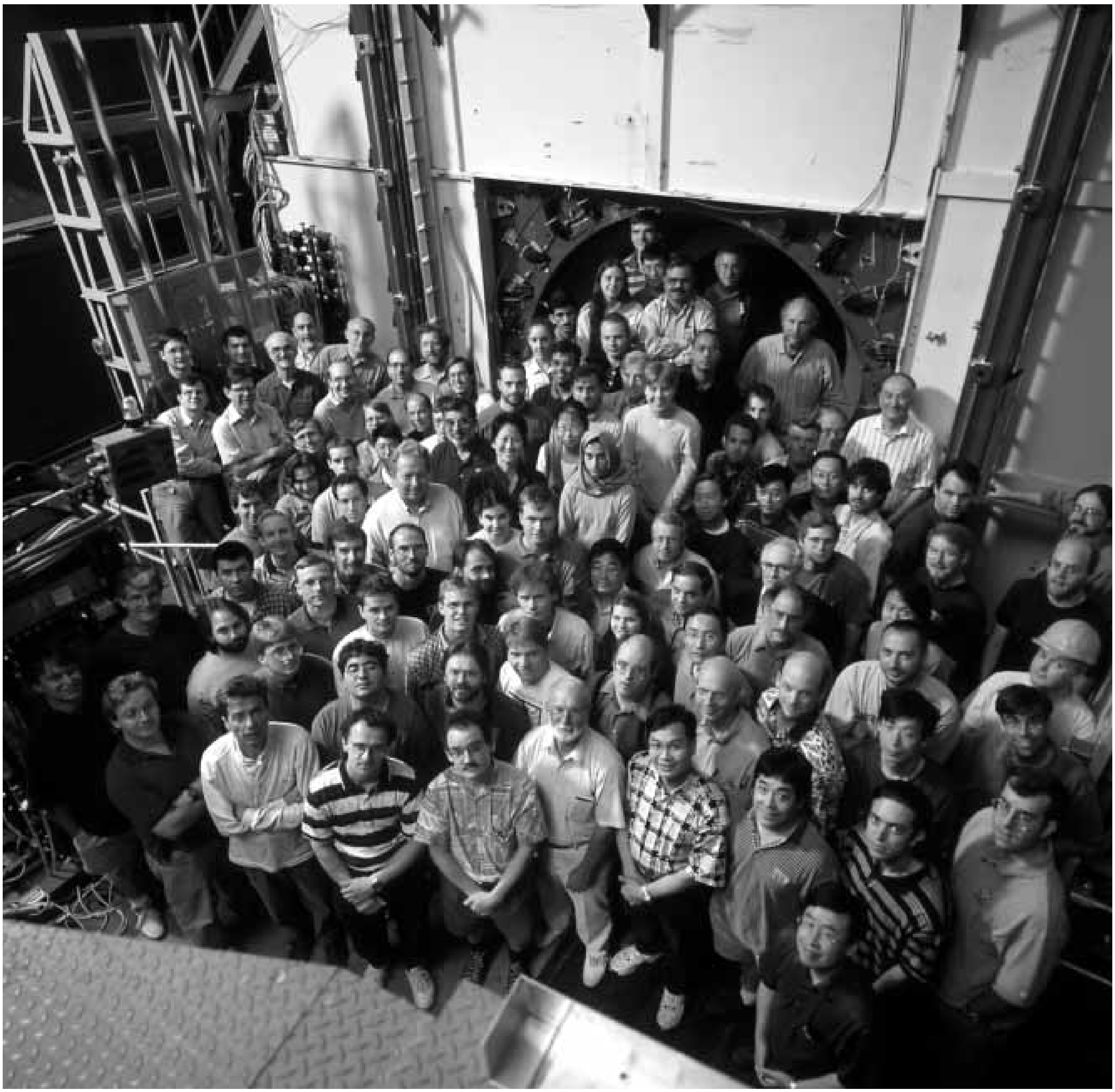
After All These Years

Cornell Still Producing F

by PERSIS S. DRELL



Mesons

THE CORNELL ELECTRON STORAGE RING CESR was designed in 1975 to produce collisions of 8 GeV beams of positrons and electrons. Its accompanying all-purpose solenoidal detector CLEO surrounds the electron-positron collision point and records the fragments emerging from their annihilations. During the construction of CESR, in 1977, Leon Lederman's group at Fermilab discovered the first evidence for the bottom, or b, quark. It was an incredible stroke of good fortune for us. The 5 GeV mass of this quark meant that CESR could easily produce particles containing them. Although the original goal of CLEO was to explore the physics of electron-positron collisions up to an energy of 16 GeV, it quickly became clear that the physics of the b quark was going to dominate the experimental program. Indeed, B mesons were discovered in 1982 using the CLEO detector, which has studied them ever since.

