NEW RESONANCES AND SPECTROSCOPY.

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We report recent results on the observation of new particles produced in e^+e^- collisions at the $\Upsilon(4S)$ based on a data sample accumulated with the Belle detector at the KEKB factory.

1. Introduction

The Belle detector [1] at the KEKB [2] factory has accumulated more than 550 fb^{-1} of data by March 2006. Such a data sample provides a possibility to study CP-violation in B-decays, charm- and τ- physics. In this presentation we report results of a search for new states observed by Belle.

There are several mechanisms of the particles production at B-factories: fragmentation of light quarks in e^+e^- annihilation, production of new particles in decay of B-mesons from the $\Upsilon(4S)$, creation of C-even states in two-photon processes, production of $J^{PC} = 1^{--}$ in initial state radiation.

2. Observation of the broad D^{**}

The $B \to D^{(*)}\pi\pi$ decay provides a possibility to study D^{**} production. Performing angular analysis of the decay products for the processes $B^- \to D^{(*)+}\pi^-\pi^-$ [3] based on 60.4 fb^{-1} we could separate contributions of all four neutral D^{**0} – the first observation of the broad states D_0^{*0} and $D_1'^0$. Their masses, widths and product of the branching fractions $Br(B^- \to D_2^{**}\pi^-) \times Br(D^{**} \to D^{(*)+}\pi^-)$ were measured [3,4]. Analysis of the $\overline{B}^0 \to D^{(*)0}\pi^+\pi^-$ [4] based on 150 fb^{-1} and recent analysis of $\overline{B}^0 \to D^0\pi^+\pi^-$ based on 360 fb^{-1} showed that the branching fraction products obtained for the narrow ($j = 3/2$) resonances are similar to the results obtained in charged B decays while the measured values of the branching fractions of the broad resonance D_0^{*+} and $D_1'^+$ production in neutral B decays are significantly

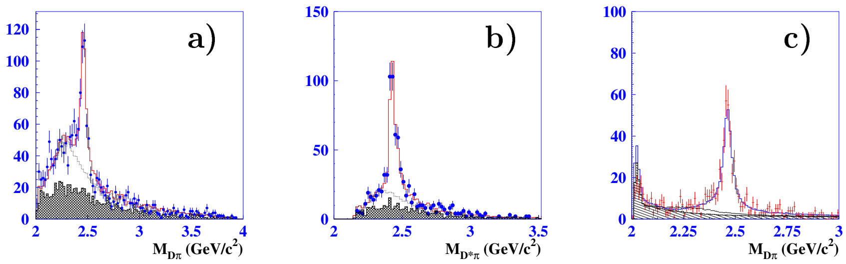

Figure 1. Mass distribution for $D^+\pi^-$ (a); $D^{*+}\pi^-$ (b); $D^0\pi^+$ (c). The points with error bars correspond to the signal box events, the hatched one — to the background obtained using generic MC events normalized to the sideband. The open histogram is the fit function after efficiency correction.

Table 1. Comparison of branching fraction products for B^0 and $B^\pm$.

	neutral B $\times 10^{-4}$	charged $B \times 10^{-4}$
$(\bar{B} \to D_2^*\pi^-)(D_2^* \to D\pi)$	$2.15 \pm 0.17 \pm 0.29 \pm 0.12$	$3.4 \pm 0.3 \pm 0.6 \pm 0.4$
$(\bar{B} \to D_2^*\pi^-)(D_2^* \to D^*\pi)$	$2.45 \pm 0.42^{+0.35+0.39}_{-0.45-0.17}$	$1.8 \pm 0.3 \pm 0.3 \pm 0.2$
$(\bar{B} \to D_1\pi^-)(D_1 \to D^*\pi)$	$3.68 \pm 0.60^{+0.71+0.65}_{-0.40-0.30}$	$6.8 \pm 0.7 \pm 1.3 \pm 0.3$
$(\bar{B} \to D_0^*\pi)(D_0^* \to D\pi)$	$0.60 \pm 0.13 \pm 0.15 \pm 0.22$	$6.1 \pm 0.6 \pm 0.9 \pm 1.6$
$(\bar{B} \to D_1'\pi^-)(D_1' \to D^*\pi)$	< 0.7 at 90 % C.L.	$5.0 \pm 0.4 \pm 1.0 \pm 0.4$

lower than those for charged B decays as shown in Table 1 and in Fig. 1. One possible explanation for this phenomenon is that for charged B decay to $D^{**}\pi$, the amplitude receives contributions from both tree and color-suppressed diagrams.

3. New charmonium states

A new charmonium state X(3872) was observed in the $\pi^+\pi^-J/\psi$ mass spectrum for $B^+ \to K^+\pi^+\pi^-J/\psi$ decay using a 152 M$B\bar{B}$ event sample [5]. The J/ψ is reconstructed from an electron or muon pair of the opposite sign. Figure 2 shows the distribution of $M(\pi^+\pi^-l^+l^-) - M(l^+l^-)$ for events in the $\Delta E - M_{\rm bc}$ signal region. Here a large peak corresponding to $\psi' \to \pi^+\pi^-J/\psi$ is evident at 0.589 GeV. In addition there is a significant spike at 0.775 GeV. A signal of 35.7±6.8 events with a significance of 10.3 σ was observed. The mass corresponding to the peak was measured to be $M = 3872.4 \pm 0.6 \pm 0.5\,\mathrm{MeV/c^2}$ and an upper limit for width was $\Gamma < 2.3\ MeV$. The $\pi\pi$ invariant mass distribution is consistent with the isospin violating $X(3872) \to J/\psi\rho^0$ intermediate state.

