New Cornell Accelerator Stores First Beam

CESR, an electron-positron colliding beam storage ring, passes its first milestone 6 months ahead of schedule

Apart from practitioners of the occult, Friday the 13th is traditionally considered a day best spent lying low and not tempting evil spirits. However, physicists at Cornell University, who have been racing for the last year and a half to get a new accelerator into operation, either in a moment of thoughtless folly or of brash optimism successfully challenged the old superstition: On Friday, 13 April, the Cornell scientists stored the first electron beam in their new electron-positron colliding beam storage ring, dubbed CESR. Still to come are producing and storing a positron (antielectron) beam and installing detectors to monitor the results of collisions between the two beams of particles. If all goes well, CESR could be operating at nearly full strength by this fall, several months ahead of schedule. Finishing ahead of schedule and within budget, which has become a habit with accelerator builders, is especially welcome at Cornell because CESR is well suited to investigate the properties of some recently discovered elementary particles (and some expected to be found) that are currently engaging the attention of physicists.

In many respects, Cornell and CESR represent an intriguing departure from the path of most high energy physics in the United States. For starters, Cornell's Wilson Synchrotron Laboratory is supported by the National Science Foundation, whereas all other major high energy physics facilities have been under the auspices of the Department of Energy or its predecessors. Prior to sponsorship by the NSF, the laboratory was funded by the Office of Naval Research, but this agency dropped high energy physics in the mid-1960's as not being related to the Navy's mission. There are other differences, as well.

The most important parameter of a colliding beam storage ring is the energy of the particles in the beams because, when electrons and positrons collide and annihilate, all of their energy can be used to create other particles, which represent the products of the collision. Generally speaking, the higher the collision energy, the more intimate the details of the forces between elementary particles that are revealed by these products. Thus, the thrust of elementary particle physics is to study collisions at ever higher energies.

In this respect, CESR cuts a bit across the grain of high energy accelerators. With a maximum energy of 8 billion electron volts (GeV) per beam, the Cornell machine lies about midway in energy between existing storage rings at the Stanford Linear Accelerator Center (4 GeV per beam maximum) and the Deutsches Elektronen Synchrotron laboratory in Hamburg (5 GeV per beam maximum) and new rings at the same institutions. The new machine at Stanford, scheduled to begin operation this fall, will have a maximum beam energy of 18 GeV, and the comparable storage ring at Hamburg, which began running last summer, will eventually reach a maximum energy of 19 GeV per beam.

Behind this choice lie several considerations, one of which has to do with the characteristics of storage rings. Rivaling the beam energy in importance is a parameter called the luminosity, which is a measure of how often electrons and positrons collide and annihilate. Typically, an electron or positron beam contains some 10^{12} particles, which make a revolution around the ring about once every 10^{-6} second. A storage ring can hold these beams several hours before they need to be replenished, but it is not because of annihilations that the beams decay. Instead, the particles in the beams are lost when they collide with residual air molecules in the ring and are deflected out of the beam. All in all, electrons and positrons collide and annihilate rather infrequently. In some experiments, it may take weeks or months to gather the thousands of events it takes to give statistically significant information.

Thus, says Boyce McDaniel, the director of the Wilson Laboratory, CESR will provide an alternative for physicists interested in experiments at intermediate energies, who might otherwise have to wait months while experiments at high energies are completed at Stanford or Hamburg. The reason for the waiting is that storage rings can operate at only one energy at a time.

A related consideration is that the luminosity is not constant at all beam energies but has a maximum value near the high end of the operating range and drops off rapidly on either side (although less rapidly on the low energy side than the high). The effect is that there is a kind of "hole" in the energy ranges accessible by the old and new storage rings at Stanford and at Hamburg where the low energy machines cannot reach and the high energy machines do not operate efficiently. It is this hole that CESR will fill.

As it happens, some exceedingly interesting physics lies just at these intermediate energies. Since this development was not entirely unexpected at the time CESR was first proposed 4 years ago, this happy situation provides one more justification for Cornell's choosing to go with a medium-sized machine.

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Currently of great concern to physicists is a family of elementary particles called the upsilon family, which was first found 2 years ago by Leon Lederman of Columbia University and his colleagues in an experiment at the Fermi National Accelerator Laboratory's proton synchrotron and more recently confirmed by a group at Hamburg using a storage ring. Additional members of the upsilon family are expected at energies most easily studied by CESR.

