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Searches for exotic X,Y, and Z^- states with *BABAR*

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Recently, 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.* $X(3872)$, $Y(3940)$). The BELLE observation of the enhancement in the $\psi(2S)\pi^-$, *i.e.* the $Z(4430)^-$ state, has generated a great deal of interest, because 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. Here we report recent *BABAR* results on the $Y(4260)$, $X(3872)$, $Y(3940)$, and a search for the $Z(4430)^-$.

1. THE $Y(4260) \rightarrow J/\psi\pi^+\pi^-$

The $Y(4260)$ was discovered [1] by *BABAR* in the Initial State Radiation (ISR) process $e^+e^- \rightarrow \gamma_{ISR}Y(4260)$, $Y(4260) \rightarrow J/\psi\pi^+\pi^-$. Being formed directly in e^+e^- annihilation, this should be a $J^{PC} = 1^{--}$ state. However, its nature is still not understood, and does not seem compatible with a charmonium interpretation. In Fig. 1, we show the ISR-produced $J/\psi\pi^+\pi^-$ invariant mass distribution for the full *BABAR* dataset (454 fb^{-1}) [2], where a clear enhancement of the $Y(4260)$ is observed. The updated $Y(4260)$ mass and width values are $m = 4252\pm6(stat)^{+2}_{-3}(syst)$ 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].

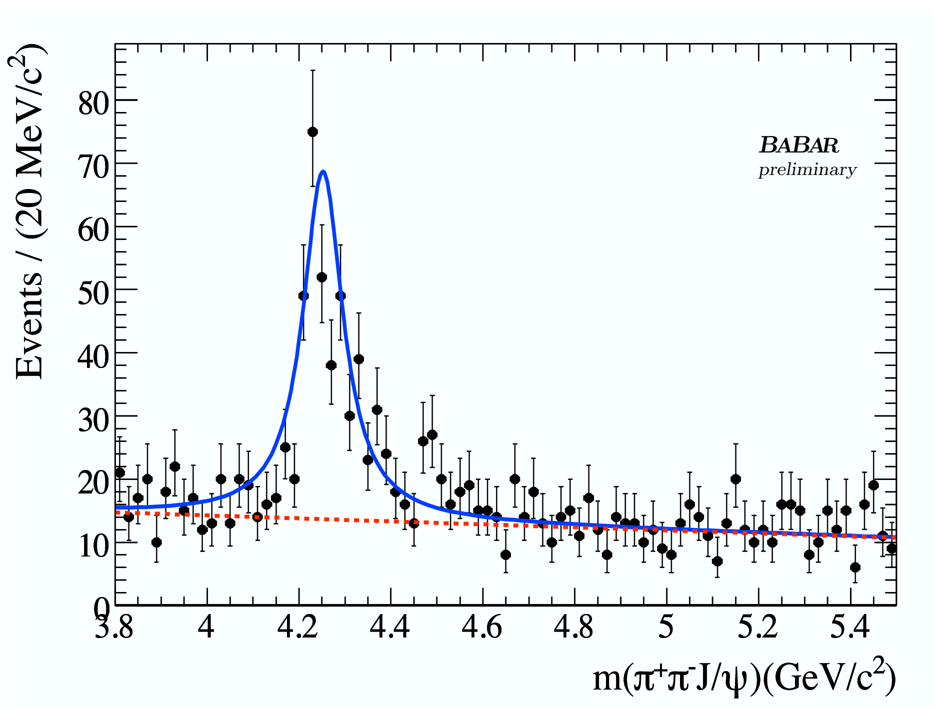

Figure 1: The ISR-produced $J/\psi\pi^+\pi^-$ invariant mass distribution. The dots represent the data, the solid curve shows the fit result, while the dashed curve represents the background contribution.

