CHARM BARYONS AND CHARMONIUM PRODUCTION IN e^+e^- COLLISIONS AT BELLE

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We report the recent results on charm baryons and charmonium production in e^-e^+ collisions at the $\Upsilon(4S)$ resonance region, based on 460 fb^{-1} data accumulated with the Belle detector at the KEK B factory.

1. Introduction

The Belle detector [1] at the KEK B factory [2] has accumulated 600 fb^{-1} data by Spring 2006, and precision measurements of CKM matrix elements and other studies have been performed. In this report, we discuss the recent results on charm baryons and charmonium productions, based on a huge data of charm quark pair production events, which is comparable to $B\bar{B}$ pair events produced at the $\Upsilon(4S)$ resonance.

2. Measurements and observation for new Charm baryons

Charm baryons with a charm quark are classified into two SU(3) multiplets according to symmetry under interchange of two light quarks: 3-plet (Λ_c^+,Ξ_c^0,Ξ_c^+) and 6-plet (Σ_c^0,Σ_c^+,Σ_c^{++},$\Xi_c^{\prime 0}$,$\Xi_c^{\prime +}$,Ω_c^0). Various charm baryons have been reported, while their spin-parity assignments are not well known [3]. Table 1 indicates the recent measurements for charm baryon properties reported by Belle, Babar and CLEO.

Belle has studied the established charm baryons $\Xi_c(2470)$ [4] and $\Xi_c(2645)$ [5] with a few orders of magnitude larger signal samples than previous measurements, and updated the masses and branching fractions for the decays of $\Xi_c(2470)^0 \to \Xi^-\pi^+$, $\Lambda K^-\pi^+$, ΛK_s^0, $pK^-K^+\pi^+$, ΛK_s^0, $pK^-K^+\pi^+$, and $\Xi_c(2470)^+ \to \Xi^+\pi^-$, $\Xi^-\pi^+\pi^+$, $\Lambda K^-\pi^+\pi^+$, and $pK_s^0K_s^0$, and $\Xi_c(2645)^0 \to \Xi_c^+\pi^-$, and $\Xi_c(2645)^+ \to \Xi_c^0\pi^+$, $\Xi_c^0\pi^+$. A decay mode

of $\Xi_c(2470) \to pK_s^0K_s^0$ is newly observed. The mass differences in the doublets are determined with improved accuracy: $\Xi_c^0(2470) - \Xi_c^+(2470) = 2.9 \pm 0.5$ MeV/c^2, and $\Xi_c^0(2645) - \Xi_c^+(2645) = 1.6 \pm 0.7$ MeV/c^2.

Based on a data sample of 281 fb^{-1}, a new isotriplet state $\Sigma_c(2800)$ [6] is observed in inclusive analysis of the $\Lambda_c^+\pi^-$, $\Lambda_c^+\pi^0$ and $\Lambda_c^+\pi^+$ mass distributions. Two significant bumps are observed in each final state, and the lower broad bump is attributed to feed downs from the decay $\Lambda_c^+(2880) \to \Lambda_c^+\pi^+\pi^-$ reported by CLEO [7]. The masses, widths and the signal yields of the three charge states are fitted by taking into account the feed downs estimated from data. The masses and widths for the three charge states are found to agree very well.

Using 462 fb^{-1} data, we have searched for a narrow signal of $\Xi_{cc}(3519)$ in the mass distribution of $\Lambda_c^+K^-\pi^+$, which is reported by SELEX [9] as observation of a candidate of doubly charmed baryon. However, we have found no evidence of the SELEX $\Xi_{cc}(3519)$ signal. On the other hand, we observe two significant peaks at 2980 and 3077 GeV/c^2 [10] as shown in Figure 1, with signal yields of 405 ± 51 (6.3σ) and 326 ± 40 (9.7σ)events, respectively. The shaded histogram presents the mass distribution of the wrong sign combination ($\Lambda_c^+K^+\pi^-$) indicating no structure. These observed charm baryons $\Xi_{cx}(2980)$ and $\Xi_{cx}(3077)$ are believed to consist of charm and strange quarks, which are carried away by different final state particles Λ_c^+ and K^-, respectively.

