Recent results on the charmed hadron systems at Belle

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CP violation and mixing in the charm meson system are expected to be very small in the standard model (SM), hence it can be a good probe to search for new physics beyond the SM. The Belle experiment, with high statistics e^+e^- collision data taken at the KEKB energy-asymmetric collider using the Belle detector, is a very good place to study charmed hadron systems. In this presentation we report recent results from Belle on CP violation and mixing in the neutral D meson system. We also present recent results from Belle in the charmed baryon spectroscopy, including new measurements of mass, width, and absolute branching fractions of various charmed baryons.

The Belle experiment is excellent place to study charmed hadron systems since it has large relative cross-section for charmed hadron production and clean event environment combined with high luminosity. In this proceeding, we report recent results from Belle on CP violation and mixing in the neutral D meson system. We also present result from Belle in the charmed baryon spectroscopy.

1 Neutral D meson system

The mixing rate and the size of CP violation (CPV) in charm sector is expected to be very small in standard model (SM) [1, 2]. Thus, the measurement of $D^0 - \bar{D}^0$ mixing and CPV could provide probe to search for beyeond SM [3, 4]. $D^0 - \bar{D}^0$ mixing occures becauase the mass eigenstate ($|D_{H,L}>$) is different from flavor eigen sate ($|D^0>, |\bar{D}^0>$). The mass eigenstate can be represented by flavor eigenstate, namely $|D_{H,L}>= p|D^0> \pm q|\bar{D}^0>$. The phenomenology of meson mixing is decribled by two parameters, $x = \Delta M/\Gamma$ and $y = \Delta\Gamma/2\Gamma$, whrere ΔM and $\Delta\Gamma$ are mass and width differnce between two mass eigen state, Γ is average decay width of mass eigenstates. The direct CPV can be measured by decay rate comparison between paricle and anti-paricle system. The indirect CPV parameters are |q/p| and arg(q/p), the former is CPV in mixing and the later is CPV in interference of decay with and without mixing.

1.1 Mixing in $D^0 \to K^+\pi^-$ decay [5]

The mixing parameters of the K^0, B^0 and B^0_S mesons are well esteblished [6]. Rcently the D^0 mixing have been observed in hadron collider experiment [7, 8]. ; This is first observation of $D^0 - \bar{D}^0$ minxing from e^+e^- collider by measuring time dependent ratio of the $D^0 \to K^+\pi^-$ and $D^0 \to K^-\pi^+$ decay. We named the $D^0 \to K^+\pi^-$ decay as wrong sign (WS) decay and $D^0 \to K^-\pi^+$ decay as right sign (RS) decay. The RS decay amplitude is sum of the amplitude from Cabibbo-favored (CF) decay $D^0 \to K^-\pi^+$ and $D^0 - \bar{D}^0$ mixing followed by the doubly Cabibbo-suppressed (DCS) decay $\bar{D}^0 \to K^-\pi^+$, where the later is much smaller than former one so it is neglected. The WS decay amplitude is sum of two comparable amplitudes from DCS decay $D^0 \to K^+\pi^-$ and $D^0 - \bar{D}^0$ mixing followed by the CF decay $\bar{D}^0 \to K^+\pi^-$. Then time-dependent WS to RS decay rates are $\Gamma_{RS}(\tilde{t}/\tau) \approx |A_{CF}|^2 e^{-\tilde{t}/\tau}$ and $\Gamma_{WS}(\tilde{t}/\tau) \approx |A_{CF}|^2 e^{-\tilde{t}/\tau}(R_D + \sqrt{R_D} y' \frac{\tilde{t}}{\tau} + \frac{x'^2+y'^2}{4}(\frac{\tilde{t}}{\tau})^2)$, respectively, the $\tilde{t}$ proper true decay time, τ is D^0 lifetime, $|A_{CF}|$ is the CF decay amplitude, R_D is the ratio of DCS to CF decay rates, $x' = xcos\delta + ysin\delta$ and $y' = ycos\delta - xsin\delta$ where δ is the strong phase difference between the DCS and CF decay. The time resolution in B factory is comparable with D^0 decay time, so we extract the time resolution function $R(t/\tau - \tilde{t}/\tau)$ from D^0 mean decay time. Then the WS, RS decay rate ratio becomes $\mathbf{R}(t/\tau) = \frac{\int_{-\infty}^{+\infty} \Gamma_{WS} R(t/\tau - \tilde{t}/\tau) d(\tilde{t}/\tau)}{\int_{-\infty}^{+\infty} \Gamma_{RS} R(t/\tau - \tilde{t}/\tau) d(\tilde{t}/\tau)}$.

The χ^2/ndf for mixing hypothesis is 4.2/7 and no mixing hypothesis is 33.5/9, the mixing hypothesis excludes non-mixing hypothesis with 5.1σ.

