The CESR High Energy Physics program

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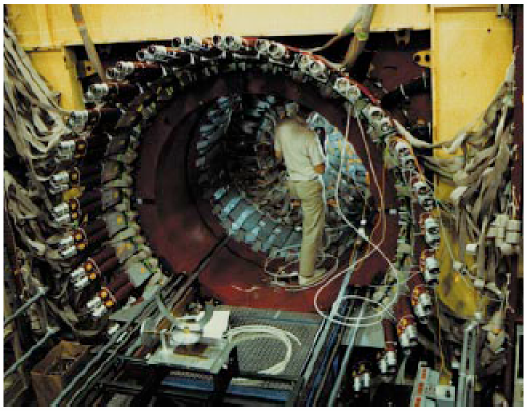
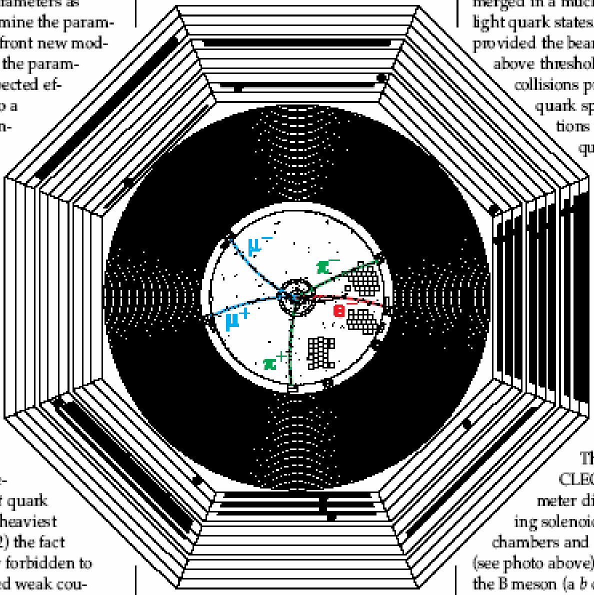


(right) A view of the CLEO detector during phase I construction.

Although the Cornell Electron Storage Ring (CESR) now serves the synchrotron radiation user community as well, CESR was originally designed and built to provide collisions of high energy electrons and positrons for particle physics experiments. The goal of the CESR high energy physics program is to advance our understanding of the "flavor sector" of the Standard Model and possible non-standard extensions, by studying the properties and interactions of the heavy quarks and leptons. The Standard Model does not tell us why there are six quark flavors and six lepton flavors, why the quarks and leptons have the masses they do, or why the heavier quarks decay to lighter quarks with the observed rates; the model takes these parameters as given. We have to determine the parameters by experiment, confront new models that purport to relate the parameters, and look for unexpected effects that could lead us to a generalization of the Standard Model.

The most interesting of the heavy quarks (charm, bottom, and top) is probably the bottom. By a fortunate coincidence of the CESR beam energy and the mass of the bottom quark, CESR is better suited for *b* quark production than any other electron-positron collider in the world. It is possible to observe the largest variety of decays to lighter quarks, because (1) along with the *t* quark the *b* is a member of the heaviest doublet of quarks, and (2) the fact that the *b* is energetically forbidden to decay via its most favored weak coupling, to its partner the *t* quark, makes it possible to observe many unusual suppressed decay modes. The *b* can decay directly (by emission of a *W* boson) to the *c* or *u* quark, and it can decay indirectly via an intermediate state containing a virtual *t* quark to the *s* or *d* quark. It is therefore possible to measure most of the weak coupling parameters in the Standard Model by observing *b* decays.

Heavy quarks, like the *b* and the *t*, can be made at proton-proton and proton-antiproton colliders, but with production cross sections that decrease rapidly with quark mass. Although the numbers of particles containing *b* quarks produced at Fermilab are substantial, they are submerged in a much larger background of light quark states. On the other hand, provided the beam energies are well above threshold, electron-positron collisions produce the different quark species with cross sections that depend only on the quark charges ($e/3$ or $2e/3$), independent of mass. Heavy quark final states are then a major part of the e^+/e^- annihilation cross section.