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2. THE $X(3872) \to J/\psi\gamma$ AND $X(3872) \to \psi(2S)\gamma$

The $X(3872)$, discovered by BELLE [4], was the first of the new charmonium-like states, and has since been confirmed by other experiments [5–7]. The $X(3872)$ was discovered in the decay mode $B \to X(3872)K$, $X(3872) \to J/\psi\pi^+\pi^-$. Subsequently other decay modes have been reported such as $X(3872) \to D^0\bar{D}^{*0}$ [8, 9], and $X(3872) \to J/\psi\gamma$ [10, 11]. The BABAR Collaboration has updated the measurement of $X(3872) \to J/\psi\gamma$ and reported a new decay mode, $X(3872) \to \psi(2S)\gamma$, using the full BABAR dataset of 424 fb^{-1} [12]. Figure 2 shows the corresponding evidence $J/\psi\gamma$ (left) and $\psi(2S)\gamma$ (right) mass distributions. We report branching fractions $\mathcal{B}(B^\pm \to X(3872)K^\pm) \cdot \mathcal{B}(X(3872) \to J/\psi\gamma) = (2.8 \pm 0.8(stat) \pm 0.2(syst)) \times 10^{-6}$ and $\mathcal{B}(B^\pm \to X(3872)K^\pm) \cdot \mathcal{B}(X(3872) \to \psi(2S)\gamma) = (9.9 \pm 2.9(stat) \pm 0.6(syst)) \times 10^{-6}$. The latter branching fraction contradicts theoretical expectation, since it was expected to be smaller than the former [13].

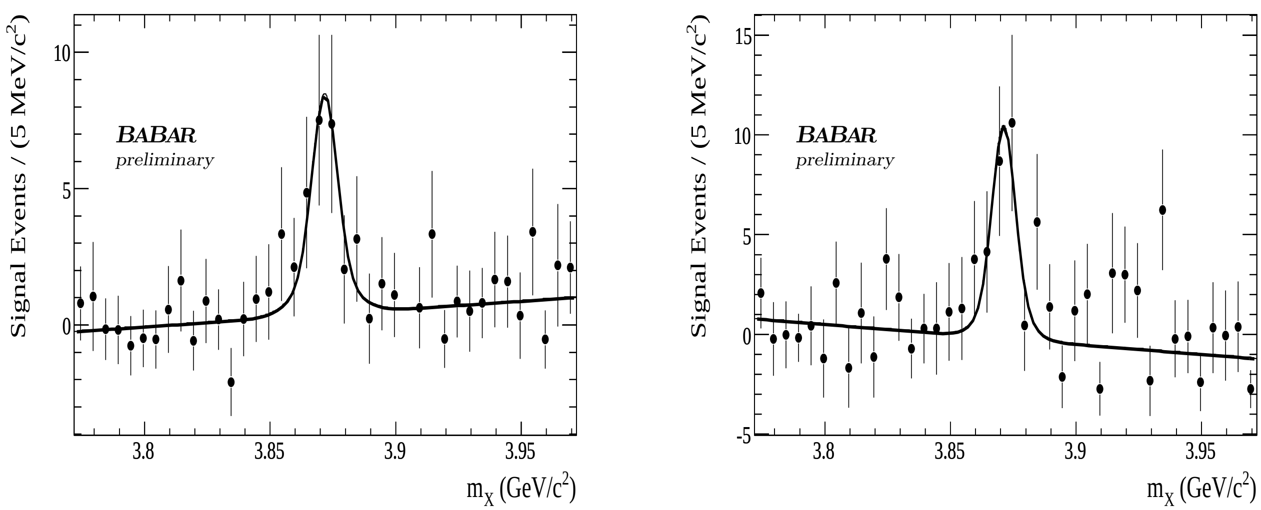

Figure 2: Left (Right): The $J/\psi\gamma$ ($\psi(2S)\gamma$) mass distribution for $B \to X(3872)K$, $X(3872) \to J/\psi\gamma$ ($\psi(2S)\gamma$). The points represent the data and the solid curves show the results of a fit to a Breit-Wigner enhancement above a linear background.

3. THE $Y(3940) \to J/\psi\omega$

The BELLE Collaboration reported evidence for the $Y(3940)$ in the decay $B \to Y(3940)K$, $Y(3940) \to J/\psi\omega$ [14], with mass and the width $3943 \pm 11(stat) \pm 13(syst)$ MeV/c^2 and $87 \pm 22(stat) \pm 26(syst)$ MeV, respectively. The BABAR Collaboration has confirmed [15] 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 BABAR ratio of B^0 and B^+ branching fractions events for the $Y(3940)$ is $0.27^{+0.28}_{-0.23}(stat)^{+0.04}_{-0.01}(syst)$. The central value of this ratio is three standard deviations below the isospin expectations, but agrees well with the corresponding $X(3872)$ ratio from BABAR [16].

