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THE FUTURE OF ELECTRON COLLIDERS*

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The construction of the first electron storage ring, the Princeton-Stanford machine, was begun in 1958. The construction of LEP, the newest and largest of the electron storage rings, is beginning now in 1982. In this period of about twenty-five years the radii of these machines have grown five-thousandfold, from about 1 meter to about 5 kilometers. At the same time the energy of the machines has increased a hundredfold, from the 500 MeV of the first machine to the 50 GeV of LEP. I believe many more storage rings will be built in the future, but these machines will not significantly advance the energy frontier for e^+e^- physics beyond that which can be reached in the second phase of LEP (about 200 GEV in the center of mass).

It is the scaling laws for storage rings which will limit their advance in energy. When electrons are bent in a circle they emit synchrotron radiation and the energy loss per turn required to make up for this synchrotron radiation

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goes up as the fourth power of the energy divided by the first power of the bending radius. Radius-dependent costs, such as magnets, tunnels, etc.; power-dependent costs for the rf system required to make up synchrotron radiation losses; constraints on machine design coming from the beam-beam interaction and the focusing system result in a system of equations that allow the designer to minimize the cost of a machine. For an electron storage ring, the minimum cost solution is one where cost and size are proportional to the square of the center-of-mass energy. The same scaling law is obtained whether a superconducting or conventional rf system is used.

LEP-I costs about \$500 million to obtain 100 GeV in the center of mass. I will guess that LEP-II at 200 GeV in the center of mass with superconducting rf will cost about \$200 million additional. Using the scaling law implies that a 1-TeV machine, which is a non-unreasonable next step, would cost about \$17.5 billion, have a circumference of nearly 700 kilometers, and consume gigawatts of electric power. While the cost of such a device is negligible compared to the arms budget of the world (very roughly \$600 billion per year), it is quite large compared to the total high energy physics budget of the world (about \$1.4 billion per year). The fiscal feasibility of such a storage ring is in doubt, and, in addition, there is some evidence that there are technical problems in building machines this large.

This situation, wherein cost or technical limitations closes the energy frontier for a given type of accelerator is not new. An examination of the Livingston plot (Fig. 1) shows that we have faced this problem often in the past. For many years the energy frontier for accelerators has moved up by a factor of 10 every six years. We have maintained the pace by switching to new types of accelerators when one type has reached technical or fiscal limitations.

Is there an alternative to the storage ring? I think there is, and I think it is the linear collider system whose scaling laws were worked out at the first ICFA workshop by Tigner (Cornell), Skrinskii (Novosibirsk), myself, and others. The luminosity of these machines is proportional to the power in the beam and independent of the energy. The scaling law is such that the cost and length of a facility, where two linacs fire intense electron and positron bullets at each other, are proportional to the first power of the energy rather than to the square. Linear colliders tolerate a much stronger beam-beam interaction than do storage rings, and the beam-beam interaction seems to enhance the luminosity rather than to decrease it, as is the case in storage rings. There are new issues in accelerator physics involved in linear colliders, among which are the production and control of micron-size beams at the collision point, and the handling of peak currents in linacs that are a hundred times more intense than we are used to.

At SLAC we hope to start building a variant of the linear collider scheme - the SLC - in late 1983, if the U.S. Government follows the recommendations of its Department of Energy Advisory Committees and supplies the funds. The SLC, when completed (at the end of 1986 at the earliest) will allow us to investigate such things as the beam accelerator interaction, the beam-beam effect, control problems, etc., as well as to carry out an exciting high energy physics experimental program at 100 GeV in the center of mass.

But what about very large linear colliders? The SLC doesn't advance the energy frontier beyond that which can be reached by the LEP storage ring. I guessed earlier that the next step in big colliders would have to reach about 1 TeV in the center of mass, where theory indicates that the next mass scale might lie. If we use the Weinberg-Salam model as a guide, such a machine will need a luminosity of $10^{33} \text{ cm}^{-2} \text{ sec}^{-1}$, for above the Z^0 mass, the cross section decreases as the square of the energy. Extrapolating from some parameters of the SLC, I find that a machine with a luminosity of 10^{33} will require a beam power of about 7 MW per beam. If we can make energy efficient, low cost per unit length accelerators the world high energy physics community can afford such a machine at its present budget level. However, we don't now know the best way to build such a machine and an intense R & D program will be required to determine the best road.

