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Charm decays at Belle

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We present our search for leptonic decay of D^0, study of $D^+_{(s)} \to K_S h^+$ decay modes, where h^+=$\{K^+, \pi^+\}$, and the first observation of the doubly Cabibbo suppressed decay in $D^+_s \to K^+K^+\pi^-$ final states. The first two measurements provide the best limits and best branching ratio values, and the last decay mode provide the first observation of our doubly Cabibbo suppressed decay mode.

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1. Search for leptonic decay of D^0

Flavour changing neutral currents (FCNC) are not possible in the Standard Model (SM) on tree level because of Cabibbo-Kobayashi-Maskawa unitarity but they are possible in higher order loops. Such contributions are small because of Glashow-Iliopoulos-Maiani suppression, but in certain new physics scenarios, it is possible that in such processes new undiscovered particles could be mediated instead of the $W^{\pm}$ boson [1] in leptonic decays of D^0.

In this analysis, we used 659 fb^{-1} of data at $\Upsilon(4S)$ resonance and at nearby non-resonant, collected with the Belle detector at the KEKB asymmetric-energy e^+e^- collider. We search for the decays: $D^0 \to \mu^+\mu^-$, $D^0 \to e^+e^-$, and $D^0 \to e^{\pm}\mu^{\mp}$ where we tag D^0 from the decay $D^{*+} \to D^0\pi^+$ in order to suppress the background. The branching fraction is then determined relative to the decay $D^0 \to \pi^+\pi^-$. We require the particle identification from reconstructed charged tracks : $\mathscr{L}_{K/\pi} < 0.9$ for slow pions from D^{*+} decays, $\mathscr{L}_{K/\pi} < 0.4$ for pions from D^0, $\mathscr{L}_{\mu} > 0.9$ for muons and $\mathscr{L}_{e} > 0.9$ for electrons where $\mathscr{L}$ is likelihood-ratio of given particle hypothesis using sub-detector responses. Further requirements such as mass window of D^0 meson to be $1.81 < m_{D^0} < 1.91$ GeV/c^2, $q = m_{D^{*+}} - m_{D^0} - m_{\pi} < 0.02$ GeV/c^2, D^{*+} interaction point constraint fit, and finally $p_{D^{*+}} > 2.5$ GeV/c is applied to remove background from B meson decays. A dedicated tuning of simulated events is carried out to match the real data [2] prior to the optimisation of further selection criteria, based on maximizing the figure-of-merit (FOM) $\varepsilon_{\ell\ell}/N_{UL}$, where $\varepsilon_{\ell\ell}$ is the efficiency for detecting $D^0 \to \ell^+\ell^-$ decays and N_{UL} is the Poisson average of Feldman-Cousins 90% confidence level upper limits on the number of observed signal events that would be obtained with the expected background and no signal events. The signal interval size (Δm_{D^0}, Δq), momentum of D^{*+} in the center-of-momentum frame, missing energy, momenta of lepton candidates and lepton identification probabilities. The random background in the signal window is estimated from the sideband data and possible peaking structure from $D^0 \to \pi^+\pi^-$ when particle identifications are incorrect is estimated by estimating the misidentification probability from the decay channel $D^0 \to K^-\pi^+$ in bins of the momentum and the polar angle. Our preliminary 90% C.L upper limits are found to be

$$\begin{aligned} \mathscr{B}(D^0 \to \mu^+\mu^-) &< 1.4 \times 10^{-7} \\ \mathscr{B}(D^0 \to e^+e^-) &< 7.9 \times 10^{-8} \\ \mathscr{B}(D^0 \to \mu^{\pm}e^{\mp}) &< 2.9 \times 10^{-7} \end{aligned} \tag{1.1}$$

and are most stringent upper limits on the branching fractions up to date.

2. Study of $D^+_{(s)} \to K_S h^+$

Decays of charmed mesons play important roles in understanding the sources of the SU(3) flavor symmetry breaking effects [3]. Such breaking effects can originate from strong final-state interactions or interference between same final states, and depend on underlying processes associated with. In particular, $D^+ \to \overline{K}^0 K^+$ and $D^+_s \to K^0\pi^+$ [4] are Cabibbo-suppressed (CS) decays with the color-favored tree, annihilation and penguin diagrams. For D^+ decays, the branching ratio $\mathscr{B}(D^+ \to \overline{K}^0 K^+)/\mathscr{B}(D^+ \to \overline{K}^0\pi^+)$ deviates from the naive expectation of $\tan^2\theta_c$ [5] as expected, due to a destructive interference in $D^+ \to \overline{K}^0\pi^+$ [6]. However, converting experimental measurements including K^0_S branching ratios to those of involving $\overline{K}^0$ is not straightforward due to the fact that one must take into account the interference between doubly Cabibbo-suppressed (DCS) and Cabibbo-favored (CF) decay modes where its interference phase is unknown [7]. In D_s^+ decays to $\overline{K}^0 K^+$ and $K^0\pi^+$ final states, the ratio of CS decay to that of the corresponding CF decay may be larger than $\tan^2\theta_c$, since $D_s^+ \to \overline{K}^0 K^+$ decay mode is a CF but color-suppserssed decay mode. In this presentation, we report an improved measurement of $D^+ \to K_S^0 K^+$ and $D_s^+ \to K_S^0\pi^+$ branching ratios. A similar standard event selection criteria described in the previous section is applied to 605 fb^{-1} of data where we use the off-resonance data for the optimization of the selection further using the variable defined as $\mathscr{A} \equiv |p_{K_S^0} - p_{h^+}|/|p_{K_S^0} + p_{h^+}|$. Here momentum is calculated in the laboratory frame and h^+ refers to either K^+ or π^+. After the optimization, we find our preliminary branching ratios with respect to the Cabibbo-favored mode and values to be $\mathscr{B}(D^+ \to K_S^0 K^+)/\mathscr{B}(D^+ \to K_S^0\pi^+) = 0.190 \pm 0.001 \pm 0.002$ and $\mathscr{B}(D_s^+ \to K_S^0\pi^+)/\mathscr{B}(D_s^+ \to K_S^0 K^+) = 0.077 \pm 0.002 \pm 0.002$ where the first uncertainties are statistical and the second are systematic. These are consistent with the present world average and best measurements up to date.

