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CP violation in charm decays at Belle

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We have searched for *CP* violation of charmed mesons in the decays $D \to K^0_S P$, where D denotes D^0 and $D^+_{(s)}$, and P denotes the pseudo-scalar mesons π^+, K^+, π^0, η, and η'. No evidence of *CP* violation in these decays is observed. We also have measured the *CP* asymmetry difference between the Cabibbo suppressed decay $D^+ \to \phi\pi^+$ and the Cabibbo favored $D^+_s \to \phi\pi^+$ decays in the region of $|M(K^+K^-) - M^{\phi}_{PDG}| < 16$ MeV/c^2. The measured asymmetry is corrected for the residual asymmetry due to detector effects, and the contributions of both *CP* and forward-backward asymmetries are determined. These results are obtained on a large data sample collected at and near the $\Upsilon(4S)$ resonance with the Belle detector operating at the KEKB asymmetric-energy e^+e^- collider.

35th International Conference of High Energy Physics - ICHEP2010,
July 22-28, 2010
Paris France

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Violation of the combined Charge-conjugation and Parity symmetries (*CP*) in the standard model (SM) is produced by a non-vanishing phase in the Cabibbo-Kobayashi-Maskawa flavor-mixing matrix [1], where the violation may be observed as a non-zero *CP* asymmetry defined as

$$A_{CP}^{D\to f} = \frac{\Gamma(D\to f) - \Gamma(\bar{D}\to \bar{f})}{\Gamma(D\to f) + \Gamma(\bar{D}\to \bar{f})} \tag{1}$$

where Γ is the partial decay width, D denotes a charmed meson, and f is a final state.

In the SM, the charged charmed meson decays for which a significant non-vanishing *CP* violation ($\mathcal{O}(0.1)\%$ or lower [2]) is expected are singly Cabibbo-suppressed (SCS) decays in which there is both interference between two different decay amplitudes and a strong phase shift from final state interactions. The expected SM *CP* violation in non-leptonic decay of the neutral charmed meson is generated from interference of decays with and without mixing in the absence of direct *CP* violation in Cabibbo favored (CF) and doubly Cabibbo suppressed (DCS) decays. The SM also predicts a *CP* asymmetry in the final states containing a neutral kaon that is produced via $K^0 - \bar{K}^0$ mixing even if no *CP* violating phase exists in the charm decays itself and we refer to it as $A_{CP}^{K_S^0}$. The magnitude of $A_{CP}^{K_S^0}$ is $(0.332 \pm 0.006)\%$ [3] if DCS decay contributions are ignored.

In this presentation, we report *CP* asymmetries of charmed mesons in the decays $D \to K_S^0 P$, where D denotes D^0 and $D_{(s)}^+$, and P denotes the pseudo-scalar mesons π^+, K^+, π^0, η, and η' [4]. We also report the *CP* asymmetry difference between SCS decay $D^+ \to \phi\pi^+$ and CF decay $D_s^+ \to \phi\pi^+$ in the region of $|M(K^+K^-) - M_{PDG}^{\phi}| < 16$ MeV/c^2. Among the decays listed above, $D^+ \to K_S^0 K^+$ and $D_s^+ \to K_S^0\pi^+$ are SCS decays and others are mixtures of CF and DCS decays, where SM *CP* violations described above are expected. Interference between CF and DCS could generate $\mathcal{O}(1)\%$ of direct *CP* asymmetry if unknown new physics processes are responsible for additional weak phases [5]. Physics beyond the SM could also induce direct *CP* asymmetry ($\mathcal{O}(1)\%$) in D meson decays [6]. Since *CP* asymmetries expected by the SM in the decays considered in this presentation is much smaller than $A_{CP}^{K_S^0}$, observing A_{CP} inconsistent with $A_{CP}^{K_S^0}$ would represent strong evidence for processes involving physics beyond the SM [5][6]. The data were recorded at or near the $\Upsilon(4S)$ resonance with the Belle detector [7] at the e^+e^- asymmetric-energy collider KEKB [8]. The sample corresponds to an integrated luminosity of 673/791/854 fb^{-1} depending on the decay mode.