The first decision which one might make I would call the "warm or cold" decision, i.e., normal or superconducting rf structures. Table I shows what one might expect for a superconducting system based on presently achievable Q. The table assumes a Q of 5×10^9 at S-band, a refrigerator efficiency of 0.1% at 2.3° K, a heat leak to room temperature of 2 watts per meter; and then displays as a function of accelerator gradient the length of the system, the refrigerator required to handle the load coming from finite Q and the refrigerator power required to handle the load from the heat leak. At present we can probably obtain a gradient of 5 MV per meter reasonably reliably. This gradient is at the power consumption minimum, but using some cost per unit length figures for superconducting structures from Tigner, it is not at the cost minimum. The cost minimum would occur at a gradient of about 20 MV per meter. At this minimum the construction costs for a superconducting system would be, very roughly, down by about a factor of 5 from the scaled storage ring. I would conclude that superconducting systems need considerable work on improving the attainable gradient and cavity Q's to reduce costs significantly.

There is much activity in the study of warm systems, all of which emphasizes high accelerating gradients which are required to reduce the effect of the beam accelerator structure interaction and to reduce capital costs. Below is a brief description of four systems that I know about -- there

may be more.

a. Conventional rf structures with high-power sources.

At SLAC in the mid 1960's it was shown that copper can stand surface fields of at least 150 MV per meter. These fields imply, in properly designed structures, accelerating gradients of more than 100 MV per meter. Such structures need gigawatt peak power sources to drive them. The Novosibirsk group will soon be testing a structure designed for these kinds of accelerating gradients, and preliminary design studies on structures and power sources are going on at SLAC.

b. RF transformer systems. These transfer the energy from a low energy, high current beam to accelerate a lower current beam. An example of this type of system is the "Wake Field" accelerator of Voss and Weiland which will be discussed later at this meeting.

c. Laser accelerators. One of the early suggestions for a laser accelerator was that of Palmer which proposed the use of the longitudinal field near a grating for accelerating particles. A system which promises a larger phase acceptance is what might be called a laser "beat wave" accelerator recently described by Tajima and Dawson. In this system two laser beams are fired into a plasma. The difference in frequency of the lasers is equal to the plasma frequency. This generates a traveling plasma wave with a large electron density that does the acceleration.

d. The ionization front accelerator. The advance of

a high current, low energy electron beam entering a neutral plasma is controlled by the ionization of the plasma with an auxiliary laser. The ionization front is made to travel in synchronism with the velocity of the particles to be accelerated. Olsen et al., Sandia, have demonstrated proton acceleration of about 5 MeV in 10 cm with this system.

One can see there are many new ideas for accelerating systems. Not all of them will be applicable to the acceleration of the very small, very intense beams required for linear colliders, but in the next few years we will have to see which of these (or other) systems shows the most promise and to begin prototype accelerator system studies to evaluate costs and technical feasibility. I would hope to see a 1 GeV accelerator, less than 10 m long, in the late 1980's. Once we have reached this stage we can then begin a large-scale physics machine aimed at reaching greater than 1 TeV in the center of mass. Since many of these promising ideas are new, there are no "experts" and any of the physics community can contribute. I look forward to an exciting decade of development.

TABLE I

Some parameters of superconducting linear colliders
 For various values of accelerating gradient (G),
 I give the total length of the two linacs ($2L$),
 the refrigerator power required because of finite
 Q (P_Q), the refrigerator power required because of heat
 leaks (P_L calculated for a heat leak of $2W/m$) and the
 total refrigerator power (P_T).

