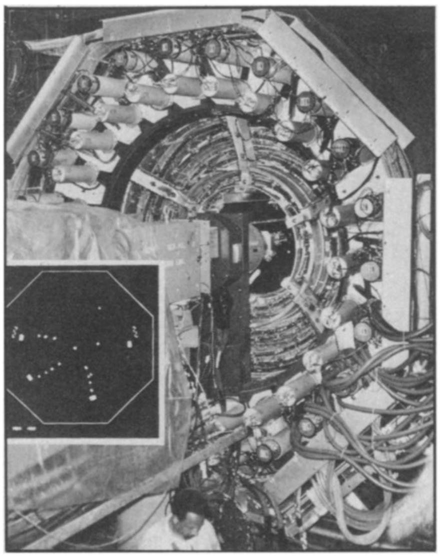
Head-On at 100 Billion Volts


Vespignani/CERN

Electron-positron collisions at fairly modest energies have already won (part of) a Nobel Prize. In future they may investigate the basic unity (or lack of it) of physics.

BY DIETRICK E. THOMSEN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Track of the first psi and its detectors.

It is characteristic of particle physicists that the equipment they are working with is always one generation behind the equipment they are building (or would like to be building) and two generations behind the equipment they are starting to plan. So when Burton K. Richter of the Stanford Linear Accelerator Center titled a talk at the recent meeting of the American Physical Society in Washington, "The Future of Electron-Positron Storage Rings," his audience could be sure that the future was at least two steps beyond the storage ring and colliding-beam installation Richter now works with, which is called SPEAR.

Colliding beam facilities are one of the great success stories of the past decade. In them two beams of accelerated particles, which have been going around and around in the storage rings, are brought together from opposite directions and collide head-on. The advantage of this is that all the energy brought by both beams is available for the generation of new phenomena to study. In the other kind of particle-physics arrangement, in which an accelerated beam strikes a stationary target, the momentum of the moving beam must be preserved, and a lot of energy is tied up in that, and otherwise unavailable. But to make colliding beams was a formidable engineering problem, involving such things as the density of particles in the beam, precise focusing and precise aiming, and when they were first proposed many physicists believed they would never succeed. When the first ones worked, they made a lot of converts. Now every particle physicist wants one.

To cite just the electron-positron variety of colliding beam facility (there are also the proton-proton kind), there are examples of SPEAR's class in Germany (at Hamburg), Italy (at Frascati) and Armenia (at Yerevan). This group can produce energies up to about 5 billion electron-volts (5 GeV) per particle beam. Two of the next generation (up to 20 GeV per beam) are under construction: PETRA at Hamburg and PEP at Stanford. What Richter was proposing (at a symposium in memory of Gersh Istkovich Budker of the Soviet Academy of Sciences at Novosibirsk, who was one of the early champions of the colliding-beam idea) was machines in the range between 50 and 100 GeV per beam. He stressed that they must be designed not merely to produce more and bigger of the same — though that might itself be interesting and important — but to enter a new territory in the study of the fundamental structure of matter.

Electron-positron collisions have an aspect that is especially significant for fundamental studies: They involve the annihilation of matter and antimatter. Thus each such collision produces a photon, which is matter, antimatter and energy at the same time. The photon can turn itself into a variety of particles and antiparticles according to the amount of energy it has, and in fact it does so quite readily. Some of the things that have been made in electron-positron collisions have never before been seen in experimental physics.

Because electrons, positrons, and photons are the basic particles of electromagnetism, a good deal has been learned about electromagnetic behavior from electron-positron collisions. But a good deal was already known about electromagnetism. What has been more exciting are the discoveries in the domain of the strong interaction. The strong interaction is the force that binds atomic nuclei together, but physicists believe more and more that the purest manifestation of the strong interaction is in the internal structure of the nuclear particles themselves, inside the protons and neutrons themselves, as well as the many particles related to them.