An event in the CLEO detector. One B meson decayed to two particles, the Ψ and K_s meson, which themselves decayed into pairs of muons (μ) and pions (π) respectively; the other B meson decayed to an electron (e) plus other unidentified particles.

The *b*-quark experiments are carried out by a typical high energy physics collaboration of about 200 faculty, post docs, and graduate students from 22 universities. The apparatus is the CLEO detector, based on a 3 meter diameter superconducting solenoid filled with tracking chambers and scintillation counters (see photo above). Since the discovery of the B meson (a *b* quark and a light antiquark) at CESR in 1980, most of what we know about *b* quarks has come from experiments at CESR. CLEO has seen and measured a large variety of *B* meson decay modes involving the $b \rightarrow c$ and $b \rightarrow u$

couplings, and is now beginning to explore the rarer modes involving the *t* quark intermediate state. Over the past decade and a half there has been a lot of progress in the measurement of the parameters of the flavor sector of the Standard Model, but so far there is no sign of physics beyond the model.

In spite of the advantages of electron-positron collisions for the study of heavy quarks, there is an important drawback; the total annihilation cross section is very small, of the order of a nanobarn. Progress is therefore always limited by the achievable beam-beam luminosity. This is the motivation for the periodic upgrades of the storage ring. The ring was originally designed to store one centimeter-long bunch each of electrons and of positrons. Now in the angle-crossing, pretzel-orbit multibunch scheme, CESR circulates 18 bunches in each beam. Although CESR holds the world's record for colliding beam luminosity, by an order of magnitude, more is needed to take advantage of new opportunities in *b* quark physics.

The new opportunities offer windows on possible new physics beyond the Standard Model: (1) the pursuit of the rare *B* meson decay modes involving the virtual *t* quark and perhaps undiscovered heavier objects, and (2) the measurement of CP violation in B decay. The violation of CP symmetry (C is charge conjugation and P is parity) is probably relevant to the question of how a matter-antimatter symmetric early universe evolved into the present universe consisting mostly of matter. CP violation has so far been observed only in *K* meson decay, but if the favored Standard Model mechanism, involving a possible imaginary contribution to the quark weak couplings, is true, then CP violation should be observable also in *B* decays, provided one has a large enough sample of decays into the right final states.

In 1993 the DOE decided to fund the construction at SLAC of a two-ring asymmetric-energy collider, which will have advantages for one of the ways of observing CP violation. There are other ways, however, to observe CP violation that can be pursued at CESR with equal beam energies, provided the luminosity is high enough and the detector is able to distinguish pions and kaons at the highest momenta. The Laboratory has been fortunate in obtaining NSF funding to upgrade the CESR luminosity and the CLEO detector capabilities.

The upgrade is to occur in two stages, labeled II and III. In phase II the CESR magnet and vacuum system components near the interaction point are being replaced to better accommodate the new angle-crossing orbits, and a silicon microstrip vertex detector is being installed in CLEO. The installation is due to be completed in fall of 1995. Phase III will include a new superconducting rf cavity system to handle higher beam currents, and will involve a complete replacement of the CLEO tracking system and the addition of a ring-imaging Cerenkov system for high momentum charged particle velocity measurement. If all goes well, the new components should be ready for installation in 1997 or 1998. Ultimately, one hopes to be able to increase the CESR luminosity by a factor of at least five. At this performance level, CESR should be a match for any asymmetric energy B Factory.

Along with the benefits to high energy physics, the increased beam currents, as much as 500 mA per beam, will result in significantly higher x-ray beam intensities at CHESS than will be available anywhere else. The upgrade will keep the CESR-CHESS facility at the forefront for years to come.