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$\mathbf{D}^+_{(\mathbf{s})}$ Decays and their CP Violation

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Hadronic decays of the charmed mesons D^0, D^+, and D^+_s offer unique opportunities to probe weak and non-perturbative strong dynamics. This includes the study of long-distance hadronic effects, the approximate symmetries of strong interactions, and precision tests of the Standard Model. The CP violating asymmetries in charm provide a unique of physics beyond the Standard Model. In this report we summarize recent CLEO-c and Belle measurements of hadronic branching fractions of $D_{(s)}$ decays to two pseudoscalar mesons and measurements searching for CP violation in these decays.

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1. Introduction

Hadronic charm decays provide opportunities to probe electro-weak and strong dynamics. Charmed nonleptonic decays are usually classified by the degree of Cabibbo-Kobayashi-Maskawa (CKM) matrix element suppression. Least suppressed, where the quark level transitions are $c \to su\overline{d}$ are labeled *Cabibbo favored* (CF) decays. The *singly Cabibbo suppressed* (SCS) decays are driven by $c \to du\overline{d}$ or $c \to su\overline{s}$ quark transitions, while *doubly Cabibbo suppressed* (DCS) decays proceed via $c \to du\overline{s}$ quark processes. The rates of the SCS and DCS decays with respect to the CF decays rates typically differ by $tan^2\theta_C$ and $\tan^4\theta_C$, i.e. by one or two to three orders of magnitude, respectively, where θ_C is the Cabibbo mixing angle [1].

Calculation of hadronic decay rates governed by these transitions are quite complicated and model-dependent [2, 3, 4, 5]. It is often useful to obtain ratios among several decay rates instead of predicting an absolute decay rate. The relations can be constructed using some symmetries, such as flavor $SU(3)$ symmetry [6, 7, 8]. However, data available experimental data show that flavor $SU(3)$ symmetry is broken in charm transitions. For example, in the flavor $SU(3)$ symmetry limit, the rates for $D^0 \to K^+K^-$ and $D^0 \to \pi^+\pi^-$ decays should be the same, but experimental data tells us that the former is around three times larger than the latter [9]. Precise experimental data on the hadronic decay rates are thus needed to allow for better understanding of the sources of the flavor $SU(3)$ symmetry breaking effects [10, 11]. Experimental data on hadronic decay rates are also needed for example in calculations of the long distance contributions to the $D^0-\overline{D}^0$ mixing parameters [12].

Study of hadronic SCS decays of charmed hadrons are also important, since they hold the potential for observation of direct *CP* violation in the *D*-system. Direct *CP* violation occurs when the absolute value of the decay amplitude for D to decay to a final state f ($\mathscr{A}_f$) is different from the one of corresponding *CP*-conjugated amplitude. This can happen if the decay amplitude can be separated into at least two parts associated with different weak and strong phases,

$$\mathscr{A}_f = |\mathscr{A}_1|e^{i\delta_1}e^{i\phi_1} + |\mathscr{A}_2|e^{i\delta_2}e^{i\phi_2}, \tag{1.1}$$

where ϕ_i represents weak phases that switch sign under *CP*-transformation, and δ_i represent strong phases which are *CP*-invariant. This ensures that *CP*-conjugated amplitude, $\overline{\mathscr{A}}_{\overline{f}}$, differs from $\mathscr{A}_f$. Experimentally, the direct *CP*-violation is probed by measuring the the difference between the partial decay widths (Γ) of $D \to f$ and $\overline{D} \to \overline{f}$ decays,

$$A_{CP} \equiv \frac{\Gamma(D \to f) - \Gamma(\overline{D} \to \overline{f})}{\Gamma(D \to f) + \Gamma(\overline{D} \to \overline{f})} \propto sin(\phi_1 - \phi_2)sin(\delta_1 - \delta_2). \tag{1.2}$$

In the Standard model (SM) direct *CP* violation can occur in SCS decays, but not in CF or DCS decays. This is due to the fact that the final state particles in SCS decays contain at least one pair of quark and anti-quark of the same flavor, which makes a contribution from penguin-type or box amplitudes induced by virtual b-quarks possible in addition to the tree amplitudes. However, the contribution of these second order amplitudes are strongly suppressed by the small combination of CKM matrix elements $V_{cb}V_{ub}{}^*$. The *CP* violating asymmetry (Eq. 1.2) is in the SM expected to be at most at the level of 0.1% [13], which is well below the current experimental sensitivity. In some New Physics models the *CP* asymmetry can be significantly enhanced and can be as large as 1%