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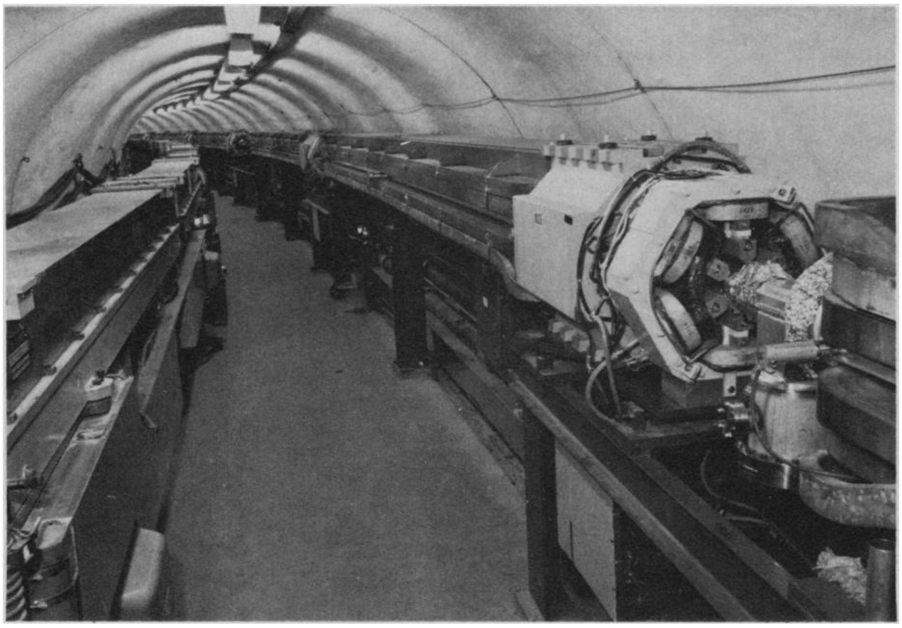


A section of the tunnel housing Cornell's 12-GeV synchrotron and 8-GeV storage ring (CESR). The synchrotron is on the left; CESR is on the right. Once a front-line research machine, the synchrotron now serves only to accelerate electrons and positrons to the energy needed for experiments in CESR.

One reason the upsilon family is of so much importance is that physicists believe these particles consist of a new quark and its antiquark bound together much like the electron and positron in positronium, except that the binding force is the strong nuclear force and not the electromagnetic. Quarks, physicists suspect, are the constituents of most elementary particles, such as the proton, the neutron, and the pi meson. The best way to be sure a new quark is involved is to find related particles that contain one new quark and one of the previously known quarks. Physicists characterize quarks with abstract properties that are given whimsical names, and both "bottom" and "beauty" have been suggested for the new quark. In the upsilon, there is no net bottomness because this property in one quark is canceled by the negative value of the property in the antiquark. The presumed particles with only one bottom quark would, however, exhibit the property of bottomness.

Verifying that there is a new quark is important because physicists do not know how many kinds of quarks there are and no existing theory sets a limit to their number. If there were a definite number of quarks (five are now known if the bottom quark is included), the number could provide constraints that future theories of elementary particles must satisfy.

In addition to settling for an intermediate energy, CESR's designers managed to come up with some other unique features, as compared to other storage rings. One of these, a factor that made the project financially feasible, is that CESR is in the same tunnel (underneath some athletic fields on the Cornell campus) as the university's existing 12-GeV electron synchrotron. Aside from building the ring itself, the only new major construction necessary was to widen the mouth of the tunnel and dig a pit for the large detector that is being placed in the existing experimental hall. The total bill will run to about $20.7 million, including the detector and a new computer to oversee operation of the machine and collect experimental data, according to McDaniel.

CESR consists essentially of an evacuated tube (10^{-9} torr) through which the electrons and positrons circulate in opposite directions. The particles in the beams are actually collected together in bunches (one for electrons and one for positrons) about 10 centimeters in length and a few millimeters in cross section. Thus, collisions occur twice, on opposite sides of the ring, during each revolution. Two particle detectors, a large one that sits in the aforementioned pit and a small one that sits 60 feet underground in a cavern on the opposite side of the ring, will monitor what happens at these collision points.