10 million B meson pairs isn't bad, but nevertheless CESR and CLEO eagerly push forward to unlock the secrets of the b quark.

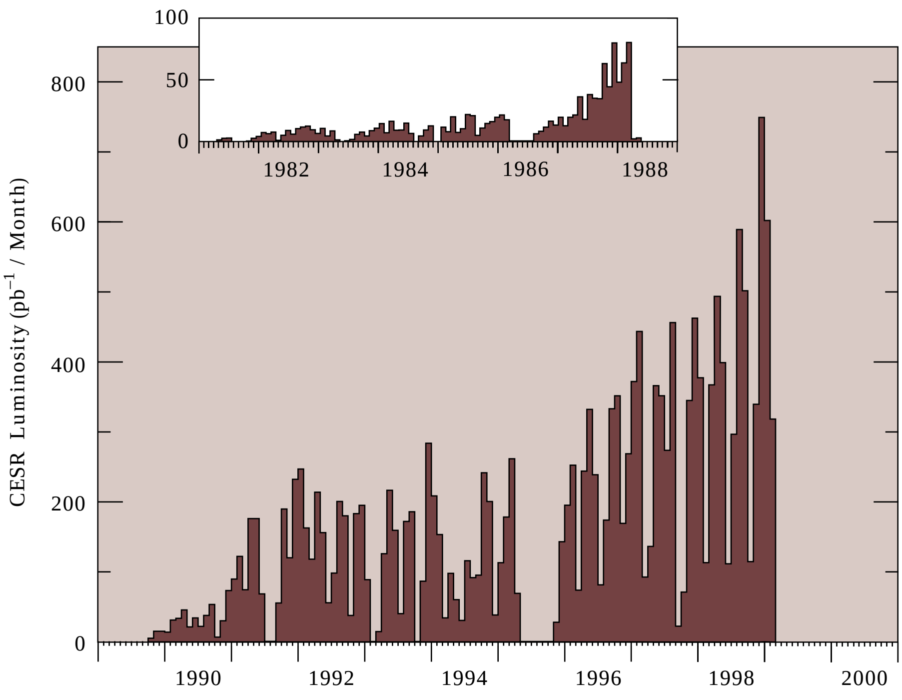
CESR's luck didn't stop there. Not only was the machine serendipitously well suited to produce B mesons, but the B meson has also turned out to be much more interesting than anyone ever expected.

The initial studies at CLEO (and the ARGUS detector studying B mesons at DESY in Germany) focused on establishing the bottom quark as the partner of another heavy quark known as top. There were important measurements of the semileptonic decay rate and the energy spectrum of resulting leptons, which established that decay via the charm quark c, $b \to cW^-$, is the dominant decay mode of the b quark. These studies, combined with measurements elsewhere of the B meson lifetime, allowed the $b \to cW^-$ coupling strength of the CKM matrix, V_{cb}, to be determined.

However, two measurements made the B meson front-page news in the physics community. In 1987, the ARGUS collaboration observed a large rate for $B\bar{B}$ mixing. The two species can change into each other billions of times per second. One interpretation of this behavior (which turned out to be correct) was that the top quark is very massive. The second important result came in 1989 from CLEO, which observed that B mesons can decay to final states without a charm quark in them. This result meant that B mesons were prime candidates to help elucidate one of the great mysteries of Nature: the question of the matter-dominated Universe. The first result meant that rare B meson decays are an excellent probe of new physics beyond the Standard Model. Nobody really expects that B meson decays will provide conclusive answers to why matter dominates in the Universe—or that the B meson will silence the lingering questions about potential sources of new physics beyond the Standard Model. But many hope that B mesons will probe the role that CP violation might play in creating the cosmic matter/antimatter asymmetry, as well as provide hints of new physics at or below the TeV scale. Interest in the B meson has grown dramatically in the two decades since its discovery!

