CLEO Dalitz plot results

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Present and future contributions of the CLEO experiment to the study of $D$ Dalitz plots are presented. Such Dalitz plots can be of help in determining weak phases from $B \rightarrow DK$ decays.

1. INTRODUCTION

$B \rightarrow D_{CP}K$ decays are a source of information on the weak phase $\gamma$. For $D$ modes such as $K_S\pi^+\pi^-$, $\pi^+\pi^-\pi^0$, $K^+K^-\pi^0$, and $K_SK^\pm\pi^\mp$, Dalitz plots yield information on CP-eigenstate and flavor-eigenstate modes and their relative phases [1]. This report will briefly review $B \rightarrow D_{CP}K$ decays and show how they determine $\gamma$. Results from CLEO on the Dalitz plots for the decays $D^0 \rightarrow K^+K^-\pi^0$, $D^0 \rightarrow K_S\pi^+\pi^-$, and $D^0 \rightarrow \pi^+\pi^-\pi^0$ will be presented, and remaining steps will be described.

2. THE CLEO-c DETECTOR

Key elements of the CLEO-c detector [2] are the Ring Imaging Cherenkov Counter for particle identification, momentum resolution $\Delta p/p \simeq 0.6\%$ at 1 GeV/c for charged particles, and a CsI calorimeter with resolution 2.2\% for $E_\gamma \approx 1$ GeV and 5\% at 100 MeV. The detector makes use of a new all-stereo inner drift chamber.

3. $\gamma$ FROM $B \rightarrow DK$ DECAYS

The interference of $b \rightarrow c\bar{u}s$ (real) and $b \rightarrow u\bar{c}s$ ($\sim e^{-i\gamma}$) subprocesses in $B^- \rightarrow D^0K^-$ and $B^- \rightarrow D^0K^-$, respectively, is sensitive to the weak phase $\gamma$. Graphs for the two processes are a tree graph $V_{cb}V_{us}\bar{s}$ and a color-suppressed graph $V_{ub}V_{rs}\bar{r}$ ($r \ll 1$). This interference may be probed by studying common decay products of $D^0$ and $D^0$ into neutral $D_{CP}$ eigenstates or into doubly-Cabibbo-suppressed modes [3].

4. $D^0 \rightarrow K^+K^-\pi^0$

The four rates $B^\pm \rightarrow K^+(K^{*+}K^-)_D$ and $B^\pm \rightarrow K^+(K^{*-}K^+_D$ provide information on $\gamma$ if the relative (strong) phase between $D^0 \rightarrow K^{*+}K^-$ and $D^0 \rightarrow K^-K^+$ is known [4]. One can learn this relative phase from the study of $D^0 \rightarrow K^+K^-\pi^0$ since both final states occur and interfere with one another where $K^{*+}$ and $K^{*-}$ bands cross on the Dalitz plot [5].

A sample of $D^0 \rightarrow K^+K^-\pi^0$ decays based on 9 fb$^{-1}$ at CLEO III (the predecessor to CLEO-c with an inner silicon vertex detector instead of the inner drift chamber) shows this interference clearly [4]. The Dalitz plot is shown in Fig. 1.

The $K^{*+}$ and $K^{*-}$ bands are found to interfere destructively where they cross. The deficit in the $M(K\pi)$ projection above $M(K^{*}(892))$ is difficult to fit using known resonances. The diagonal band at the upper right of the plot is the $\phi(1020)$ resonance, with fit fraction (as defined in [7]) $\approx 10\%$.

These data were taken at an $e^+e^-$ energy at or near the $\Upsilon(4S)$. The $K^{*+}$ band is $\approx 3-4$ times as strong as the $K^{*-}$ band, reflecting differences in form factors and $f_{K^{*+}} > f_{K^-}$. Note the opposite signs of interference with background on the low sides of the $K^{*+}$ and $K^{*-}$ bands. Fits with Breit-Wigner and K-matrix forms are in progress.

5. $D^0 \rightarrow K_S^{0}\pi^+\pi^-$

One can determine $\gamma$ using $B^\pm \rightarrow DK^\pm$ followed by (e.g.) $D \rightarrow K_S\pi^+\pi^-$, $K_SK^+K^-$, $K_S\pi^+\pi^-\pi^0$ [8]. The method uses interference between $b \rightarrow c\bar{u}s$ and $b \rightarrow u\bar{c}s$ sub-
processes. Its advantages are: (1) Resonances entail large strong phases, useful for direct CP asymmetries; (2) one uses only Cabibbo-favored D decay modes; and (3) one can consider final states involving only charged particles (e.g., K_S^+π^-). The method has been utilized by Belle [3], yielding ϕ_3 = (67 ± 28 ± 13 ± 11)° for DK and D^*K modes combined based on 275 M BB pairs, and by BaBar [10], yielding γ = (67 ± 28 ± 13 ± 11)° for DK, D^*K, and DK* modes combined, based on 227 M BB pairs. In each case the last error corresponds to uncertainty in D decay modeling, which CLEO can help to resolve [11].

