SLAC's Asymmetric B Factory Will Study *CP* Violation

Showing off an acceleration section of PEP-II, the brand new "asymmetic B factory" at the Stanford Linear Accelerator Center (SLAC), are Jonathan Dorfan (rear), the project's director, and Pier Oddone (Lawrence Berkeley National Laboratory), who first suggested ten years ago that particle physicists seeking to find and study *CP* symmetry violation in B meson systems ought to build such asymmetric electron–positron colliders. B mesons, first observed in the early 1980s, carry the heavy b (bottom) quark.

Generally, an e^-e^+ storage-ring collider brings electrons and positrons of *equal* energy into head-on collision. But Oddone pointed out that making the colliding beam energies significantly different would bring crucial advantages to this very demanding and important experimental search. *CP* is the joint symmetry operation of charge conjugation (which turns a particle into its antiparticle) and parity inversion. Until now, clear *CP* symmetry violation has been seen only in the neutral kaon system (though very recent B-meson experiments at Fermilab[1] and CERN[2] have given tantalizing hints).


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Although many thousands of *CP*-violating kaon decays have been harvested in the last quarter century, we still don't know whether the *CP* violation involves more than what's predicted by the standard model of particle theory. The standard model seems to predict too little *CP* violation to account, by itself, for the predominance of matter over antimatter in the early cosmos. That might be regarded as evidence for "new physics" in *CP*-violating phenomena. In any case, there's good reason to believe that decays of the neutral B mesons will be particularly sensitive probes of the underlying physics. They may be our best hope of a first glimpse beyond the incredibly successful, but obviously provisional, standard model.

PEP-II is designed to collide a beam of 9 GeV electrons with a countercirculating beam of 3.1 GeV positrons. Construction began in 1994, using the tunnel and magnets of SLAC's old 15-on-15 GeV PEP collider for the new 9 GeV electron ring. Hence the name. With the 3.1 GeV positron ring completed last summer, PEP-II was ceremonially dedicated in October, and commissioning is now well under way. The elaborate BaBar detector will be rolled into the collision region in March, and physics runs are scheduled to begin soon thereafter. A very similar asymmetric collider, called KEKB, is nearing completion at the site of the old TRISTAN collider in Japan.

The energies of the electron and positron beams are chosen so that the center-of-mass collision energy is 10.58 GeV, precisely at the peak of the $\Upsilon(10580)$ resonance, the lightest bound state of the b quark and its antiquark that's heavy enough to decay into a $B^0\bar{B}^0$ pair. The B mesons, with masses of 5.279 GeV, are bound states of a b or $\bar{b}$ and an ordinary light quark. At the $\Upsilon(10580)$ resonant peak, fully 25% of all e^+e^- collisions produce simply a $B^0\bar{B}^0$ pair, accompanied by nothing else that might complicate the final state.

Like the neutral-kaon system, the neutral B mesons exhibit significant mixing: An initially pure B^0 state acquires a time-oscillating $\bar{B}^0$ component, essentially because the two are coupled by common decay modes and the weak interactions can change a quark's flavor. Such mixing does not demonstrate *CP* violation, but it's a prerequisite for the search.

Any observed difference between initially pure B^0 and $\bar{B}^0$ states in the time-dependent rate of their decay to a common *CP* eigenstate (for example, $\pi^+\pi^-$) would be a manifestation of *CP* violation. That's where the asymmetric-collider trick comes in. One looks for events in which one of the B's decays to a *CP* eigenstate while the other one decays into a "tagging" state (for example, $\pi\nu e^{\pm}$) that reveals its flavor (bottom or antibottom) at the moment of decay. But one has to measure the relative times of the tagging and *CP* eigenstate decays.

Unfortunately the lifetime of the B meson is less than 2 picoseconds. In a symmetric collider, the parent $\Upsilon(10580)$ is created at rest and its two B daughters are moving apart so slowly that a vertex detector, even with BaBar's high-resolution silicon microstrips, could not in general disentangle the two decay vertices. But in the asymmetric PEP-II configuration, the Υ acquires a significant velocity and the B's get Lorentz-boosted lifetimes such that the typical distance between their decay vertices is several hundred microns, a manageable separation for BaBar.

To collect adequate statistics for its *CP*-violation studies, PEP-II needs more than just a Lorentz boost. Its design luminosity is a very ambitious 3×10^{33} events per second per cm^2 of scattering cross section. That's about five times the upgraded luminosity of Cornell's CESR, a symmetrical e^-e^+ collider that has been a principal source of B mesons for two decades. As we go to press, the PEP-II commissioning team has already reached about 1% of the design luminosity.

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References

1. F. Abe *et al.*, Phys. Rev. Lett. **81**, 5513 (1998).
2. K. Ackerstaff *et al.*, Eur. Phys. J. **C5**, 379 (1998). ■