As the B meson has become increasingly well understood through detailed studies of its decays , the desire has grown to produce and detect many more of them. Ever since it was first turned on, the CESR accelerator has been continuously upgraded to satisfy the seemingly insatiable demands of experimenters. The figure at left shows the integrated luminosity (which is directly related to the number of B mesons) delivered per month, and always the demand is for more. When CESR first operated in September 1979, it had a single bunch of electrons and a single bunch of positrons in the same circular orbit colliding head-on at two opposite places in the ring. A steady series of upgrades followed; a "pretzel" orbit scheme allowed the storage of up to seven bunches in each beam without their colliding at multiple points around the ring. The final focusing quadrupole magnets were inserted inside the CLEO detector to decrease the cross-sectional area of the beams when they intersect, thus increasing the luminosity. A small crossing angle of 2 milliradians introduced at the intersection point allowed 45 bunches in each beam to circulate in side-by-side

A plot of the integrated luminosity per month of the CESR accelerator from 1981 until the February 1999 shutdown for the current upgrade. The height of each bar is directly proportional to the number of B meson pairs produced each month.



pretzel orbits, colliding at a single point in the center of the detector.

By February 15, 1999, when a much-improved CESR turned off for another upgrade, the collider had achieved a world-record peak luminosity of 8×10^{32} cm^{-2}s^{-1} and had produced over 10 million pairs of b quarks for the CLEO detector. The main components of this current upgrade are to replace the copper microwave cavities in the machine with niobium superconducting ones and to install new superconducting quadrupole focusing magnets around the interaction point. In addition to providing stronger focusing of the beams, the new quadrupole magnets also help minimize the long range beam-beam interaction, where different electron and positron bunches interact as they approach and depart from the actual point of collision. The superconducting cavities will feed power to the beams much more efficiently and also lower the impedance of the machine, thus helping reduce multi-bunch beam instabilities. Additional work is being done so that the CESR vacuum system will be able to handle the increased currents, and the linac will feed electrons and positrons to the machine more rapidly. When the upgrade is finished, the rate of B meson production should increase by yet another factor of 2; when it turns back on this fall, the luminosity will approach 2×10^{33}cm^{-2}s^{-1}.

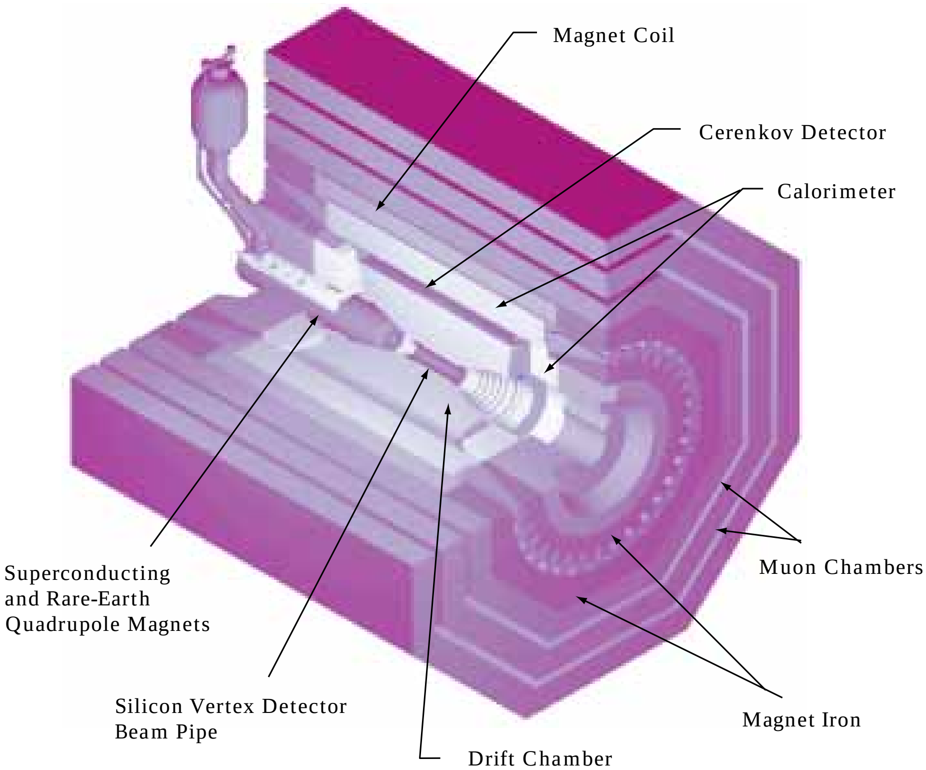
The CLEO collaboration has steadily upgraded its detector as well. When it first turned on in 1979, its main goal was to establish the basic properties of the b quark. The essential features of the detector were excellent particle-tracking capabilities and the ability to detect the charged leptons that would be the smoking gun for the weak decay of a heavy quark. As the CLEO effort matured, the importance of high-efficiency detection of photons from decays of neutral pions became clear. Upgraded in 1989 to CLEO II, the detector included even better tracking with a new drift chamber and vertex detector, as well as a spectacular cesium iodide calorimeter with high efficiency and good resolution for detecting 10 MeV to 5 GeV photons. Further upgraded in 1995 with the addition of a three-layer, double-sided silicon detector, the CLEO detector has now recorded the decays of 10 million B meson pairs.

