PROCEEDINGS OF SCIENCE

Studies of conventional quarkonia at Belle

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Studies of conventional quarkonia using 250-400 fb^{-1} of data collected with the Belle detector at the KEKB asymmetric-energy e^+e^- collider are presented.

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1. Study of charmonia in four-meson final states produced in two-photon collisions

We have measured the production of the charmonium states, $\eta_c(1S)$, χ_{c0} and χ_{c2}, from two-photon collisions in decay modes to four-meson final states, $\pi^+\pi^-\pi^+\pi^-$, $K^+K^-\pi^+\pi^-$ and $K^+K^-K^+K^-$, with the Belle detector. We have also searched for production of $\eta_c(2S)$ in the same final states. All the results of this study are preliminary.

We used 280 fb^{-1} of data recorded by the Belle detector [1] at the KEKB asymmetric-energy e^+e^- collider [2]. The candidate events are selected by requiring four charged particles with the zero net charge. The analysis is performed in the "no-tag" mode, where neither the recoil electron nor positron is detected. The vector sum of four tracks transverse momenta with respect to the e^+e^- -beam axis in the c.m. frame, $\Sigma\mathbf{p}_t^*$, is less 0.1 GeV/c. K/π separation is made using a likelihood ratio from the ACC, TOF and CDC information [1].

In the following analysis, we take only the combinations in which the net strangeness is conserved, $\pi^+\pi^-\pi^+\pi^-$, $K^+K^-\pi^+\pi^-$ and $K^+K^-K^+K^-$. We determine the yields of charmonium events using the invariant mass distributions in each of the three final states. We find clear enhancements at the $\eta_c(1S)$ at ~ 2.98 GeV/c^2, χ_{c0} at ~ 3.41 GeV/c^2, and χ_{c2} at ~ 3.555 GeV/c^2 in all the final states. We do not see any clear signatures of $\eta_c(2S)$. We study quasi-two-body decays of charmonia, in which a charmonium meson decays into two resonances, and each resonance decays to two final-state mesons.

The present and previous measurements [3, 4] give the "direct" $\mathscr{G} \equiv \Gamma_{\gamma\gamma}\mathscr{B}$ parameters for the processes discussed here. "Indirect" comparisons are also possible by converting the $\mathscr{G}$ parameter measured for a certain decay mode to the present measured mode using the ratio of the branching fractions, $\mathscr{G}(R \to X) = \mathscr{G}(R \to A) \cdot (\mathscr{B}(R \to X)/\mathscr{B}(R \to A))$, where $R \to A$ is a "normalization" process for which previous measurement(s) are available. The results for $\mathscr{G}$ are summarized in Table 1. In the η_c results, we find large systematic deviations between the present and previous results. In contrast, all the χ_{c0} and χ_{c2} results show good agreement. No clear signature for the $\eta_c(2S)$ is seen in these decay processes. We find prominent two-body $\eta_c(1S)$ and χ_{c2} decays to $K^*(892)^0\bar{K}^*(892)^0$ as well as $\eta_c(1S)$, χ_{c0} and χ_{c2} decays to $\phi\phi$. In addition, we observe $\eta_c(1S) \to f_2(1270) f_2(1270)$.

2. Study of Charmonium Decays into Baryon-Antibaryon Pairs

Visible structures in the mass spectra of a baryon-antibaryon pair of three-body B decays arise from charmonium decays. There is particular interest in $J/\psi \to p\bar{p}$, where the proton angular distribution has been studied. The baryon angular distribution can be parameterized as $\sim 1 + \alpha\cos^2\theta$, where θ is the baryon polar angle in the J/ψ helicity frame.

In this study of two-body baryonic decays of charmonia we focus on the decay processes, $B^+ \to p\bar{p}K^+$ and $B^+ \to \Lambda\bar{\Lambda}K^+$. We use a 350 fb^{-1} data sample, consisting of 386×10^6 $B\bar{B}$ pairs, collected by the Belle detector [1].

To isolate the signal and suppress the dominant background arising from the continuum $e^+e^- \to q\bar{q}$ process we follow the scheme suggested in Ref. [6]. An unbinned likelihood fit is used to estimate the B yield. There are clear η_c and J/ψ peaks in the $M_{p\bar{p}}$ mass spectrum. The measured branching fractions for charmonia decaying into $p\bar{p}$ are $\mathscr{B}(\eta_c \to p\bar{p}) = (1.58 \pm 0.12(stat) \pm$

Table 1: The present results of the $\mathscr{G} \equiv \Gamma_{\gamma\gamma}\mathscr{B}$ and comparisons with previous measurements (shown as "direct" and "indirect", see text) [5].