1.2 Mixing and indirect CPV in $D^0 \to K_s^0\pi^+\pi^-$ decay [9]

So far there is no evidence of indirect CP violation in D meson system. Experimental estimation of indirect CP violation is $1-|q/p| = 0.12 \pm 0.17$ [6]. This study is search for indirect CP violation using $D^0 \to K_s^0\pi^+\pi^-$ decay channel. The analysis is done with three dimensional decay amplitude analysis, two is dalizt plot variable $m(K_s^0\pi^+)$ and $m(K_s^0\pi^-)$, and the rest one is time. As a result, the indirect parameter is $|q/p| = 0.90^{+0.16+0.05+0.06}_{-0.15-0.04-0.05}$ and $arg(q/p)(^\circ) = -6 \pm 11 \pm 3^{+3}_{-4}$. It shows no evidence of indirect CP violation.

1.3 CPV in $D^0 \to \pi^0\pi^0$ decay [10]

CP violation in charm decay is very small to observe so experimantal observation could indicate new physics. So far only existing CP violation study of $D^0 \to \pi^0\pi^0$ decay is from CLEO [11], the direct CP asymmetry ΔA_{CP} is $(0.1 \pm 4.8)\%$. In this study, direct CPV is estimated using $D^0 \to \pi^0\pi^0$ decay. The asymmetry is $A_{rec} = \frac{N_{rec}^{D^{*+} \to D^0\pi_x^+} - N_{rec}^{D^{*-} \to D^0\pi_x^+}}{N_{rec}^{D^{*+} \to D^0\pi_x^+} + N_{rec}^{D^{*-} \to D^0\pi_x^+}} \approx A_{CP} + A_{FB}(cos\theta^*)$. The A_{CP} can be extracted removing A_{FB} using asymmetry on the $cos\theta^*$ where θ^* is polar angle of D^*. Using decay channel $D^0 \to \pi^0\pi^0$, the measured asymmetry is $A_{CP}(D^0 \to \pi^0\pi^0) = (-0.03 \pm 0.64(stat) \pm 0.10(sys))\%$ which is consistent with no CP violation.

2 New measurement of charmed baryon

2.1 Branching fraction of $\Lambda_c^+ \to pK^-\pi^+$ decay [12]

A number of charmed baryons decay into Λ_c^+. And $\Lambda_c^+ \to pK^-\pi^+$ is the reference mode for the measurement of branching fractions of the Λ_c^+ baryon, so it's important to measure the absolute branching fraction. The Particle Data Group combines several measurements from the ARGUS and CLEO Collaborations to determine $\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+) = (5.0 \pm 1.3)\%$ [13, 14]. The dominant contribution to the uncertainty is from the model dependce of branching fraction extraction [15]. In the proceeding, we present the first model-independent absolute branching fraction measurement of the $\Lambda_c^+ \to pK^-\pi^+$ decay.

The absolute branching fraction is given by $\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+) = \frac{N(\Lambda_c^+ \to pK^-\pi^+)}{N_{inc}^{\Lambda_c^+} f_{bias} \varepsilon(\Lambda_c^+ \to pK^-\pi^+)}$, where $N_{inc}^{\Lambda_c^+}$ is the number of inclusively reconstructed Λ_c^+, $N(\Lambda_c^+ \to pK^-\pi^+)$ is the number of reconstructed $\Lambda_c^+ \to pK^-\pi^+$ within inclusive Λ_c^+ sample, $\varepsilon(\Lambda_c^+ \to pK^-\pi^+)$ is reconstruction efficiency of $\Lambda_c^+ \to pK^-\pi^+$ decay within inclusive Λ_c^+ sample, f_{bias} is the factor that takes into account potential dependenace of the inclusiv Λ_c^+ reconstruction efficiency on the Λ_c^+ decay mode.

To get the inclusive Λ_c^+ baryons, we used missing mass method for $e^+e^- \to c\bar{c} \to D^{(*)-}\bar{p}\pi^+\Lambda_c^+$ decay. Then we search the decay product of $\Lambda_c^+ \to pK^-\pi^+$ decay in the sample of inclusive Λ_c^+ baryon. The efficiency of $\Lambda_c^+ \to pK^-\pi^+$ and f_{bias} are detemined by MC simluation. The MC simulation shows that Λ_c^+ inclusive reconstruction efficiency weakly depends on the Λ_c^+ decay mode, therefore we need correction for true inclusive Λ_c^+ sample. The factor $f_{bias} = \varepsilon^{inc}_{\Lambda_c^+ \to pK^-\pi^+}/\bar{\varepsilon}^{inc}_{\Lambda_c^+}$ is necessay for this correction.

As a result, the branching fraction is $\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+) = (6.84 \pm 0.24(stat) \pm^{+0.21}_{-0.27} (sys))\%$, that is consistant with previous result and this result improves the previous measurement by factor 5.

