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PANEL DISCUSSION ON LABORATORY ACCELERATOR PROGRAMS – PRESENT AND FUTURE*

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In this talk I will briefly summarize the present SLAC accelerator program and then spend most of my time talking about the future of electron-positron linear colliders.

SLAC's present complex of accelerators includes the PEP storage ring (up to 30 GeV in the center of mass), the SPEAR storage ring (up to 7.5 GeV in the center of mass), and the Linear Accelerator (up to 32 GeV, increasing next year to 50 GeV). We are completing the SLAC Linear Collider (SLC) project and will start the physics program of this new colliding beam facility next year. The main parameters of the SLC are a center-of-mass energy up to 100 GeV, an invariant beam emittance of 3×10^{-5} m, an energy spread of $\pm 0.2\%$, a design luminosity of 6×10^{30} cm^{-2} s^{-1}, and a beam radius at the collision point of about 1.5 microns. A schematic of the SLC is shown in Figure 1. This project uses a single linac to accelerate both electrons and positrons in a single pulse of the machine and bring these beams into collision with a magnet system. This "one linac" variant of a linear collider can, in principle, be used up to an energy of about 100 GeV per beam before the emittance growth from quantum fluctuations in synchrotron radiation occurring in the magnet system begins to cost too much in luminosity.

The status of the SLC can be briefly summarized as follows. Tests of many of the systems associated with the linear accelerator have already started. Beams of the required emittance have been produced in one of the damping rings,

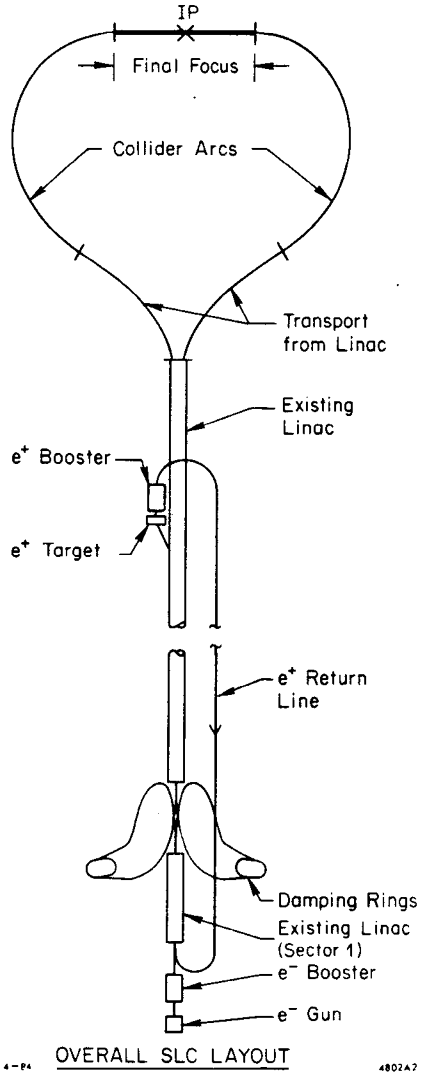

Figure 1. Schematic of SLC.

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Invited talk presented at the XXIII International Conference on High Energy Physics, Berkeley, California, July 16-23, 1986 reinjected into the linac and accelerated to about the 2/3 point of the machine. About 60% of the new 50 MW klystrons required for the energy upgrade of the linac are in place, and we expect to have the full complement of these high-powered tubes installed by the Spring of 1987. All of the magnets for the collider arcs are completed, and about 85% of them are installed in the tunnel. The interaction hall is also completed, and the major components of the Mark II detector are in place. The project is well on its way, and given luck and a sufficient FY87 budget, we expect to start colliding beam trials around the first of the year and hope to begin the first physics experiments in the springtime. The cross-section for Z^0 production is so large that we will get around 15 Z^0 events per day at a luminosity of only 10^{-3} of the design luminosity. It is only because of this very large cross-section and the scarcity of Z^0 events in the world that it will be productive from a physics point of view to begin experimentation at a luminosity much below the design luminosity.

I now want to change the direction of this discussion from "now" to "next." We at SLAC believe that "next" for us is a larger scale linear collider, and we also think that for the distant future, when effective center-of-mass energies beyond those attainable with the SSC are needed, linear colliders will be there to do the work. An increasing number of physicists at other institutions in the U.S., in Europe, in the U.S.S.R., and in Japan are also becoming convinced that linear colliders are the wave of the future. That may seem to be a strange statement when such lovely physics is coming from the CERN $Sp\bar{p}S$ (600 GeV c.m.), the Fermilab Tevatron collider (2 TeV c.m.) is about to turn on, and the U.S. high-energy physics community is hard at work on the details of design of the SSC (40 TeV c.m.). To extend the comparison between linear colliders and proton machines, I must first digress a bit into the physics of proton colliders.

