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Studies of charmonium-like states at BABAR

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Several charmonium-like states above $D\bar{D}$ threshold have been discovered at the Belle and BABAR B-factories. Some of these states are produced via Initial State Radiation (*e.g.* $Y(4260)$ and $Y(4350)$), and some are observed in B-meson decays (*e.g.* $X(3872)$, and $Y(3940)$). The Belle observations of the enhancements in the $\psi(2S)\pi^-$ and $\chi_{c1}\pi^-$, *i. e.* the $Z(4430)^-$, $Z_1(4050)^-$, and $Z_2(4250)^-$, have generated a great deal of interest, because such states must have minimum quark content $(c\bar{c}d\bar{u})$, *i.e.* these are four-quark states. The BABAR Collaboration does not confirm the existinence of the $Z(4430)^-$.

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1. Introduction

Many charmonium states have been predicted by a variety of theoretical models. All predicted states below open-charm threshold have been discovered. At the *B*-factories, many new states above open-charm threshold have been discovered, but no new candidate states have been reported below this threshold. An overview of the charmonium and charmonium-like states is shown in Fig. 1. The quantum numbers (J^{PC}) of some of the new states have not yet been determined.

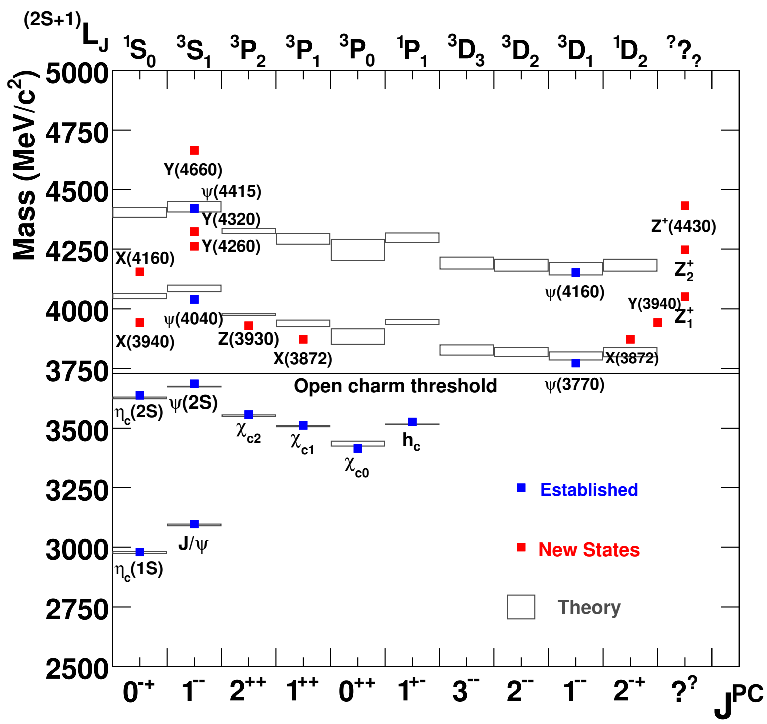

Figure 1: The mass versus the quantum numbers (J^{PC}) for the charmonium-like states. The boxes represent the predictions; blue boxes show the established states, and the red boxes indicate the new states discovered at the *B*-factories.

2. The $Y(4260) \to J/\psi\pi^+\pi^-$

The $Y(4260)$ was discovered [1] by BABAR in the Initial State Radiation (ISR) process $e^+e^- \to \gamma_{ISR}Y(4260)$, $Y(4260) \to J/\psi\pi^+\pi^-$. Being formed directly in e^+e^- annihilation, this should be a $J^{PC} = 1^{--}$ state. However, its nature is not yet understood, and does not fit into a simple charmonium model. The BABAR Collaboration is finalizing an update, using the full dataset with 454 fb^{-1} [2], on the decay mode $Y(4260) \to J/\psi\pi^+\pi^-$. The preliminary updated $Y(4260)$ mass and width values are $m = 4252 \pm 6(stat)^{+2}_{-3}(syst)$ MeV/c^2 and $\Gamma = 105 \pm 18(stat)^{+4}_{-6}(syst)$ MeV, respectively. There is no evidence for the enhancement at ~ 4005 MeV/c^2 reported by the Belle Collaboration [3].