In CLEO II the physics focus shifted from the initial measurements of the basic properties of b quarks to detailed studies of quark mixing. The B meson is a wonderful laboratory for determining the parameters of quark mixing, and CLEO II has made measurements of two of them—V_{cb} and V_{ub} with ever increasing precision. It has also done detailed studies of the dynamics of B meson decays and verified that (at least at tree level) the Standard Model picture of quark mixing is correct.

The greatest triumph of all will be to find surprising new physics where we least expect it.

While not all of the CLEO II data are fully analyzed, many rare decays are also being measured. This will continue as the large data set is fully exploited. New higher-order processes that have been discovered offer useful windows on new physics. As one example, measurements of the rate for the $b \rightarrow s\gamma$ decay are already probing physics at the 600 GeV mass scale; a new particle this heavy could significantly alter the rates for such decays from those predicted by the Standard Model. Rare decays (which occur once in every 10,000 or 100,000 B decays) are definitely a growth industry right now. One of the goals for CLEO's future is to continue to use B mesons to look for physics beyond the Standard Model by studying these highly suppressed processes.

The current upgrade of the detector to CLEO III, now being completed, is designed to meet the challenges of these physics goals. Two major areas of investigation will be continued studies of rare decay modes and studies that probe direct CP violation through the decays such as $B \rightarrow \pi\pi$ and $B \rightarrow K\pi$. A crucial aspect of the detector upgrade is the addition of a high-performance ring-imaging Cerenkov detector to improve CLEO's ability to distinguish pions from kaons with high efficiency. The CLEO III detector will also have improved tracking capabilities with a new silicon vertex detector and drift chamber. In addition, upgraded data-handling capabilities



A cutaway view of the CLEO III detector. The calorimeter, magnet, and muon system are preserved from CLEO II. The Cerenkov detector, drift chamber, and silicon detector are new. Also shown are the new CESR superconducting and rare-earth quadrupole magnets that are part of the machine upgrade.

will help us cope with CESR's increased luminosity. The figure on the left shows a schematic of the new detector. The components are now being assembled and tested, with installation scheduled to be completed in September 1999.

If the CKM matrix (see the previous article by Robert Cahn) provides the complete explanation for quark mixing—and if there are no new and surprising heavy particles to be discovered—then the work accomplished in the next decade or so by CLEO III and our colleagues at Belle and BaBar will be a triumph of detailed and precise measurements. They will expose the *B* meson system in all its complexity and elegance. What we hope, however, is that our luck will continue and that the *B* meson is in fact much richer than we can currently imagine. Perhaps the value of the mixing angle β will be inconsistent with the measurements of the sides of the CKM triangle, or the CP violation pattern observed in *K* decays. Perhaps the rates of certain rare *B* decays will turn out surprisingly large or startlingly small when compared with Standard Model expectations. The greatest triumph of all will be to find surprising new physics where we least expect it!