the horizontal and vertical scan.

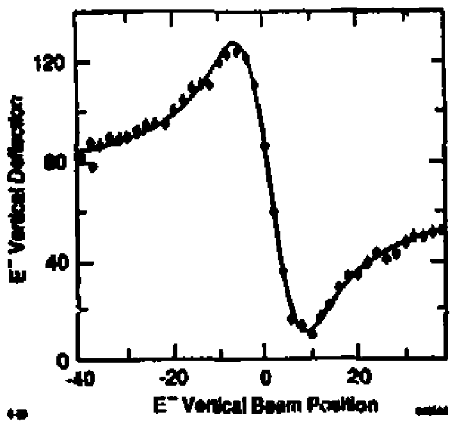

FIGURE 4 Data from a typical beam deflection scan.

This is a tool we use to optimize all of the conditions in the Final Focus. For example, if we wish to set the minimum of the envelope function of one of the beams at the exact interaction point (thus minimizing the size of the beam and maximizing the luminosity), we do it with a series of beam deflections scans. A typical waist scan is shown in Fig. 5. Here, the computer adjusts various quadrupoles to move the position of the vertical waist while holding the position of horizontal waist constant, carries out the beam deflection scan and analyzes the results, moves the waist position again and does another beam deflection scan, etc. In the example shown in Fig. 5, the vertical waist of one of the beams was off by approximately 3 cm from its nominal position. The accelerator operator accepted the result and allowed the computer to shift the minimum to the collision point. A similar system is used to adjust all of the Final Focus parameters.

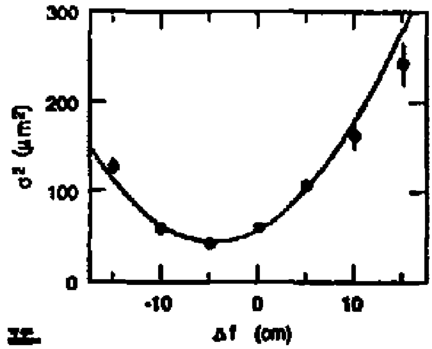

FIGURE 5 Data from a typical waist scan.

Two other monitors are also in qualitative use to help in tuning up the machine. One of these is the so-called beamstrahlung monitor that measures the MeV synchrotron radiation photons emitted by particles of one beam when they cross the very large electromagnetic field of the other beam. We also have a bremsstrahlung monitor which detects degraded electrons from $e^+e^- \rightarrow e^+e^- + \gamma$. These two monitors will play a more important role in our diagnostics when the beam intensities reach higher values.

Beam deflection scans can be used to monitor the luminosity by using the measured rms sizes and beam currents to calculate the expected luminosity. Figure 6 shows the luminosity as a function of time for a 60-hour period. Typically, it takes about 8 hour to achieve high luminosity and low backgrounds at the detector simultaneously.

The long-term variability in luminosity can mostly be accounted for by the difficulties the operators were experiencing in this period in keeping the background low in the Mark II. From the start of operations in April 1987, the SLC has been capable of delivering higher luminosity than the detector could stand. Very recently, we have discovered a misalignment in some of the synchrotron radiation masks in

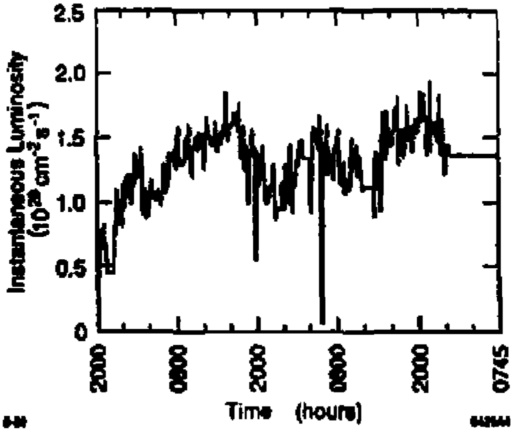

FIGURE 6 Instantaneous luminosity versus time taken in early August 1989.

the detector, and with the correction of this misalignment we expect the luminosity to increase, for it will be much simpler to keep backgrounds under control.