The BABAR Collaboration has searched also for the decays $Y(4260) \to D\bar{D}$, $Y(4260) \to D^*\bar{D}$, and $Y(4260) \to D^*\bar{D}^*$ in ISR events [5]. The $D\bar{D}$ mass distribution for these decay modes is shown in Fig. 2. No evidence for the $Y(4260)$ is observed in any of these distributions.

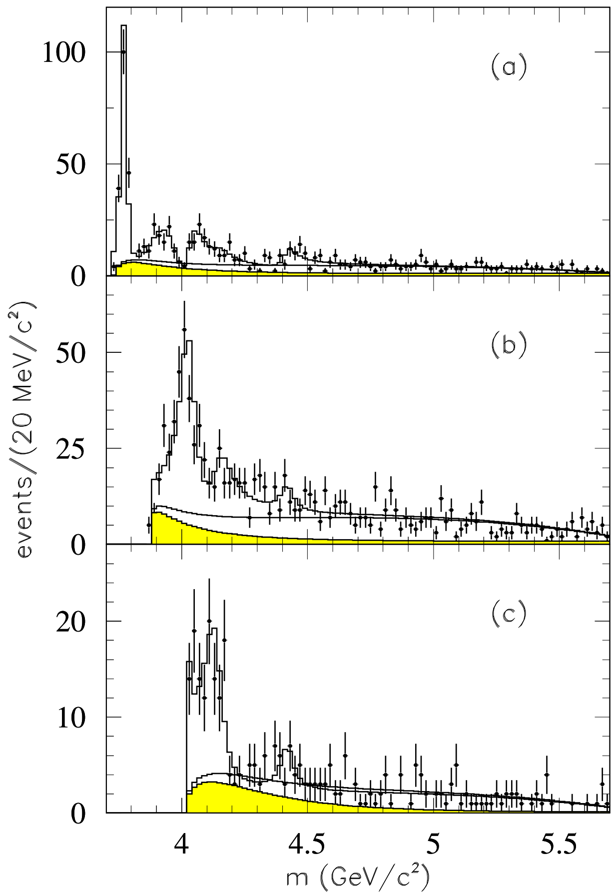

Figure 2: Fits to the (a) $D\bar{D}$, (b) $D^*\bar{D}$, and (c) $D^*\bar{D}^*$ mass spectra. The points represent the data and the curves show the fitted functions. The shaded histograms correspond to the smoothed incoherent background estimated from sidebands. The smooth solid curves represent the nonresonant contributions.

3. The $Y(4350) \to \psi(2S)\pi^+\pi^-$

BABAR has searched for the decay $Y(4260) \to \psi(2S)\pi^+\pi^-$ using a dataset of 298 fb^{-1} [4]. A new structure at ~ 4.32 GeV/c^2 in the $\psi(2S)\pi^+\pi^-$ invariant-mass spectrum, not consistent with the decay $\psi(4415) \to \psi(2S)\pi^+\pi^-$, has been observed. The structure also differs from that reported for the $Y(4260)$ in Ref. [1]. The possibility that it represents evidence for a new decay mode for the $Y(4260)$ cannot be entirely ruled out. The mass and width obtained from a fit to this structure are $m = 4324 \pm 24$ MeV/c^2 and $\Gamma = 172 \pm 33$ MeV.

4. The $X(3872) \to J/\psi\gamma$ and $X(3872) \to \psi(2S)\gamma$

The $X(3872)$ was discovered by the Belle Collaboration in the decay mode $B \to X(3872)K$,

$X(3872) \to J/\psi\pi^+\pi^-$ [6]. Confirmation of this observation came from CDF, D0, and BaBar experiments [7, 8, 9]. Subsequently other decay modes have been reported such as $X(3872) \to D^0\bar{D}^*$ [10, 11], and $X(3872) \to J/\psi\gamma$ [12, 13]. The BaBar Collaboration has updated the measurement of $X(3872) \to J/\psi\gamma$, and also reported a new decay mode $X(3872) \to \psi(2S)\gamma$ using a dataset corresponding to luminosity of 424 fb^{-1} [14]. We measure the branching fractions $\mathscr{B}(B^\pm \to X(3872)K^\pm) \times \mathscr{B}(X(3872) \to J/\psi\gamma) = (2.8 \pm 0.8(stat) \pm 0.2(syst)) \times 10^{-6}$ and $\mathscr{B}(B^\pm \to X(3872)K^\pm) \times \mathscr{B}(X(3872) \to \psi(2S)\gamma) = (9.9 \pm 2.9(stat) \pm 0.6(syst)) \times 10^{-6}$. The resulting branching fraction ratio contradicts theoretical expectation [15]. Observation of the decays $X(3872) \to J/\psi\gamma$ and $X(3872) \to \psi(2S)\gamma$ establishes positive C-parity for the $X(3872)$.

