CP VIOLATION IN B MESON DECAYS AT THE TEVATRON

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The study of CP violation has proved to be a rather intractable problem. Since the discovery of this effect in 1964, violations have been discovered at the level of parts per thousand in neutral kaon decays, but nowhere else. All measurements appear consistent with a superweak theory which predicts only small effects due to mass mixing.

In the past several years theorists have discovered that the Kobayashi-Maskawa six-quark formalism, while yielding results equivalent to superweak theory in kaon decays, allows large CP violating effects in the decays of B mesons, provided the extended Cabibbo angles θ_2 and θ_3 are sufficiently small. Stated simply, if these angles are sufficiently small, normal decay modes become suppressed to the level where CP violating decays become competitive. Though it is in principle possible to observe CP violating effects in the decays of charged B's, we prefer for the moment to discuss only neutral decays.

If (as expected) the $B^0{}_{short}$ and $B^0{}_{long}$ lifetimes are comparable, CP violation could create a difference in the rate of B^0 and $\bar{B}^0$ decays into common CP eigenstates. A typical decay chain could be $B^0 \to D^0 + X \to K_s{}^0 + Y + X$. For sufficiently small θ_2, θ_3, the ratio

$$\text{Ratio} = \frac{R(B^0 \to K_S^0 + Y + X) - R(\bar{B}^0 \to K_S^0 + Y + X)}{R(B^0 \to K_S^0 + Y + X) + R(B^0 \to K_S^0 + Y + X)}$$

could approach unity, and for expected angles ranges from 1 to 30%. In all these cases, the Kobayashi-Maskawa formalism predicts CP violating effects which far exceed simple mass mixing, providing a means to differentiate superweak from other models. As a parenthetical note, studying the time dependence of such ratios could permit an experimental separation of the contribution to CP violation from mass mixing as opposed to violations occurring directly in the decays.

The problems are threefold. First, one must determine whether the initial state is B^0 or $\bar{B}^0$, which probably requires "seeing" one of the decay vertices in associated $B\bar{B}$ production. Second, decay channels with known CP must be observed. This means good reconstruction capability, particularly of neutrals, as the CP content of neutral final states is more readily determined. Finally, as the decay branching ratios to useful final states will be of order 1%, a copious rate of B production will be required.

In the unlikely event that the short and long lifetimes are quite different, one can prepare an initial state of known CP by observing only B^0_{long} decays, then search for a few decays in which the final state has opposite CP eigenvalue. Such a fortunate happening would reduce the number of produced B's needed by more than an order of magnitude, decrease the effect of systematic error and require only observation of the longer lifetime decay vertex.

It has become increasingly clear that such effects are accessible only through fixed-target experiments at the Tevatron. The requirement of observation of the production vertex, a high rate of B production and good fitting capability place these experiments beyond the reach of colliding machines.

Whether such experiments are possible requires a series of preliminary experiments to determine B lifetimes and decay modes. However, for the moment let us assume favorable modes exist and the relevant lifetimes are longer than 5×10^{-14} seconds. It is then clear that the feasibility of these experiments depends on development of a high resolution vertex detector with high rate capability. Probably such devices will have to be electronic, as optical procedures will drastically reduce the number of events which can be studied. With this caveat, since one of the associatively produced B's may be sacrificed for the trigger and the acceptable final states for the other are determined, both on-line and off-line selection criteria can be made quite powerful. Possible criteria include a stiff high $P_\perp$ muon, a charged K emanating from a secondary charm vertex together with a K^0 in the spectrometer, more than one secondary vertex, at least two neutral pions, at least one of which is quite stiff. This list is not at all inclusive, but it is evident that an on-line trigger reduction of 10^4 and an off-line reduction in excess of 10^5 could be maintained in the face of acceptance for desired events as large as several per cent. It is then easily shown that a total number of interactions of 10^{12}, easily tolerated in a typical Tevatron experiment, could result in detection of perhaps 1000 B's into a useful decay channel, provided the production cross section is as large as 50 nb:

$$(\#\ \text{B's}) = (\#\ \text{interactions})(\text{acceptance})(\text{Branching ratio})\left(\frac{50\ \text{nb}}{20\ \text{mb/nucleon}}\right)$$

where the 20mb/nucleon is for production in a heavy target.

Thus,

$$(\#\ \text{B's}) = (10^{12})(0.02)(0.02)(2.5\times10^{-6}) = 10^3.$$

We realize these estimates are not particularly conservative but are given in the spirit that today's tough signal is tomorrow's calibration.

The most important concept to carry away is that if such experiments are ever to become a reality, they must be performed at the Tevatron.