According to the most current theory such particles, called as a class hadrons, are built up out of subparticles called quarks, which are bound together inside the hadrons by an extremely strong force. It has not been possible so far to observe a free quark nor to study directly the forces between quarks, but the theory is widely accepted because it predicts the properties of the known hadrons quite well.

It has proved possible in the current generation of electron-positron collision experiments to produce a whole family of hadrons that were unknown before, the so-called psi particles. (The discovery of the first psi, in 1974, won the 1976 Nobel Prize in physics for Richter and for Samuel C.C. Ting of the Massachusetts Institute of Technology.) The existence and behavior of the psi family permits new comparisons between the predictions of the quark theory and reality, especially as it appears that the structure of the psi's involves a variety of quark not present in the hadrons known before the discovery of the psi's, the so-called charmed quark.

The charmed quark was the fourth quark to manifest itself. The hadrons known before the psi's require three varieties of quark to explain their properties. Lately a fifth variety, the "bottom" quark, has shown up in the particle called upsilon, which was first found at the Fermi National Accelerator Laboratory in the summer of 1977. Now the upsilon has also been found at the DORIS storage ring, the electron-positron facility in Hamburg.

So Richter can say that the present generation of electron-positron facilities have learned a good deal about the strong interaction. It is expected that the second generation, the PETRA machine at Hamburg and the PEP machine at Stanford, will learn a good deal more. It is likely that they will find more new hadrons, possibly some that contain the sixth variety of quark, which is the only undiscovered one that theory now envisions. But it is not more of the same, or only more of the same, that Richter invokes to justify the third generation machine he proposes.

There is still another force active among the subatomic particles. It is called the weak interaction or weak force because it is much weaker than the strong force. The weak interaction is less understood than

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... Colliding Beams

the other kinds of force in nature, but it has a particular importance in the present state of physical theory. In the theorists' grand attempt to develop a unified field theory, a scheme that will collect all the varieties of force in nature into a single explanatory framework, it happens that the weak interaction is one of the most convenient for mathematical physicists to start with. An experimental entry into the domain peculiar to the weak interaction could thus test the current unifying efforts and give some indication whether the mathematical architecture on which they are based is likely to hold up when the strong interaction and gravity are added to the present efforts, which bring together the weak interaction and electromagnetism.

It is this domain that Richter proposes that the third generation electron-positron colliding-beam facility enter. The energy criteria can be determined by a simple question: What is the threshold at which the intermediate vector boson, the particle that embodies the forces of the weak interaction, can be produced? (In modern physical theory, forces are represented by particles: A force between two bodies is equivalent to the exchange of a stream of intermediate particles between them. Each kind of force has its own particular intermediaries.)

Richter determines the lower threshold on the basis of producing a single, electrically neutral intermediate vector boson — they are also called W or Z particles. That is about 100 GeV. Furthermore, if the machine gets above this level, "the weak interaction will dominate no matter what theory is true." The upper threshold is determined by the unified field theories, which add to the electrically neutral W^0 a pair of charged intermediate vector bosons, Z^+ and Z^-. The charged ones must be produced in pairs, so the higher threshold is 200 GeV.

Richter reviews a number of options for reaching this energy range and finally concludes that the sort of machine he calls a "big 50" would be best. This would be built to produce first a beam of 50-GeV electrons and one of 50-GeV positrons (thus 100 GeV in all) and be expandable in energy to 100 GeV per beam. The energy expansion would be done by substituting superconducting elements for ones employing ordinary conductors as they become available. It would not be wise to wait until superconducting equipmment is available and build the 100-GeV beams right off, Richter says. Little money would be saved, and time would be lost.

Will such a thing ever be built in the world? Richter believes that it will be — in Europe. "How are we [American physicists] going to get involved?" he asks. "As visitors." Historically there has been much more interest in storage rings and colliding beams in Europe and somewhat more support from European governments than in the United States.

If one such machine is built in Europe, does the world need two? Richter answers yes, because the competition is healthy scientifically and psychologically. But if one is built in the United States, it should not come along five years after the European effort. Every machine needs a period of excitement when it represents the newest physical effort in the world. Five years later it has already been upstaged. ☐

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