Protons are composite particles, and the energy of the proton is shared among its constituents. The collisions in which we are really interested are not proton-proton collisions, but rather hard parton-parton collisions. The mass reach of a proton collider is determined by the parton distribution within the colliding protons, by the energy of the protons, and by the luminosity of the machine. Thus the 600 GeV $Sp\bar{p}S$ can access states with masses of up to 100 or 150 GeV; the 2 TeV Tevatron I has a mass reach of 300 to 400 GeV; and the 40 TeV SSC with its very high luminosity has a mass reach of about 3 TeV. Because of the scaling of parton-parton cross-sections with final-state mass and beam energy, an increase in mass reach beyond the SSC by a factor of 10 requires both an increase in machine energy by a factor of 10 and an increase in luminosity by about a factor of 100. For many technical reasons (including such things as synchrotron radiation, luminosity lifetime, detector problems, multiple events per crossing, etc.), I doubt that we can go significantly beyond the mass reach of the SSC using proton colliders.

In contrast to protons, electrons and positrons are elementary particles (at least so far), and the collision energy is not shared among constituents. Thus, to equal the SSC in mass reach one need only build a 3 TeV c.m. electron-positron machine. The luminosity requirements for e^+e^- machines are large if one is to get sufficient events in the face of a cross-section decreasing like E^{-2}.

It is possible to specify most of the parameters of an electron-positron linear collider using as input only the desired energy, the luminosity, and the properties of the beam–beam interaction. Table I shows the parameters of some variants of a 10 TeV c.m. linear collider compared with the parameters of the SLC. The luminosity required is up by more than three orders of magnitude; the beam power is up by one to two orders of magnitude; and the beam size at the collision point is down by about three orders of magnitude. These parameters pose a formidable challenge to the accelerator designer, and the biggest problem will probably be that of getting beams with transverse dimensions measured in tens of angstroms to reliably and stably collide with each other.

All of these parameters are derived without considering the acceleration system at all. However, most of the cost of the project will be in the cost of the acceleration system, and we can set three general requirements that must be satisfied by any suitable acceleration system. It must be cheap, it must be stable, and it must be efficient. Groups are working on a variety of new technologies for acceleration, including lasers, plasmas, and a variety of what might be called two-beam acceleration systems. These two-beam systems share the general characteristic of having a high-intensity, low-energy beam somehow transfer power to a lower intensity beam which is then accelerated to high energy. Examples of two-beam systems include such things as conventional linacs, where one of

Table I. Parameters of some 10 TeV (c.m.) linear colliders compared to the parameters of the SLC. The c.m. energy spread, σ_{E^*}/E^*, is the contribution of beamstrahlung only.

MACHINE	L.L.C.			SLC
E^* (TeV)	10			0.1
$\mathcal{L}$ ($\mathrm{cm}^{-2}\mathrm{s}^{-1}$)	10^{34}			6×10^{30}
σ_{E^*}/E^* (%)	10			0.04
β^* (cm)	0.1			0.5
D	0.1			1.0
P (MW)	1	3	10	0.16
f (Hz)	3000	9000	30,000	180
N (e^+ or e^-)	4.1×10^8	4.1×10^8	4.1×10^8	5×10^{10}
ϵ_N (M)	4×10^{-9}	1.2×10^{-8}	4×10^{-8}	3×10^{-5}
σ_{r_o} (micron)	6.4×10^{-4}	1.1×10^{-3}	2×10^{-3}	1.5
σ_z (mm)	3.4×10^{-4}	1×10^{-3}	3.4×10^{-3}	1.5

the beams is in a klystron while the other is in the accelerator; wakefield accelerators like those under development at DESY; free electron lasers driving conventional structures; etc.

It is my personal opinion that the stability requirement will rule out laser, plasma, and some of the wakefield accelerators. To see why, I must define what is meant by stable acceleration. "Stability" simply means that the random transverse momentum delivered to the two beams is sufficiently small so that they can be made to collide with each other on each pulse of the accelerator. Very roughly, that stability criterion turns out to require that the random transverse component of the acceleration be about 10^{-6} of the longitudinal acceleration per stage.

I don't believe that lasers can satisfy the stability requirement, for all efficient high-power lasers are multi-mode lasers, and this type of laser does not have a stable mode pattern. I don't believe plasma accelerators can make it, for the plasma density has to be excruciatingly uniform. I don't believe that low-Q wakefield accelerators can make it, for the requirements on uniformity of the driving beam are extremely tight. To my mind, conventional linacs driven by conventional (klystron-like) or unconventional RF sources (FEL's like Sessler's or superconducting power generators like Schnell's) are what is required to do the job.

Until recently, the bulk of the R&D work had been done in the U.S. on these types of systems, but now Japan and Europe are making increasingly important contributions. I believe it will be easy and appropriate to get international cooperation in this R&D phase of linear collider development. Of course things may get a bit more tense in the international relations field when it comes time to choose Geneva, Stanford or Tsukuba as the site for the next machine. We will learn a lot in the next few years from the operation of the SLC and from the multinational R&D program that will occur. I do not believe that the next step in linear colliders beyond the SLC will be the 10 TeV machine described in my Table. That is too big a distance from the parameters of the SLC to be covered in a single step. Thus we will have to see a machine of 1 ± 1/2 TeV as a "intermediate" machine. It is "intermediate" only when compared to the machine of Table I — it will be a very exciting research tool in its own right. Our own accelerator R&D program at SLAC is aimed at trying to produce a design for this intermediate machine in about five years. That is an extremely difficult task, but will be made much easier by the entry of many more groups around the world in the R&D program.