4. SEARCH FOR $Z(4430)^- \to J/\psi\pi^-$ AND $Z(4430)^- \to \psi(2S)\pi^-$

The BELLE Collaboration reported [17] a new 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 the entire 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^+. The $\psi\pi^-$ mass resolution is $\sim 7(4)$ MeV/c^2 at the $Z(4430)^-$ mass for the J/ψ ($\psi(2S)$) modes. The $K\pi^-$ mass distributions, after efficiency-correction and background-subtraction, for the decay modes $B^{-,0} \to J/\psi\pi^- K^{0,-}$ and $B^{-,0} \to \psi(2S)\pi^- K^{0,-}$ are shown in Figs. 3(a) and (b). The data are well-described as a sum of $K\pi^-$ S-, P-, and D-wave intensity contributions with clear enhancement of the $K^*(892)$ and $K_2^*(1430)$. The $K^*(892)$ mass and width values obtained are in good agreement with the PDG values [18].

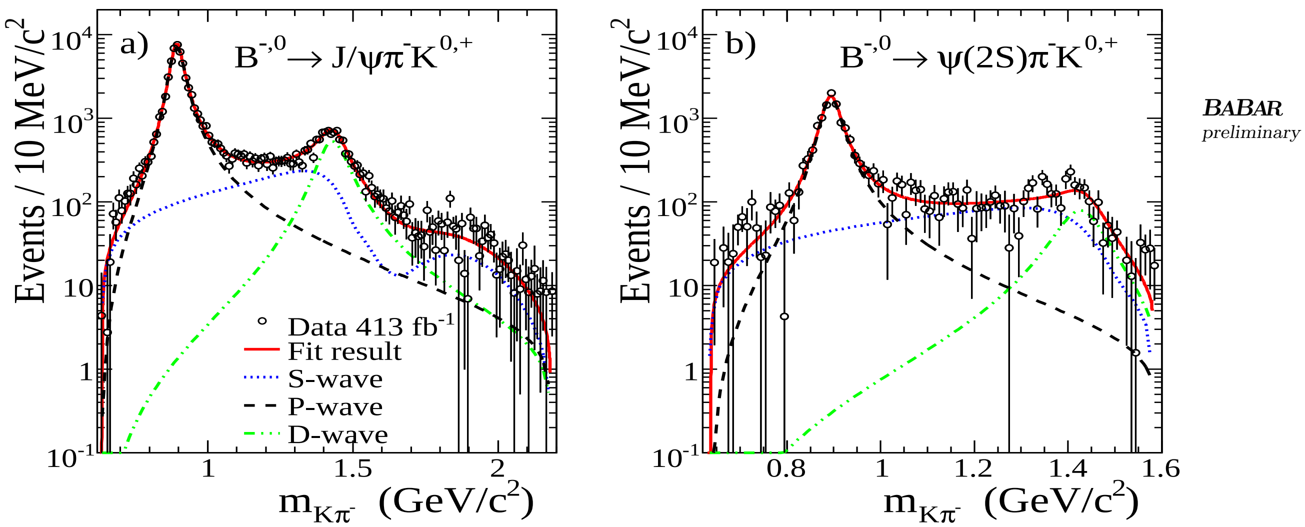

Figure 3: The results of the fits to the $K\pi^-$ mass distributions for the combined $K\pi^-$ charge configurations (a) $B^{-,0} \to J/\psi\pi^- K^{0,+}$ and (b) $B^{-,0} \to \psi(2S)\pi^- K^{0,+}$. The individual intensity contributions due to S-, P-, and D-waves are as indicated.

