Charmonium and charmonium-like results from *BABAR*

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We present new results on charmonium and charmonium-like states from the *BABAR* experiment located at the PEP-II asymmetric energy e^+e^- storage ring at the SLAC National Accelerator Laboratory.

1 Study of the process $\gamma\gamma \to J/\psi\omega$

The charmonium-like state X(3915) was first observed by Belle [1] in two-photon fusion events decaying into $J/\psi\omega$. In addition, it was seen decaying into $J/\psi\omega$ in B decays by *BABAR* [2], along with the X(3872).
We study the process $\gamma\gamma \to J/\psi\omega$ at *BABAR* to search for the X(3915) and the X(3872) resonances via the decay to $J/\psi\omega$, using a data sample of 519 fb^{-1}. Figure 1 presents the reconstructed $J/\psi\omega$ invariant mass distribution after all the selection criteria have been applied. We perform an extended maximum likelihood fit to the efficiency-corrected spectrum. A large peak at near 3915 MeV/c^2 is observed with a significance of 7.6σ. The measured resonance parameters are $m[X(3915)] = (3919.4 \pm 2.2 \pm 1.6)$ MeV/c^2, $\Gamma[X(3915)] = (13 \pm 6 \pm 3)$ MeV. The measured value of the two-photon width times the branching fraction, $\Gamma_{\gamma\gamma}[X(3915)]$ x $\mathcal{B}(X(3915) \to J/\psi\omega)$ is $(52 \pm 10 \pm 3)$ eV and $(10.5 \pm 1.9 \pm 0.6)$ eV for two spin hypotheses $J = 0$ and $J = 2$, respectively, where the first error is statistical and the second is systematic. In addition, a Bayesian upper limit (UL) at 90% confidence level (CL) is obtained for the X(3872), $\Gamma_{\gamma\gamma}[X(3872)]$ x $\mathcal{B}(X(3872) \to J/\psi\omega) < 1.7$ eV, assuming J=2.

2 Study of the process $\gamma\gamma \to \eta_c\pi^+\pi^-$

This analysis has been studied for the first time and is performed to search for resonances decaying into $\eta_c\pi^+\pi^-$, using a data sample of 474 fb^{-1}. The η_c was reconstructed via its decay to $K^0_S K^+\pi^-$, with $K^0_S \to \pi^+\pi^-$. The signal yield for each X resonance is extracted from a two-dimensional fit to $m(K^0_S K^+\pi^-)$ and $m(K^0_S K^+\pi^-\pi^+\pi^-)$. Figure 2 presents the two dimensional fits around each of the resonances. No significant signal is observed in any of the fits. Table 1 summarizes these results. ULs are obtained on the branching fractions $\mathcal{B}(\eta_c(2S) \to \eta_c\pi^+\pi^-) < 7.4\%$ and $\mathcal{B}(\chi_{c2}(1P) \to \eta_c\pi^+\pi^-) < 2.2\%$ at 90% CL.

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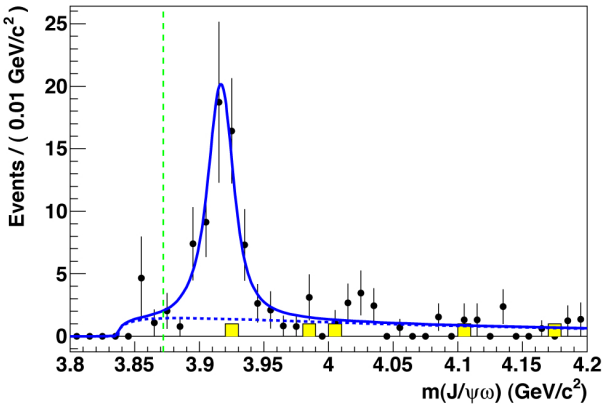

Figure 1: The efficiency-corrected invariant mass distribution for the $J/\psi\omega$ final state. The vertical dashed line is placed at the X(3872) mass.

Resonances	M_X (MeV/c^2)	Γ_X (MeV)	$\Gamma_{\gamma\gamma}\mathcal{B}$ (eV)	
			Central Value	UL
$\chi_{c2}(1P)$	3556.20±0.09	1.97±0.11	$7.2^{+5.5}_{-4.4} \pm 2.9$	15.7
$\eta_c(2S)$	3638.5±1.7	13.4±5.6	$65^{+47}_{-44} \pm 18$	133
$X(3872)$	3871.57±0.25	3.0±2.1	$-4.5^{+7.7}_{-6.7} \pm 2.9$	11.1
$X(3915)$	3915.0±3.6	17.0±10.4	$-13^{+12}_{-12} \pm 8$	16
$\chi_{c2}(2P)$	3927.2±2.6	24±6	$-16^{+15}_{-14} \pm 6$	19

Table 1: Results of the $\gamma\gamma \to \eta_c\pi^+\pi^-$ fits. For each resonance X, we show the peak mass and width used in the fit; the product of the two-photon partial width $\Gamma_{\gamma\gamma}$ and the $X \to \eta_c\pi\pi$ branching fraction, and the 90% CL upper limits on this product.