G MV/m	$2L$ km	P_Q MW	P_L MW	P_T MW
0	∞	0	∞	∞
1	1000	42	2000	2040
2	500	84	1000	1080
5	200	210	400	610
10	100	420	200	620
20	50	840	100	940
50	20	2100	40	2140
100	10	4200	20	4220

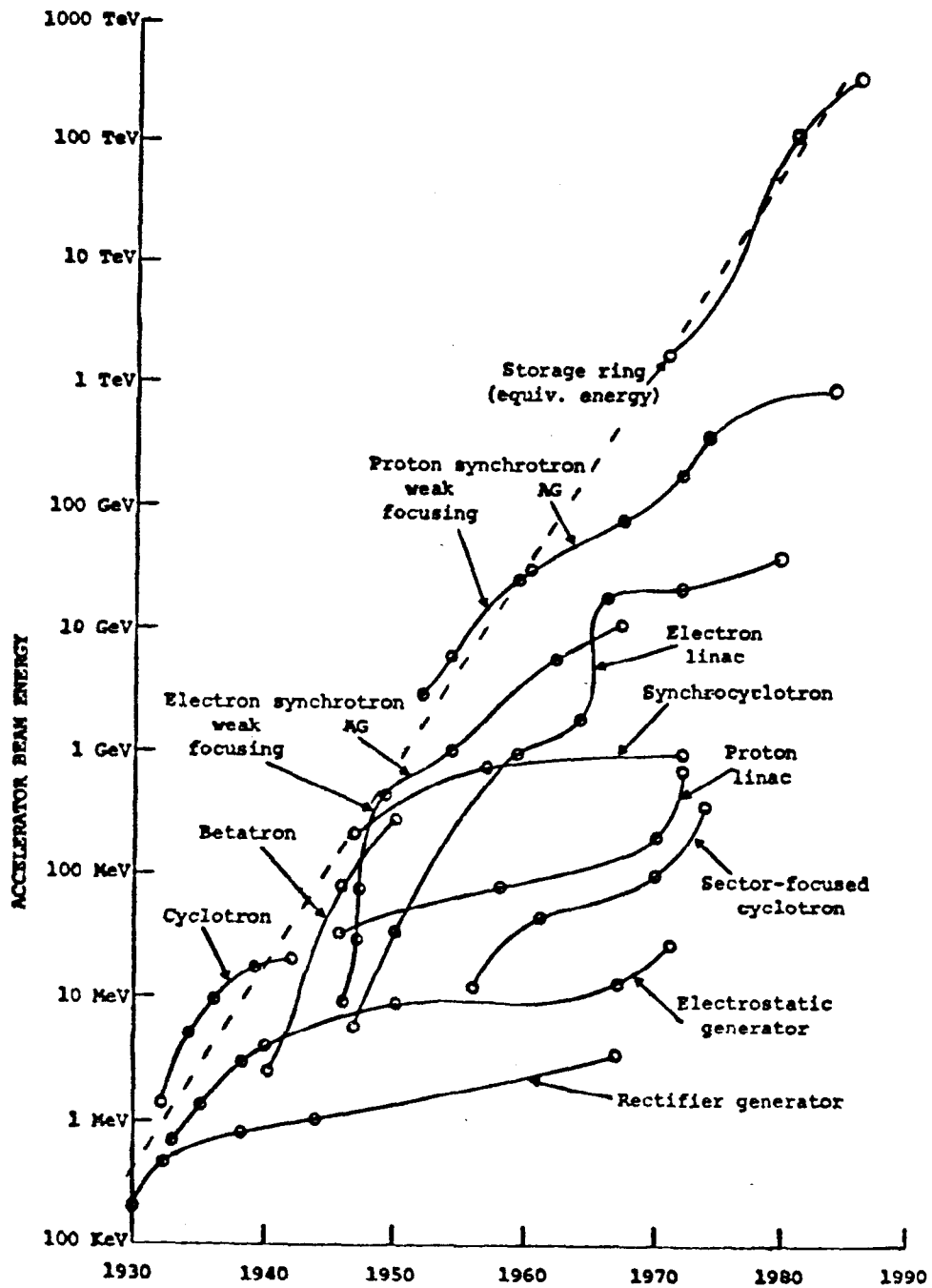


Figure 1
Energy growth of accelerators and storage rings

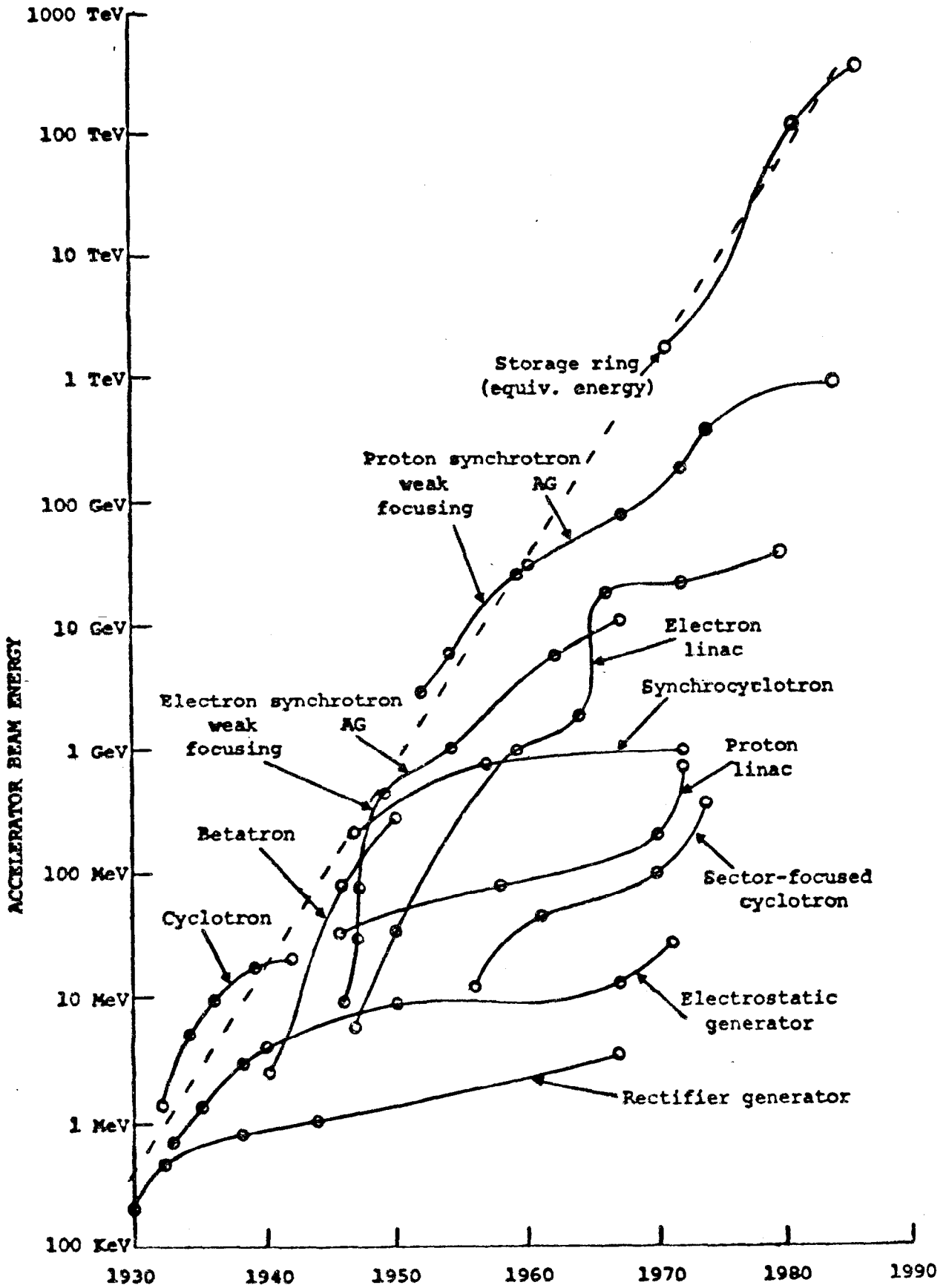


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