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. The $\cos\theta_K$ versus $m_{K\pi^-}$ distributions for the J/ψ and $\psi(2S)$ samples are shown in Fig. 4, and both exhibit backward-forward asymmetry in $\cos\theta_K$. The $K\pi^-$ mass and angular structure has a significant impact on the corresponding $\psi\pi^-$ mass distribution. This structure is shown in Fig. 5, where we plot $\cos\theta_\psi$ versus $m_{\psi\pi^-}$; θ_ψ is the angle between the ψ in the $\psi\pi^-$ rest frame, and the $\psi\pi^-$ direction in the B rest frame. The $K^*(892)$ bands are observed and a $K_2^*(1430)$ band can be seen in Fig. 5(a). The regions corresponding to the the $K\pi^-$ mass intervals (A) below the $K^*(892)$, (B) within 100 MeV/c^2 of the $K^*(892)$ nominal mass, (C) between the $K^*(892)$ and $K_2^*(1430)$, (D) within 100 MeV/c^2 of the $K_2^*(1430)$ nominal mass, and (E) above the $K_2^*(1430)$ are labeled.

The $Z(4430)^-$ signal in Ref. [17] corresponds to regions A, C, and E combined; Fig. 5(d) shows that, at the $Z(4430)^-$ mass position, only about half of the decay angular distribution is then being selected.

The $\psi\pi^-$ mass distributions in the five $K\pi^-$ mass ranges (A-E) are shown in Fig. 6 for the samples with J/ψ and $\psi(2S)$ candidates. The solid curves represent the $K\pi^-$ reflection into the $\psi\pi^-$ mass distribution, taking into account the $K\pi^-$ mass structure through the fit functions of Fig. 3, and the $\cos\theta_K$ dependence via the normalized Legendre polynomial moments. The bands indicate the uncertainties resulting from the uncertainties in the Legendre moments. No significant enhancement of the data and the solid curves is observed at the $Z(4430)^-$ mass in any $K\pi^-$ region.

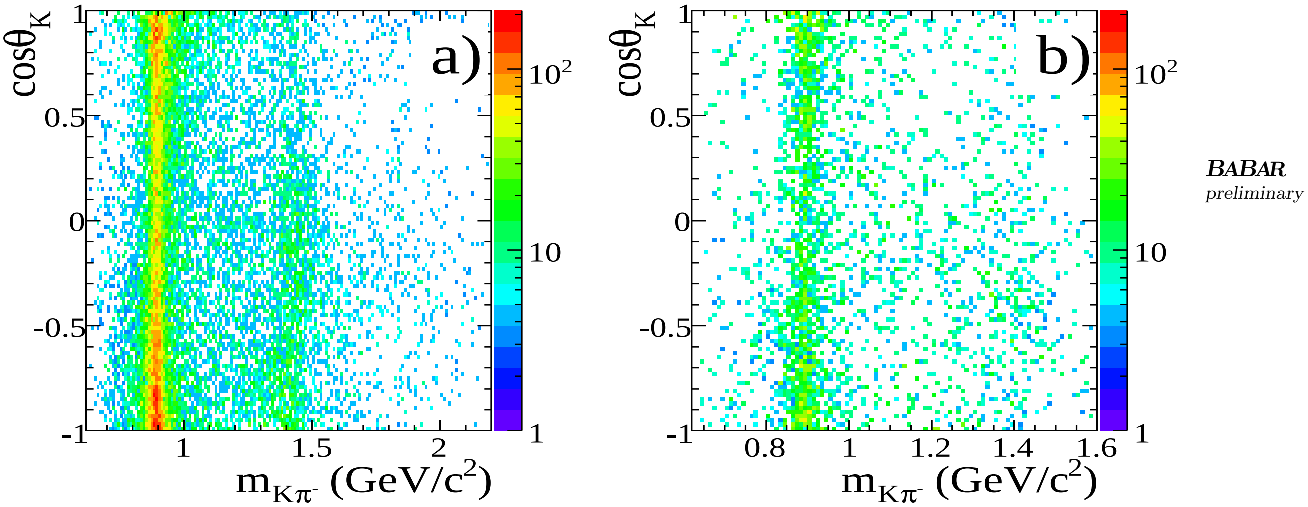

Figure 4: The $\cos\theta_K$ versus $m_{K\pi^-}$ for the combined decay modes (a) $B^{-,0} \to J/\psi\pi^- K^{0,+}$, (b) $B^{-,0} \to \psi(2S)\pi^- K^{0,+}$; the data samples are corrected for efficiency.