3 Search for the $Z_1(4050)^+$ and $Z_2(4250)^+$

Belle reported the observation of two resonance-like structures, $Z_1(4050)^+$ and $Z_2(4250)^+$ in the study of $\bar{B}^0 \to \chi_{c1}K^-\pi^+$, both decaying to $\chi_{c1}\pi^+$ [3].
BABAR studied the same final states [4] to search for the $Z_1(4050)^+$ and $Z_2(4250)^+$ decay into $\chi_{c1}\pi^+$ in $\bar{B}^0 \to \chi_{c1}K^-\pi^+$ and $B^+ \to K^0_S\chi_{c1}\pi^+$ where $\chi_{c1} \to J/\psi\gamma$, using a data sample of 429 fb^{-1}. The $\chi_{c1}\pi^+$ mass distribution, background-subtracted and efficiency-corrected, was modeled using the $K\pi$ mass distribution and the corresponding normalized $K\pi$ Legendre polynomial moments. Figure 3 shows the results of the fits done on the $\chi_{c1}\pi^+$ mass spectrum. The fit shown in Figure 3(a) includes both $Z_1(4050)^+$ and $Z_2(4250)^+$ resonances and the fit shown in Figure 3(b) includes a single broad $Z(4150)^+$ resonance. The Figures 3(c,d) show the $\chi_{c1}\pi$ mass spectrum fitted in the Dalitz plot region $1.0 \leq m^2(K\pi) < 1.75$ GeV^2/c^4 in order to make a direct comparison to the Belle results [3] (this region is labeled as "window" in Table 2). The results of the fits are summarized in Table 2 and in every case the yield significance does not exceed 2σ. The ULs on the 90% CL on the branching fractions are: $\mathcal{B}(\bar{B}^0 \to Z_1(4050)^+K^-)$ x $\mathcal{B}(Z_1(4050)^+ \to \chi_{c1}\pi^+) < 1.8$ x 10^{-5}; $\mathcal{B}(\bar{B}^0 \to Z_2(4250)^+K^-)$ x $\mathcal{B}(Z_2(4250)^+ \to \chi_{c1}\pi^+) <$ 4.0 x 10^{-5} and $\mathcal{B}(\bar{B}^0 \to Z^+K^-)$ x $\mathcal{B}(Z^+ \to \chi_{c1}\pi^+) < 4.7$ x 10^{-5}.

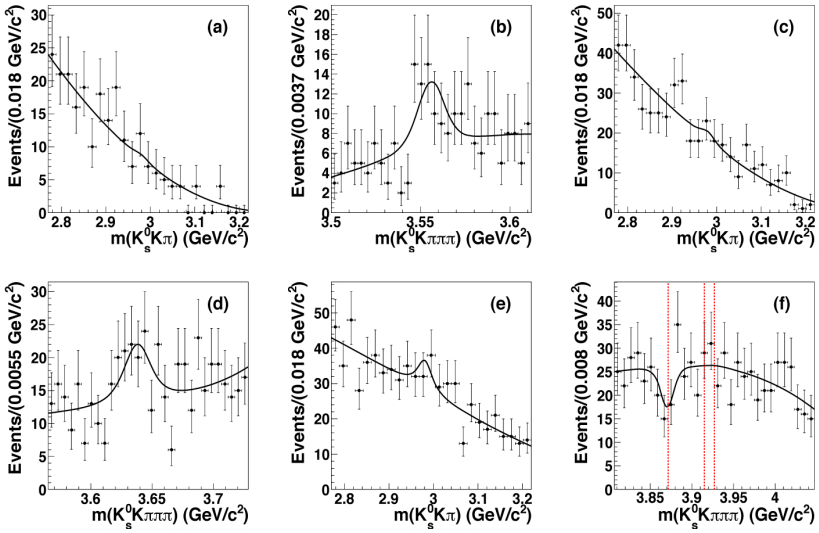

Figure 2: Distributions of (a,c,e) $m(K^0_S K^+\pi^-)$ and (b,d,f) $m(K^0_S K^+\pi^-\pi^+\pi^-)$ with the fit function overlaid for the fit regions of the (a,b) $\chi_{c2}(1P)$, (c,d) $\eta_c(2S)$, and (e,f) X(3872), X(3915) and $\chi_{c2}(2P)$. The vertical dashed lines in (f) indicates the peak mass positions of the X(3872), X(3915) and $\chi_{c2}(2P)$.

