

CESR

CREATING NEW FORMS OF MATTER

Meet CESR in Action

Imagine a circular aluminum tube shaped like the inner tube of a bicycle tire. The tube is one-half mile in circumference, and its cross section is about two inches in diameter. The tube is evacuated and buried in a tunnel 50 feet below Alumni Fields. Now look down at the tube. Electrons circulate in a counter-clockwise direction through the tube, which is surrounded by powerful magnets steering the electrons around the tube's curvature. The energy of the electrons is 5.3 GeV. This is the energy that an electron would gain if accelerated through an electric field of 5.3 billion volts. Nearly 100 billion electrons are bunched together into a packet that is 2 millimeters wide, 0.2 millimeters tall, and 10 millimeters long. The electron packet, or bunch, travels at nearly the speed of light, corresponding to 400,000 revolutions around the ring per second.

Positrons, the antimatter counterpart of electrons, circulate in a clockwise direction around the ring. Electrons and positrons have the same mass, but opposite electric charges—electrons are negative and positrons are positive. In a magnetic guide field, trajectories for oppositely charged particles traveling in opposite directions have identical but time-reversed trajectories. At the interaction point (IP) in the experimental hall in Wilson

Lab, superconducting quadrupole magnets focus the counter-rotating packets of electrons and positrons to a thread with a cross section of a human hair, and the packets collide. The objective is for an electron and positron to come so close together that they annihilate one another, and new forms of matter emerge from the intensely concentrated ball of energy. The particles are so small that, in spite of the tiny spot into which they are focused, annihilations are rare and may occur only once in every 100,000 passages of electron bunch through positron bunch. The annihilation rate depends on the luminosity, which scales with the number of particles in the bunch and inversely with the cross-sectional area of the bunch.

To Increase Luminosity

Very soon after the first beam was circulated in the storage ring in 1979, the LEPP accelerator group began to develop and implement strategies for increasing the luminosity. The strategies are simply stated: increase the number of particles by adding more packets; reduce the spot size, or IP, by making the final focus quadrupoles stronger and moving them nearer to the collision point; and reduce the length of the packet by increasing the accelerating voltage.



BY THE END OF THE 1990s, THE COPPER CAVITIES IN THE ORIGINAL EQUIPMENT WERE REPLACED WITH SUPERCONDUCTING NIOBIUM CAVITIES.

Increasing the Number of Particles

With a single bunch of electrons traveling in the counterclockwise direction and positrons in the clockwise direction, the bunches will collide at two places: at the interaction point in the middle of the CLEO detector and again halfway around the ring. The unwanted second collision causes the beam size to increase unnecessarily and is avoided by placing a pair of electrostatic deflectors around the parasitic collision point. The deflectors kick electrons and positrons in opposite directions and provide for a vertical separation of the beams by about one centimeter, well beyond the reach of deleterious electromagnetic fields.

NEARLY 100 BILLION ELECTRONS ARE BUNCHED TOGETHER INTO A PACKET THAT IS 2 MILLIMETERS WIDE, 0.2 MILLIMETERS TALL, AND 10 MILLIMETERS LONG. THE ELECTRON PACKET, OR BUNCH, TRAVELS AT NEARLY THE SPEED OF LIGHT, CORRESPONDING TO 400,000 REVOLUTIONS AROUND THE RING PER SECOND.

Increasing the number of bunches of electrons and positrons will naturally increase the number of parasitic collision points. LEPP's initial goal was to raise the number of bunches from one to seven, but that required a scheme to separate the beams transversely at 12 additional places around the ring. A dozen pairs of electrostatic separators were impractical. A clever alternative, invented by Raphael Littauer, Physics Emeritus, and dubbed the electrostatic "pretzel," achieves horizontal separation at all 12 crossing points with two pairs of strategically placed deflectors. By mid-1987, LEPP began operating with seven bunches per beam and had increased luminosity nearly sevenfold.

Reducing "Spot" Size

Meanwhile, a parallel effort was under way to reduce the spot size. The bulky iron electromagnetic quadrupoles located just outside the CLEO detector (about 3.5 meters from the IP) were replaced by compact, but very high gradient, permanent magnet quadrupoles. The 1.5-meter quadrupoles were fabricated from hundreds of smaller pieces of permanent magnet material arranged to produce a nearly perfect lens. The magnets are only 30 centimeters in diameter and fit well inside of the CLEO detector and within 60 centimeters of the IP.