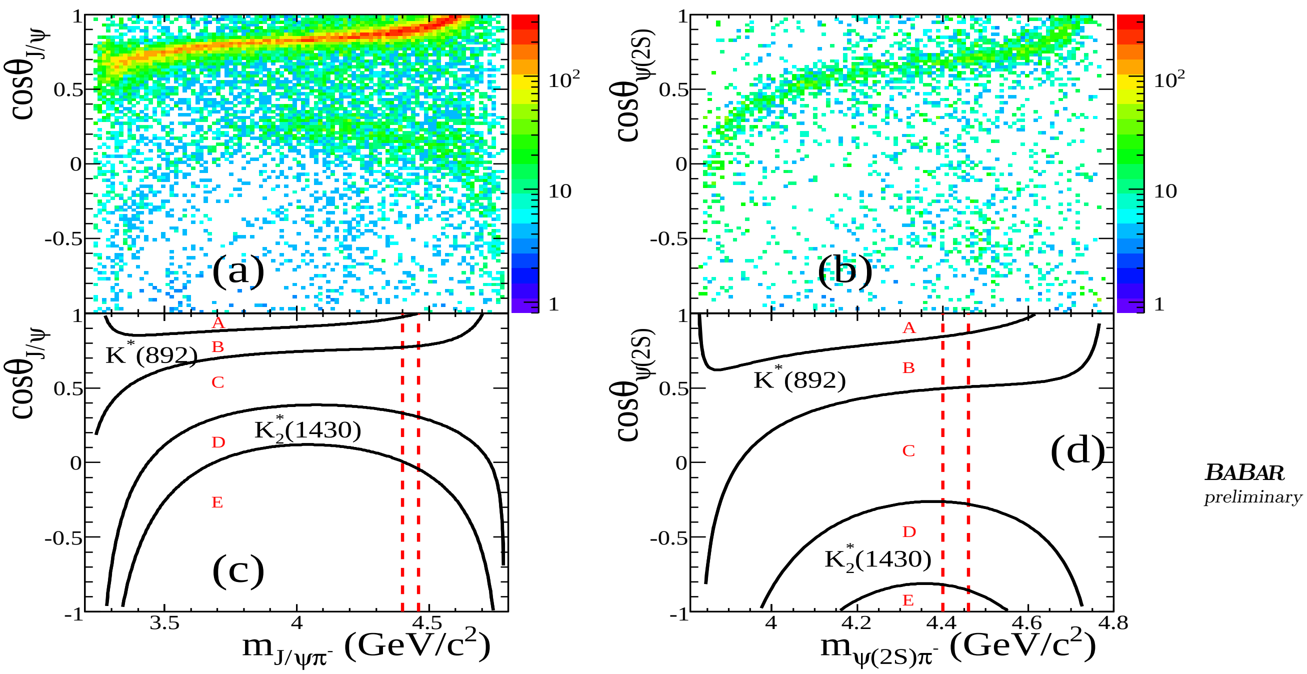

Figure 5: The $\cos\theta_\psi$ versus $m_{\psi\pi^-}$ rectangular Dalitz plots for (a) $B^{-,0} \to J/\psi\pi^- K^{0,+}$, and (b) $B^{-,0} \to \psi(2S)\pi^- K^{0,+}$; (c) and (d), the corresponding plots indicating the loci of the $K^*(892)$ and $K_2^*(1430)$ resonance bands defined in the text; regions A-E, as defined in the text, are indicated. The dashed vertical lines indicate the mass range $4.400 < m_{\psi\pi^-} < 4.460$ GeV/c^2.

In Fig. 7 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 signal function. The solid curves represent the fit results while the dashed curves show the $K\pi^-$ background. The BW parameters are free in the fits. Figures 7(a) and (d) are for the entire-data samples; Figures 7(b) and (e) are for the K^* regions (B plus D), and Figs 7(c) and (f) are for regions A, C, and E combined (the BELLE selection). For J/ψ samples, no evidence for any enhancements is obtained. For the $\psi(2S)$ data small