3. Observations of $X(3940) \to D\bar{D}^*$ and $Z(3930) \to D\bar{D}$

Figure 2 (top) [11] shows the recoiled mass distribution against the reconstructed J/ψ particle in $e^-e^+ \to J/\psi + X$. The lower three peaks correspond to the known charmonia η_c, χ_{c0} and $\eta(2S)$, respectively. The signal at around 3940 MeV/c^2 is further investigated. Figure 2 (bottom) indicates the X' mass for $e^-e^+ \to J/\psi D + X'$. We see three bumps corresponding to $e^+e^- \to J/\psi D\bar{D}$, $J/\psi D\bar{D}^*$ and $J/\psi D^*\bar{D}^*$ processes. Figure 3(bot) shows the $D\bar{D}$ mass recoiling against J/ψ for the events of $e^+e^- \to J/\psi D\bar{D}$. The bottom figure indicates the $D\bar{D}^*$ mass distribution for $e^+e^- \to J/\psi D\bar{D}^*$, showing a significant signal named $X(3940)$ [11]. A mass of 3.943 ± 0.006 GeV/c^2 and a width of 15.4 ± 10.1 MeV/c^2 are obtained by a fit to the $D\bar{D}^*$ mass distribution, with a signal yield of 24.5 ± 6.9 events and a statistical significance of 5.0 σ.

Figure 4 [12] presents a new charmonium state $Z(3930)$ observed in two photon process $\gamma\gamma \to D\bar{D}$, based on 395 fb^{-1} data. Those two photon

events are selected with a cut on transverse momentum of the $D\bar{D}$ system, and the D mesons are reconstructed in decays of $D^0 \to K^-\pi^+$, $\bar{D}^0 \to K^+\pi^-, K^+\pi^-\pi^0, K^+\pi^-\pi^+\pi^-$ and $D^\pm \to K^\mp\pi^\pm\pi^\pm$. We find a signal peak in both of the $D^0\bar{D}^0$ and D^+D^- mass distributions. The mass of $3929 \pm 5 \pm 2$ MeV/c^2 and the width of $\Gamma_{BW} = 29 \pm 10 \pm 2$ MeV/c^2 are obtained with 64 ± 18 events and a statistical significance of 5.3 σ by a fit to the summed $D\bar{D}$ distribution. The left plot shows the mass distribution for $|\cos\theta| \leq 0.5$ (top) and $|\cos\theta| \leq 0.5$ (bottom), where the $Z(3930)$ signal is dominated in the $|\cos\theta| \leq 0.5$ region. The right figure indicates the $|\cos\theta|$ distribution of $D\bar{D}$ signal yields corrected for the signal efficiency. Either of spins $J = 0$ (dashed curve) or 2 (solid curve)is allowed in the two photon process. The production rate and the angular distribution suggests that the observed $Z(3930)$ state is a χ'_{c2} 2^3P_2 charmonium sate.

Table 1. Summary of new measurements for charmed baryons.