Data	Resonances	N_σ	Fraction (%)	χ^2/NDF
a) Total	$Z_1(4050)^+$	1.1	1.6±1.4	57/57
	$Z_2(4250)^+$	2.0	4.8±2.4	
b) Total	$Z(4150)^+$	1.1	4.0±3.8	61/58
a) Window	$Z_1(4050)^+$	1.2	3.5±3.0	53/46
	$Z_2(4250)^+$	1.3	6.7±5.1	
b) Window	$Z(4150)^+$	1.7	1.37±8.0	53/47

Table 2: Results of the $\chi_{c1}\pi$ fits. N_σ and Fraction give, for each fit, the significance and the fractional contribution of the Z resonances.

4 Study of the $J/\psi\pi^+\pi^-$ via Initial State Radiation (ISR)

The Y(4260) charmonium-like resonance was discovered by *BABAR* [5] in ISR production of $J/\psi\pi^+\pi^-$. A subsequent Belle analysis [6] of the same final state suggested also the existence of an additional resonance around 4.1 GeV/c^2 that they dubbed the Y(4008).
This analysis [7] is performed to study the reaction $J/\psi\pi^+\pi^-$ in ISR using a data sample of 454 fb^{-1}.
The $J/\psi\pi^+\pi^-$ mass region below ∼4 GeV/c^2 is investigated for the first time. In that region an excess of events has been observed and the conclusion, after a detailed study of the $\psi(2S)$ lineshape (to estimate the $\psi(2S)$ tail contribution to that region), is that it is not possible to discount the possibilty of a contribution from a $J/\psi\pi^+\pi^-$ continuum cross section in this region. From this study we obtain the cross section value 14.05 ± 0.26 (stat) pb for radiative return to the $\psi(2S)$ and the measurement of the width $\Gamma(\psi(2S)\to e^+e^-) = 2.31\pm0.05$ (stat) keV. Figure

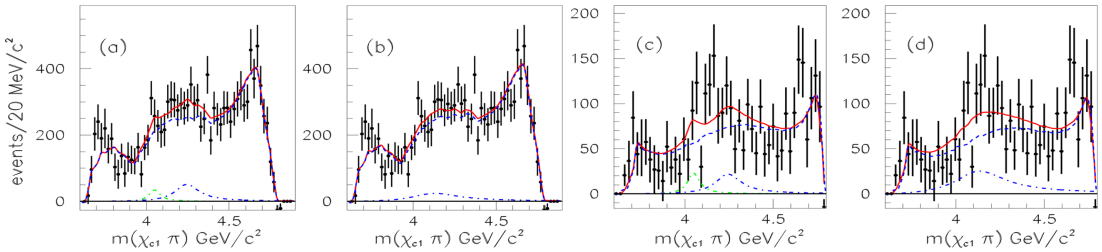

Figure 3: Fit on the background-subtracted and efficiency-corrected $\chi_{c1}\pi$ mass distribution. See text for more details.

4(a) shows the fit to the $J/\psi\pi^+\pi^-$ distribution. A clear signal of the Y(4260) is observed for which the values obtained are $m[Y(4260)] = 4244 \pm 5 \pm 4$ MeV/c^2, $\Gamma[Y(4260)] = 114^{+16}_{-15} \pm 7$ MeV and Γ_{ee} x $\mathcal{B}(J/\psi\pi^+\pi^-) = 9.2 \pm 0.8$ (stat) $\pm$ 0.7 (syst) eV. No evidence for the state at $\sim$ 4 GeV/c^2 reported by Belle [6] was seen. A study of the $\pi^+\pi^-$ system from the Y(4260) decay to $J/\psi\pi^+\pi^-$ is done. The dipion system is in a predominantly S-wave state. The mass distribution exhibits an $f_0(980)$ signal, for which a simple model indicates a branching ratio with respect to $J/\psi\pi^+\pi^-$ of 0.17 ± 0.13 (stat). The fit to the dipion invariant mass distribution is shown in Figure 4(b).

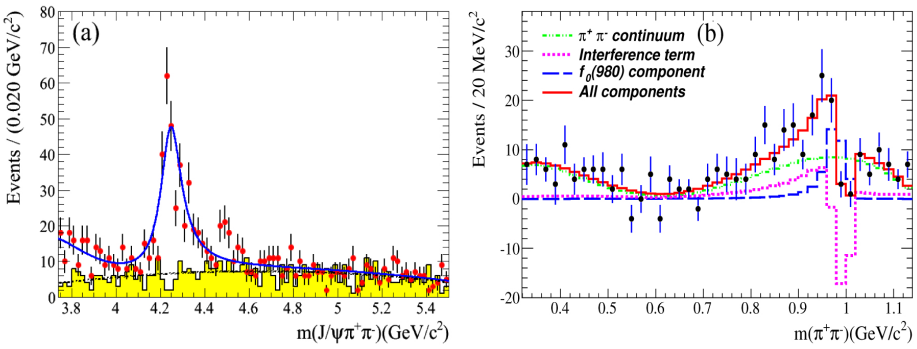

Figure 4: Figure (a) shows the fit to the $J/\psi\pi^+\pi^-$ invariant mass distribution. The Figure (b) shows the fit to the dipion invariant mass distribution.

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