An important issue for linear colliders is that of the relative pulse-to-pulse jitter of the two beams at the collision point. Figure 7 shows the difference in the horizontal position of the two beams at the collision point as determined by a measurement of the deflection angle of the two beams from a series of successive pulses

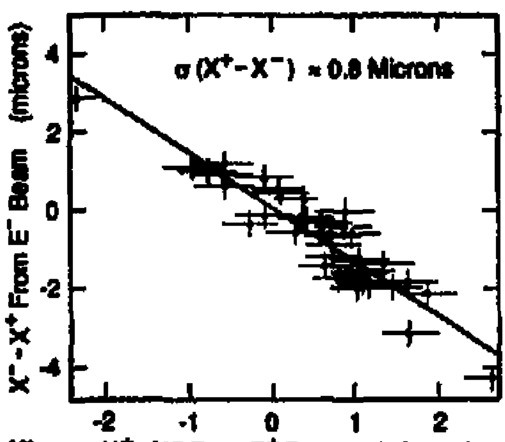

FIGURE 7 Correlation plot showing the pulse-to-pulse jitter in centering of the two beams. The spread of points along the heavy line indicates true beam jitter, while the spread around the line is caused by electronic noise in the pickup system.

TABLE II Performance, 1989.

	May	August	December?
f	30	60	60
N^-	1.1×10^{10}	1.8×10^{10}	2.0×10^{10}
N^+	0.8×10^{10}	1.6×10^{10}	2.0×10^{10}
σ_x	4 μm	3.3 μm	3.0 μm
σ_y	4 μm	3.3 μm	3.0 μm
$\mathcal{L}$ (Z/hr)	0.15	1.5	2.5

of the SLC. The heavy lines show the correlation expected from a true separation of the beams. The rms jitter is determined from this measurement to be approximately 0.8 μm; the spread of the points about the line is caused by noise in the beam position monitor electronics.

The performance of the SLC for 1989 is shown in Table II. Between May and early August, we have doubled the repetition rate, nearly doubled the beam currents, and reduced the beam size, increasing the luminosity by a factor of ten. We expect to be able to increase the luminosity by another factor of roughly two between August and December 1989.

Around the end of the year, we expect to make further improvements. Upgrades to the pulsed magnet extractors in the damping rings will allow us to run at the design repetition rate of 120 Hz. In addition, some smoothing of the bellows in the damping rings will be done to allow the storage of higher currents. A new positron target will be installed that can stand the higher intensity and higher repetition rates which are planned for 1990.

Table III shows our expectations for operations in the Spring of 1990. The column labeled "Low Luminosity" shows what we expect early in the run; the column labeled "High Luminosity" shows where we expect to be after several months of operation. The last column shows the ultimate performance we might achieve with the machine without making major improvements. We expect to improve the luminosity in 1990 by an order of magnitude over that achievable in 1989 without a marked reduction in beam size, for we are going to have to learn to live with all of the wake field effects coming from higher currents. For 1991, we expect to continue to increase the current and to decrease the beam size, resulting in an increase in the

TABLE III Expectations for the 1990 Spring run: $\mathcal{L} = f \frac{N^- N^+}{4\pi \sigma_x \sigma_y} \cdot H(D)$.

	Low $\mathcal{L}$	High $\mathcal{L}$	Design
f	60 Hz	120 Hz	120 Hz
N^-	2.2×10^{10}	4.5×10^{10}	6×10^{10}
N^+	2.2×10^{10}	4.5×10^{10}	6×10^{10}
σ_x	3 μm	3 μm	1.65 μm
σ_y	3 μm	3 μm	1.65 μm
$H(D)$	1	1	3
$\mathcal{L}$ (cm^{-2} s^{-1})	2.6×10^{28}	2.1×10^{29}	4×10^{30}
Z^0 rate	3/hr	25/hr	470/hr

luminosity by another factor of five to ten. Many subsystems will have to be very well tuned up or improved to achieve this goal.

