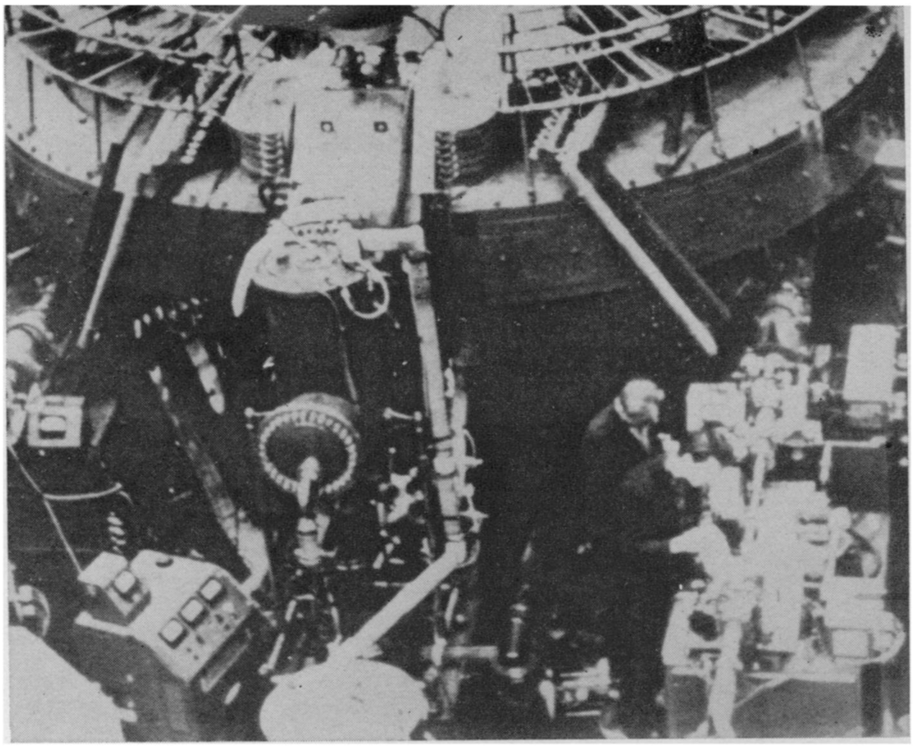
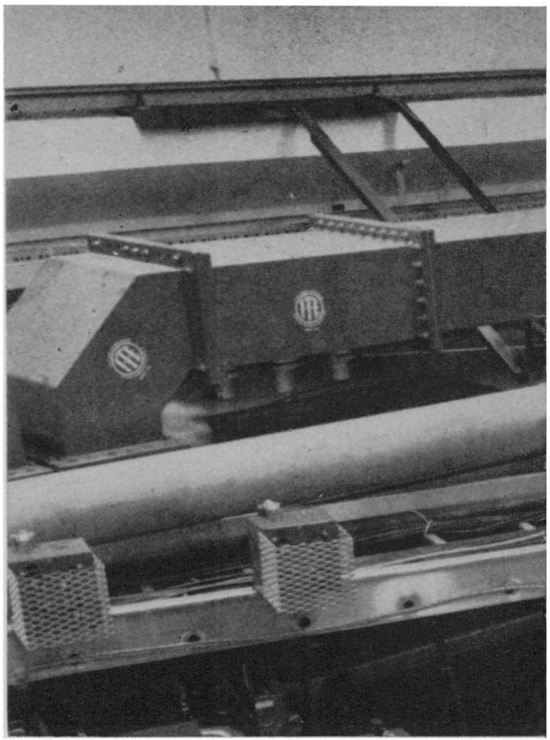