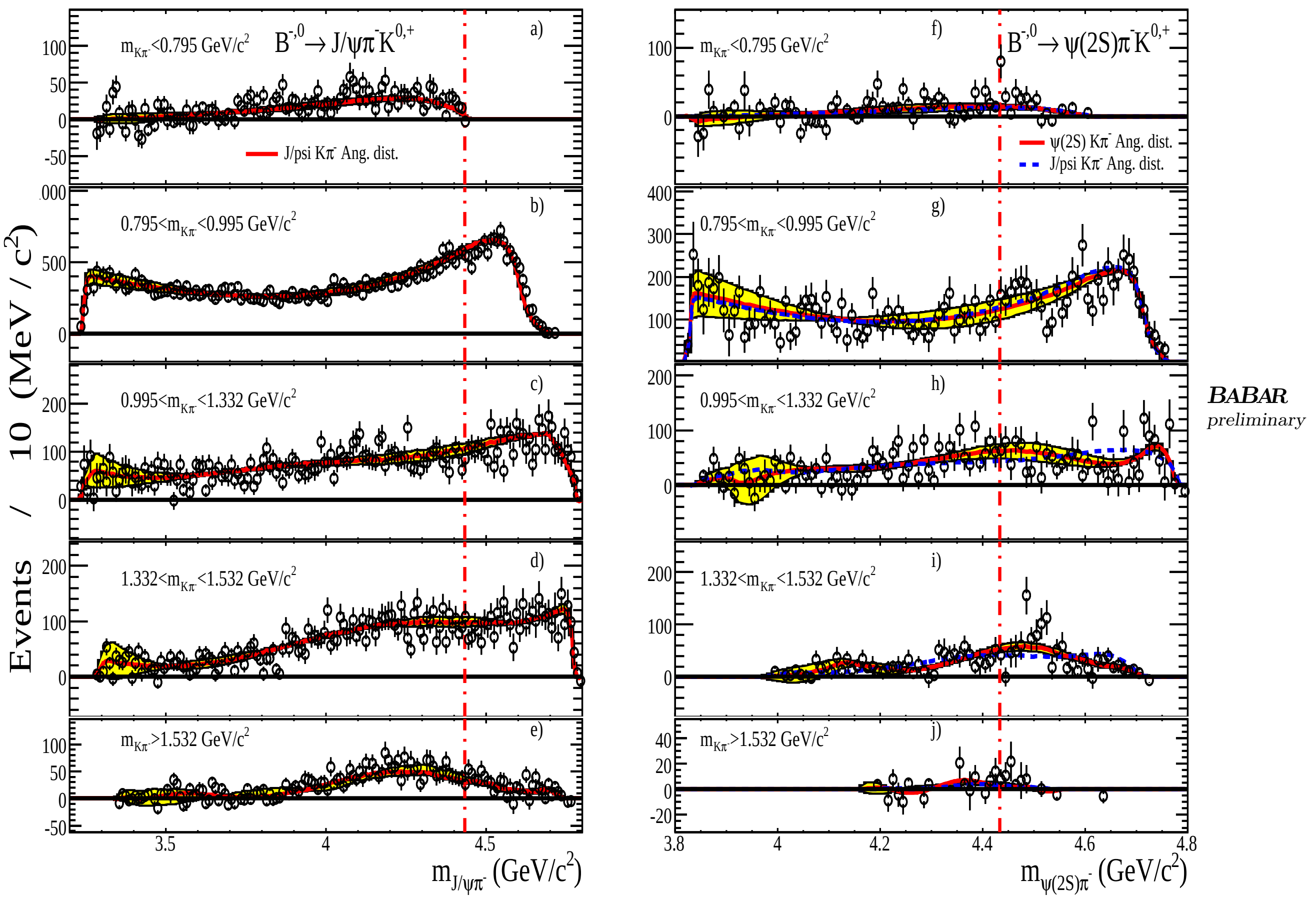

Figure 6: The $\psi\pi^-$ mass distributions in regions A-E of $K\pi^-$ mass for the combined decay modes (a-e) $B^{-,0} \to J/\psi\pi^- K^{0,+}$, and (f-j) $B^{-,0} \to \psi(2S)\pi^- K^{0,+}$; the solid curves and shaded bands are described in the text. In (f-j), the dot-dashed curves are obtained using $K\pi^-$ normalized moments for $B^{-,0} \to J/\psi\pi^- K^{0,+}$, instead of those from $B^{-,0} \to \psi(2S)\pi^- K^{0,+}$; the dashed vertical lines indicate $m_{\psi\pi^-} = 4.433$ GeV/c^2.

signals are obtained, but their significance is only in the $2-3\sigma$ range, and in Fig. 7(d) and (e) the fitted mass is significantly different from the BELLE value. In Fig. 7(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 $Z(4430)^-$.

