CLEO RESULTS ON HEAVY MESON MIXING

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We discuss recent CLEO results on $D^0 - \overline{D^0}$ and $B^0_d - \overline{B^0_d}$ mixing. The principal results are that for the $D^0$ system, allowing for CP violations, the mixing amplitude $x' < 2.9\%$ (95\% C.L.), and for the $B^0_d$ system, $\chi = 0.198 \pm 0.013 \pm 0.014$. We make projections for future sensitivity to $D^0 - \overline{D^0}$ mixing, and to $\sin(2\beta + \gamma)$.

1 Introduction

The $D^0 - \overline{D^0}$ system is unlike other systems that mix, such as $K^0 - \overline{K^0}$, $B^0_d - \overline{B^0_d}$, and $B^0_s - \overline{B^0_s}$ in at least two respects: first, the Standard Model contributions are thought to be extremely small, so non-Standard contributions might be obvious; second, $D^0 - \overline{D^0}$ is the only system that consists of up type quarks. New physics that differentiates between up and down type quarks could be revealed by study of $D^0 - \overline{D^0}$. Indeed, there are numerous models, with relevant particles as massive as 100 TeV, that predict large $D^0 - \overline{D^0}$ mixing.

We describe recent results from CLEO II.V on $D^0 - \overline{D^0}$ mixing, where we use the sequence $D^{*+} \rightarrow D^0 \pi^+$, where the charged pion is ‘slow’ in momentum, followed by the appearance of a $K^+ \pi^-$ final state, and the sequence formed by application of charge conjugations. We also describe results on $B^0_d - \overline{B^0_d}$ mixing at the $\Upsilon(4s)$. Following the decay of the $\Upsilon(4s)$ to $B^0_d \overline{B^0_d}$, we tag one $B^0_d$ with a semileptonic decay, and the other by a partial reconstruction of the exclusive final state $D^{*+} \pi^-$. We present the results for the ‘wrong sign’ decay $D^0 \rightarrow K^+ \pi^-$, projected onto $Q$ (a) and $M$ (b). The fit for the signal and various backgrounds are given by the hatched and colored histograms.

2 $D^0 - \overline{D^0}$ Mixing

The final configuration of the CLEO II detector, known as CLEO II.V, took 9.0 fb$^{-1}$ of $e^+e^-$ collisions between 1996 and 1999. CLEO II.V featured a vertex detector...
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gin are from this work, where the inner(outer) region

requires(does not require) CP conservation.

(SVX) consisting of three layers of double-

side aluminum, and helium as the drift cham-

ber gas. The measurement of z by the SVX

narrowed the resolution in Q, the energy re-

leased in the $D^{*+} \to D^{0} \pi^{+}$ decay to $\sigma_{Q} = 190$ KeV, or about 1/4 that obtained in ear-

lier CLEO work. The use of helium narrowed

the resolution in $M$, the mass reconstructed in $D^{0} \to K^{\pm} \pi^{\mp}$, to $\sigma_{M} = 6.4$ MeV, which is

nearly 1/2 that of earlier CLEO work. Both

of these resolution improvements are impor-

tant for detecting the signal of $D^{0} \to K^{\mp} \pi^{\pm}$, which is shown in Fig. 1.

The fit in Fig. 1 indicates $44.8^{+6.7}_{-8.7}$ signal events. The rate of 'wrong-sign' decay, relative to 'right-sign decay' is $0.332^{+0.063}_{-0.065} \pm 0.040\%$, which is close to tan4 $\theta_C$.

We analyze the decay times of the events

in the signal region to deduce results on the

$D^{0} \to \bar{D}^{0}$ mixing amplitudes. The normalized amplitude $x(y)$ describes transitions through off(on)-shell intermediate states. The existence of a direct decay amplitude for $D^{0} \to K^{\mp} \pi^{\pm}$ complicates the analysis. The direct decay contributes a purely exponential dis-

tribution of decay times. The direct decay amplitude might have a strong phase shift

$\delta$ relative to the favored decay amplitude, $\bar{D}^{0} \to K^{\mp} \pi^{\pm}$, and so the interference of mixing

and direct decay contributes decay times according to the distribution $y'te^{-t}$, where

$y' = (y \cos \delta - x \sin \delta)$. Pure mixing then con-

tributes decay times according to the distribution

$(1/4)(x^2 + y^2)^{1/2} e^{-t}$.

