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New results on charmonium like states at Belle

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Abstract.

New results on charmonium-like states measured by the Belle experiment at the KEKB asymmetric e^+e^- collider are presented, in particular (a) Search for the Z_c pair production in $\Upsilon(1\mathrm{S})$,$\Upsilon(2S)$ decays and in e^+e^- annihilation at $\sqrt{s}$ of 10.52, 10.58, and 10.867 GeV. (b) Measurement of the absolute branching fractions of $B^+ \to X_{c\bar{c}}K^+$ decays. (c) Observation of $\Xi_c(2930)^0$ in the updated measurement of $B^- \to K^-\Lambda_c^+\bar{\Lambda}_c^-$. (d) Angular analysis of $e^+e^- \to D^{(*)\pm}D^{*\mp}$ process near the open charm threshold using initial state radiation.

1 Introduction

The Belle [1] is the first generation B-factory uses e^+e^- asymmetric collider at the KEKB [2] in KEK Japan. It has collected a total data sample of 711 fb^{-1} at $\Upsilon(4S)$ resonance. The Belle has played a leading role in the charmonium spectroscopy by finding many new charmonium like states. The recent results on charmonium like states with Belle are discussed in further sections.

2 Search for Z_c Pair Production in $\Upsilon(1S)$, $\Upsilon(2S)$ decays and e^+e^- annihilation

We report the search for Z_c pair production in $\Upsilon(1S)$, $\Upsilon(2S)$ decays as well as in e^+e^- annihilation using the data sample of 5.74 fb^{-1} at $\Upsilon(1S)$, 24.91 fb^{-1} at $\Upsilon(2S)$, and 89.5 fb^{-1} at $\sqrt{s} = 10.52$ GeV, 711 fb^{-1} at $\sqrt{s} = 10.58$ GeV ($\Upsilon(4S)$ resonance), 121.4 fb^{-1} at $\sqrt{s} = 10.867$ GeV ($\Upsilon(5S)$ resonance) with Belle detector. In this work, our aim is to observe the Z_c signals and determine the cross section dependence on the centre of mass energy s, as this study will help to understand the nature of Z_c. We have measured the production rates of $\Upsilon(1S)$ and $\Upsilon(2S)$ decay into a pair of Z_c states and the Born cross sections of $e^+e^- \to Z_c^+Z_c^{'-}$ at $\sqrt{s} = 10.52$, 10.58, and 10.867 GeV. In the analysis, one of the $Z_c^\pm$ decays into the final states containing a $\pi^\pm$ and a J/ψ, χ_{c1} or $\psi(2S)$, while the other is simulated with inclusive decays ($e^+e^- \to u\bar{u}/d\bar{d}/s\bar{s}/c\bar{c}$). Here Z_c denotes $Z_c^+(3900)$, $Z_c^+(4200)$, $Z_{c1}^+(4050)$, $Z_{c2}^+(4250)$, $Z_c^+(4050)$, or $Z_c^+(4430)$. The signals are extracted from the invariant mass distribution of Z_c. The detail of physics analysis is described in [3]. It is found that no clear signals of Z_c are observed in the studied modes. We determined the 90% C.L. upper limits on $\mathcal{B}(\Upsilon(1S,2S) \to Z_c^+Z_c^{'-}) \times \mathcal{B}(Z_c^+ \to \pi^+ + c\bar{c})$ and $\sigma(e^+e^- \to Z_c^+Z_c^{'-}) \times \mathcal{B}(Z_c^+ \to \pi^+ + c\bar{c})$ at $\sqrt{s} = 10.52$, 10.58, and 10.867 GeV and these results are shown graphically in Fig. 1 (a, b).

