COMPARISON OF COLLIDING AND SINGLE BEAM PROTON ACCELERATORS

William M. Brobeck
William M. Brobeck & Associates
Berkeley, California

Summary

Above the presently available energies, the center-of-mass energy per dollar of colliding beam accelerators becomes greater than that of single beam machines. As the energy increases, the economy of colliding beams becomes more pronounced.

The difficulties in using colliding beams are typical of the difficulties accompanying each step made into a higher energy region. It is argued that colliding beams are usable and that the ability to enter an energy region otherwise unattainable justifies the difficulties. Preparing for a major colliding beam installation to come into operation around 1985 is suggested.

The purpose of this paper is to present the argument that the development of ultrahigh energy accelerators must inevitably include colliding beam machines and to suggest how this development might proceed.

The energy obtainable as a function of the construction cost of high-energy proton accelerators is shown in Fig. 1. These costs include the accelerator, its building and utilities, but do not include experimental facilities. The cost of colliding beam machines is estimated for the purpose of this discussion at two and a half times the cost of machines having the energy of one of the colliding beams.

The crossover point at which both single and colliding beam machines cost the same for the same center-of-mass energy should be noted. It occurs at near 50 million dollars and 8 GeV. No great accuracy is claimed for the location of this point, but it is claimed that there is such a point and that it is in the general region of cost and energy of the existing highest-energy machines. Above the crossover point, which is the region in which the next generation of machines will be built, colliding beam machines produce more center-of-mass energy per dollar than single beam machines, and the energy advantage of the colliding beam machines continues to increase monotonically with energy. The relative energy obtained per dollar spent on single and colliding beams is illustrated in Fig. 2. At an expenditure of 1000 million dollars, the factor is sixteen. It is clear that in the 100 to 1000 million-dollar region colliding beams must be taken very seriously. Wherever the upper limit of available funding occurs, the last machine to be built must certainly make use of colliding beams.

There is little reason to doubt that high-energy physics can count on the strong support of the United States government for many years to come. The evolution of our economic system will certainly favor continually increasing expenditures of government funds on undertakings which do not compete with the private economy. The construction of high-energy accelerators is a prime example of such an undertaking. With even the present government research budget of about five billion dollars per year, the funding of a new billion-dollar accelerator installation every ten years or so seems almost a trivial expense. From the standpoint of availability of funds, there seems no reason to doubt the practicality of continually increasing the highest attainable energy for at least several decades to come.

As an engineer, I am in no position to predict the usefulness of this continual increase in available energy. However, I note that over the last thirty years the increase in energy achieved has resulted in production of information that everyone agrees has been worth the cost. In other words, the effort has been to a large extent successful. It is true that the information produced has been greatest in energy bands located usually just above the thresholds for the production of particular particles. However, there seem to be few, if any, barren regions having an energy range of more than three to one. Of course, this line of reasoning is no guarantee that anything will be learned above the present energy level, but it strongly suggests that it will. One may argue that justification must rise in proportion to cost and that pious hope is inadequate justification for spending a billion dollars. On the other hand, the alternative uses of the country's human and material resources may not be justified at all. Accelerator enthusiasts, I feel, have no reason to be embarrassed in the presence of other contenders for government funds.

It is conceivable that theory could evolve to a point at which it could be proved conclusively that an upper energy limit exists beyond which no new information could be obtained. My understanding is that there is no reason to expect such a development.

The prospects for funding and the demand for increasingly higher energies seem good. We should now consider the practical utility of colliding beams in actual experiments.

The difficulties of experimental work with colliding beams compared to the use of single beams mainly involve three considerations.

These are:

a) the collision frequency;
b) the accessibility of the collision region;
c) the background radiation.

Studies[1] of colliding beam accelerator designs lead to the optimistic estimate that circulating currents of 100 amperes with diameters of the order of one millimeter can be obtained.

Two such beams colliding will produce one event per second per meter length at a cross section of 10^{-35} square centimeters. For comparison, a single beam of 10^{13} particles per second will produce 1000 events per second of the same cross section in passing through the same length of liquid hydrogen. This factor of 1000 is the handicap of the colliding beam system at the state of the art circa 1960.