W. K. H. Panofsky



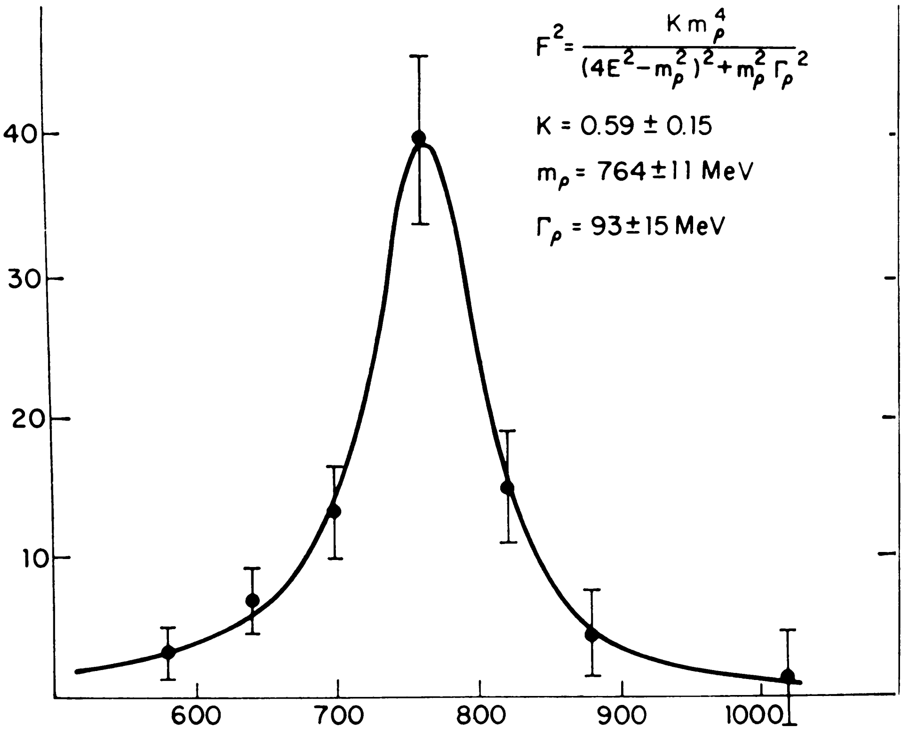
The storage ring at Novosibirsk is the envy of less fortunate physicists.

A surge of colliding beams

Head-on collisions of particle beams in storage rings promise economical attainment of high-energy reactions

by Dietrick E. Thomsen

The "beautiful, clean curve" from the Novosibirsk experiment peaks at the rho meson mass-energy of 750 Mev.