5. The $Y(3940) \to J/\psi\omega$

The Belle Collaboration reported evidence for the $Y(3940)$ in the decay $B \to Y(3940)K$, $Y(3940) \to J/\psi\omega$ [16], with mass and width $3943 \pm 11(stat) \pm 13(syst)$ MeV/c^2 and $87 \pm 22(stat) \pm 26(syst)$ MeV, respectively. The BaBar Collaboration confirmed [17] the existence of the $Y(3940)$ using a data sample of 348 fb^{-1}, but measured a lower mass ($3914.6^{+3.8}_{-3.4}(stat) \pm 2(syst)$ MeV/c^2) and smaller width ($34^{+12}_{-8}(stat) \pm 5(syst)$ MeV) than in the Belle analysis. The Belle Collaboration has recently reported [18] a new state observed in two-photon production with a mass of $3914 \pm 3(stat) \pm 2(syst)$ MeV/c^2, and a width of $23 \pm 10(stat)^{+2}_{-8}(syst)$ MeV. These mass and width values are in a good agreement with the BaBar values for the $Y(3940)$, and so might indicate that these are different decay modes of the same state. The BaBar ratio of the B^0 and B^+ branching fractions for the $Y(3940)$ is $0.27^{+0.28}_{-0.23}(stat)^{+0.04}_{-0.01}(syst)$. The central value is thus three standard deviations below the isospin expectation, but agrees well with the corresponding $X(3872)$ ratio from BaBar [19].

6. Search for the $Z(4430)^-$

The Belle Collaboration report [20] of a charged charmonium-like structure, the $Z(4430)^-$, in the $\psi(2S)\pi^-$ system produced in the decays $B^{-,0} \to \psi(2S)\pi^-K^{0,-}$ has generated a great deal of interest. If confirmed, such a state must have minimum quark content ($c\bar{c}d\bar{u}$) so that it would represent the unequivocal manifestation of a four-quark meson state.

The BaBar Collaboration has analyzed a data sample collected at the $\Upsilon(4S)$ resonance (413 fb^{-1}) to search for the $Z(4430)^-$ state in four decay modes $B \to \psi\pi^-K$, where $\psi = J/\psi$ or $\psi(2S)$ and $K = K^0_S$ or K^+. We represent the $K\pi^-$ mass dependence of the angular structure in the $K\pi^-$ angular distribution at a given $m_{K\pi^-}$ in terms of Legendre polynomials, $P_l(\cos\theta_K)$, where the angle θ_K is between the K in the $K\pi^-$ rest frame and the $K\pi^-$ direction in the B rest frame. A backward-forward asymmetry in $\cos\theta_K$ has been measured, and the details of the observed $K\pi^-$ mass and angular structure have been carefully taken into account in evaluating their impact on the corresponding $\psi\pi^-$ mass distribution.

We compare the data and the reflections of the $K\pi^-$ structure into the $\psi\pi^-$ mass distributions for the five $K\pi^-$ regions relevant to the Belle analysis (see Fig. 25 in Ref. [21]): below the $K^*(892)$; within 100 MeV/c^2 of the $K^*(892)$; between the $K^*(892)$ and the $K_2^*(1430)$; within 100 MeV/c^2 of the $K_2^*(1430)$; and above the $K_2^*(1430)$. Overall, good agreement between data and $K\pi^-$ reflection