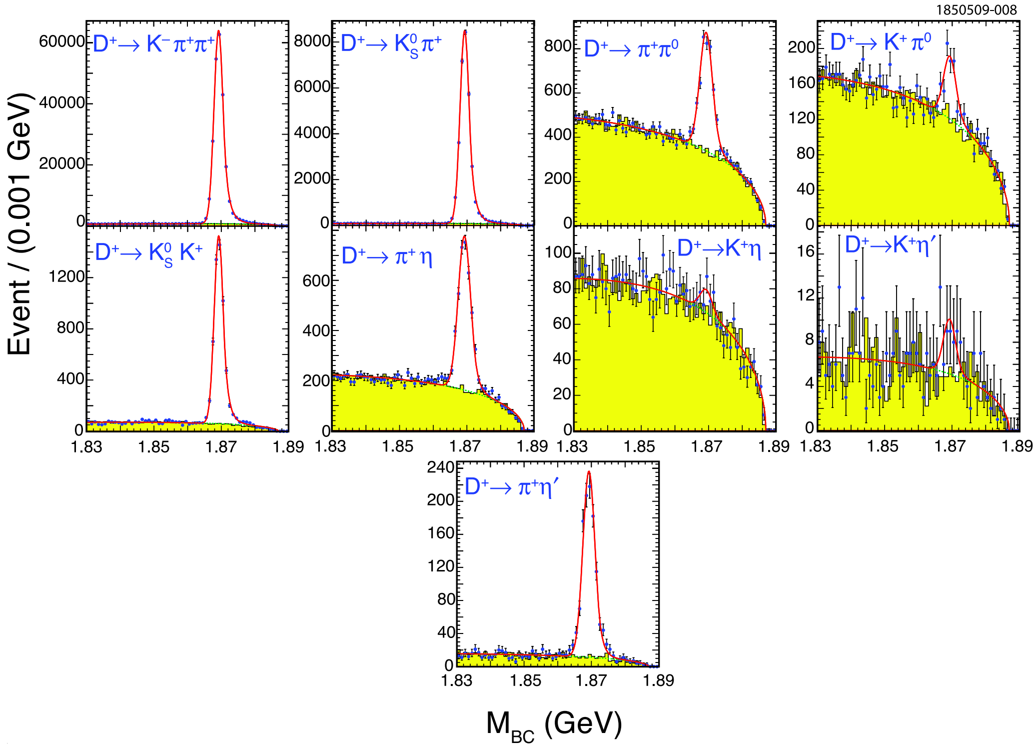

Figure 1: The M_{bc} distribution of D^+ modes, reproduced from [18]. For each distribution, the points are obtained from the ΔE signal region, the shaded histogram is from ΔE sidebands, and the line is the fit.

[14, 15, 16, 17]. It is thus widely believed that the observation of large *CP* violation ($\mathscr{O}(\infty\%)$) in charm decays would be an unambiguous sign for processes beyond the SM.

In these proceedings we summarize recent results in non-leptonic branching fraction measurements of D^+ and D^+_s mesons and measurements of direct *CP* violation in their decays.

2. Charm decays to two pseudoscalar mesons

CLEO-c has recently published [18] the results of ratios of branching fractions of D^0, D^+, and D^+_s decays to any pair of K^+, K^-, π^+, π^-, η, η', π^0, K^0, or $\overline{K}^0$[1] relative to $D^0 \to K^-\pi^+$, $D^+ \to K^-\pi^+\pi^+$, and $D^+_s \to K^0_S K^+$ decays. The measurement used CLEO-c's full data set, containing around 2.4×10^6 D^+D^- pairs, 3.0×10^6 $D^0\overline{D}^0$ pairs, and 0.54×10^5 $D^{*\pm}_s D^{\mp}_s$ pairs, collected in e^+e^- collisions at center-of-mass (CM) energies near 3774 MeV ($D\overline{D}$ sample) and 4170 MeV ($D^{*\pm}_s D^{\mp}_s$ sample).

The signal yields of reconstructed D^0 and D^+ mesons are determined from the fits to the beam-constrained mass, M_{bc}, distributions, shown in Fig. 1 for D^+ modes, while the D^+_s signal yields are determined from the invariant mass distributions, $M(D_s)$, shown in Fig. 2. For most of the studied decay modes, very clear signals are found. Many of the resulting branching fraction measurements are more precise than the previous world average [9], and some decay modes have been seen for

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[1] The detectable neutral kaons are K^0_S and K^0_L, not K^0 and $\overline{K}^0$, so the experimentally observable decays are XK^0_S and XK^0_L. In the presented study, CLEO-c considered decays involving K^0_S, not K^0_L.