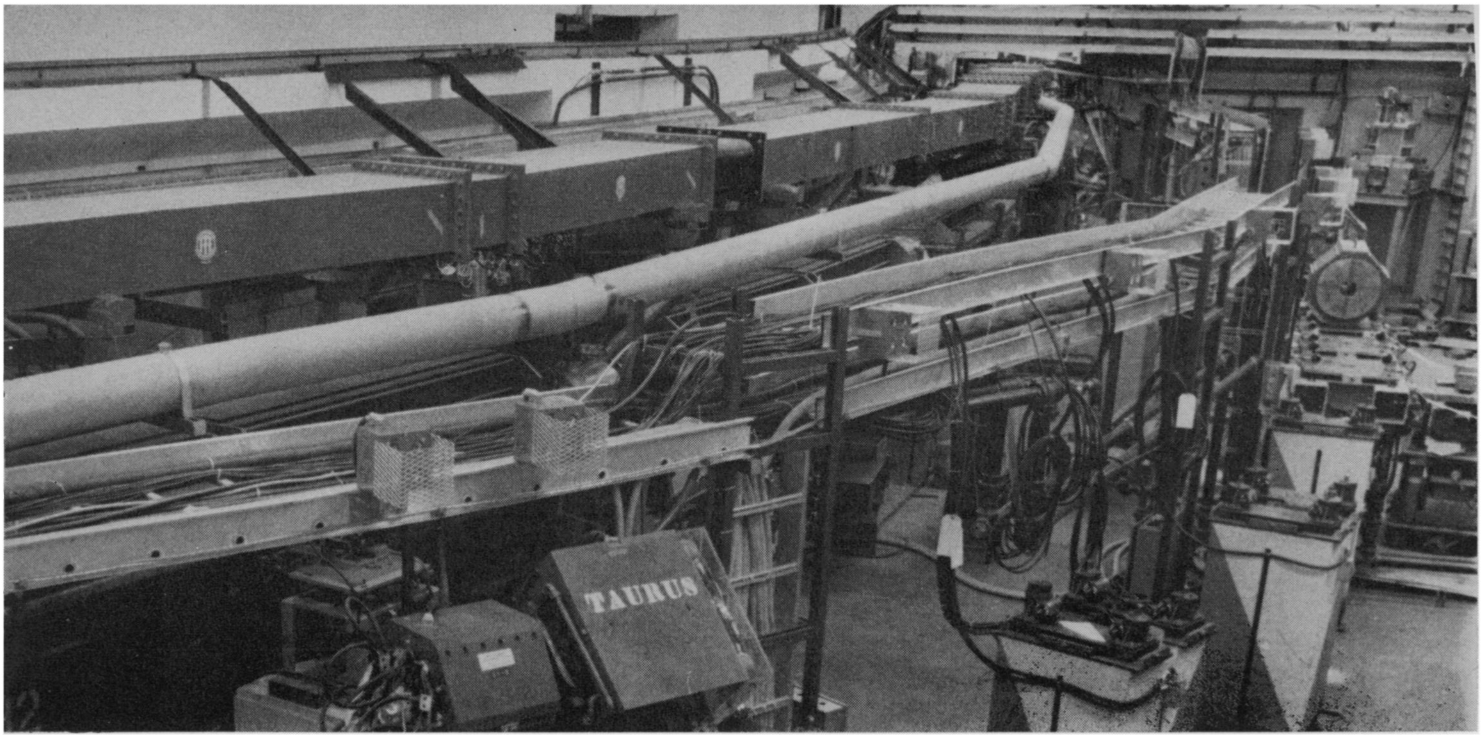


Particle physicists seek to discover the principles that govern the microcosm by studying the structure of elementary particles, the ways in which they are formed and destroyed, and the forces they exert on each other.

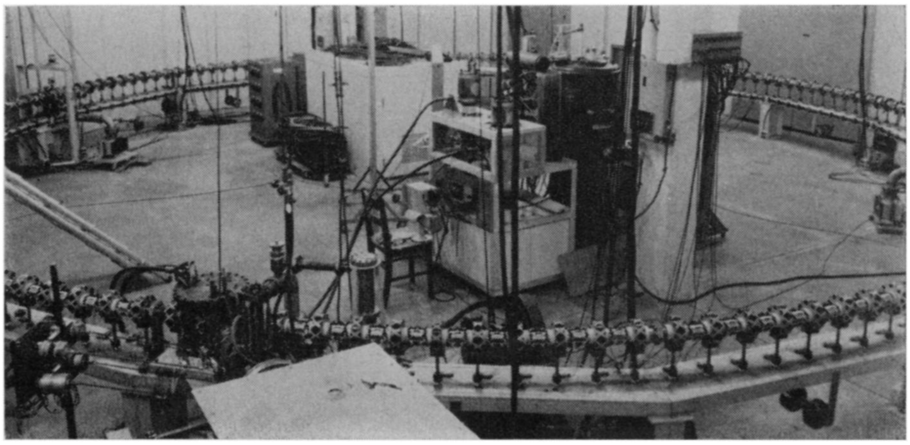
The usual way of doing this has been to accelerate either protons or electrons in an accelerator and let them strike a stationary target. The target either contains some other particle to be investigated—say protons in liquid hydrogen—or by interacting with the incoming particles produces a stream of some third kind of particle to be used in the experiment.

The finer the effect to be studied, the higher the energy (shorter the wavelength) needed to bring into the interaction. For this purpose bigger and bigger accelerators are continually being built. But as energies get higher, a large increase in accelerator energy produces only a small increase in interaction energy.

This diminishing return occurs because the momentum that the acceler-



CEA
The Cambridge Electron Accelerator is being modified with a bypass to create a working storage ring capability.



NRL
An early prototype electron storage ring was built at the Naval Research Lab.

ated particles bring to the interaction must be carried away by particles coming out of the event. In an inelastic collision the impinging particle and the target join together and donate the energy of the former and the mass of both, to create one or more others.

But these daughter particles move away more or less in the same direction that the impinging particle was going. This takes energy, and to provide that energy, part of what was brought by the accelerated particles becomes unavailable for creation of the masses of daughter particles.