We determine the quantity $A_{CP}^{D\to f}$ defined in Eq. (1) by measuring the asymmetry in the signal yield

$$A_{\rm rec}^{D\to f} \;=\; \frac{N_{\rm rec}^{D\to f} - N_{\rm rec}^{\bar{D}\to \bar{f}}}{N_{\rm rec}^{D\to f} + N_{\rm rec}^{\bar{D}\to \bar{f}}} \;=\; A_{CP}^{D\to f} \;+\; A_{\rm other}, \tag{2}$$

where $N_{\rm rec}$ is the number of reconstructed decays. $A_{\rm other}$ is asymmetry other than A_{CP} and it contains the forward-backward asymmetry (A_{FB}) due to $\gamma^* - Z^0$ interference in $e^+e^- \to c\bar{c}$ and the other is a detection efficiency asymmetry between positively and negatively charged hadrons and the latter depends on decay mode. With assumption the A_{FB} is the same for all charmed mesons, we correct for $A_{\rm other}$ using a large statistics of real data samples. The detailed correction procedures are described in Refs. [9][10][11]. Once we correct for $A_{\rm other}$, then $A_{CP}^{D\to f}$ is obtained in bins of corresponding phase spaces (shown in Fig. 1) and the measured A_{CP} values are listed in Table 1.

The *CP* asymmetry difference between SCS decay $D^+ \to \phi\pi^+$ and CF decay $D_s^+ \to \phi\pi^+$ (ΔA_{CP}) is obtained by subtracting $A_{\rm rec}^{D_s^+\to\phi\pi^+}$ from $A_{\rm rec}^{D^+\to\phi\pi^+}$ since the kinematics of $D^+ \to \phi\pi^+$

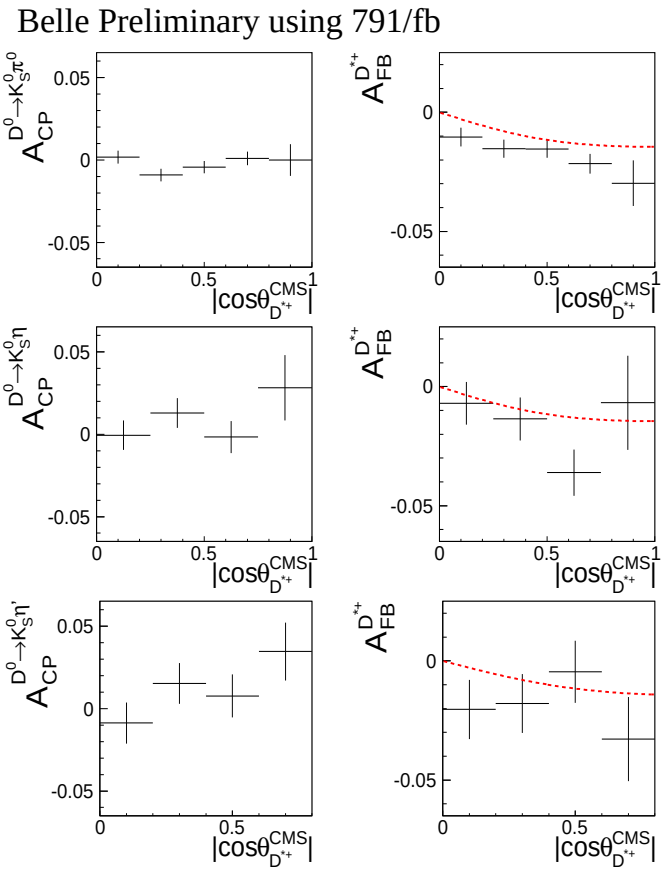

Figure 1: Preliminary results of A_{CP} (left) and A_{FB} (right) values as a function of $|\cos\theta_{D^{*+}}^{\rm CMS}|$. Top plots are for $K_S^0\pi^0$, middle plots for $K_S^0\eta$, and bottom plots for $K_S^0\eta'$ final states. The dashed curves show the leading-order prediction for $A_{FB}^{c\bar{c}}$.