1991 should also see the first operation for physics experiments of the polarized beam. The gallium arsenide photocathode electron gun is already installed on the linear accelerator and the laser to drive it will be installed in the next few months. Thus, tests of the source can begin. In 1990, the solenoids required for spin manipulation will be installed in the damping ring and linac. One polarimeter is already installed at the end of the linac, one is installed at the Final Focus, and it only remains to complete the high-precision polarimeter at the interaction point. With this system, we hope to achieve polarizations of 45% around the end of 1990.

We are considering a series of major improvement projects which could increase the luminosity of the SLC to beyond its initial design specifications. An increase of repetition rate in the linac from 120 to 180 Hz is completely designed and ready to be fabricated when funds become available.

The high energy collider R&D program, together with experience with the SLC, has taught us a good deal about optimizing Final Focus systems. We believe it is possible to replace the Final Focus in the SLC and reduce the minimum value of β to approximately 1 mm. If we could do this, the luminosity would increase by a factor of five to ten. This major project is still in the early stages of conceptual design, and we are not yet ready to proceed.

Another product of the large linear collider R&D program and the experience with the SLC is a better understanding of damping rings to produce small emittance. We believe that it should be possible to reduce the emittance coming from the damping ring by about a factor of 2.5, by redesigning the ring while keeping the size such that it still fits in the same enclosure. This is a major project whose benefits cannot be realized until we learn better methods of control of the apparent emittance growth in the linear accelerator.

If all of these improvements are feasible and installed, the maximum luminosity of the SLC would be about 10^{32} cm^{-2} s^{-1}. Only the increase in repetition rate is ready to implement when funds are available; the other two projects will require one to two years of further study.

ADVANCED LINEAR COLLIDER R&D

The SLC was designed both as a proof principle device and to do high energy physics research. The next generation machine must serve primarily as a physics research tool, and thus, must be configured to give with high confidence an energy and luminosity sufficient to advance the science. The energy must clearly be significantly higher than LEP II (160 to 200 GeV in the center of mass). The luminosity must be sufficiently large to allow a certain minimum amount of data to be obtained in a reasonable time.

To us, it seems that the minimum center-of- mass energy for a new machine should be 400 to 500 GeV. More would be better, but I believe that the linear collider technique is too new to allow a very much larger step than that for the next machine beyond the SLC. I believe that the best answer to the energy question is to build near the minimum energy and include some possibility for expansion, either by improved technology or by increasing the length of the facility. The SLAC Linac itself has gone this route, starting operation in 1966 at an energy of 18 GeV, and now is capable of running at 60 GeV through improvement in RF power sources.

It is generally agreed that the minimum luminosity for a next-generation linear collider is given by

$$\mathcal{L} \;=\; 10^{33}\; E^2\;(\mathrm{TeV})\;\mathrm{cm}^{-2}\;\mathrm{s}^{-1} \quad . \tag{1}$$

This luminosity gives 1000 events per unit of R (the electromagnetic μ pair cross section) per 10^7 seconds. The total e^+e^- annihilation cross section is about 80 units of R at 500 GeV, and most new processes now hypothesized are expected to have cross sections between 0.1 and a few units of R. Here too, more would be better, but at least this minimum must be achievable with high confidence within a year or so after turn-on.

In the design of the next-generation linear collider, three broad areas must be addressed. The first is the development of low-emittance sources. The second is the development of reliable energy-efficient accelerators. The third is the development of Final Focus systems that are capable of producing submicron beams. The R&D program now proceeding is international in scope. The major players in the game are Europe, Japan, the US, and the USSR. Technical information exchange between these programs is very good, and some joint R&D programs are being carried out. In this section, I will mix some comments on the state of the art with descriptions of parts of the SLAC program. More details on the SLAC program and on the other programs can be found in other papers in this conference.