To keep the speeding electrons and positrons in their approximately circular trajectories 760 meters in circumference, 264 magnets are used. Of these, 88 are dipole magnets whose purpose is to bend the particles into a curved path. The rest are quadrupole (98) and sextapole (78) magnets whose purpose is to keep the beams focused to a small cross section. Without the focusing magnets, the beams would quickly diverge to a diameter larger than that of the evacuated tube holding them, which would end any experiment.

Creating a positron beam with 10^{12} particles in it is often a task that requires more than a little creativity. The difficulty arises because positrons, unlike electrons, cannot be obtained by such simple means as heating a filament. What is necessary is to accelerate electrons, usually in a small linear accelerator, and crash them into a solid metal target. Positrons are produced in these collisions, but in much lower numbers than characterized the original electron beam. It is here that complications arise, because some means must be found for constructing one large positron bunch from many small ones.

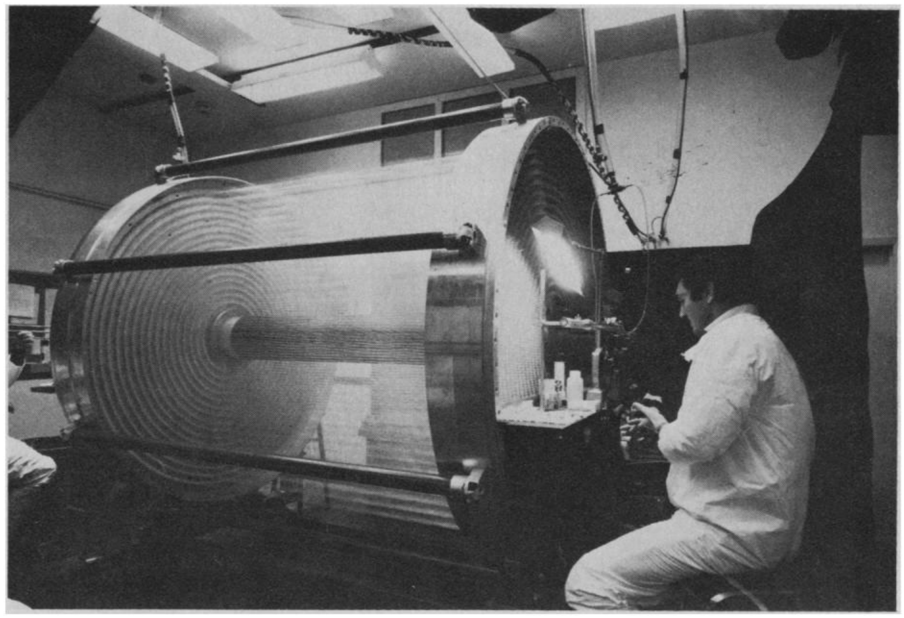
The unique approach taken at Cornell has a name—Vernier phase space compression—as formidable as the method is intricate. In essence, the method invented by Maury Tigner, director of operations of the Wilson Laboratory, goes like this: 60 small bunches of positrons having an energy of 0.15 GeV are injected by the linear accelerator into the synchrotron, where they are further accelerated to the desired beam energy and transferred into CESR. This process is repeated as many times as necessary to build up the circulating bunches in the storage ring to the required number of particles. When this is achieved, the first of the 60 circulating positron bunches is transferred back to the synchrotron. Because the synchrotron and the storage ring have slightly different circumferences, after one revolution the single bunch in the synchrotron, when transferred back once again to CESR, is advanced in position by the distance separating the bunches. By successively repeating this process for each of the 60 bunches, all can eventually be brought together into one large bunch in as short a time as 2 seconds. For this scheme to work, each succeeding bunch must go around the synchrotron one more time than the preceding bunch. The simpler-sounding alternative of injecting a single bunch of positrons into the synchrotron, accelerating this bunch, transferring it to CESR, and repeating enough times to build up a single large positron bunch would, it turns out, be much more time-consuming.

To detect the products of the collisions between electrons and positrons, a large magnetic detector is being constructed by collaborating groups from Cornell, Harvard University, the University of Rochester, Rutgers University, Syracuse University, and Vanderbilt University plus individual participants from two smaller colleges. The detector is a general-purpose device—that is, it is expected to measure the energy and momentum of as many particles emanating from a collision as possible—similar to the Mark II detector now operating at Stanford. Called CLEO, the Cornell detector will take up about \$5 million of the \$20.7 million allocated for construction of CESR.