Table 1: Summary of the A_{CP} measurements. The first uncertainties are statistical and the second are systematic. The ‡ is the total uncertainty. The †'s are preliminary results.

Decay Mode	A_{CP} (%) (Belle)	A_{CP} (%) (current world best or world average)	$A_{CP}^{K_S^0}$ (%)
$D^+\to K_S^0\pi^+$	$-0.71\pm0.19\pm0.20$	$-1.3\pm0.7\pm0.3$	-0.332
$D^+\to K_S^0K^+$	$-0.16\pm0.58\pm0.25$	$-0.2\pm1.5\pm0.9$	-0.332
$D_s^+\to K_S^0\pi^+$	$+5.45\pm2.50\pm0.33$	$+16.3\pm7.3\pm0.3$	$+0.332$
$D_s^+\to K_S^0K^+$	$+0.12\pm0.36\pm0.22$	$+4.7\pm1.8\pm0.9$	-0.332
$D^0\to K_S^0\pi^0$	$-0.28\pm0.19\pm0.10^\dagger$	$+0.1\pm1.3^\ddagger$	-0.332
$D^0\to K_S^0\eta$	$+0.54\pm0.51\pm0.16^\dagger$	N.A.	-0.332
$D^0\to K_S^0\eta'$	$+0.90\pm0.67\pm0.14^\dagger$	N.A.	-0.332

and $D_s^+ \to \phi\pi^+$ are quite similar with each other. Besides the ΔA_{CP}, the production difference between D^+ and D_s^+ (ΔA_{FB}) is also obtained by the subtraction. Figure 2 shows the measured ΔA_{CP} and ΔA_{FB} in bins of corresponding phase space in the region of $|M(K^+K^-) - M^{\phi}_{PDG}| < 16$ MeV/c^2. By fitting the ΔA_{CP} points with a constant, we obtain a preliminary result of $\Delta A_{CP} = (0.62 \pm 0.30 \pm 0.15)\%$ where the first uncertainty is statistical and the second is systematic. The ΔA_{FB} plot in Fig. 2 shows no significant difference between forward-backward asymmetries in the production of the D^+ and D_s^+ mesons.

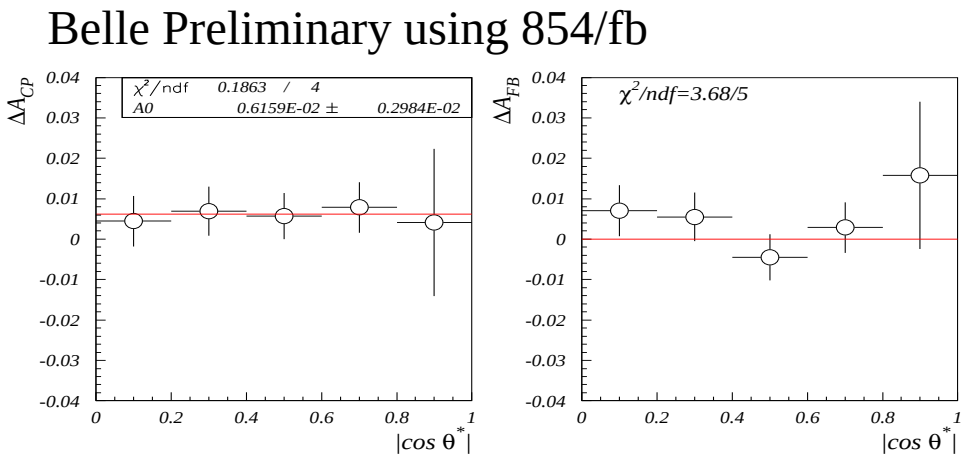

Figure 2: Preliminary results of ΔA_{CP} (left) and ΔA_{FB} (right) values as a function of $|\cos\theta^*|$. The line in left plot shows the fit with a constant and that of right shows the hypothesis test for a null ΔA_{FB} hypothesis.

In summary, we have searched for *CP* violation in several charm decays. No evidence for *CP* violation is observed at sensitivities greater than 0.2% depending on the decay mode. We also find no significant difference between forward-backward asymmetries in the production of the D^+ and D_s^+ mesons.

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