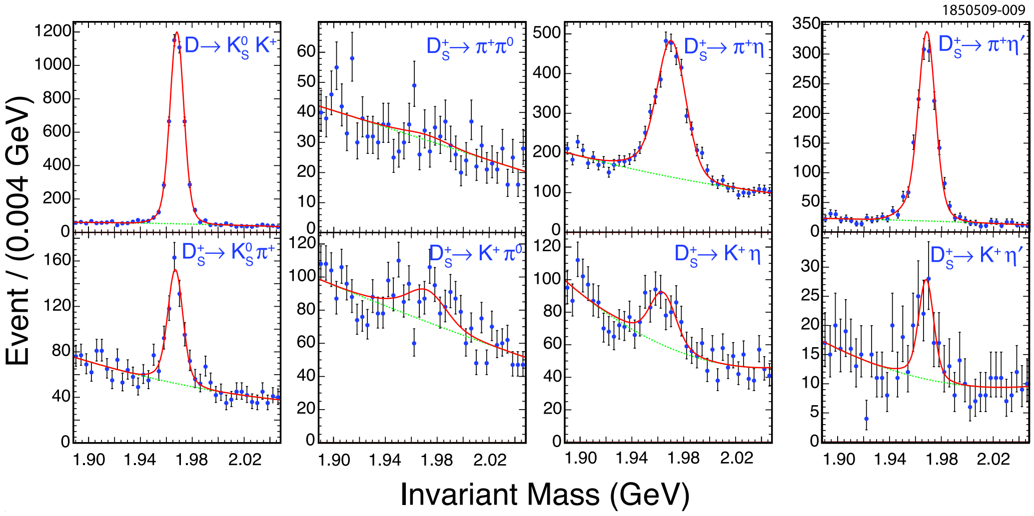

Figure 2: The $M(D_s)$ distribution of D_s modes, reproduced from [18]. For each distribution, the points are the data and the superimposed line is the fit (the dotted line is the fitted background).

the first time. In addition, CLEO-c measured separate yields and efficiencies for D and $\overline{D}$ events, from which they computed A_{CP} asymmetries. These results are summarized in Table 3. In addition

Belle reported a measurement of the of the SCS $D^+ \to K^0_S K^+$ and $D^+_s \to K^0_S \pi^+$ branching ratios with respect to the corresponding CF modes [21]. The invariant mass distributions of the selected events are shown in Fig. 3. Using the data sample of 605 fb^{-1} recorded at or near $\Upsilon(4S)$ resonance, Belle founds $R(D^+) \equiv \mathscr{B}(D^+ \to K^0_S K^+)/\mathscr{B}(D^+ \to K^0_S \pi^+) = 0.1899 \pm 0.0011 \pm 0.0022$ and $R(D^+_s) \equiv \mathscr{B}(D^+_s \to K^0_S \pi^+)/\mathscr{B}(D^+_s \to K^0_S K^+) = 0.0803 \pm 0.0024 \pm 0.0019$, where the first uncertainties are statistical and second systematic. Using the world average values of CF decay rates [9], Belle obtains the most precise branching fractions $\mathscr{B}(D^+ \to K^0_S K^+) = (2.75 \pm 0.08) \times 10^{-3}$ and $\mathscr{B}(D^+_s \to K^0_s \pi^+) = (1.20 \pm 0.09) \times 10^{-3}$ up to now.

In the diagrammatic approach based on the framework of flavor $SU(3)$ [10, 11] the decay amplitudes are expressed in terms of topological quark flow diagrams: Tree, Color-suppressed tree, Annihilation, Singlet-emission with Annihilation, Exchange, and Singlet-emission with Exchange. Each diagram represents an amplitude which accounts for weak and strong interaction effects, to all orders, including long distance effects. Different D^0, D^+, and D^+_s two-body decay amplitudes are expressed in terms of these six diagrams using the flavor symmetries. The experimental information is sufficient to use the CF decays to fit for the quark flow diagram amplitudes, their relative phases, and the octet-singlet mixing angle θ_η, which is found to be 11.7°. These best fit values are then used to predict SCS and DCS decay rates in the flavor $SU(3)$ symmetry, some of them given in Table 1. In some SCS decays, as for example in $D^0 \to K^+K^-$ and $D^0 \to \pi^+\pi^-$ decays, the approach does not work very well, which points to sizable violation of flavor $SU(3)$ symmetry in these decays.

