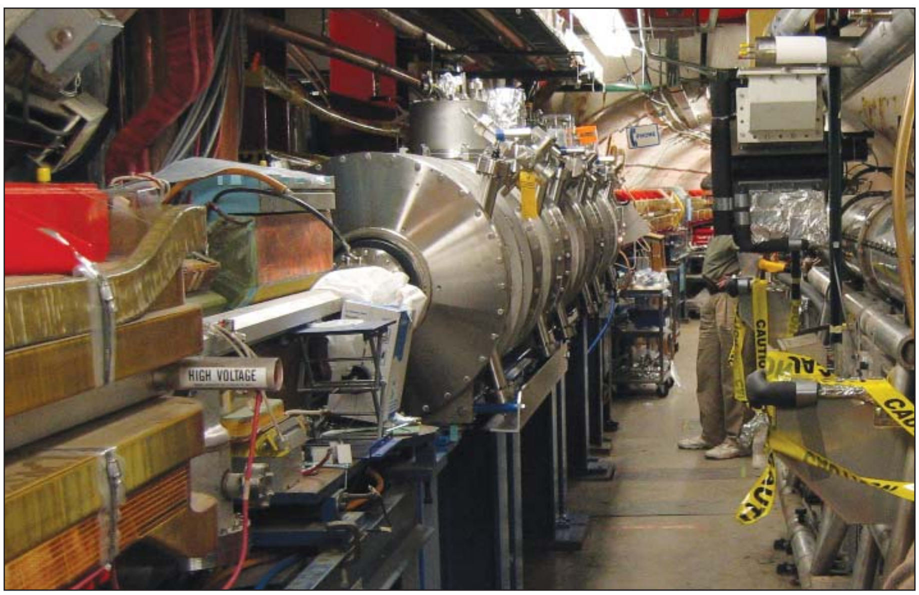
Physicists working with Cornell University's CESR particle collider embark on the venerable machine's final mission: to decipher the strong force that binds quarks to one another

CESR Launches Last Campaign

Ithaca, New York—Perforating the woolly hum of electronics, a voice crackles over the intercom: "Tuning is complete. Experimenters please acknowledge. Tuning is complete." In a windowless, slightly disheveled room that has the feel of a partially finished basement, technician Donald Beyer III sits before a small wall of computer monitors. He makes several clicks with his computer's mouse and studies the screens as brightly colored graphs climb and numbers increase. Recorded applause issues softly from a speaker, followed by the playful strains of funk music. Leaning toward the microphone to his right, Beyer responds smartly: "CLEO acknowledges—and thanks you."

Thus, on a blustery Friday night here another run begins at Cornell University's Wilson Synchrotron Laboratory. In a circular tunnel not far below, electrons and their antimatter partners, positrons, whirl at near light speed through the 768-meter-long Cornell Electron Storage Ring (CESR). Speeding in opposite directions, the electrons and positrons slam into each other to produce more massive particles in the heart of the accelerator's mate, the three-story-tall particle detector CLEO, which squats in a cavernous hall on the other side of a cement wall. Those exotic particles quickly explode into more-familiar ones, and barrellike CLEO faithfully tracks the shards.

For nearly 25 years, CESR has cranked out collisions and CLEO has studied the particles they produce. Now the two machines are at it again, as they embark on their last major project. When this series of experiments is finished in 3 or 4 years' time, CESR and CLEO will stop taking data for good. The end of their romance will mark the closing of an era in particle physics, for Wilson Lab is the last major particle physics laboratory in the center of a university campus. No longer will professors or graduate students be able to stroll from lecture hall to laboratory to tinker with a world-class high-energy physics experiment. A tie to the field's less formal and more freewheeling past will be cut. "I do think something will be lost," says Cornell's Albert Silverman, who directed construction of the original CLEO detector. "But it's inevitable." High-energy physics "no longer fits a university."



Hail, CESR! Since 1979, the Cornell Electron Storage Ring has produced world-class physics.

In the world of particle physics—the exemplar of big science—Cornell's Wilson Lab is the little lab that could. Whereas more than 1000 physicists may work together on a single particle detector at larger national or international laboratories, no more than about 250 physicists have worked at Wilson Lab at any one time. Other laboratories have annual budgets pushing into the hundreds of millions of dollars, but the Cornell lab gets by on $20 million each year from the U.S. National Science Foundation. Yet, through a combination of ingenuity, flexibility, daring, and plain good luck, researchers working on CESR and CLEO have managed to stay at the forefront of particle physics.