2.2 Measurement of mass and width of the $\Sigma_c(2455)^{0/++}$ and $\Sigma_c(2520)^{0/++}$ baryons [16]

The properties of the $\Sigma_c^{0/++}$ baryons have been measured many experiments, but uncertainty remains large [15]. For example, decay width of the $\Sigma_c^{0/++}$ is 10% of its central value, and the mass spilitting $m(\Sigma_c(2455)^{++}) - m(\Sigma_c(2455)^0)$ is about 40%. Because of mass hierarchy between u and d quarks, mass of $\Sigma_c^0(udc)$ should be havier than $\Sigma_c^{++}(uuc)$. However the experimetal results shows opposite mass hiearchy with large error [17]. In this situation, precise mass and width measurement is necessay.

The $\Sigma_c^{0/++}$ baryons are reconstructed via $\Sigma_c^{0/++} \to \Lambda_c^+(\to pK^-\pi^+)\pi_s^{-/+}$ decay channel, where π_s is low momentum pion. The feed down from $\Lambda_c(2595, 2620)^+$ is removed with mass cut on $m(\Lambda_c^+\pi^+\pi^-)$,

The fitting functions for signal is Breit-Wiegner function convolved with detector resolution function. The random back ground function is threshold function. There is feed down around $\Delta M = 185$ MeV/c^2, we confirmed that the origin of the peak is from $\Xi_c^0 \to \Lambda_c^+\pi^-$. This peak is described by Gaussian funcion. The χ^2/ndf for fit result is 350/347 for zero charge, 343/350 for double charge. The mass and width from fitting result is on table 1. This result shows better uncertainty than previous result.

	ΔM_0(MeV/c^2)	Γ(MeV/c^2)	M_0(MeV/c^2)
$\Sigma_c(2455)^0$	$167.29 \pm 0.01 \pm 0.02$	$1.76 \pm 0.04^{+0.09}_{-0.21}$	$2453.75 \pm 0.01 \pm 0.02 \pm 0.14$
$\Sigma_c(2455)^{++}$	$167.51 \pm 0.01 \pm 0.02$	$1.84 \pm 0.04^{+0.07}_{-0.20}$	$2453.97 \pm 0.01 \pm 0.02 \pm 0.14$
$\Sigma_c(2520)^0$	$231.98 \pm 0.11 \pm 0.04$	$15.41 \pm 0.41^{+0.20}_{-0.32}$	$2518.44 \pm 0.11 \pm 0.04 \pm 0.14$
$\Sigma_c(2520)^{++}$	$231.99 \pm 0.10 \pm 0.02$	$14.77 \pm 0.25^{+0.18}_{-0.30}$	$2518.45 \pm 0.10 \pm 0.02 \pm 0.14$

Table 1: The measurement of mass and with of the $\Sigma_c(2455)^{0/++}$ and $\Sigma_c(2520)^{0/++}$. The first error is stastical error and second error is systematical error. The third error on M_0 is from mass error of Λ_c^+

2.3 Search for doubly charmed baryon and charmed strange baryon at Belle [18]

In recent years, there has been significant progress in charmed baryon spectroscopy. So far, there are no experimentally established doubley charmed baryon. The SELEX collaboration reported evidence of Ξ_{cc}^{+} in the $\Lambda_c^+ K^- \pi^+$ and pD^+K^- final state [19]. However, the result is not supported by FOCUS, BABAR, Belle nor LHCb. In this study, we improve the search using more data and more channels.

The first decay channel is $\Xi_{cc}^{+(+)} \to \Lambda_c^+ K^- \pi^+(\pi^+)$ and $\Lambda_c^+ \to pK^-\pi^+$. We searched the mass region of 3.2∼4.0 GeV/c^2, no significance signal is seen in the data. The local significance is lower than 3σ. The upper limit of production cross section and Branching fraction with 95% C.L. is around 10fb^{-1}.

The sesond decay channel is $\Xi_{cc}^{+(+)} \to \Xi_x^0 \pi^+(\pi^+)$ and $\Xi_c^0 \to \Xi^0\pi-, \Lambda K^-\pi^+, pK^-K^-\pi^+$. We searched same mass range with first decay cheannel, still there is no significant signal over mass range. The highst signal is around 3.553 GeV/c^2, but it is not significant with look elsewhere effect.

And we also searched the strange charmed baryon $\Xi_c^+(3055)$ and $\Xi_c^+(3123)$, using the decay channel $\Xi_c^+(3055, 3123) \to \Lambda_c^+ K^- \pi^-$ over the mass range 2.9∼3.2 GeV/c^2. We observed the significant signal of $\Xi_c^+(3055)$ with 6.8σ, while no peak of $\Xi_c^+(3123)$. The upper limit of $\Xi_c^+(3123)$ cross section and branching ratio is $1.6 \pm 0.6 \pm 0.2$fb^{-1}.

In summary, searching $\Xi_{cc}^{+(+)}$ using more data and more decay channels doesn't show the signal over the mass range of 3.2∼4.0 GeV/c^2. For the strange charmed baryon search, we obersed $\Xi_c^+(3055)$ with 6.8σ, but couldn't see the peak of $\Xi_c^+(3123)$.

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