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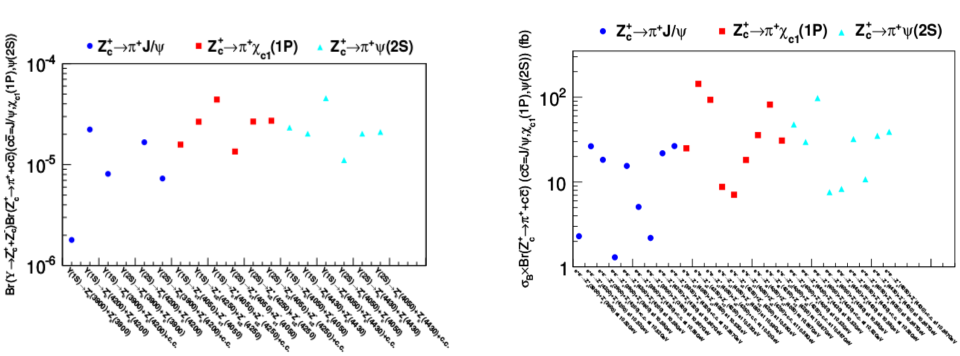

Figure 1: 90% C.L. upper limits on (a) $\mathcal{B}(\Upsilon(1S,2S) \to Z_c^+ Z_c^{'-}) \times \mathcal{B}(Z_c^+ \to \pi^+ + c\bar{c})$ (b) $\sigma(e^+e^- \to Z_c^+ Z_c^{'-}) \times \mathcal{B}(Z_c^+ \to \pi^+ + c\bar{c})$, ($c\bar{c} = J/\psi, \chi_{c1}, \psi(2S)$) at $\sqrt{s}$ = 10.52, 10.58, and 10.867 GeV [3].

3 Measurements of Absolute Branching Fractions of $B^+ \to X_{c\bar{c}} K^+$

An independent measurement of the absolute branching fraction of $B^+ \to X(3872)K^+$ is required to understand the nature of X(3872). The physics analysis for this measurement is performed using the data sample of $772 \times 10^6 B\bar{B}$ pairs collected at the $\Upsilon(4S)$ resonance with Belle [4]. In the reconstruction method, one of the B-meson decays hadronically and K^+ is reconstructed from the other B-meson and we determine the missing mass of kaon using the relation $M_{miss(h)} = \sqrt{(p^*_{e^+e^-} - p^*_{tag} - p^*_h)^2}/c$, where $p^*_{e^+e^-}$, p^*_{tag}, p^*_h are four momenta of electron-positron initial state, B_{tag} and kaon, respectively. With this method of reconstruction, we have simultaneously measured various charmonium like states, which appears in the missing mass spectrum of kaon [4]. The final results on the measurement of the branching fraction of $B^+ \to X_{c\bar{c}} K^+$ are summarized in Table 1. We do not observe significant signals for X(3872) and X(3915) and have set the 90% confidence level upper limits on $\mathcal{B}(B^+ \to X(3872)K^+) < 2.6 \times 10^{-4}$ and $\mathcal{B}(B^+ \to X(3915)K^+) < 2.8 \times 10^{-4}$. The branching fraction for η_c and $\eta_c(2S)$ are also measured to be $\mathcal{B}(B^+ \to \eta_c K^+) = (12.0 \pm 0.8 \pm 0.7) \times 10^{-4}$ and $\mathcal{B}(B^+ \to \eta_c(2S)K^+) = (4.8 \pm 1.1 \pm 0.3) \times 10^{-4}$, respectively, which are the most precise results to date.

Table 1: Summary of the branching fraction measurements for $B^+ \to X_{c\bar{c}} K^+$ [4].

Mode	Yield	Sig.(σ)	$\epsilon(10^{-3})$	$\mathcal{B}(10^{-4})$	World Avg. $\mathcal{B}(10^{-4})$ [5]
η_c	2590 ± 180	14.2	2.73 ± 0.02	12.0 ± 0.8 ± 0.7	9.6 ± 1.1
J/ψ	1860 ± 140	13.7	2.65 ± 0.02	8.9 ± 0.6 ± 0.5	10.26 ± 0.031
χ_{c0}	430 ± 190	2.2	2.67 ± 0.02	2.0 ± 0.9 ± 0.1 (<3.3)	$1.50^{+0.15}_{-0.14}$
χ_{c1}	1230 ± 180	6.8	2.68 ± 0.02	5.8 ± 0.9 ± 0.5	4.79 ± 0.23
$\eta_c(2S)$	1050 ± 240	4.1	2.77 ± 0.02	4.8 ± 1.1 ± 0.3	3.4 ± 1.8
ψ(2S)	1410 ± 210	6.6	2.79 ± 0.02	6.4 ± 1.0 ± 0.4	6.26 ± 0.24
ψ(3770)	-40 ± 310	-	2.76 ± 0.02	-0.2 ± 1.4 ± 0.0 (<2.3)	4.9 ± 1.3
X(3872)	260 ± 230	1.1	2.79 ± 0.01	1.2 ± 1.1 ± 0.1(<2.6)	(< 3.2)
X(3915)	80 ± 350	0.3	2.79 ± 0.01	0.4 ± 1.6 ± 0.0 (<2.8)	-