3. *CP* violation in D^+ and D^+_s decays to two pseudoscalar mesons

Searches of direct *CP* violation (Eq. 1.2) were performed in last 15 years in over 30 D^0, D^+ and D^+_s decay modes by Belle, Babar, CLEO-c, CDF, FOCUS, E796, and E687 experiments. Full

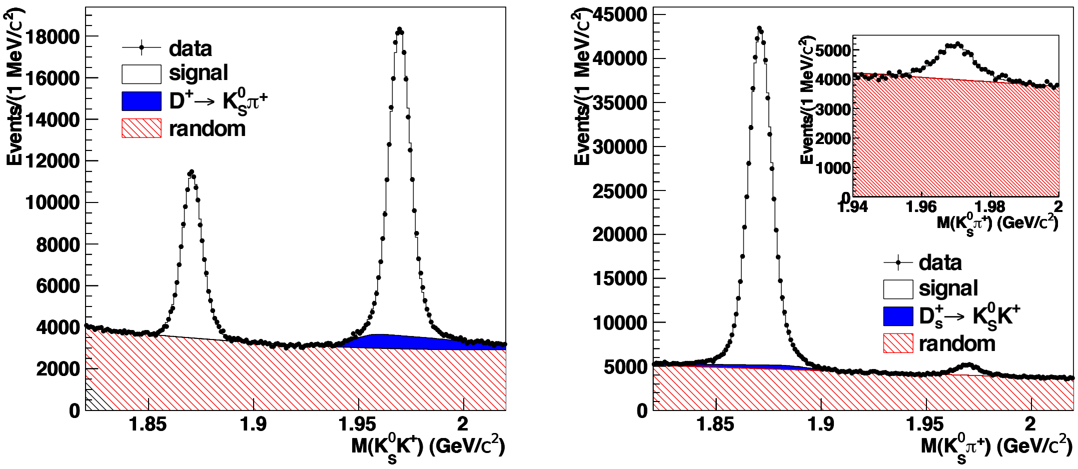

Figure 3: Invariant mass distributions of selected $K_S^0K^+$ and $K_S^0\pi^+$ pairs, reproduced from [21]. Points with error bars show the data and histograms show the results of the fits. The inset is an enlarged view of the D_s^+ region.

Meson	Mode	Representation	$\mathscr{B}_{\rm exp}$ $[\times 10^{-3}]$	$\mathscr{B}_{\rm fit}$ $[\times 10^{-3}]$
D^0	$K^-\pi^+$	$V_{cs}^*V_{ud}(T+E)$	39.1 ± 0.8	39.1 ± 1.7
D^+	$\overline{K}^0\pi^+$	$V_{cs}^*V_{ud}(T+C)$	30.7 ± 1.0	30.8 ± 3.6
D_s^+	$\overline{K}^0K^+$	$V_{cs}^*V_{ud}(C+A)$	29.8 ± 1.7	29.7 ± 3.2
D^0	$\pi^+\pi^-$	$V_{cd}^*V_{ud}(T'+E')$	1.45 ± 0.05	2.24 ± 0.10
	$\pi^0\pi^0$	$\frac{1}{\sqrt{2}}V_{cd}^*V_{ud}(C'-E')$	0.81 ± 0.05	1.35 ± 0.05
	K^+K^-	$V_{cs}^*V_{us}(T'+E')$	4.07 ± 0.10	1.92 ± 0.08
D^+	$K^+\overline{K}^0$	$V_{cd}^*V_{ud}A'+V_{cs}^*V_{us}T'$	6.12 ± 0.22	5.46 ± 0.53
D_s^+	π^+K^0	$V_{cd}^*V_{ud}T'+V_{cs}^*V_{us}A'$	2.52 ± 0.027	0.273 ± 0.026
D^0	$K^+\pi^-$	$V_{cd}^*V_{us}(T''+E'')$	0.148 ± 0.007	0.112 ± 0.005
D^+	$K^+\pi^0$	$\frac{1}{\sqrt{2}}V_{cd}^*V_{us}(T''-A'')$	0.172 ± 0.019	0.159 ± 0.015
D_s^+	K^0K^+	$V_{cd}^*V_{us}(T''+C'')$		0.038 ± 0.004

Table 1: Branching fractions and invariant amplitudes for some CF, SCS and DCS decays of charmed mesons to two pseudoscalar mesons, reproduced from [11]. Data are taken from [18]. Predictions based on best-fitted results are given in the last column.

