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SEARCHES FOR DIRECT CP VIOLATION IN D$^+$ DECAYS AND FOR $D^0 - \overline{D}^0$ MIXING

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We present preliminary results of a search for direct CP violation in $D^+ \to K^+K^-\pi^+$ decays using 87 fb^{-1} of data acquired by the Babar experiment running on and near the Υ(4S) from 1999-2002. We report the asymmetries in the signal mode and in the main resonant subchannels. Based on the same dataset, we also report a new 90% CL upper limit of 0.0042 on the rate of D^0–$\overline{D}^0$ mixing using the decay modes $D^{*+} \to D^0\pi^+$, $D^0 \to [K/K^*]e\nu$ (+c.c.).

1 Introduction

This talk reports on the results of two analyses using $\sim 87 fb^{-1}$ of data from the BaBar experiment, which has collected $\sim 250 fb^{-1}$ of data at or near the $\Upsilon(4S)$ resonance so far. The first analysis is a search for a difference (CP asymmetry) in the branching fractions for $D^+ \to K^-K^+\pi^+$ and for $D^- \to K^-K^+\pi^-$. The second analysis reported is a search for $D^0 - \overline{D}^0$ mixing in semielectronic decays of the neutral D meson. The BaBar collaboration comprises 609 members from 78 institutions and the detector is described in detail elsewhere[1].

2 CP Violation in D$^+$ decays

CP violation in singly Cabibbo-Suppressed (SCS) charged D meson decays is predicted by the Standard Model (SM) to have asymmetries of the order of 10^{-3} [2,3]. Direct CP violation in SCS decays is possible in the interference between tree-level and penguin decay processes. Doubly Cabibbo-Suppressed (DCS) and Cabibbo-Favored (CF) decays are expected to be CP invariant in the SM since they are dominated by a single weak amplitude. CP asymmetries greater than $\sim 10^{-3}$ would be strong evidence of physics beyond the SM [4].

We define the CP asymmetry by

$$A_{CP} = \frac{|\mathcal{A}|^2 - |\overline{\mathcal{A}}|^2}{|\mathcal{A}|^2 + |\overline{\mathcal{A}}|^2} \qquad (1)$$

where $\mathcal{A}$ is the total decay amplitude for D^+ decays and $\overline{\mathcal{A}}$ is the amplitude for corresponding D^- decays. Assuming further that CF decays are invariant under CP transformation, we use them as normalization factors and measure the redefined asymmetry,

$$A_{CP} = \frac{\frac{\mathcal{B}(D^+\to K^+K^-\pi^+)}{\mathcal{B}(D_s^+\to K^+K^-\pi^+)} - \frac{\mathcal{B}(D^-\to K^+K^-\pi^-)}{\mathcal{B}(D_s^-\to K^+K^-\pi^-)}}{\frac{\mathcal{B}(D^+\to K^+K^-\pi^+)}{\mathcal{B}(D_s^+\to K^+K^-\pi^+)} + \frac{\mathcal{B}(D^-\to K^+K^-\pi^-)}{\mathcal{B}(D_s^-\to K^+K^-\pi^-)}}. \qquad (2)$$

In this analysis, the CF $D_s^+ \to K^-K^+\pi^+$ branching fraction is used as normalization. This procedure reduces systematic errors since most of the particle identification (PID) and tracking errors cancel out. As cross checks, we calculate the CP asymmetry (i) using the CF $D^+ \to K^-\pi^+\pi^+$ branching fraction as normalization and denote it as $A_{CP}^{(1)}$, and (ii) without any normalization factor and denote it as $A_{CP}^{(2)}$.

We also measure the CP asymmetry for the quasi-two-body final states $D^+ \to \phi\pi^+$ and $D^+ \to \overline{K}^{*0}K^+$, which are selected by requiring that the invariant mass of the resonant decays be within 0.01 GeV/c^2 and

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Table 1. Summary of CP asymmetries in units of 10^{-2}. The top, middle and bottom rows correspond to $K^-K^+\pi^\pm$ inclusive, $\phi\pi^\pm$ and $\overline{K}^{*0}K^\pm$ decays, respectively. Errors are statistical only.

A_{CP}	$A_{CP}^{(1)}$	$A_{CP}^{(2)}$
$+1.36 \pm 1.03$	$+0.58 \pm 0.86$	$+2.07 \pm 0.84$
$+0.24 \pm 1.52$	-0.54 ± 1.35	$+0.94 \pm 1.33$
$+0.88 \pm 1.77$	$+0.10 \pm 1.58$	$+1.58 \pm 1.57$

$0.05\ GeV/c^2$ of the nominal ϕ and $\overline{K}^{*0}$ masses respectively. In addition, we require that the cosine of the helicity angle, $|\cos\theta_H|$, be greater than 0.2 and 0.3 for $D^+ \to \phi\pi^+$ and $D^+ \to \overline{K}^{*0}K^+$ decays respectively.