State	J^P	decay mode	mass (MeV/c^2)	Γ (MeV/c^2)	Ref
$\Xi_c(2470)^0$	$\frac{1}{2}^+$	see text.	$2471.0 \pm 0.3^{+0.2}_{-1.4}$	-	Belle [4]
$\Xi_c(2470)^+$		see text.	$2468.1 \pm 0.4^{+0.2}_{-1.4}$	-	
$\Xi_c(2645)^0$	$\frac{3}{2}^+$	$\Xi_c^+\pi^-$	$2643.1 \pm 0.6 \pm 0.4$	-	Belle [5]
$\Xi_c(2645)^+$		$\Xi_c^0\pi^+$, $\Xi_c^0\pi^+$	$2644.7 \pm 0.4 \pm 0.4$	-	
$\Sigma_c(2800)^0$	$\frac{3}{2}^-$	$\Lambda_c^+\pi^-$	$2801.9^{+3.2+2.1}_{-3.1-6.0}$	61^{+18+22}_{-13-13}	Belle [6]
$\Sigma_c(2800)^+$		$\Lambda_c^+\pi^0$	$2791.9^{+5.8+12.4}_{-4.6-2.0}$	62^{+37+52}_{-23-38}	
$\Sigma_c(2800)^{++}$		$\Lambda_c^+\pi^+$	$2801.0^{+3.4+2.8}_{-3.1-4.9}$	75^{+18+12}_{-13-11}	
$\Lambda_c(2765)^+$		$\Lambda_c^+\pi^-\pi^+$	$2765 \pm 8.8 \pm 3.5$	~ 50	CLEO [7]
$\Lambda_c(2880)^+$		$\Lambda_c^+\pi^-\pi^+$	$2881 \pm 1 \pm 2$	$4 \pm 2 \pm 2$	
$\Lambda_c(2880)^+$		D^0p	$2881.9 \pm 0.1 \pm 0.5$	$5.8 \pm 1.5 \pm 1.1$	Babar [8]
$\Lambda_c(2940)^+$		D^0p	$2939.8 \pm 1.3 \pm 1.0$	$17.5 \pm 5.2 \pm 5.9$	
$\Xi_{cx}(2980)^+$		$\Lambda_c^+K^-\pi^+$	$2978.5 \pm 2.1 \pm 2.0$	$43.5 \pm 7.5 \pm 7.0$	Belle [10]
$\Xi_{cx}(3077)^+$		$\Lambda_c^+K^-\pi^+$	$3076.7 \pm 0.9 \pm 0.5$	$6.2 \pm 1.2 \pm 0.8$	

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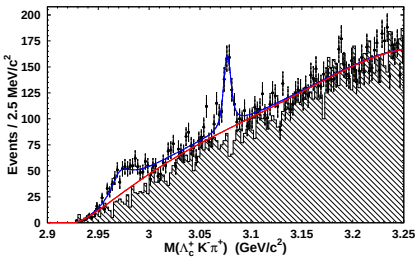

Figure 1. $\Lambda_c^+ K^- \pi^+$ mass distribution. The shaded histogram indicates the wrong sign combination.

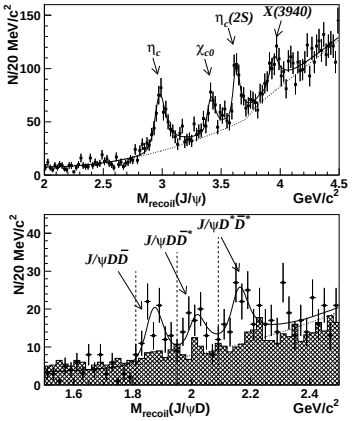

Figure 2. Recoil mass distributions against (a) J/ψ (top) and (b) $J/\psi D$ (bot).

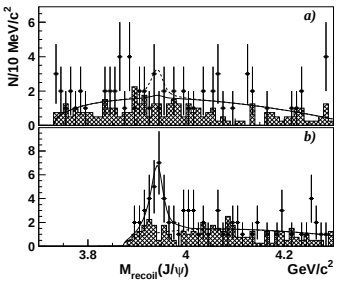

Figure 3. (a) $D\bar{D}$ and (b) $D\bar{D}^*$ mass distributions. Histograms indicate the scaled D sidebands.

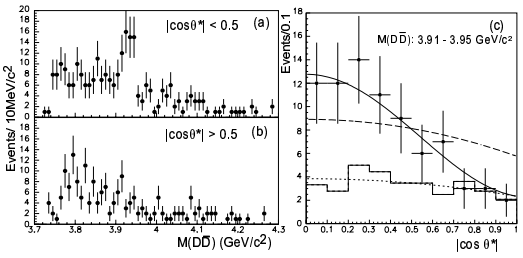

Figure 4. $D\bar{D}$ mass distributions for (a) $|\cos\theta| \leq 0.5$ and (b) $|\cos\theta| \geq 0.5$. (c) $Z(3940) \to D\bar{D}$ signal yield vs $|\cos\theta|$. Histograms indicate $|\cos\theta|$ distribution for the $D\bar{D}$ sideband events.

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