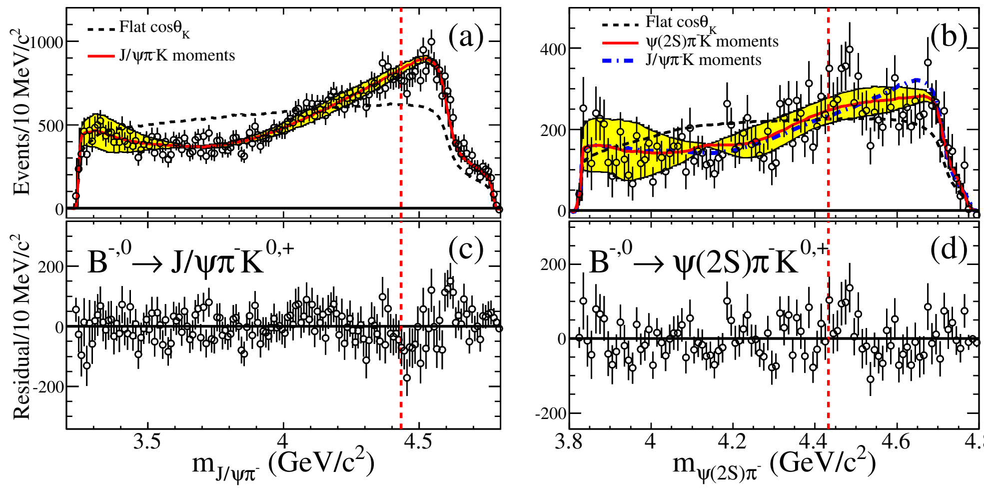

Figure 3: The $\psi\pi^-$ mass distributions for the combined decay modes (a) $B^{-,0} \to J/\psi\pi^- K^{0,+}$ and (b) $B^{-,0} \to \psi(2S)\pi^- K^{0,+}$. The points show the data after efficiency correction and ΔE sideband subtraction. The dashed curves show the $K\pi^-$ reflection for a flat $\cos\theta_K$ distribution, while the solid curves show the result of $\cos\theta_K$ weighting. The shaded bands represent the effect of statistical uncertainty on the normalized moments. In (b), the dot-dashed curve indicates the effect of weighting with the normalized $J/\psi\pi^- K$ moments. The dashed vertical lines indicate the value of $m_{\psi\pi^-} = 4.433$ GeV/c^2. In (c) and (d), we show the residuals (data-solid curve) for (a) and (b), respectively.

is obtained in the different $K\pi^-$ regions, indicating that no additional structure is needed to describe the data. In Fig. 3, we show the $\psi\pi^-$ mass distributions for all of the data. No compelling evidence for the $Z(4430)^-$ is observed.

In Fig. 4 we show fits to the $\psi\pi^-$ mass distributions in which the $K\pi^-$ background shape is fixed and an S-wave Breit Wigner (BW) is used as a signal function. The BW parameters are free in the fits. Figures 4(a) and (d) are for the entire data samples; Figures 4(b) and (e) are for the K^* regions, and Figs 4(c) and (f) are for the $K^*(892)$ and $K_2^*(1430)$ veto regions combined (the Belle selection). For the J/ψ samples, no evidence for any enhancement is obtained. For the $\psi(2S)$ data small signals are obtained, but their significance is only in the $2-3\sigma$ range, and in Fig. 4(d) and (e) the fitted mass is significantly different from the Belle value. In Fig. 4(f), the signal mass and width are consistent with the Belle values, but the signal significance is only 1.9σ. We conclude that the BABAR data provide no significant evidence for the existence of the $Z(4430)^-$.

References

[1] B. Aubert *et al.* [BABAR Collaboration], Phys. Rev. Lett. **95**, 142001 (2005).

[2] B. Aubert *et al.* [BABAR Collaboration], arXiv:0808.1543 [hep-ex] (2008).

[3] C. Z. Yuan *et al.* [Belle Collaboration], Phys. Rev. Lett. **99**, 182004 (2007).

[4] B. Aubert *et al.* [BABAR Collaboration], Phys. Rev. Lett. **98**, 212001 (2007).

[5] B. Aubert *et al.* [BABAR Collaboration], Phys. Rev. **D79**, 092001 (2009).

[6] S. K. Choi *et al.* [Belle Collaboration], Phys. Rev. Lett. **91**, 262001 (2003).