list of all measurements with the averages can be found on the HFAG website [22]. No evidence for *CP* violation was found so far, however the measurements have only started reaching interesting level of sensitivity below 1% in some decay modes. In order to increase the sensitivity to or below 0.1% level not only larger samples but also very good control over the systematic uncertainties will be needed. These uncertainties are dominated by the uncertainties in asymmetries in the detection and reconstruction of particles of opposite charge. In addition, forward-backward production asymmetries, resulting from Z^0/γ interference and higher order loops in the production of $c\bar{c}$ quark pairs, results in asymmetries in the distribution of D decay products in regions of varying efficiency in the detector. Estimation of these factors used to rely upon Monte Carlo simulated studies, with questionable assumptions about charge-dependent interaction effects, resulting in systematic uncertainties in A_{CP}'s in the 1-5% range. In the past years, new insights in using real data rather than simulations have led to reduction of these uncertainties to the 0.2-0.5% range. These uncertainties are determined by the statistics of the sample and will thus decrease with increasing sample sizes.

Belle published recently the most precise measurement of the CP violating asymmetry A_{CP} in $D^+_{(s)} \to K^0_S\pi^+$ and $D^+_{(s)} \to K^0_S K^+$ decays [23]. Using the data sample of 673 fb^{-1} recorded at or near the $\Upsilon(4S)$ resonance, Belle determined the CP violating asymmetry A_{CP} by measuring the signal yield asymmetry

$$A^{\rm rec} = \frac{N^{\rm rec}_{D^+_{(s)}} - N^{\rm rec}_{D^-_{(s)}}}{N^{\rm rec}_{D^+_{(s)}} - N^{\rm rec}_{D^-_{(s)}}} \tag{3.1}$$

where $N^{\rm rec}_{D^+_{(s)}}$ and $N^{\rm rec}_{D^-_{(s)}}$ are the numbers of reconstructed decays of $D^+_{(s)}$ and $D^-_{(s)}$, respectively. The measured asymmetry in Eq. 3.1 includes two contributions other than A_{CP}. One is the forward-backward asymmetry, A_{FB} and the other is the detection efficiency asymmetry between positively and negatively charged tracks, A^h_ε. No additional detection asymmetry arises from reconstruction of K^0_S mesons since they are formed from a $\pi^+\pi^-$ pair. The signal yield asymmetry can therefore be expressed as

$$A^{\rm rec} = A_{CP} + A_{FB} + A^h_\varepsilon. \tag{3.2}$$

To correct for the symmetries other than A_{CP}, Belle used reconstructed asymmetries measured in $D^+_s \to \phi\pi^+$ and $D^0 \to K^-\pi^+$ decays, which are given by

$$\begin{align} A^{\rm rec}(D^+_s \to \phi\pi^+) &= A_{FB}(D^+_s) + A^{\pi^+}_\varepsilon, \tag{3.3} \\ A^{\rm rec}(D^0 \to K^-\pi^+) &= A_{FB}(D^0) + A^{K^-}_\varepsilon + A^{\pi^+}_\varepsilon. \tag{3.4} \end{align}$$

The A_{CP} is assumed to be negligibly small at the current experimental sensitivity for CF $D^+_s \to \phi\pi^+$ and $D^0 \to K^-\pi^+$ decays and that A_{FB} is the same for all charmed mesons. The subtraction of measured asymmetry for $D^+_s \to \phi\pi^+$ (Eq. 3.3) from that for $D^+_{(s)} \to K^0_S\pi^+$ (Eq. 3.2) yields A_{CP} in the latter decays. The subtraction is performed in bins of π^+ momentum, $p^{\rm lab}_\pi$, and polar angle in the laboratory system, $cos\theta^{\rm lab}_\pi$, and the charmed meson's polar angle in the CM system, $cos\theta^{\rm CM}_{D_{(s)+}}$, since A^h_ε depends on $p^{\rm lab}_h$ and $cos\theta^{\rm lab}_h$, and $cos\theta^{\rm CM}_{D_{(s)+}}$ is correlated with $cos\theta^{\rm lab}_h$ and A_{FB} depends on it. Figure 4 shows the A_{CP} map of $D^+ \to K^0_S\pi^+$ in bins of ($p^{\rm lab}_\pi$, $cos\theta^{\rm lab}_\pi$, $cos\theta^{\rm CM}_{D_{(s)+}}$). The inclusive correction of $A_{FB} + A^{\pi^+}_\varepsilon$ in $D^+ \to K^0_S\pi^+$ decays was found to be $(-0.34\pm0.18)\%$ and was used to correct for asymmetries other than A_{CP} in $D^+_s \to K^0_S\pi^+$ decays, since the statistical precision of the latter sample was to low for a three-dimensional correction.