"Per person, they have accomplished much more than anyone else," says Martin Perl of the Stanford Linear Accelerator Center (SLAC) in Menlo Park, California, who worked on CLEO briefly in the 1990s. Gordon Kane, a theoretical physicist at the University of Michigan, Ann Arbor, attributes the lab's success to the relative informality of the place. "They do things the way you do them in your kitchen," Kane says. "So, of course, they get a lot done."

And now physicists at Wilson Lab have found themselves one last meaty task by redirecting their efforts in an unusual way. Whereas particle physicists generally strive for ever-higher energies, researchers at Wilson Lab are tuning their accelerator to lower energies to produce particles that have already been studied and look for some that may have been missed. The new high-precision measurements should nail down parameters and test new theoretical tools that are crucial for making sense of data taken at higher energies, says Cornell physicist and former lab director Karl Berkelman, who shares the Friday evening shift with Beyer. "CLEO keeps going," he says, "because it keeps reinventing itself."

Tops at the bottom

Wilson Lab nestles into a steep hillside beside a creek that runs into the woods and down into one of Ithaca's famous gorges. Apart from its gracefully rounded corners, the chocolate-brown brick building looks like a small factory. The accelerator tunnel loops behind the building northward, 15 meters below a parking lot and an athletic field.

CREDIT: RUTH SPROUL

Within the tube run two accelerators. Hugging the inner wall is CESR's predecessor, a 35-year-old synchrotron that now accelerates the electrons and positrons and injects them into the newer machine. CESR runs along the outer wall, bigger and beefier, a mechanical caterpillar consisting of orange, blue, and yellow magnets and shiny steel "RF cavities" that push particles along on electromagnetic waves. Here and there tiny stalactites hang from the tunnel's white ceiling, and in places technicians have cobbled together plastic shields to protect the machines from dripping water. Viewed from the tight confines of the tunnel, CESR looks rather humble and homemade.

And yet, for more than a decade it produced the world's most intense colliding beams. Thanks to that torrent of data—and some extraordinary good fortune—CLEO researchers have played a key role in fleshing out the reigning theory of particle interactions, the Standard Model.

In the 1970s, while researchers at other labs planned higher energy electron-positron colliders, researchers at Cornell designed CESR to fit inside the tunnel they already had. At the time, physicists knew that the protons and neutrons in atomic nuclei consist of smaller fundamental particles they dubbed the up and down quarks. They also knew that those quarks possess a pair of heavier cousins, the charm and strange quarks, which appear in particles generated in high-energy collisions. And some theorists suspected that there were at least two more quarks, the top and bottom. But no one knew how massive they might be.

Then, in 1977, 2 years before CESR collided its first particle beams, researchers at the Fermi National Accelerator Laboratory (Fermilab) in Batavia, Illinois, discovered the bottom quark. Its mass was roughly five times that of a proton, smack in the middle of CESR's energy sweet spot. "The fact that the bottom quark was in the range of the collider we were designing was just dumb luck," says Cornell's Silverman.

Throughout the 1980s and '90s, Wilson Lab researchers pumped out particles called B mesons, which consist of a bottom antiquark and an up or down quark. CLEO researchers concentrated on the so-called weak interactions through which the bottom quark inside the meson decays into a charm or up quark. At the same time, CESR researchers developed clever schemes to cram ever more electrons and positrons into the ring. "There was a period of about 15 years where we had the best tool for doing that work," Silverman says.

In the end, however, Wilson Lab physicists found themselves hoist with their own petard. Their measurements and others showed that the weak decays of B mesons might yield new insights into the subtle flaw in the mirrorlike symmetry between matter and antimatter, an imbalance known as CP violation that's key to understanding why the universe contains so much more matter than antimatter. Four years ago, two specially designed "B factories"—one at SLAC and the other at the Japanese High Energy Accelerator Research Organization (KEK) in Tsukuba—started spewing B mesons at a far greater rate than CESR can. In 2001, experimenters at both laboratories observed CP violation in B meson decays.

So Wilson Lab researchers have moved down in energy to measure the properties of other particles. Ironically, the data they're collecting may prove crucial to understanding the results from the B factories.