We use Eq. (2) (recognizing that branching fractions are proportional to yields divided by efficiencies) to obtain A_{CP}. Similarly, we obtain $A_{CP}^{(1)}$ and $A_{CP}^{(2)}$ with appropriate normalization and the results are listed in Table 1. A study of the CP asymmetry in bins of the $D^+ \to K^-K^+\pi^+$ Dalitz plot indicates that the asymmetry is consistent with being constant and zero.

The relative branching ratio $\frac{\Gamma(D^+\to K^-K^+\pi^+)}{\Gamma(D^+\to K^-\pi^+\pi^+)}$ has also been calculated as follows. The CF and SCS Dalitz plots are first binned adaptively to have bins with equal populations. Then the signal and normalization yields and efficiencies are calculated bin by bin. The efficiency corrected yields are then summed and divided to obtain the ratio. We obtain a branching ratio of $(10.7 \pm 0.1(\text{stat.}))\%$ using the final sample.

We estimate the systematic error on the CP asymmetries in three different ways. In the first method, we estimate the errors due to MC statistics, background estimation and selection criteria. These errors are listed in table 2. We also estimate the systematic errors by measuring CP asymmetries for $D^+ \to K^-\pi^+\pi^+$ and $D_s^+ \to K^-K^+\pi^+$ control samples for which we obtain $(1.1 \pm 0.2)\%$ and $(0.6 \pm 0.8)\%$ (statistical errors only) respectively. We chose as our preliminary systematic error in the CP asymmetry, the largest

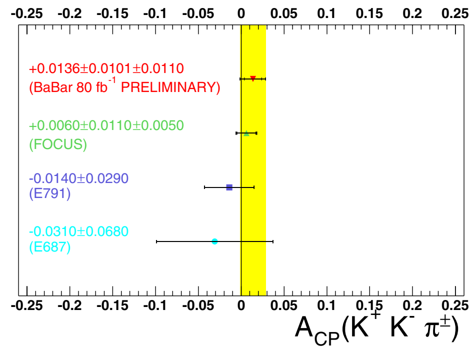

Figure 1. A comparison of BaBar results for the CP asymmetry in inclusive $K^-K^+\pi^\pm$ decays to those from other experiments.

of the estimates from MC and the central values and errors from the control samples, viz., 1.1%. The systematic error for the relative branching fraction has been estimated as 2.1%, computed as the sum in quadrature of 1.1% for PID and 1.8% for tracking.

In summary, preliminary measurements of the CP asymmetries obtained are $A_{CP}(K^+K^-\pi^\pm) = (1.4 \pm 1.0(\text{stat.}) \pm 1.1(\text{syst.}))\%$, $A_{CP}(\phi\pi^\pm) = (0.2 \pm 1.5(\text{stat.}) \pm 0.8(\text{syst.}))\%$, and $A_{CP}(K^\pm\overline{K}^{*0}) = (0.9 \pm 1.8(\text{stat.}) \pm 0.8(\text{syst.}))\%$. These results are in agreement with previously published results [5] (see figures 1, 2), with the results in the resonant modes having significantly reduced errors.

Further, we obtain a preliminary branching ratio for $D^+ \to K^-K^+\pi^+$ decays relative to $D^+ \to K^-\pi^+\pi^+$ decays of $(10.7 \pm 0.1(\text{stat.}) \pm 0.2(\text{syst.}))\%$, a significant improvement over previous measurements [6].

3 Search for $D^0 - \overline{D}^0$ MIXING

The charm (or anti-charm) of a neutral D meson produced in $D^{*+} \to D^0\pi^+$ (or c.c.) decays can be tagged using the charge of the pion. The meson may then mix to its antiparticle before decay and this mixing

Table 2. Summary of systematic errors for the CP asymmetries. Errors are in percent [%].

Source	$(K^-K^+\pi^\pm)$			$(\phi\pi^\pm)$			$(\overline{K}^{*0}\ K^\pm)$		
	$A_{CP}^{(1)}$	$A_{CP}^{(2)}$	A_{CP}	$A_{CP}^{(1)}$	$A_{CP}^{(2)}$	A_{CP}	$A_{CP}^{(1)}$	$A_{CP}^{(2)}$	A_{CP}
MC Simulation	0.07	0.26	0.06	0.07	0.26	0.06	0.07	0.26	0.06
Background Estimate	0.35	0.37	0.63	0.04	0.05	0.32	0.21	0.22	0.49
Selection - 1	0.45	0.53	0.22	0.08	0.15	0.15	0.24	0.31	0.01
Selection - 2	0.96	1.13	0.46	0.05	0.11	0.54	0.05	0.11	0.54
Total	1.12	1.33	0.81	0.12	0.32	0.65	0.33	0.47	0.73

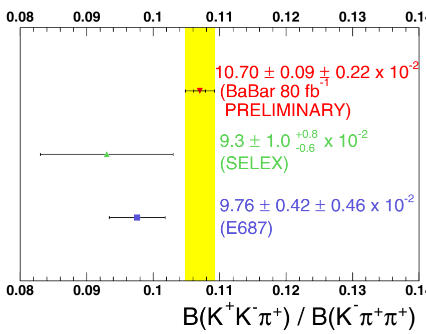

Figure 2. A comparison of BaBar results for the branching ratio of D^+ decays to $K^-K^+\pi^\pm$ and $K^-\pi^+\pi^+$ to those from other experiments.