The method for the measurement of A_{CP} in the $K^0_S K^+$ final states is different from that of the $K^0_S\pi^+$ final states. There is no corresponding large statistics decay mode that can be used to directly measure A_{FB} and A^K_ε in A^{rec} for $D^+_s \to K^0_S K^+$ decays (Eq. 3.2). Thus, to correct the reconstructed asymmetry in these decays the $D^0 \to K^-\pi^+$ and the $D^+_s \to \phi\pi^+$ decays are used. From the reconstructed asymmetry for $D^0 \to K^-\pi^+$ decays (Eq. 3.4) the $A^{K^-}_\varepsilon$ correction is obtained in bins of (($p^{\rm lab}_K$, $cos\theta^{\rm lab}_K$) by using π^+ correction map determined for $D^+_s \to \phi\pi^+$ (Eq. 3.3) from that for

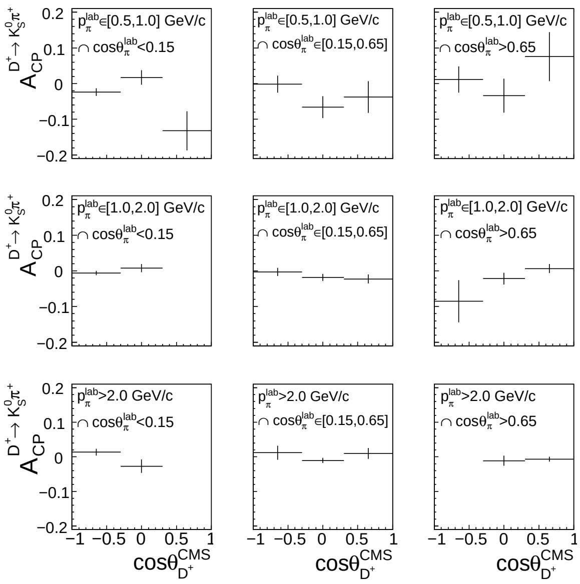

Figure 4: Measured A_{CP} values for $D^+ \to K_S^0\pi^+$ decays in bins of ($p_\pi^{\rm lab}$, $cos\theta_\pi^{\rm lab}$, $cos\theta^{\rm CM}_{D_{(s)^+}}$), reproduced from [23].

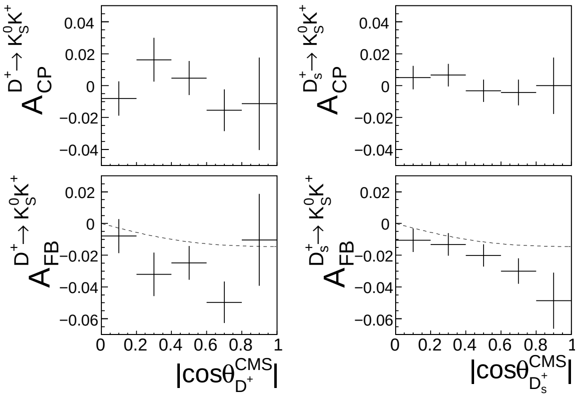

Figure 5: Measured A_{CP} and A_{FB} values for $D^+_{(s)} \to K^0_S K^+$ decays as a function of $cos\theta^{\rm CM}_{D^+_{(s)}}$, reproduced from [23]. The dashed curves show the leading-order prediction for $A^{c\bar{c}}_{FB}$ [24].

$D^0 \to K^-\pi^+$ (Eq. 3.4) in bins of ($p_\pi^{\rm lab}$, $cos\theta_\pi^{\rm lab}$, $cos\theta^{\rm CM}_{D_{(s)^+}}$). However, the corrected reconstructed symmetry $A^{\rm rec} - A^K_\varepsilon$ includes not only an A_{CP} component but also the A_{FB} component. Since A_{CP} is independent of all kinematic variables, while A_{FB} is an odd function of $cos\theta^{\rm CM}_{D^+_{(s)}}$, both can be deduced by addition and subtraction in bins of $cos\theta^{\rm CM}_{D^+_{(s)}}$. Figure 5 shows the results.