It may well be that colliding beam machines will never equal the possible interaction rate of single machines. If this should prove to be the case, then the inability to see what is happening at cross sections smaller than 1000 times that observable with single beam machines would be the price that must be paid for the higher attainable center-of-mass energy. Note, however, that no machine can go down to zero cross section—there is always room below any particular size as there is above any particular energy. There is good reason to expect that through the results of energetic development present optimistic expectations of beam density can be realized. Furthermore, the possibility of real "breakthroughs" in performance are certainly not ruled out.

The poor accessibility of the colliding beam region compared to the external target of a single beam machine is a matter of the degree of inconvenience and expense that can be tolerated. The use of a single-beam, high-energy accelerator is anything but convenient as it is. However, the necessity for hundreds of tons of shielding, thousands of feet of wire, and dozens of people, not to mention the immense computers required to do experiments in the multi-GeV range, must be, and is, taken in stride by the experimenters. Perhaps there should be a simpler way, but there isn't, and the complication and difficulties are not going to stop the users from getting the information they want. The same philosophy will govern the colliding beam work. It will be even more difficult to work with 500 GeV in the center-of-mass than it is with ten, but we can be sure that there are people who will be willing to do it.

Colliding beam experiments will have to be built into the accelerator to a much greater extent than is the case with single beams. It can be expected that the colliding beam area will have to be rebuilt for each experiment and perhaps only a few experiments can be done per year. Coordination between the machine and the experiment may rise to a new order of difficulty, but the alternative idea that the energy is not worth the effort has never been acceptable in the past and is not likely to be in the future.

Historically, the increase in attainable energy has been paralleled by the improvement of means for discriminating between wanted information and the background. These advances in signal-to-noise ratio have been marked by breakthroughs as have the advances in energy and have owed as much to ingenuity and invention. Typically, each new particle or effect must be found like a needle in a haystack of background radiation.

The background problem in colliding beam experiments to the extent that it is caused by residual gas in the accelerating tube seems the most tractable of the colliding beam difficulties. Background estimates have been based on pressures of 10^{-8} to 10^{-9} torr, a respectable pressure in 1960. By 1980 or so, thanks to cryo techniques and the continued effort to be expected, due in part to NASA, pressures of 10^{-12} or better should be attainable. Attainment of such pressures will require only plenty of refrigeration and meticulous attention to detail on a large scale—things that can be bought with money.

If the case has been presented fairly, colliding machines are useful, are wanted, and are within our means. There remains the question of how best to plan for their realization.

The first possibility that comes to mind is, of course, the attachment of colliding beam facilities to single beam accelerators. This can be objected to on good grounds. First, consider the case of addition to the present CERN and Brookhaven AGS machines. The energy of these machines is so low that it is difficult to justify spending the money for their colliding beam facilities instead of using it to build higher energy, single beam machines. The advantages of colliding beams are just not sufficiently outstanding to make them the obvious choice for the next step in energy.

At the next higher level of expenditure—say 500 million—the situation is different. Here, colliding beams give ten times the energy per dollar of single beam machines. As this level of spending is probably a decade away, recommendation of how half a billion dollars should be spent ten years from now would be unreasonable. However, one can theorize about the situation. One not unlikely combination is the following: There is no problem in funding of several machines, many physicists favor single beam machines at all expenditure levels, and there is no reason to change our opinion as to the utility and economy of colliding beam machines. In this case, the obvious solution is to build both. It is difficult to argue that this is not a real possibility.

If a colliding beam machine in the "under a billion" dollar class is to be built, it is clear that a considerable study effort should be made before construction is begun. Such an effort should include the construction of a test machine of the order of 10 GeV on which physics as well as machine experiments could be run. This development should not take place in a laboratory built around an existing high-energy machine for the reason that, in this case, the colliding beam work would necessarily have second priority. To ensure the best work, development of the colliding beam machine should be the principal purpose of the laboratory.

The colliding beam machine study should be timed to correspond to the completion of the full-scale machine in approximately fifteen years. A longer period would make it difficult to hold the required staff, considering the human desire to see the results of one's work. It would be appropriate for the full-scale colliding beam installation to follow a 1000 GeV accelerator by, say, five years. Such a decent interval would, among other things, reduce competition for personnel. Figure 3 illustrates such a time sequence with the full-scale colliding beam machine completed in 1985.

