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CLEO RESULTS ON HEAVY MESON MIXING

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We discuss recent CLEO results on $D^0 - \overline{D}^0$ and $B_d^0 - \overline{B}_d^0$ 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_d^0 system, $\chi = 0.198 \pm 0.013 \pm 0.014$. We make projections for future sensistivity 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 $K^0 - \overline{K}^0$, $B_d^0 - \overline{B}_d^0$, and $B_s^0 - \overline{B}_s^0$ 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.[1]

We describe recent results from CLEO II.V on $D^0 - \overline{D}^0$ mixing, where we use the sequence $D^{*+} \to D^0 \pi_s^+$, where the charged pion is 'slow' in momentum, followed by the appearence of a $K^+\pi^-$ final state, and the sequence formed by application of charge conjugations. We also describe results on B_d^0–$\overline{B}_d^0$ mixing at the Υ(4s). Following the decay of the Υ(4s) to $B_d^0 \overline{B}_d^0$, we tag one B_d^0 with a semileptonic decay, and the other by a partial reconstruction of the exclusive final state $D^{*+}\pi^-$.

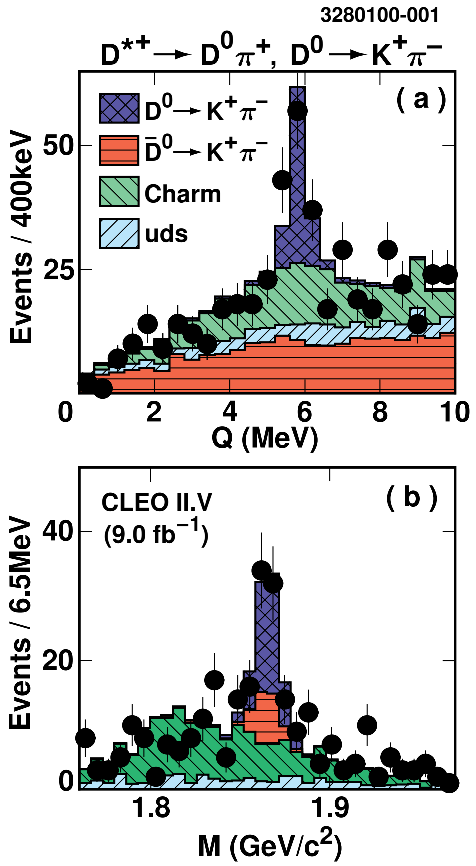

Figure 1. Signal for the 'wrong sign' decay $D^0 \to K^+\pi^-$, projected onto Q (a) and M (b). The fit for the signal and various backgrounds are given by the hatched and colored histograms.

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

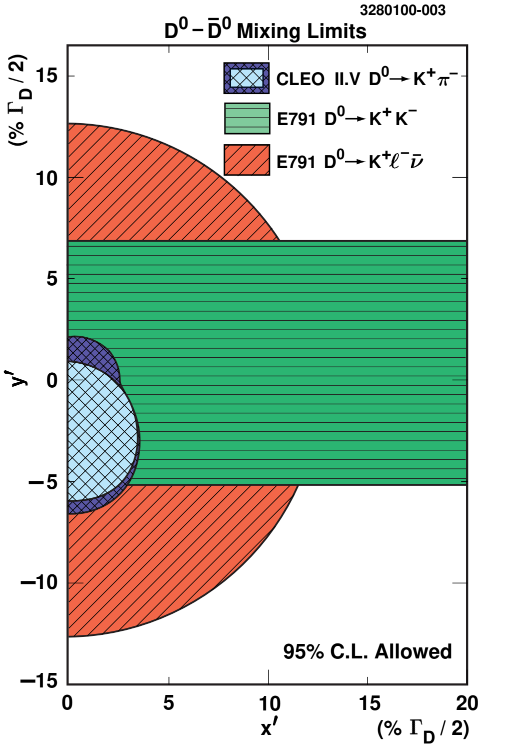

Figure 2. Allowed regions for the mixing amplitudes, x' and y', at the 95% C.L. Those nearest the origin are from this work, where the inner(outer) region requires(does not require) CP conservation.