4 Observation of $\Xi_c(2930)^0$ in B decay

An updated measurement of $\mathcal{B}(B^- \to K^-\Lambda_c^+\bar{\Lambda}_c^-)$ is performed using the data sample of 772 $\times\, 10^6$ $B\bar{B}$ pairs at $\Upsilon(4S)$ resonance, which is 3 times larger statistics than BaBar [6] and 2 times larger statistics than previous Belle study [7]. We reconstruct the Λ_c^+ via the $\Lambda_c^+ \to pK^-\pi^+$, pK_s^0, $\Lambda\pi^+$, $pK_s^0\pi^+\pi^-$, $\Lambda\pi^+\pi^+\pi^-$ decay channels. When a Λ_c^+ and $\bar{\Lambda}_c^-$ are combined to reconstruct a B candidate, at least one is required to have been reconstructed via the $pK^+\pi^-$ or $\bar{p}K^-\pi^+$ decay process. The detail of the event selection criteria and physics analysis method are described in [8]. Fig. 2 (a) shows B signal enhanced $K^-\Lambda_c^+$ mass spectrum. An unbinned

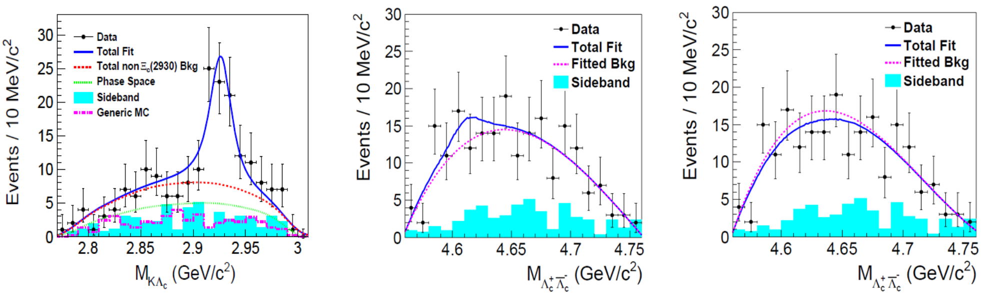

Figure 2: Invariant mass of (a) $K^-\Lambda_c^+$ (b) $\Lambda_c^+\bar{\Lambda}_c^-$ with Y_η (left) and $Y(4660)$ (right) signals included in the fit [8].

simultaneous extended maximum likelihood fit is performed to the $K^-\Lambda_c^+$ invariant mass spectra for selected B and Λ_c signal events and Λ_c^+ and $\bar{\Lambda}_c^-$ mass side-bands. The fit results are shown in Fig. 2 (a). In the mass spectrum of $K^-\Lambda_c^+$, the charmed baryon state $\Xi_c(2930)^0$ is clearly observed for the first time with a statistical significance greater than 5σ. The measured mass and width of the $\Xi_c(2930)$ are $M_{\Xi_c}(2930) = [2928.9 \pm 3.0 + 0.8/ - 12.0]$ MeV$/c^2$ and $\Gamma_{\Xi_c(2930)} = [19.5 \pm 8.4 + 5.4/ -7.9]$ MeV. The yield of the $\Xi_c(2930)$ signal is measured to be 61$\pm$16 events. The invariant mass of $\Lambda_c^+\bar{\Lambda}_c^-$ is shown in Fig. 2 (b, c) in which no clear Y_η (left) and $Y(4660)$ (right) signals are observed. In addition, the charged $\Xi_c(2930)$ is also observed with an evidence greater than 3σ. The measured mass and width are consistent with neutral $\Xi_c(2930)$ [9].