In a so-called solenoidal detector of CLEO's type, a magnetic field that runs parallel to the storage ring deflects into curved paths any charged particles produced in collision events. Those particles can be sensed by a device called a drift chamber. The drift chamber in CLEO consists of more than 5000 closely spaced wires maintained at a high potential in a cylindrical volume 3 meters in length and 2 meters in diameter that surrounds the collision point. The charged particles ionize a gas in the drift chamber as they pass through, and it is the charge built up near the wires by the ionized gas that the wires sense. In this way, the paths of charged particles can be traced with an accuracy of about 120 micrometers.

Outside the coils of the magnet producing the solenoidal field are numerous other types of detectors that attempt to identify the particles making tracks in the drift chamber and to detect photons (gamma rays), which are electrically neutral. As events have unfolded in recent years, it has become especially important to detect any muons (muons are in the class of elementary particles, including the electron and the neutrino, that are not made up of quarks). But muons are highly penetrating entities. Thus, many current particle detectors, including CLEO, are surrounded by several thick sheets of iron that prevent almost anything but muons from getting through. In this way, any particle detected outside the iron shields is most likely a muon.

The second CESR detector is a more modest, although still substantial (it costs over \$1 million), device being constructed by a joint Columbia University–State University of New York at Stony Brook team. This detector, which does not use a magnet, is designed primarily for high-resolution studies of photons. One reason photons are of interest is that, if the upsilon family is anything like its earlier discovered relatives the psi family, some higher energy upsilon particles may decay into lower energy upsilons by emitting photons.



The drift chamber portion of the CLEO detector. Electrons and positrons collide and annihilate in the tube running through the center of the cylindrical drift space. The wires sense electrical charge produced when elementary particles created in the collision ionize a gas as they pass through the drift chamber. In this way the trajectory of the particles can be measured.

Where do things stand right now? As of 13 April, Cornell physicists have stored an electron beam in CESR for about 20 seconds. The electron beam itself also had about 200 times fewer particles in it than will be necessary to achieve collision rates high enough to make experiments possible. Thus, there is a great deal to do. But there is excitement at this moment over storing a beam, a major milestone on the road to getting a storage ring into commission, a full 6 months ahead of the originally proposed schedule.

To accomplish this feat, the Cornell physicists adopted a revised construction calendar. The idea was to get something running as quickly as possible and save the development of full capability for later, according to Tigner. Among the capabilities postponed was reaching the highest beam energy and beam intensity from the start. Thus, originally designed to reach a maximum of 8 GeV (upgradable eventually to 10 GeV), CESR is now only up to 5.5 GeV per beam. The motivation for sacrificing beam energy for a faster startup was, in part, the fact that the known members of the upsilon family can be produced at beam energies of 4.7 to 5.2 GeV.

In the immediate future, says McDaniel, the goals are achieving better control of the electron beam, so that it can be stored for hours instead of seconds and so that beams with many more particles in them can be stored. The Cornell physicists are already well on the road to achieving this. Two weeks after storing the first beam, they were able, by rewiring some magnets and other minor adjustments, to hold a beam for 2 minutes with an intensity only a factor of 20 below the design specifications. The limitation now is that the still incomplete vacuum system is unable to provide a vacuum good enough to store beams for a longer time. Next comes producing and storing positrons. Last summer, the positron production equipment was tested and worked well. Now it is a matter of recommissioning this equipment, which was partially torn apart when the final sectors of CESR were being put into place. When recommissioning is accomplished, the Vernier phase space compression scheme of positron beam construction can be tested. All of this could happen by next month. But it will probably be midsummer before useful luminosities can be obtained and the CLEO detector can be tested.

Because of the simultaneous upgrading of CESR to its designed capability, which should also be completed by this fall, and testing of the machine in its existing bare-bones state, a work schedule has been devised in which construction work goes on during the week and machine testing proceeds on weekends. Perhaps for this reason, attempting to store a beam on Friday the 13th was more a necessity than a thumb of the nose at superstition. Gradually, however, more time will be devoted to machine operation and less to construction and testing until full-time operation begins in late summer; then a new accelerator will join in contributing to what elementary particle physicists consider a most exciting era.

—Arthur L. Robinson