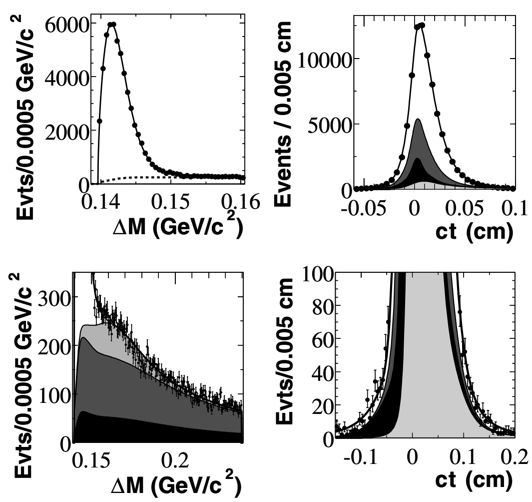

Figure 3. RS data ΔM and ct plots. The lower plots have an expanded scale to display greater detail. The dashed line in the first plot corresponds to background. The shaded regions in the other plots correspond to unmixed signal (white), D^+ background (light shading), D^0 background (medium shading) and zero-lifetime background (black).

can be detected using the lepton charge in, e.g., $D^0 \to K^-e^+\nu_e$ decays. There is no DCS background in these semileptonic decays. The rate of wrong-sign (WS) decays relative to the Cabibbo-favored right-sign (RS) decays is called r_{mix}, and is predicted to be rather small in the Standard Model. Calculations based on the box diagram alone predict $r_{mix} \sim 10^{-7}$, while long distance effects and new physics models can make this rate much larger, $\sim 10^{-3}$ [4,7,8].

Using $\sim 87 fb^{-1}$ of data we extract a sample of $\sim 50,000$ $K^\pm e^\mp \nu$ decays, where the neutral D is created in $D^{*\pm}$ decays. Figures 3, 4 display the ΔM and lifetime distributions obtained in RS and WS decays, where ΔM is the mass difference between the measured $D^{*\pm}$ and neutral D masses. We use neural networks both for the selection of our events as well as for reconstructing the neutral D meson momentum. We then fit the RS sample to obtain the number of unmixed events (49620 ± 324) and to obtain the ΔM and lifetime pdfs, which are then used to obtain the WS yield of 114 ± 61 events.

The error on the WS yield indicates that our sensitivity to r_{mix} is ~ 0.001; however, the $\sim 2\sigma$ WS yield leads to the limit $r_{mix} <$ 0.0042 (90% CL) [9]. The measured value

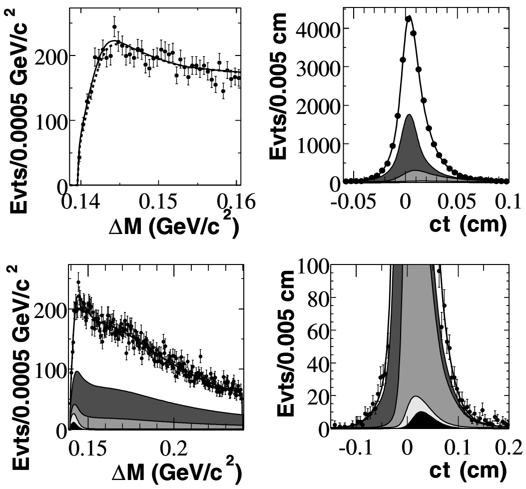

Figure 4. WS data ΔM and ct plots. The lower plots have an expanded scale to display greater detail. The mixed signal in the first plot lies between the two lines. The shaded regions in the other plots correspond, from lowest on up, to mixed signal (black), peaking D^+ background (light grey), non-peaking D^+ background (medium grey), zero-lifetime background (dark grey) and D^0 background (white).

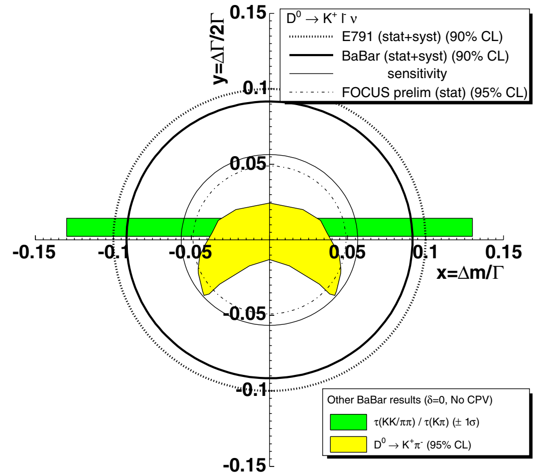

Figure 5. Comparison of mixing results from various experiments.

is $r_{mix} = 0.0023 \pm 0.0012 \pm 0.0004$, where the last value is the systematic error arising mainly from uncertainties in the ΔM pdf and in the background models. A comparison to other results [10] is shown in Figure 5.

Acknowledgments

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