The problem of low-emittance sources seems to be solved at least for all but very high repetition rate machines. There is general agreement among all the research groups that the solution will be the so-called wiggler damping ring, wherein wiggler magnets are employed between bending sections to enhance the synchrotron radiation and reduce the damping time. Energies of these damping rings will be between 1 and 2 GeV; the circumferences from 100 to 150 m; horizontal invariant emittance ($\gamma\sigma\sigma'$) of 1 to 3 μm; vertical emittance of 1 to 10% of the horizontal emittance; and a damping time of 1 to 3 msec. Several conceptual design variants have been produced and their seems to be no fundamental problem in this area.

The main accelerator, and the power sources for that accelerator, are where the bulk of the cost of a next generation linear collider will reside. After innumerable workshops, there is general agreement that all such exotic ideas as lasers, plasmas, wake fields, etc., are not practical for the foreseeable future. All of the major groups are working on linear accelerators with conventional or exotic power generators. If we knew the unit costs of linacs, modulators, power sources as a function of power level, pulse length, efficiency, etc., we could probably write a computer program to optimize the design of the linac and achieve a machine at minimum cost.

However, the technology for these items is not fully developed and it is not possible as yet to do a "mechanical" optimization. There is a good deal of experience and instinct that goes into selecting the parameters for the machines under study by the various research groups. That is a good thing and as we get further in this R&D program, and we know more about the technology, it will become possible to properly optimize these machines. In any event, the optimum is usually a broad one and we will probably find out later on that most designs are feasible.

One of the major programs at SLAC is the development of RF power sources suitable to drive a linear accelerator operating at higher frequency than the SLAC Linac. Higher frequency allows improvement in the efficiency of energy transfer from the linac to the beam. We are settling down at 11.4 GHz (four times the present SLAC frequency). Four main lines are being pursued at the present moment in collaboration with other laboratories or industry.

The first of these is the induction linac driven "relativistic klystron" (LLNL/LBL/SLAC). In this program, a Livermore induction linac is used to drive a SLAC klystron body (11.4 GHz). The beam voltage is about 1.4 MV, with a current about 400 A. The klystron body consists of a drive cavity (300 W), three gain cavities, and a travelling-wave output cavity. This system has produced more than 200 MW of peak RF power and has been used to drive a 26-cm-long accelerator section that has operated at up to 130 MV/m accelerating gradient.

At present, our view is that this technology seems to be too expensive to drive a large linear collider when compared with other possibilities. However, the relativistic klystron is the only technique available now that can produce very high output powers at this high frequency and allow us to test linac sections. The collaboration intends to continue pursuing this line, upgrading the induction linac to about 2 MV energy, increasing the current, and redesigning the output section to give four outputs each at 200 MW. Combining all the outputs should give sufficient power to test accelerating sections at up to 200 MV/m accelerating gradient.

The second technique is a conventional 100 MW klystron with "binary pulse compression." The pulse compression scheme makes use of the ability of klystrons to rapidly change phase in combination with a series of low-loss delay lines and 90° hybrids to compress the pulse and increase the peak power. Figure 8 shows schematically a two-stage compressor scheme. A pulse compressor has been built and

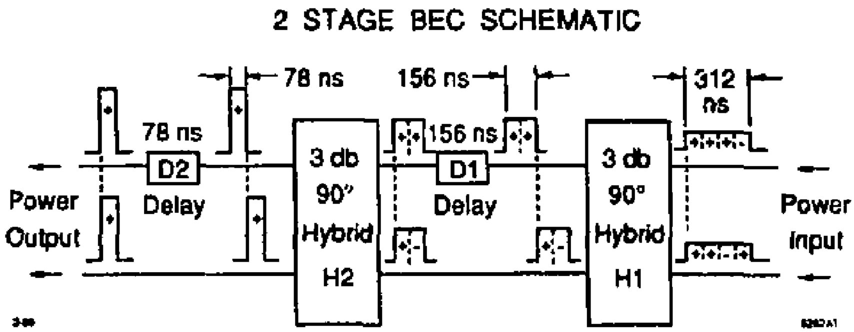

FIGURE 8 Schematic of a two-stage binary pulse compression system is showing the relative phase during the pulse and the length of the required delay lines.

tested at low power. A three-stage device had an efficiency of 71%. The 11.4 GHz klystron is being fabricated. It is designed for 100 megawatts of peak power.