The higher the accelerated energy, the greater the proportion that goes into moving the daughter particles and the smaller the percentage available to create them.

One can get around the momentum problem by having two beams of particles hit each other head on. If they have the same momentum—and two beams of the same particle with the same energy will—then they will stop each other short. All the energy brought by both beams goes to creating masses of daughter particles, which come into existence essentially at rest.

Such colliding beams can be made in a new breed of physics equipment called storage rings, which collect the beams in a circular track until they are dense enough for a convenient number of collisions, and then strike them together. Protons, electrons and the antiparticles of both—antiprotons and positrons—can be used. Storage rings promise to be an energetically—and therefore monetarily—cheap way of doing certain high energy experiments. The price paid is in the number of reactions that take place: A dense stationary target produces a much higher number than a thin stream of moving particles.

An example of possible saving is a frequently done experiment using protons to produce a proton-antiproton pair. It takes about two billion electron volts of energy to create the masses of the pair. In a colliding beam experiment each beam need bring in only one billion volts of the energy. Using a proton beam against a stationary target requires that the impinging beam carry 10 billion electron volts; eight billion go away as motion of the daughter particles. At higher energies the saving with colliding beams is even greater.

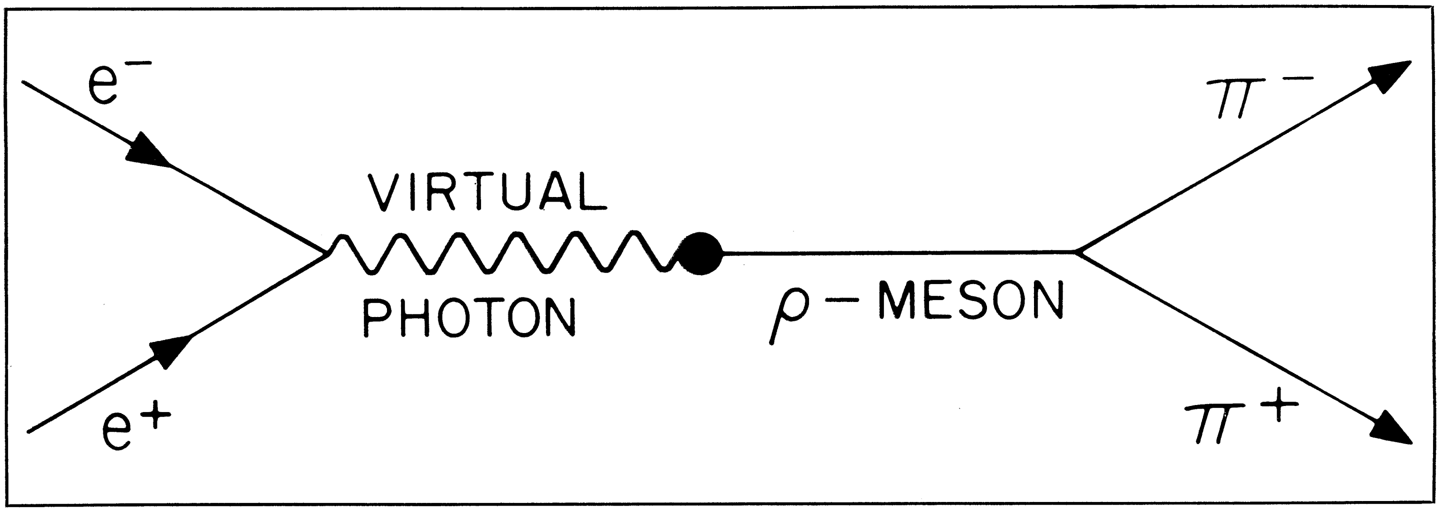
Another area where the energy-efficient storage rings could be used is in testing out electromagnetic theory on the particle level.

Of the four kinds of forces—strong, weak, electromagnetic and gravitational—that govern the interactions of particles, the most useful to the physicist is the electromagnetic. It is of great practical importance because all of chemistry depends on it. Physicists know it best because they have had long opportunity to study it on a macroscopic level. Thus it has served as a way into the microscopic domain—a known key with which to enter the unknown.