Fits to our data result in the allowed re-

gions in Fig. 2. In our principal results we al-

ow CP violation simultaneously in all three

terms of the time evolution: in direct decay, interference, and in mixing.

New physics would most probably appear in the amplitude $x$. When $\delta = 0$, $x' = x$, and

our limit is $x < 2.9\%$ at 95% C.L. At roughly

$x \sim 1.0\%$, $D^{0} \to \bar{D}^{0}$ mixing would surpass $K^{0} -

\bar{K}^{0}$ mixing as the most tight constraint on flavor changing neutral currents.

Our technique is now limited by wrong-

sign 'background' from the direct decay. We

then predict that for future work at the B-

factories, this technique will give new sensi-

tivity only as the one-quarter power of the integrated luminosity, and will reach about

$x' = 0.7\%$ at 1000 fb$^{-1}$. In contrast, there are techniques that might be background-free at the $\psi''$, and so the scaling with luminos-

ity would go as the one-half power, and hit about $x = 0.1\%$ at 1000 fb$^{-1}$.

3 $B^0_d$-$\bar{B}^0_d$ Mixing

At CESR, the B’s do not move sufficiently to allow the measurement of decay times. Thus, we are sensitive only to the effect of mixing after integration over the decay time variables, in particular,

$\chi = [\Gamma(B^0_d \to \bar{B}^0_d)]/[\Gamma(B^0_d \to B^0_d) + \Gamma(B^0_d \to \bar{B}^0_d)] \approx (x^2 +$

Figure 2. Allowed regions for the mixing amplitudes, $x'$ and $y'$, at the 95% C.L. Those nearest the origin are from this work, where the inner(outer) region requires(does not require) CP conservation.
Figure 3. Like sign events, which contain the B mixing signal, as a function of the decay angle of the $D^{*+}$, $\cos \theta^*$. The data are the points, and the fit results are full histograms, with backgrounds colored.

$y^2)/2/(1+x^2)$, where $x$ and $y$ were described earlier, but in this case are for the $B^0_d - \overline{B}^0_d$ system.

We look for the process $\Upsilon(4s) \rightarrow B^0_d \overline{B}^0_d \rightarrow \overline{B}^0_d B^0_d$, followed by one $\overline{B}^0_d \rightarrow X \ell^- \nu$, and the other $\overline{B}^0_d \rightarrow D^{*+} h^-$, and the processes obtained by charge conjugations. The hadron from the $W^-$, $h^-$, can be either a $\pi^-$ or a $\rho^-$, and is fully reconstructed. We reconstruct only the slow pion from $D^{*+} \rightarrow D^0 \pi^+$; there is sufficient information to reconstruct all of the decay kinematics with zero constraints.

The complete CLEO-II data set of 9.1 fb$^{-1}$ taken on the $\Upsilon(4s)$ resonance is used to measure the mixing signal, and 4.4 fb$^{-1}$ taken off-resonance is used to estimate various backgrounds. We observe 458 mixed or ‘like sign’ events ($\ell^\pm h^\mp_W$), shown in Fig. 3 and 1524 unmixed or ‘unlike sign’ events ($\ell^\pm h_W^\mp$).

After correction, we find $\chi = 0.198 \pm 0.013 \pm 0.014$. The principal contributions to the systematic error come from cases where the $\overline{B}^0_d \rightarrow D^{*+} h^- W$ decay is a mis-tagged $B^0_d$ decay (0.009), charged $B$ background (0.007), and uncertainty over two body background (0.006).

If we assume that $|y| \ll x$, as is theoretically expected, we can conclude that $\Delta m = 0.523 \pm 0.029 \pm 0.031$ ps$^{-1}$. Comparison of the charge states of the like sign events allows us to restrict CP violation in $B^0_d$ state mixing by $|\text{Re}(\epsilon_B)| < 3.4\%$, 95% C.L.

At an accelerator where the $B$ decay times can be measured, the events used here to measure mixing can be used to measure $\sin(2\beta + \gamma)$. The work in Ref. 5 omitted a form factor suppression in the path through Cabibbo-suppressed decay, and so resulted in an optimistic projection. Using the results here, and with improvements expected at the $B$-factories from better tagging and use of decay time dependence, we can project that an error on $\sin(2\beta + \gamma)$ of about 1/3 can be reached with 200 fb$^{-1}$.

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