Process	present $\mathscr{G}$ (eV)	direct $\mathscr{G}$ (eV)	indirect $\mathscr{G}$ (eV)
$\eta_c \to \pi^+\pi^-\pi^+\pi^-$	$26.4 \pm 3.7 \pm 3.2$	$180 \pm 70 \pm 20$	101 ± 40
$\eta_c \to K^+K^-\pi^+\pi^-$	$23.7 \pm 3.4 \pm 2.8$	210 ± 70	126 ± 64
$\eta_c \to K^+K^-K^+K^-$	$7.3 \pm 1.6 \pm 1.0$	280 ± 70	13 ± 7
$\eta_c \to f_2 f_2$	$72 \pm 24 \pm 12$	–	–
$\eta_c \to K^*\bar{K}^*$	$35 \pm 6 \pm 5$	–	72 ± 34
$\eta_c \to f_2 f_2'$	$34 \pm 12 \pm 6$	–	–
$\eta_c \to \phi\phi$	$7.0 \pm 1.4 \pm 1.3$	–	21 ± 10
$\chi_{c0} \to \pi^+\pi^-\pi^+\pi^-$	$48.8 \pm 5.9 \pm 4.4$	$75 \pm 13 \pm 8$	67 ± 14
$\chi_{c0} \to K^+K^-\pi^+\pi^-$	$39.9 \pm 4.8 \pm 4.0$	–	55 ± 18
$\chi_{c0} \to K^+K^-K^+K^-$	$8.7 \pm 1.5 \pm 1.2$	–	6.0 ± 2.0
$\chi_{c0} \to K^{*0}K^-\pi^+ + \text{c.c.}$	$16.4 \pm 6.1 \pm 2.5$	–	31 ± 13
$\chi_{c0} \to \phi\phi$	$2.5 \pm 1.0 \pm 0.4$	–	2.6 ± 1.7
$\chi_{c2} \to \pi^+\pi^-\pi^+\pi^-$	$4.73 \pm 0.49 \pm 0.57$	6.4 ± 1.8	7.7 ± 1.5
$\chi_{c2} \to K^+K^-\pi^+\pi^-$	$4.92 \pm 0.54 \pm 0.59$	–	6.4 ± 1.9
$\chi_{c2} \to K^+K^-K^+K^-$	$1.23 \pm 0.20 \pm 0.17$	–	0.94 ± 0.29
$\chi_{c2} \to \rho^0\pi^+\pi^-$	$3.9 \pm 1.9 \pm 0.5$	–	3.6 ± 2.1
$\chi_{c2} \to K^*\bar{K}^*$	$2.61 \pm 0.54 \pm 0.89$	–	–
$\chi_{c2} \to \phi\phi$	$0.63 \pm 0.22 \pm 0.17$	–	1.3 ± 0.5

$0.22(syst) \pm 0.47(\text{PDG})) \times 10^{-3}$ and $\mathscr{B}(J/\psi \to p\bar{p}) = (2.24 \pm 0.13(stat) \pm 0.31(syst) \pm 0.01(\text{PDG})) \times 10^{-3}$. α is determined from the fit of the $\cos\theta$ distribution for J/ψ candidates to be 0.54 ± 0.14. From the baryon-antibaryon mass spectrum in $B^+ \to \Lambda\bar{\Lambda}K^+$ decays we estimate the branching fraction of $\eta_c \to \Lambda\bar{\Lambda}$ and $J/\psi \to \Lambda\bar{\Lambda}$. The results are $\mathscr{B}(\eta_c \to \Lambda\bar{\Lambda}) = (0.87^{+0.24}_{-0.21}(stat) \pm 0.14(syst) \pm 0.27(\text{PDG})) \times 10^{-3}$ and $\mathscr{B}(J/\psi \to \Lambda\bar{\Lambda}) = (2.00^{+0.33}_{-0.29}(stat) \pm 0.34(syst) \pm 0.08(\text{PDG})) \times 10^{-3}$.

3. Search for the h_c meson in $B^+ \to h_c K^+$

The h_c meson is the 1^1P_1 spin singlet state of $c\bar{c}$, which is expected to be a narrow resonance ($\Gamma_{h_c} < 1.1$ MeV/c^2) that lies between $J/\psi(1S)$ and $\psi(2S)$. Recently, CLEO[7] has reported the observation of $h_c \to \gamma\eta_c$ at a mass of $M = 3524.4 \pm 0.6 \pm 0.4$ MeV/c^2.

M. Suzuki [8] has proposed using the decay chain $B \to h_c K$, $h_c \to \eta_c\gamma$ to look for the h_c meson. Measurement of the branching fraction for $B \to h_c K$ will provide useful information on non-factorizable contributions in B to charmonium decays.