3. First observation of DCSD in $D_s^+ \to K^+K^+\pi^-$

Cabibbo-suppressed and doubly Cabibbo-suppressed decays play an important role in studies of charmed hadron dynamics. CS decays of nearly all the charmed hadrons have been observed, while DCS decays have been observed for only the D^+ and D^0 mesons. The naïve expectation for the DCS decay rate is of the order of $\tan^4\theta_C$, where θ_C is the Cabibbo mixing angle [8], or about 0.29% [9] relative to its Cabibbo-favored counterpart. Current measurements [10] roughly support this expectation. It is natural to extend the searches for DCS decays to other charmed hadrons in order to further understand the decay dynamics of charmed hadrons and complete the picture.

Furthermore, one expects that the branching ratio of $D^+ \to K^+\pi^+\pi^-$ [4] is about 2 $\tan^4\theta_C$ relative to its CF counterpart since the phase space for $D^+ \to K^-\pi^+\pi^+$ is suppressed due to the two identical pions in the final state. This expectation is consistent with current experimental results [10]. Therefore, we also expect the branching ratio of $D_s^+ \to K^+K^+\pi^-$ is about 1/2 $\tan^4\theta_C$ relative to its CF counterpart. Lipkin [11] argues that SU(3) flavor symmetry [12] implies

$$\frac{\mathscr{B}(D_s^+ \to K^+K^+\pi^-)}{\mathscr{B}(D_s^+ \to K^+K^-\pi^+)} \times \frac{\mathscr{B}(D^+ \to K^+\pi^+\pi^-)}{\mathscr{B}(D^+ \to K^-\pi^+\pi^+)} = \tan^8\theta_C, \tag{3.1}$$

where differences in the phase space for CF and DCS decay modes cancel in the ratios. The above relation does not take into account possible SU(3) breaking effects that could arise due to resonant intermediate states in the three-body final states considered here [11].

In this presentation, we report the first observation of the DCS decay $D_s^+ \to K^+K^+\pi^-$ and its inclusive branching ratio relative to its CF counterpart, $D_s^+ \to K^+K^-\pi^+$. We also report a new measurement of the inclusive decay rate $D^+ \to K^+\pi^+\pi^-$ relative to its CF counterpart, $D^+ \to K^-\pi^+\pi^+$. The current upper limit on $\mathscr{B}(D_s^+ \to K^+K^+\pi^-)/\mathscr{B}(D_s^+ \to K^+K^-\pi^+)$ is 0.78% at the 90% confidence level (C.L.) [13] and the world-average of the $D^+ \to K^+\pi^+\pi^-$ branching ratio is $\mathscr{B}(D^+ \to K^+\pi^+\pi^-)/\mathscr{B}(D^+ \to K^-\pi^+\pi^+)$=(0.68±0.08)% [10]. We also test the validity of prediction (3.1).

Assuming no signal in the DCS decay channel, we maximize $\mathscr{N}_S/\sqrt{\mathscr{N}_B}$, where $\mathscr{N}_S$ is the CF signal yield which has similar properties to the DCS signal and $\mathscr{N}_B$ is the background yield

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from the sideband regions in the DCS sample. Tighter requirements on charged kaon identification (>0.9) and x_p (>0.7) are also chosen for the final selection, which improves the signal sensitivity. After these further requirements, we observed for the first time the decay $D_s^+ \to K^+K^+\pi^-$ with a statistical significance of 9.1 standard deviations. This is the first DCS decay mode of the D_s^+ meson. The branching ratio with respect to the CF decay is (0.229±0.028±0.012)%, where the first uncertainty is statistical and the second is systematic. We have also determined the D^+ DCS decay branching ratio, $\mathscr{B}(D^+ \to K^+\pi^+\pi^-)/\mathscr{B}(D^+ \to K^-\pi^+\pi^+)$=(0.569±0.018±0.014)%, where the first uncertainty is statistical and the second is systematic, with a significantly improved precision compared to the current world-average [10]. We find the product of the two relative branching ratios, $\frac{\mathscr{B}(D_s^+ \to K^+K^+\pi^-)}{\mathscr{B}(D_s^+ \to K^+K^-\pi^+)} \times \frac{\mathscr{B}(D^+ \to K^+\pi^+\pi^-)}{\mathscr{B}(D^+ \to K^-\pi^+\pi^+)}$ to be $(1.57 \pm 0.21) \times \tan^8\theta_C$. This is consistent with SU(3) flavor symmetry within three standard deviations; note that the effect of (different) resonant intermediate states is not taken into account in the prediction [11]. Our results are final and published in [14].

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