Ralph Littauer

Raphael Littauer, Physics Emeritus, cleverly invented (and dubbed it) the electrostatic "pretzel."

Frank D'Amico

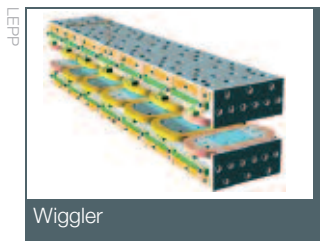


David Rubin

THE PARTICLES ARE SO SMALL THAT, IN SPITE OF THE TINY SPOT INTO WHICH THEY ARE FOCUSED, ANNIHILATIONS ARE RARE AND MAY OCCUR ONLY ONCE IN EVERY 100,000 PASSAGES OF ELECTRON BUNCH THROUGH POSITRON BUNCH.



CESR ACHIEVED AND MAINTAINED THE HIGHEST LUMINOSITY OF ANY STORAGE RING COLLIDER IN THE WORLD. IT HAS MAINTAINED AN ACTIVE AND PRODUCTIVE PROGRAM OF PARTICLE PHYSICS FOR LONGER THAN ANY OTHER ELECTRON-POSITRON COLLIDER EVER BUILT.



Watching the Glow

When charged particles are forced along a curved trajectory by a magnetic field, the particles radiate photons. The bunch begins to glow as it goes into a turn, and then the glow diminishes in the straight. Some of

the synchrotron radiation is in a part of the spectrum that is visible to the eye, so the image of the glowing bunch is transmitted by a television camera to a video monitor in the control room. But most of the radiation is in the x-ray regime and is the source of the x-ray microscopy at CHESS.

Increasing Energy

In the early nineties, Robert Meller, LEPP researcher, in a moment of inspired creativity, realized that the number of bunches in each beam might be increased well beyond seven if a small horizontal crossing angle was introduced at the IP. Trains of closely spaced bunches could be made to collide at the IP, while maintaining some horizontal separation at the parasitic crossing points on either side. By the end of the decade CESR operated with 45 bunches in each beam.

Total beam current was approaching 750 milliamperes (mA), and the synchrotron radiation power was in excess of 800 kilowatts. The energy was restored to the beam by radio frequency resonant cavities. By the end of the 1990s, the copper cavities in the original equipment were replaced with superconducting niobium cavities. Dissipation in the walls of the superconducting cavities was reduced almost to zero, so that energy is transferred with high efficiency from the radio frequency transmitter to the circulating beams.

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The permanent magnet interaction region quadrupoles, while powerful and compact, limited the energy reach of the storage ring. In 2001, the permanent magnets were replaced with superconducting magnets. As LEPP scientists turned their attention from the study of the b quark to the lighter c quark, they exploited that flexibility. The mass of the c quark is about one-third of the mass of the b quark, and its study requires a corresponding reduction in beam energy from 5.3 GeV to 1.9 GeV. A consequence of the reduced beam energy is that the glow of the synchrotron radiation is sharply diminished, and the heat generated by the disruptive forces of the beam interaction is not as effectively dissipated. High field superconducting wiggler magnets were installed in CESR to restore the requisite beam-cooling mechanism. A wiggler is a series of short magnets with alternating bending fields. The wiggler has no net effect on the beam trajectory, but generates substantial synchrotron radiation emission. At a beam energy of 1.9 GeV, the 2.1 Tesla wigglers increase the synchrotron radiation power by an order of magnitude.

A WIGGLER IS A SERIES OF SHORT MAGNETS WITH ALTERNATING BENDING FIELDS. AT A BEAM ENERGY OF 1.9 GEV, THE 2.1 TESLA WIGGLERS INCREASE THE SYNCHOTRON RADIATION POWER BY AN ORDER OF MAGNITUDE.



Frank DiMeo

The history of CESR is one of ongoing efforts to develop and adapt new technologies, to improve operational efficiency, and to expand the physics reach. There have been flashes of brilliant creativity. During the late 1980s and throughout the 1990s, CESR achieved and maintained the highest luminosity of any storage ring collider in the world. It has maintained an active and productive program of particle physics for longer than any other electron-positron collider ever built.

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Physics

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