Table 2 summarizes measured A_{CP} in $D_s^+ \to K_S^0\pi^+$ and $D_s^+ \to K_S^0K^+$ by Belle and CLEO-c experiments. No evidence for CP violation was found for these decay modes. The dominant source of systematic uncertainties in the measurement performed by Belle are the uncertainties of $A^{rec}(D_s^+ \to \phi\pi^+)$ and $A^{rec}(D^0 \to K^-\pi^+)$, which are given mainly by the limited statistics and will thus decrease with larger data samples. It is interesting to note, that expected SM magnitude of A_{CP} in decays of charmed hadrons to a final state containing K_S^0 or K_L^0 mesons is $(0.332\pm0.006)\%$,

A_{CP} in	Belle (%)	CLEO-c (%)	HFAG WA (%)	A_{CP}^{SM} (%)
$D^+ \to K_S\pi^+$	$-0.71\pm0.19\pm0.20$	$-1.3\pm0.7\pm0.3$	-0.72 ± 0.26	$-0.332^\dagger$
$D_s^+ \to K_S\pi^+$	$+5.45\pm2.50\pm0.33$	$+16.3\pm7.3\pm0.3$	$+6.5\pm2.5$	$+0.332$
$D^+ \to K_SK^+$	$-0.16\pm0.58\pm0.25$	$-0.2\pm1.5\pm0.9$	-0.09 ± 0.63	-0.332
$D_s^+ \to K_SK^+$	$+0.12\pm0.36\pm0.22$	$+4.7\pm1.8\pm0.9$	$+0.28\pm0.41$	$-0.332^\dagger$

Table 2: Summary of the A_{CP} measurements in $D_s^+ \to K_S^0\pi^+$ and $D_s^+ \to K_S^0K^+$ decays performed by Belle [23] and CLEO-c [18]. The world averages given in third column are taken from [22]. The first uncertainties in the second and third column are statistical and and the second are systematic. DCS decay contributions are ignored for the decays denoted by †'s in the last column.

which is induced by the *CP* impurity in the K_S^0 wave function [14].

4. Conclusions

Our knowledge of hadronic charm decays has improved significantly over the last few years, mainly due to the studies performed at CLEO-c and *B*-factory experiments, Belle and BaBar. These studies provide tests of symmetries of the strong interaction such as $SU(3)$ and give important input for the analysis of *B* decays, as most of them decay to charm. Charm physics, and in particular studies of *CP* violation, could provide new and unique opportunities for indirect searches for New Physics, which are complementary to those performed in kaon, B_d and B_s systems. Measurements searching for *CP* violation have in some decay modes reached few permil level. All of them are statistically limited and will thus improve with increased data samples. *B*-factories experiments, Belle and Babar and CDF experiment have large data samples, which were not yet entirely used in charm studies. LHCb at LHC, which started to collect data last year, will collect unprecedented charm samples. BESIII currently collects data at the charm threshold. Large charm samples will also be available at future Super-*B*-factories. The prospects for charm physics are thus very bright.