Analyzing the data of a 275 M$B\bar{B}$ event sample Belle found evidence of decays $X(3872) \to \gamma J/\psi$ and $X(3872) \to \pi^+\pi^-\pi^0 J/\psi$ [5]. In the latter, the $\pi^+\pi^-\pi^0$ invariant mass distribution was in agreement with the dominance of the sub-threshold decay $X \to \omega J/\psi$. These results established the charge-conjugation parity of $X(3872)$ as $C = +1$.

Using a larger data sample we examined a possible J^{PC} quantum numbers assignment for the $X(3872)$ [7]. Angular correlations between the final state particles in $X \to \pi^+\pi^- J/\psi$ ruled out the 0^{++} and 0^{-+} options. The shape of the $\pi\pi$ mass distribution favors $S-$wave over $P-$wave as a relative orbital momentum between the final state dipion and J/ψ strongly disfavoring $1, 2^{-+}$ assignments. The accumulated evidence strongly favors a 1^{++} assignment for the $X(3872)$.

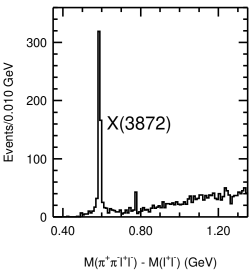

Figure 2. Distribution of $M(\pi^+\pi^-l^+l^-) - M(l^+l^-)$ for selected events in the $\Delta E - M_{\rm bc}$ signal region.

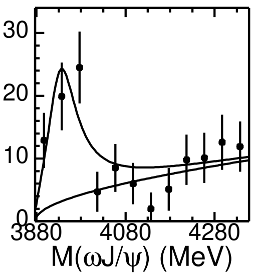

Figure 3. $B \to K\omega J/\psi$ signal yield *vs* $M(\omega J/\psi)$.

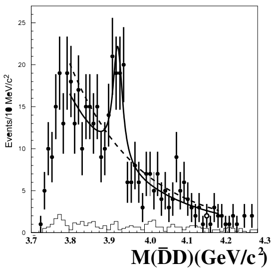

Figure 4. Mass distribution for $D\bar{D}$. The curves show the fits with and without resonance component.

The charmonium χ'_{c1} state is an unlikely assignment for the observed state. Potential model predict about 100 MeV higher mass for χ'_{c1} [8] and an essentially larger ratio of branching fractions $X \to \gamma J/\psi$ over $X \to \pi\pi J/\psi$.

The model which treat $X(3872)$ as a molecule-like $D^0\bar{D^{*)}}$ bound state [9,10] is one of the hypothesis for this state.

Another charmonium state observed by Belle in B decays was enhancement in the $\omega J/\psi$ invariant mass distribution for exclusive $B \to K\omega J/\psi$ decays [11]. The analysis was performed using a data sample of 275 M$B\bar{B}$ events. The Dalitz plot distribution of $M^2(\omega J/\psi)$ *vs* $M^2(\omega K)$ from the $M_{\rm bc}\Delta E$ signal region shows clustering of events with low $\omega J/\psi$ invariant masses near the bottom of Dalitz plot. The B-meson signal yields from the fits to the individual bins are plotted *vs* $M(\omega J/\psi)$ in Fig. 3. Here a cut to invariant mass of $M(\omega K) > 1.6\ GeV$ was applied to reject the events of $B \to K_X J/\psi$; $K_X \to K\omega$.

The fit of the enhancement to S-wave Breit-Wigner function gives a signal yield of 58 ± 11 events with mass $M = 3943 \pm 11 \pm 13\ MeV$ and width $\Gamma = 87 \pm 22 \pm 26\ MeV$ with statistical significance of 8.1σ [11]. The mass of the state is very close to that of the state $X(3940)$ observed by Belle in the J/ψ recoil mass spectrum for inclusive $e^+e^- \to J/\psi X$ events near $\sqrt{s} = 10.56$ GeV [12]. However the width of X was measured to be less than 52 MeV. The dominant decay mode of this state is DD^* and no evidence of $X(3940) \to J/\psi\omega$ is found. So we conclude that these states are different.

Analyzing two-photon processes of the data sample of 395 fb^{-1} Belle found a new resonance state in the process $\gamma\gamma \to D\bar{D}$ [13]. The mass distribution for $D\bar{D}$ is shown in Fig. 4. The results for the mass width and the product of the two-photon decay width times the branching fraction to $D\bar{D}$ are: $M = 3929 \pm 5 \pm 2\ MeV$, $\Gamma = 29 \pm 10 \pm 2\ MeV$, $\Gamma_{\gamma\gamma}(Z)Br(Z \to D\bar{D}) = 0.18 \pm 0.05 \pm 0.03\ keV$, respectively. The distribution of the cosine angle of a D relative to the beam axis in $\gamma\gamma$ c.m. frame is in agreement with a spin 2 hypothesis. The measured properties are consistent with a previously unseen χ'_{c2} charmonium state.

High luminosity of KEKB and the Belle detector with good performance both for charged particles and photons make the Belle experiment a unique source for a search of new particles. During the operation time more than ten new states have been discovered. Some of the states were predicted, some of particles show unexpected properties and are a good test for theoretical models. New data promises more interesting results.

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