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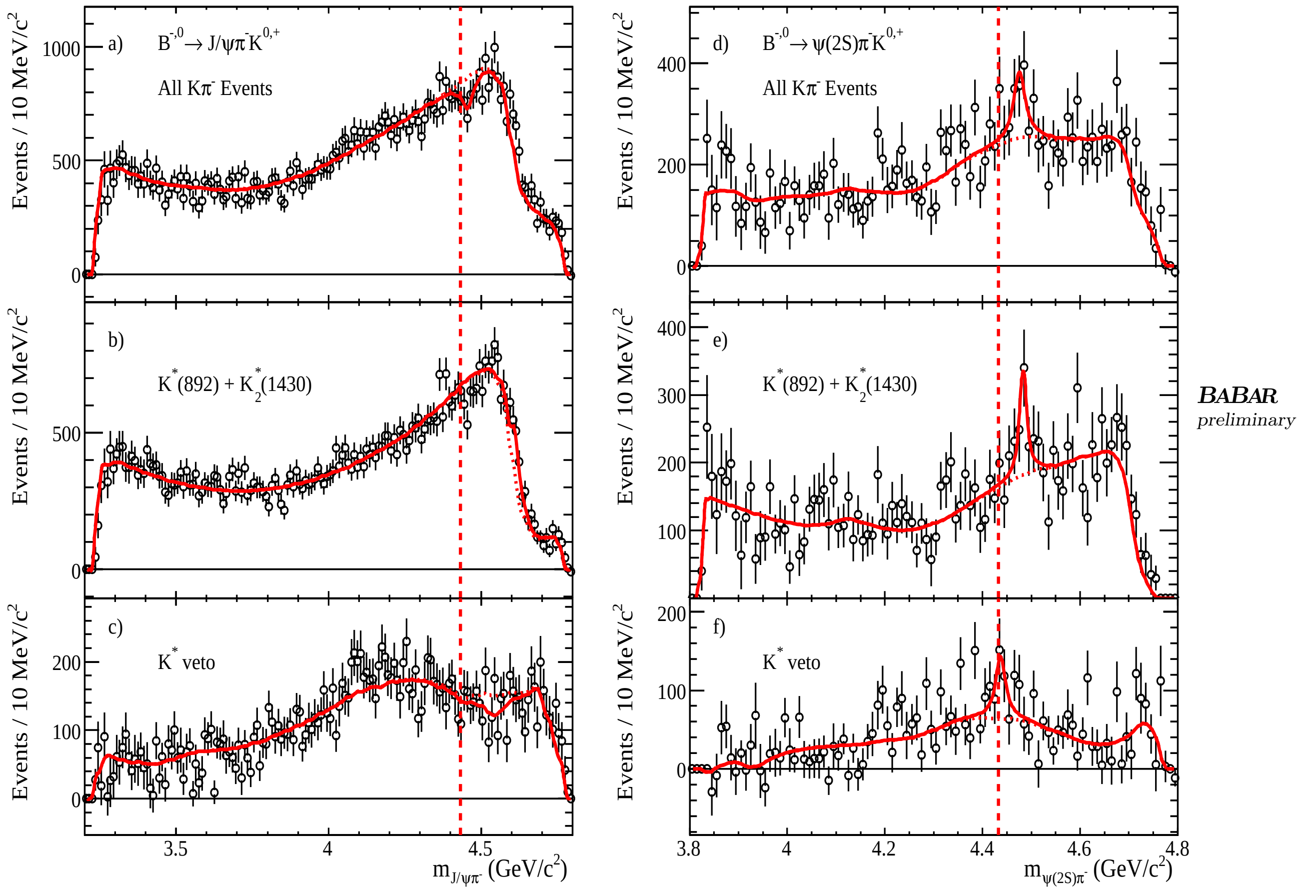

Figure 7: The results of the fits to the corrected mass distributions, (a)-(c) for $J/\psi\pi^-$, and (d)-(f) for $\psi(2S)\pi^-$. The curves are described in the text; the dashed vertical lines indicate $m_{\psi\pi^-} = 4.433$ GeV/c^2.

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