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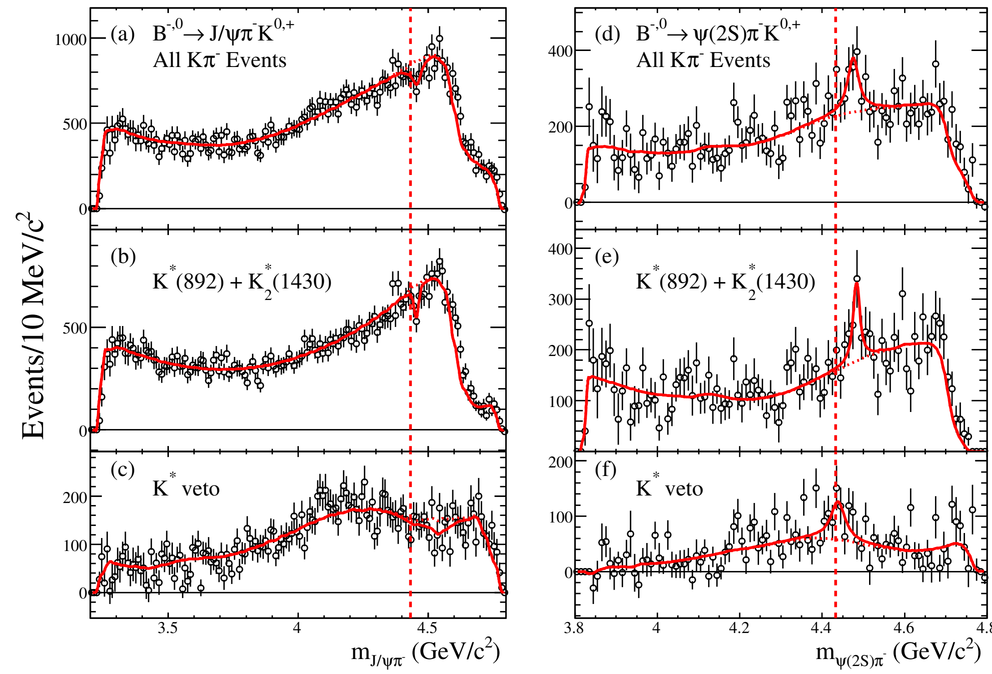

Figure 4: The results of the fits to the corrected mass distributions, (a)-(c) for $J/\psi\pi^-$, and (d)-(f) for $\psi(2S)\pi^-$. The curves are described in the text; the dashed vertical lines indicate $m_{\psi\pi^-} = 4.433$ GeV/c^2.

[7] D. E. Acosta *et al.*, [CDF II Collaboration],Phys. Rev. Lett. **93**, 072001 (2004).

[8] V. M. Abazov *et al.*, [D0 Collaboration], Phys. Rev. Lett. **93**, 162002 (2004).

[9] B. Aubert *et al.*, [BABAR Collaboration], Phys. Rev. D **71**, 071103 (2005).

[10] G. Gokhroo *et al.*, [Belle Collaboration], Phys. Rev. Lett. **97**, 162002 (2006).

[11] B. Aubert *et al.*, [BABAR Collaboration], Phys. Rev. D **77**, 011102 (2008).

[12] K. Abe *et al.*, [Belle Collaboration], arXiv:0505037 [hep-ex].

[13] B. Aubert *et al.*, [BABAR Collaboration], Phys. Rev. D **74**, 071101 (2006).

[14] B. Aubert *et al.* [BABAR Collaboration], Phys. Rev. Lett. **102**, 132001 (2009).

[15] E. S. Swanson, Phys. Rept. **429**, 243 (2006).

[16] K. Abe *et al.*, [Belle Collaboration], Phys. Rev. Lett. **94**, 182002 (2005).

[17] B. Aubert *et al.*, [BABAR Collaboration], Phys. Rev. Lett. **101**, 082001 (2008).

[18] S. L. Olsen, arXiv:0909.2713 [hep-ex] (2009).

[19] B. Aubert *et al.*, [BABAR Collaboration], Phys. Rev. D **77**, 111101 (2008).

[20] S. K. Choi *et al.* [Belle Collaboration], Phys. Rev. Lett. **100**, 142001 (2008).

[21] B. Aubert *et al.* [BABAR Collaboration], Phys. Rev. D **79**, 112001 (2009).