The microscopic theory of electromagnetism, known as quantum electrodynamics, has been elaborately developed and makes extremely accurate predictions—as far as it goes. It goes now to distances as small as one million-billionth (10^{-15}) centimeter and collision energies of a billion electron volts. The push is to see whether the theory is valid at shorter distances and greater energies—that is, whether the theory is really exact or only an approximation. Colliding beam experiments with electrons and positrons are expected to help, since the interactions among these particles are purely electromagnetic—no other interaction mixes in to confuse things.

Electron-positron collisions are also promising in the particle creation field. They are, says Prof. Wolfgang K. H. Panofsky of Stanford University, "the cleanest possible situation in which one can create new structures."

When an electron and a positron meet they annihilate to form a photon, which is as near to being a pure bundle of energy as there is. The photon thus produced can change into other particles. It goes most easily into a class called vector mesons because they are "essentially heavy photons," says Prof. Panofsky.



W. K. H. Panofsky

Rho meson production. Electron and positron produce virtual photon that changes to rho, which decays to pi-mesons.

These vector mesons are important because they are believed to transmit some of the forces that exist between particles, and a precise knowledge of their masses and manner of creation is essential to high energy physics.

Vector mesons can be produced in stationary-target interactions—electrons against protons, for example—but in these cases there are always other factors present to complicate matters and render the data imprecise. By contrast, in a positron-electron collision the vector meson, for example a rho meson, may be the only thing that comes out, and the data can then be quite precise—as happened in an experiment done at Novosibirsk in Siberia, which yielded "a very beautiful clean curve from which you can determine the mass," says Prof. Panofsky.

The mass of a rho meson is equivalent to 750 million electron volts of energy; it takes that much to create one. The Novosibirsk experiment was done in a ring whose design energy for each beam is 700 million volts. "Even with a 12 Bev positron ring, which we have at SLAC [Stanford Linear Accelerator], one does not have enough energy to create rho mesons if you hit electrons at rest," says Prof. Panofsky.

With proton and antiproton beams one can study the strong interaction, which is responsible for holding atomic nuclei together but is far less well understood than electromagnetism, and do similar creation experiments.

Storage rings may take their particles already accelerated from another machine, as is planned for protons in a ring to operate with the proton synchrotron at the CERN laboratory in Geneva, or they may act as their own accelerators. The Adone electron ring at the Frascati Laboratory in Italy was planned as a storage ring that contains its own accelerator. The Cambridge Electron Accelerator in Massachusetts was built first as a synchrotron for stationary-target experiments and is now being altered by addition of a bypass so that it will be its own storage ring.

Usually both beams are stored within the same ring and kept separate electromagnetically until time for collision. If both are the same particle, magnetic switching is used to achieve opposition of direction. In the particle-antiparticle case opposition of direction is automatic.

With one exception, all storage rings now in operation use electrons; one at CERN uses mu mesons. All are of rather low energy—the 700 million volt ring at Novosibirsk is exceptional at today's power scale. That laboratory, which is directed by Dr. Gersh Istkovitch Budker, one of the world's most enthusiastic storage ring proponents, is constructing an electron-positron ring for 3.5 billion volts and a proton ring for 25 billion volts.

Dr. Budker does not wait on bureaucrats or budget estimates: "Our chiefs in the Academy of Sciences did not know about this accelerator [the proton ring] until we had built the tunnel."

The only other proton ring now under construction is the 28 billion volt machine at CERN.

Two large electron rings are about to start operating: Adone, 1.5 billion volts, and Cambridge, 3 billion volts. Electron rings at 3 billion volts have been proposed for the Stanford Linear Accelerator and for the Deutsches Elektronen-Synchrotron at Hamburg. And Dr. Panofsky, noted for his ability to get high energy equipment when no one else can, is maintaining pressure for the day when money can be found for the Stanford ring.

Storage rings, useful as they may prove to be, will not put stationary target techniques and their ever more energetic accelerators out of business.

Many experiments in which the event sought is a rare occurrence require the density of a solid target to produce many interactions and so boost the chances. And in cases where the experiment deals with secondary beams of short lived particles that cannot be held in accelerators or storage rings, the momentum properties of stationary-target experiments are beneficial.