5 Angular analysis of $e^+e^- \to D^{(*)\pm}D^{*\mp}$ near the open charm threshold using initial state radiation

We report a new measurement of the exclusive $e^+e^- \to D^{(*)\pm}D^{*\mp}$ cross sections as a function of the center of mass energy from $D^{(*)\pm}D^{*\mp}$ threshold through $\sqrt{s} = 6.0$ GeV using the initial state radiation technique. This study will help us to understand the internal structure of cross section of such process. The analysis is based on a data sample collected with Belle detector at an integrated luminosity of 951 fb^{-1}. Due to larger data set, improved track reconstruction and additional modes used in the D and D* reconstruction allowed us to obtain more precise determination of their cross sections. The detailed description of physics analysis is discussed in [10]. The exclusive cross sections as a function of $\sqrt{s}$ is obtained from $D^{(*)+}D^{(*)-}$ mass spectrum. The final results on the measurement of the exclusive cross section for the processes $e^+e^- \to D^+D^{*-}$, $e^+e^- \to D^{(*)+}D^{(*)-}$ are shown in the Fig. 3 (a, b). The accuracy of the cross section measurement is increased by a factor of 2 over the previous Belle study [11]. Angular analysis for the process $e^+e^- \to D^{*\pm}D^{*\mp}$ is also performed. This

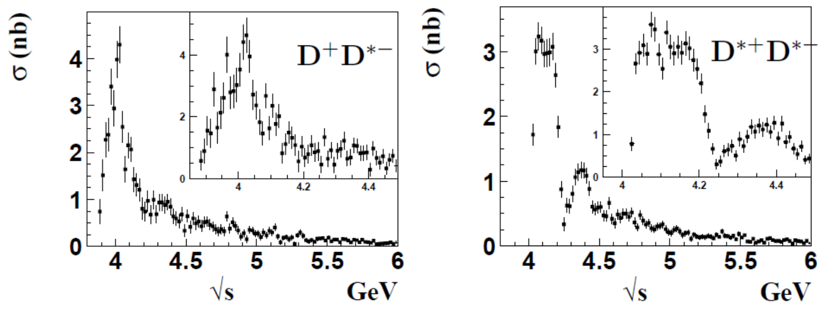

Figure 3: The exclusive cross sections as functions of $\sqrt{s}$ for (a) $e^+e^- \to D^+D^{*-}$ (b) $e^+e^- \to D^{(*)+}D^{(*)-}$ [10].

study allows us to decompose the corresponding exclusive cross section into three possible components for the longitudinally and transversely polarized $D^{*\pm}$ mesons [10].

6 Summary

Following conclusions have been made from the four physics analyses: (a) No clear signal of Z_c is observed in the $\Upsilon(1S)$, $\Upsilon(2S)$ decays as well as in e^+e^- annihilation. We have determined the 90% C.L upper limits on $\mathcal{B}(\Upsilon(1S,2S) \to Z_c^+ Z_c^{'-}) \times B(Z_c^+ \to \pi^+ c\bar{c})$ and $\sigma(e^+e^- \to Z_c^+ Z_c^{'-}) \times \mathcal{B}(Z_c^+ \to \pi^+ c\bar{c})$ at $\sqrt{s}$ = 10.52, 10.58 and 10.867 GeV. (b) We have set 90% C.L upper limit of $\mathcal{B}(B^+ \to X(3872)K^+) < 2.6\times10^{-4}$, which is more stringent than BABAR (3.2×10^{-4}) [12]. We have also measured $\mathcal{B}(B^+ \to \eta_c K^+) = (12.0 \pm 0.8 \pm 0.7)\times10^{-4}$ and $\mathcal{B}(B^+ \to \eta_c(2S)K^+) = (4.8 \pm 1.1 \pm 0.3) \times 10^{-4}$, which are the most accurate measurements to date. (c) In the updated measurement of $B^- \to K^-\Lambda_c^+\bar{\Lambda}_c^-$, the $\Xi_c(2930)^0$ is clearly observed for the first time with statistical significance greater than 5σ. (d) The accuracy of the cross section measurement is increased by a factor of 2 over the previous Belle study [11].

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