(SVX) consisting of three layers of double-sided silicon, and helium as the drift chamber gas. The measurement of z by the SVX narrowed the resolution in Q, the energy released in the $D^{*+} \to D^0\pi^+$ decay to σ_Q = 190 KeV, or about 1/4 that obtained in earlier CLEO work. The use of helium narrowed the resolution in M, the mass reconstructed in $D^0 \to K^\mp\pi^\pm$, to $\sigma_M = 6.4\,$MeV, which is nearly 1/2 that of earlier CLEO work. Both of these resolution improvements are important for detecting the signal of $D^0 \to K^+\pi^-$, which is shown in Fig. 1.

The fit in Fig. 1 indicates $44.8^{+9.7}_{-8.7}$ signal events.[2] 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 $\tan^4\theta_C$.

We analyze the decay times of the events in the signal region to deduce results on the $D^0 \to \overline{D}^0$ mixing amplitudes. The normalized amplitude $x(y)$ describes transitions through off(on)-shell intermediate states. The existence of a direct decay amplitude for $D^0 \to K^+\pi^-$ complicates the analysis. The direct decay contributes a purely exponential distribution of decay times. The direct decay amplitude might have a strong phase shift δ relative to the favored decay amplitude, $\overline{D}^0 \to K^+\pi^-$, 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 contributes decay times according to the distribution $(1/4)(x^2+y^2)t^2e^{-t}$.

Fits to our data result in the allowed regions in Fig. 2. In our principal results we allow 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–$\overline{D}^0$ mixing would surpass K^0–$\overline{K}^0$ 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 sensitivity 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 ψ'', and so the scaling with luminosity would go as the one-half power, and hit about $x = 0.1\%$ at 1000 fb^{-1}.

3 $\mathrm{B^0_d}$-$\overline{\mathrm{B}}{}^0_\mathrm{d}$ 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, $\chi = \Gamma(B^0_d \to \overline{B}{}^0_d)/[\Gamma(B^0_d \to B^0_d) + \Gamma(B^0_d \to \overline{B}{}^0_d)] \approx (x^2 +$

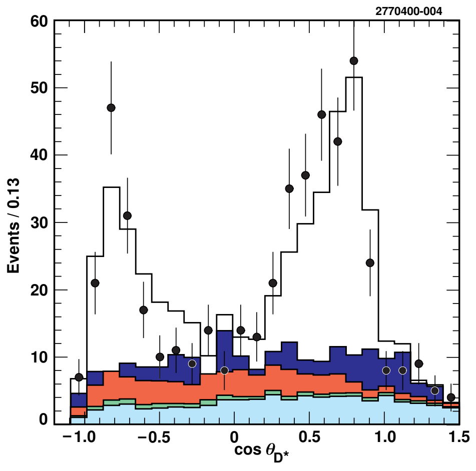

Figure 3. Like sign events, which contain the B mixing signal, as a function of the decay angle of the D^{*+}, $\cos\theta^*$. The data are the points, and the fit results are full histograms, with backgrounds colored.

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

We look for the process $\Upsilon(4s)\to B_d^0\overline{B}_d^0\to \overline{B}_d^0\overline{B}_d^0$, followed by one $\overline{B}_d^0\to X\ell^-\overline{\nu}_\ell$, and the other $\overline{B}_d^0\to D^{*+}h_W^-$, and the processes obtained by charge conjugations. The hadron from the W^-, h_W^-, can be either a π^- or a ρ^-, and is fully reconstructed. We reconstruct only the slow pion from $D^{*+}\to D^0\pi_s^+$; there is sufficient information to reconstruct all of the decay kinematics with zero constraints.[3]

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 ($\ell^\pm h_W^\pm$), shown in Fig. 3, and 1524 unmixed or 'unlike sign' events ($\ell^\pm h_W^\mp$).[4]

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 $\overline{B}_d^0\to D^{*+}h_W^-$ decay is a mis-tagged B_d^0 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 $\Delta m = 0.523\pm 0.029\pm 0.031\mathrm{ps}^{-1}$. Comparison of the charge states of the like sign events allows us to restrict CP violation in B_d^0 state mixing by $|\mathrm{Re}(\epsilon_B)| < 3.4\%$, 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 $\sin(2\beta+\gamma)$.[5] 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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