If one agrees with the discussion presented, it seems inescapable that a colliding beam facility having a center-of-mass energy of 500 GeV should be planned for completion in 1985 or thereabouts and that a development project at its own site should be started around 1970. Such a program can be expected to advance our knowledge in the important and expensive field of nuclear physics with all deliberate speed.

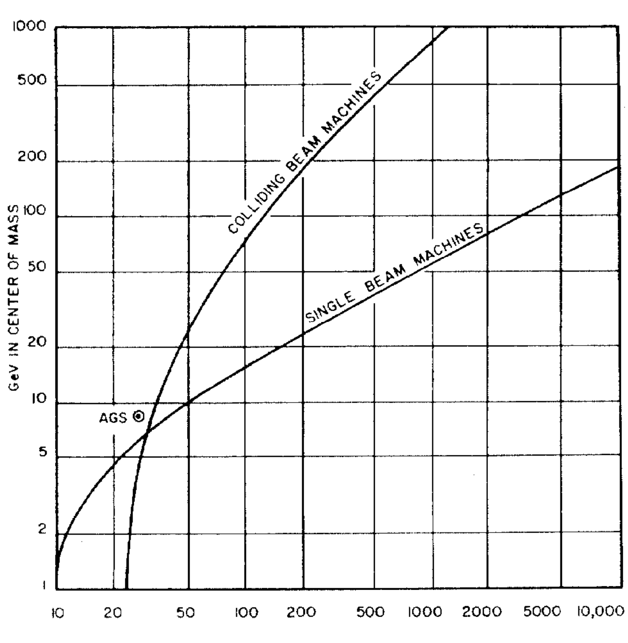

Fig. 1. Costs of proton accelerators.

References

1. 1961 Intl. Conf. on High Energy Accelerators, Proceedings:
H.G. Hereward, K. Johnsen, A. Schoch, and C.J. Zilverschoon, "Feasibility of storage rings for the CERN proton synchrotron," pp. 265-271.

Intl. Conf. on High-Energy Accelerators and Instrumentation, CERN 1959, Proceedings:

L.W. Jones, "Experimental utilization of colliding beams," pp. 15-22;
G.K. O'Neill, "Experimental methods for colliding beams," pp. 23-26;
K.M. Terwilliger, "Achieving higher beam densities by superposing equilibrium orbits," pp. 53-57;
G.K. O'Neill, "Storage rings for electrons and protons," pp. 125-134.

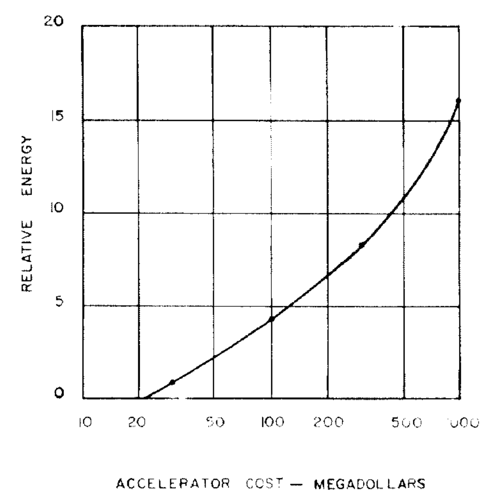

Fig. 2. Relative center-of-mass energy per dollar--colliding vs single beam machines.

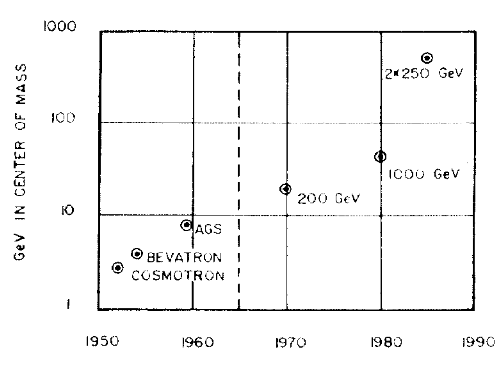

Fig. 3. Possible future energy limits.