The Dalitz plots for \( D^0 \rightarrow K^0_S \pi^+\pi^- \) and \( \bar{D}^0 \rightarrow K^0_S \pi^+\pi^- \) obtained from 9.0 fb^{-1} at the CLEO II.V detector are shown in Fig. 2. The doubly-Cabibbo-suppressed \( D^0 \rightarrow K^*+\pi^- \) mode is visible through destructive interference with the Cabibbo-favored \( D^0 \rightarrow K^*+\pi^- \) “right-sign” mode. The dominant fit fractions are \( K^*-(892)\pi^+ \) (\( \sim 2/3 \)) and \( \bar{K}^0 \rho^0 \) (\( \sim 27\% \)). The latter is CP-odd for \( \bar{K}^0 \) detected as \( K^0_S \). CP-even modes such as \( K^0_S f_2(1270), K^0_S f_0(980, 1370) \) give rise to a fit fraction of \( \sim 1/3 \). As usual in such analyses, fit fractions need not add up to 100%.

One can use the Dalitz plot of \( D^0 \rightarrow K^0_S \pi^+\pi^- \) to search for \( D^0-D\bar{D}^0 \) mixing [12]. We define \( \Gamma \equiv \frac{x+i \gamma}{\sqrt{2}}, x \equiv \frac{m-\Delta m}{2\Delta m}, y \equiv \frac{m+\Delta m}{2\Delta m} \). Mass eigenstates evolve in time as \( |D_{1,2}(t)| = |D_{1,2}(0)|e^{-(m_1,2-(\Delta m/2))t} \). One tags \( D^0(t = 0) \) flavor using \( D^{*+} \rightarrow \pi^+D^0 \). A time-dependent Dalitz plot fit then is sensitive to \( D^0-D\bar{D}^0 \) mixing, leading to the CLEO 95% c.l. moon-shaped region shown in Fig. 8. In the fit shown (“A”) no CP conservation was assumed.

6. \( D^0 \rightarrow \pi^+\pi^-\pi^0 \)

A search for CP violation and a study of the \( \pi\pi \) S-wave in the decay \( D^0 \rightarrow \pi^+\pi^-\pi^0 \) has been performed using 9.0 fb^{-1} of CLEO II.V data [13]. The corresponding Dalitz plot and some of its projections are shown in Fig. 4. The projections, points correspond to data while curves are based on a fit describing the S waves with a K-matrix following the formalism of [14].

The CP asymmetry as defined in Ref. 7 is found to be \( A_{CP} = 0.01^{+0.03}_{-0.025} \pm 0.05 \). This mode may be useful in analyzing B decays since \( B^- \rightarrow D_{s+}\pi^-\pi^-K^- \) has been seen [15], with a sample of 133 events in 229 M BB pairs, corresponding to a combined branching ratio of \( B = (5.5 \pm 1.0 \pm 0.7) \times 10^{-6} \). The decay asymmetry in this mode has been found to be \( A = 0.02 \pm 0.16 \pm 0.03 \).

All fits to the \( D^0 \rightarrow \pi^+\pi^-\pi^0 \) Dalitz plot are dominated by the \( \rho^0 \) and \( \rho^0 \) bands, with negli-
Figure 3. Constraints in the x–y plane from various experiments on $D^0 - \bar{D}^0$ mixing.

Figure 4. (a) $D^0 \rightarrow \pi^+ \pi^- \pi^0$ Dalitz plot; (b) $\pi^+ \pi^0$ projection; (c) $\pi^+ \pi^-$ projection; (d) $\pi^- \pi^0$ projection.

7. REMAINING STEPS

So far CESR has accumulated 281 pb$^{-1}$ at the $\psi''(3770)$. More data at this energy will provide a clean sample of $D^0\bar{D}^0$ and $D^+D^-$, with tagging on one side giving the flavor or CP eigenvalue on the other. Examples of CP-odd three-body $D^0$ modes are $K_{S\rho}$, $K_{S\omega}$, $K_{S\phi}$, while some CP-even three-body $D^0$ modes are $K_{Sf_0}(980)$, $K_{Sf_2}(1270)$, $K_{Sf_0}(1370)$.

Once a sufficient sample of $\psi''(3770)$ has been accumulated, it is planned to run at an energy optimized for $D_s$ production. Optimization studies are to begin in August 2005. Subsequently a year’s worth of $J/\psi$ data will shed light on light-quark and glue states.

In future Dalitz plot analyses the approximate relative phase of $\gamma$ between $K^{+}\bar{K}^{-}$ and $K^{-}\bar{K}^{+}$ in $D^0 \rightarrow K^{+}K^{-}\pi^0$ may be used to obtain $\gamma$ from $B^+ \rightarrow D^0 K^-$ as suggested in Ref. [9]. A sample of $D \rightarrow K_S\pi^+\pi^-$ based 281 pb$^{-1}$ from CLEO-c, for which the Dalitz plot is shown in Fig. 4, is currently under analysis. This sample will permit reduction of the Dalitz plot modeling error in obtaining $\gamma$ from $B^\pm \rightarrow DK^\pm$ followed by $D^0 \rightarrow K_S\pi^+\pi^-$ from its current value of $\pm10^\circ$ to about $\pm5^\circ$. One expects about 100 each of even and odd CP tags in the present sample, and eventually up to 10 times that if CLEO-c’s luminosity goals are met.

The CLEO Collaboration gratefully acknowledges the effort of the CESR staff in providing us with excellent luminosity and running conditions. This work was supported by the National Science Foundation and the United States De-
Figure 5. Fits to S-wave component in $D^0 \to \pi^+\pi^-\pi^0$. (a) Flat non-resonant; (b) Breit-Wigner $\sigma(500)$; (c) Breit-Wigner $f_0(980)$; (d) K-matrix.

Department of Energy. I thank M. Tigner for hospitality of the Laboratory for Elementary-Particle Physics at Cornell and the John Simon Guggenheim Foundation for partial support.

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