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Mode	$\mathscr{B}_{\text{mode}}/\mathscr{B}_{\text{Normalization}}$ (%)	This result $\mathscr{B}$ (%)	$\mathscr{A}_{CP}$ (%)
$D^0 \to K^+K^-$	$10.41 \pm 0.11 \pm 0.11$	$0.407 \pm 0.004 \pm 0.004 \pm 0.008$	
$D^0 \to K^0_S K^0_S$	$0.41 \pm 0.04 \pm 0.02$	$0.0160 \pm 0.0017 \pm 0.0008 \pm 0.0003$	
$D^0 \to \pi^+\pi^-$	$3.70 \pm 0.06 \pm 0.09$	$0.145 \pm 0.002 \pm 0.004 \pm 0.003$	
$D^0 \to \pi^0\pi^0$	$2.06 \pm 0.07 \pm 0.10$	$0.081 \pm 0.003 \pm 0.004 \pm 0.002$	
$D^0 \to K^-\pi^+$	100	3.9058 external input [19]	$0.5 \pm 0.4 \pm 0.9$
$D^0 \to K^0_S\pi^0$	$30.4 \pm 0.3 \pm 0.9$	$1.19 \pm 0.01 \pm 0.04 \pm 0.02$	
$D^0 \to K^0_S\eta$	$12.3 \pm 0.3 \pm 0.7$	$0.481 \pm 0.011 \pm 0.026 \pm 0.010$	
$D^0 \to \pi^0\eta$	$1.74 \pm 0.15 \pm 0.11$	$0.068 \pm 0.006 \pm 0.004 \pm 0.001$	
$D^0 \to K^0_S\eta'$	$24.3 \pm 0.8 \pm 1.1$	$0.95 \pm 0.03 \pm 0.04 \pm 0.02$	
$D^0 \to \pi^0\eta'$	$2.3 \pm 0.3 \pm 0.2$	$0.091 \pm 0.011 \pm 0.006 \pm 0.002$	
$D^0 \to \eta\eta$	$4.3 \pm 0.3 \pm 0.4$	$0.167 \pm 0.011 \pm 0.014 \pm 0.003$	
$D^0 \to \eta\eta'$	$2.7 \pm 0.6 \pm 0.3$	$0.105 \pm 0.024 \pm 0.010 \pm 0.002$	
$D^+ \to K^-\pi^+\pi^+$	100	9.1400 external input [19]	$-0.1 \pm 0.4 \pm 0.9$
$D^+ \to K^0_S K^+$	$3.35 \pm 0.06 \pm 0.07$	$0.306 \pm 0.005 \pm 0.007 \pm 0.007$	$-0.2 \pm 1.5 \pm 0.9$
$D^+ \to \pi^+\pi^0$	$1.29 \pm 0.04 \pm 0.05$	$0.118 \pm 0.003 \pm 0.005 \pm 0.003$	$2.9 \pm 2.9 \pm 0.3$
$D^+ \to K^0_S\pi^+$	$16.82 \pm 0.12 \pm 0.37$	$1.537 \pm 0.011 \pm 0.034 \pm 0.033$	$-1.3 \pm 0.7 \pm 0.3$
$D^+ \to K^+\pi^0$	$0.19 \pm 0.02 \pm 0.01$	$0.0172 \pm 0.0018 \pm 0.0006 \pm 0.0004$	$-3.5 \pm 10.7 \pm 0.9$
$D^+ \to K^+\eta$	< 0.14 (90% C.L.)	< 0.013 (90% C.L.)	
$D^+ \to \pi^+\eta$	$3.87 \pm 0.09 \pm 0.19$	$0.354 \pm 0.008 \pm 0.018 \pm 0.008$	$-2.0 \pm 2.3 \pm 0.3$
$D^+ \to K^+\eta'$	< 0.20 (90% C.L.)	< 0.018 (90% C.L.)	
$D^+ \to \pi^+\eta'$	$5.12 \pm 0.17 \pm 0.25$	$0.468 \pm 0.016 \pm 0.023 \pm 0.010$	$-4.0 \pm 3.4 \pm 0.3$
$D^+_s \to K^0_S K^+$	100	1.4900 external input [20]	$4.7 \pm 1.8 \pm 0.9$
$D^+_s \to \pi^+\pi^0$	< 2.3 (90% C.L.)	< 0.037 (90% C.L.)	
$D^+_s \to K^0_S\pi^+$	$8.5 \pm 0.7 \pm 0.2$	$0.126 \pm 0.011 \pm 0.003 \pm 0.007$	$16.3 \pm 7.3 \pm 0.3$
$D^+_s \to K^+\pi^0$	$4.2 \pm 1.4 \pm 0.2$	$0.062 \pm 0.022 \pm 0.004 \pm 0.004$	$-26.6 \pm 23.8 \pm 0.9$
$D^+_s \to K^+\eta$	$11.8 \pm 2.2 \pm 0.6$	$0.176 \pm 0.033 \pm 0.009 \pm 0.010$	$9.3 \pm 15.2 \pm 0.9$
$D^+_s \to \pi^+\eta$	$123.6 \pm 4.3 \pm 6.2$	$1.84 \pm 0.06 \pm 0.09 \pm 0.11$	$-4.6 \pm 2.9 \pm 0.3$
$D^+_s \to K^+\eta'$	$11.8 \pm 3.6 \pm 0.6$	$0.18 \pm 0.05 \pm 0.01 \pm 0.01$	$6.0 \pm 18.9 \pm 0.9$
$D^+_s \to \pi^+\eta'$	$265.4 \pm 8.8 \pm 13.9$	$3.95 \pm 0.13 \pm 0.21 \pm 0.23$	$-6.1 \pm 3.0 \pm 0.3$

Table 3: Ratios of branching fractions to the corresponding normalization modes $D^0 \to K^-\pi^+$, $D^+ \to K^-\pi^+\pi^+$, and $D^+_s \to K^0_S K^+$; branching fractions results from this analysis; and charge asymmetries $\mathscr{A}_{CP}$, reproduced from [18]. Uncertainties are statistical error, systematic error, and the error from the input branching fractions of normalization modes. (For D^0, the normalization mode is the sum of $D^0 \to K^-\pi^+$ and $D^0 \to K^+\pi^-$ – the latter is 0.4% of the former.)

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