Here we present the results of a search for $B^+ \to h_c K^+$, $h_c \to \eta_c\gamma$ with $\eta_c \to K_S^0 K^\pm \pi^\mp$ and $p\bar{p}$ using a 253 fb^{-1} data sample, which contains 275×10^6 produced $B\bar{B}$ pairs, collected with the Belle detector[1]. To isolate the signal and suppress the large background from continuum $e^+e^- \to q\bar{q}$

we follow the scheme suggested in Ref. [6]. No significant signals are seen for $3.17 < M(\eta_c\gamma) \leq 3.67$ GeV/c^2. To obtain upper limits on the branching fractions for $B^+ \to \eta_c\gamma K^+$ we combine the likelihoods for the $\eta_c \to K^0_S K^-\pi^+$ and $\eta_c \to p\bar{p}$ modes. Assuming $\mathscr{B}(h_c \to \eta_c\gamma) = 0.5$, we obtain 90% C.L. upper limits on branching fractions for $B^+ \to h_c K^+$ as a function of the h_c mass. For $M_{h_c} = 3.527$ GeV/c^2, we find $\mathscr{B}(B^+ \to h_c K^+) < 3.8 \times 10^{-5}$. This is consistent, but only barely, with the lower bound on the $B \to h_c K$ branching fraction obtained by Colangelo, Fazio and Pham [9], which is $\mathscr{B}(B \to h_c K) = (2-12) \times 10^{-4}$.

4. Search for the decay $\Upsilon(4S) \to \Upsilon(1S)\pi^+\pi^-$

The bottomonium state $\Upsilon(4S)$ has a mass above the threshold for $B\bar{B}$ pair production and decays mainly into these B-meson pairs ($\mathscr{B}(\Upsilon(4S) \to B\bar{B})$ >96% [5]). Here we report the first evidence for the non-$B\bar{B}$ decay mode $\Upsilon(4S) \to \Upsilon(1S)\pi^+\pi^-$ from the Belle experiment.

In this study 398 fb^{-1} of data collected by the Belle detector [1] on the $\Upsilon(4S)$ resonance and in the nearby continuum is used. Well reconstructed charged particles are used to reconstruct the decay $\Upsilon(4S) \to \Upsilon(1S)\pi^+\pi^-$ with the subsequent leptonic decay $\Upsilon(1S) \to \ell^+\ell^-$.

$\mu^+\mu^-\pi^+\pi^-X$ events with an invariant mass $M_{\mu^+\mu^-}$ >9 GeV/c^2 were selected from the sample selected by the standard Belle hadronic selection. The muon pair invariant mass distribution, $M_{\mu^+\mu^-}$, for the $\mu^+\mu^-\pi^+\pi^-X$ events has a clear low background signal for $\Upsilon(1S) \to \mu^+\mu^-$. To observe resonance states that decay into the $\Upsilon(1S)$ $\pi^+\pi^-$ final state the distribution of the mass difference $\Delta M = (M_{\mu^+\mu^-\pi^+\pi^-} - M_{\mu^+\mu^-})$ where $M_{\mu^+\mu^-}$ is restricted to $|M_{\mu^+\mu^-} - M_{\Upsilon(1S)}|$ <6 MeV/c^2 was examined. Three peaks exist in the ΔM distribution. The first (second, third) peaks correspond to $\Delta M \sim 0.56(0.89, 1.12)$ GeV/c^2, respectively. The first and second peaks originate from the decays $\Upsilon(2S,3S) \to \Upsilon(1S)\pi^+\pi^-$ with a subsequent $\Upsilon(1S) \to \mu^+\mu^-$ transition, respectively. The position of the third peak, $\Delta M = (1119.0 \pm 1.4)$ MeV/c^2, is in good agreement with the mass difference $(M_{\Upsilon(4S)} - M_{\Upsilon(1S)})$ from the PDG [5]. The signal above background is determined from the fit to be, $N_{ev} = (38 \pm 6.9)$, with a statistical significance of 7.3 standard deviations. This peak is interpreted as a signal from the decay $\Upsilon(4S) \to \Upsilon(1S)\pi^+\pi^-$ with a subsequent $\Upsilon(1S) \to \mu^+\mu^-$ transition. This is the first example of a non-$B\bar{B}$ decay of the $\Upsilon(4S)$ resonance. The preliminary result for the branching fraction is $\mathscr{B}(\Upsilon(4S) \to \Upsilon(1S)\pi^+\pi^-) = (1.1 \pm 0.2(\text{stat.}) \pm 0.4(\text{syst.})) \cdot 10^{-4}$.

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