Pouring on the charm

One door down from the CLEO "counting room" where Beyer and Berkelman monitor the flow of data—and separated from it by a row of bookshelves serving as a wall—lies the CESR control room. Stepping into it is like stepping back in time, at least with one foot. Whereas the control rooms of other accelerators now gleam with bright lights and fancy computer monitors, the CESR control room remains almost perpetually dark, as once was common. A broad console stretches across racks of electronics festooned with old-fashioned cables, dials, and switches. Yet, within the racks, old and new mingle; a sleek new digital oscilloscope sits cheek-by-jowl with an aging television screen. "At first all the knobs and switches are kind of overwhelming," says operator Lawrence Wilkins. "There are over a thousand things you can adjust." Seemingly, none of them is clearly labeled.

Researchers have tuned CESR to produce D mesons, particles that consist of a charm quark, which is roughly one-and-a-half times as massive as a proton, and an up or down antiquark. And they have shifted their focus from the weak interactions, through which heavier quarks decay to lighter ones, to the strong interactions, through which quarks and antiquarks bind to one another by exchanging shadowy particles called gluons. "The strong interaction is like a curtain over the window" to the weak interaction, says Ian Shipsey of Purdue University in West Lafayette, Indiana.

That's because the strong force is so strong that it's physically impossible to isolate a quark and watch it decay. Instead, researchers must study the decays of particles that contain quarks, whose tangled webs of strong interactions inevitably affect the results in ways that are nearly impossible to calculate.

Old school. With its perpetual dark and motley electronics, the CESR control room harks back to the early days of particle physics.

CREDIT: (RIGHT) RUTH SPROUL

Laurels for CESR and CLEO

Accelerator accomplishments

- A CESR predecessor was the first synchrotron to employ "strong focusing," a technique that uses magnets as lenses to keep a beam compressed.
- Invented "pretzel orbits" that allow multiple bunches of electrons and positrons to counter-circulate, boosting the collision rate.
- Developed superconducting RF cavities to accelerate particles. Cornell's designs are used at a variety of synchrotrons.

Particle physics firsts

- Discovered and measured basic properties of the B meson. (Researchers at DESY in Hamburg also claimed priority.)
- Observed rare decays of bottom quarks into up quarks, decays that are essential to the Standard Model's explanation of matter-antimatter asymmetry, or CP violation.
- Observed the first "penguin decay," in which a very massive particle pops into and out of existence. Penguin decays of B mesons might reveal new particles (*Science*, 22 August 2003, p. 1026).

Recently, some theorists have claimed that a computer-intensive technique called lattice quantum chromodynamics (lattice QCD) can finally provide truly precise calculations of the effects of the strong interactions (*Science*, 16 May 2003, p. 1076). That claim is controversial, and to test it, Wilson Lab researchers will compare lattice QCD predictions against their very precise measurements on D mesons, says Cornell's David Cassel. "If theorists can successfully calculate the parameters that we can measure," he says, "that will give us a great deal of confidence in their calculations of the parameters in B decays, which we desperately need."

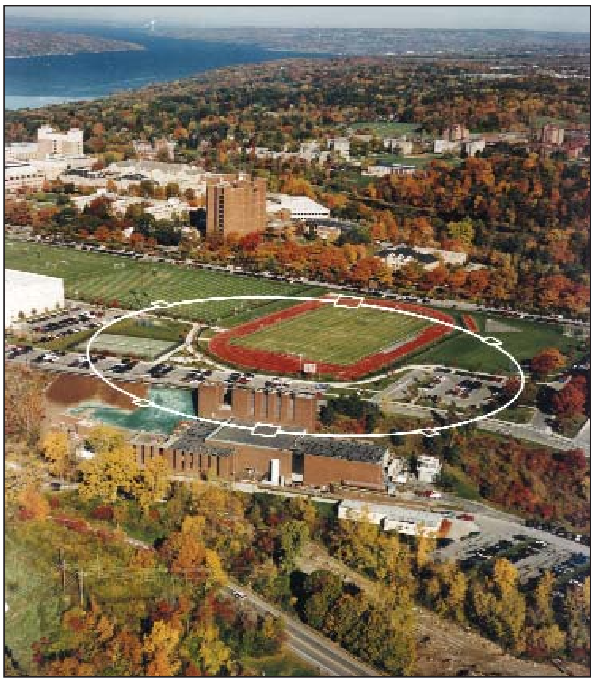
CLEO researchers will also measure the precise rates at which D mesons decay into specific combinations of lighter particles. Those measurements will yield a more immediate payoff for physicists studying B mesons, because B's decay primarily into D's. So to know the absolute probability that a B meson will decay in a particular way, researchers need to know the absolute probability of the subsequent D meson decay. Finally, physicists at Wilson Lab will hunt for oddball particles that contain no quarks but only gluons. The theory of the strong interaction predicts that such "gluballs" must exist, but none has been definitively identified yet. In formulating their assault on the strong interaction, Wilson Lab researchers have "found an important piece of physics that had been left behind," says Michael Witherell, director of Fermilab and a former member of the CLEO collaboration.