The third technique is the "cluster klystron" (BNL/SLAC). This is an old idea reborn and perhaps made feasible by modern cathode developments and computer modeling. Basically it combines roughly 30 small 30 MW klystrons in one vacuum body and one magnetic field. It requires 40 A/sq cm cathodes, and these are under development for other applications in industry. This concept is in the advanced design phase and we should begin soon to build a single subklystron to test the idea. If it works, it could be relatively high in electrical efficiency and moderate in cost.

The fourth RF program is the crossed-field amplifier (industry/SLAC). This device is a magnetron-style amplifier, and it is in commercial production at relatively low power levels. The attraction of this device is its apparent simplicity and correspondingly low manufacturing costs. Our main concern about it is spectral purity. A 150 MW device is early in the design stage, and it is too soon to say whether it will be practical.

Final Focus systems for the next generation machines pose a very difficult challenge. Most designs for future machines aim at using flat beams with a vertical-to-horizontal aspect ratio of 1/30 to 1/300. Vertical beam sizes will be tens of nanometers. Interaction region β functions will be small fractions of a millimeter. Simulations have shown that such focusing systems can be made if the elements, the alignment procedures, the final lenses, the position monitoring systems, and the profile monitors are good enough.

A very important step toward developing this technology is an international collaboration aimed at developing a Final Focus Test Beam at SLAC using the very low-emittance SLC beam as input. The purpose of the project is to demonstrate the optics; develop the alignment procedures which must use the beam (survey techniques are not good enough); test various kinds of final lens systems ranging from conventional lenses to plasmas; develop monitoring systems of sufficient precision; and develop means for measuring the beam size at the interaction point (none now exists except for beam deflection systems). KEK and Novosibirsk are committed to participating. Discussions are going on with European laboratories, and we hope that they too will join the collaboration. The project will take two to three years to complete to the point where testing could begin.

This brief description of the advanced linear collider program has omitted much that is underway at SLAC on structures, alignment techniques, interaction region geometries, detector backgrounds, etc. There are more details in other papers in these proceedings.

CONCLUSION

The SLC has already taught us much about linear collider technology, and the experience to date has had considerable effect on the design of future machines. I expect that we have a great deal more to learn and will do so over the next few years, as the intensities of the SLC beams increase and emittance growth in the linac is better understood.

The SLC has just begun to produce the experimental physics results that are so important to our understanding of the Standard Model. The present luminosity is about 1.5×10^{28} (about 1.5 Z^0 per hour), and we expect to produce 500 to 1000 events this year. We believe that we understand how to increase the luminosity by a factor of ten in each of the next two years and will begin with the installation of some new devices in a two-month down period early next year.

The polarized beam project is going well, and the polarized source and laser will be ready for test operation before the end of the year. We expect to begin to be able to deliver polarized beams to the interaction point about a year from now.

The advanced linear collider R&D program is proceeding at a rate which is paced more by available funding than by anything else. Our focus for the past year or so has been on a machine of 500 GeV center-of-mass energy, which is already a large step from the SLC, since it will involve new technology as well as a higher energy and smaller beam sizes. I believe that it will be three or four years before we (or anyone else) is in a position to produce a conceptual design with final choices of technology made and with a believable cost estimate. The R&D program is international in scope, and the collaborations between the various laboratories engaged in this effort are reasonably effective. Perhaps at the next accelerator conference (three years from now), we will be able to see the details of many versions of the next-generation machine.