Dialing the accelerator down to lower energies isn't as simple as turning down a dimmer switch, however. As the electrons and positrons zing around the ring at nearly 400,000 revolutions per second, they radiate x-rays, and that radiation helps cool the beam so the particles can snuggle into tightly squeezed bunches. At lower energy, that helpful energy loss declines dramatically, so CESR researchers have installed special "wiggler" magnets that shake the beam back and forth and squeeze out x-rays. In the new configuration, the wigglers provide 90% of the cooling, says Cornell accelerator physicist David Rice, far more than at any other accelerator.

Taking chances

A curious mixture of the practical and the purely aesthetic flavors Wilson Lab. Full-scale blueprints of particle detectors, pieces of accelerators, displays of key particle decays, and pictures of important moments in lab history adorn the paneled hallways. In a stairwell hangs a reproduction of John Singer Sargent's controversial portrait *Madame X*. In the lab's upper entrance, an enigmatic sculpture—the figurehead from a wooden ship—greets visitors. The jumble must have pleased the lab's founder, the eponymous Robert Rathbun Wilson, who died in 2000, and whom all credit for establishing the institution's can-do attitude.

Wilson arrived at Cornell in 1947, a time when many major universities had particle accelerators. With right-hand man Boyce McDaniel, who died in 2002, he spent 2 decades building ever-more-powerful machines, including the synchrotron that preceded CESR, before leaving to direct the construction of Fermilab in 1967. Wilson possessed an artist's refinement and compared the value of high-energy physics to that of great poetry or painting, but he also had a ranch hand's sense of how to get things done quickly and cheaply. "If we had any secret in constructing machines rapidly and at not great cost," he once wrote, "that secret was our willingness, almost our eagerness to make mistakes—to get a piece of equipment together first and then to change it so that it will work."



Big machine on campus. The last particle physics accelerator at a university, CESR circles beneath the Cornell running track.

Although researchers at Wilson Lab may not be as plainly reckless as Wilson could be (he also writes of crawling into a magnet so strong it made him see strange colors), they have maintained a tradition of taking risks. That's true not only technologically but personally as well, says particle physicist Persis Drell, director of research at SLAC and a former member of the Cornell faculty. "People [at Wilson Lab] are flexible in what they're willing to do and what they're willing to try," she says. "Maybe it's the long winters, but they get more out of people than any other place I've ever been."

By maintaining unusually close ties between particle and accelerator physicists, professors and students, the homey lab has fostered innovations in accelerator technology that may constitute its most far-reaching legacy, says John Seeman, an accelerator physicist at SLAC who was a graduate student at Wilson Lab. "There was a sense that, even as a student, if you had a good idea they would find a way to do it," Seeman says.

Now, however, Wilson Lab researchers are preparing for what may be their biggest challenge: sustaining that culture of innovation without the machine in their basement. When the current study of D mesons and gluballs ends around 2007, CESR will no longer generate particle collisions for CLEO. The accelerator may continue to run for a while as an x-ray source, but CESR's reign as a leading particle physics machine will come to an end.

Wilson Lab researchers face that eventuality matter-of-factly. Many are preparing to pour their efforts into a proposed linear electron-positron collider that will stretch more than 30 kilometers in length and may reveal the properties of a whole slew of new particles (*Science*, 21 February 2003, p. 1168). Decked out with its wigglers, CESR is already a prototype for the two "cooling rings" needed to compress the gargantuan collider's beams. Particle physicists are hoping that Wilson Lab will serve as one of several centers around the world from which the collider may be remotely controlled. The little lab may play a big part in the international project thanks, once again, to its strength in both accelerator and particle physics, says lab director Maury Tigner. "That's going to give us an opportunity to make contributions that are disproportionate to our numbers," says Tigner, who also heads the International Linear Collider Steering Committee.

For the moment, however, there are D mesons to be made and studied. So while the wind whips snow flurries along the ground outside, 15 meters below, matter rushes into antimatter, otherworldly particles are born and die, and slowly fragments of a deeper understanding accumulate in the heart of a grand machine. –ADRIAN CHO

Adrian Cho is a freelance science writer in Grosse Point Woods, Michigan.

CREDIT: INTERACTIONS.ORG, COURTESY OF CORNELL UNIVERSITY