

# Charmonium and charmonium-like results from *BABAR*

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DOI: <http://dx.doi.org/10.3204/DESY-PROC-2012-02/195>

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 $\gamma\gamma \rightarrow J/\psi\omega$

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  $\gamma\gamma \rightarrow J/\psi\omega$  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<sup>-1</sup>. 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<sup>2</sup> is observed with a significance of 7.6 $\sigma$ . The measured resonance parameters are  $m[X(3915)] = (3919.4 \pm 2.2 \pm 1.6)$  MeV/c<sup>2</sup>,  $\Gamma[X(3915)] = (13 \pm 6 \pm 3)$  MeV. The measured value of the two-photon width times the branching fraction,  $\Gamma_{\gamma\gamma}[X(3915)] \times \mathcal{B}(X(3915) \rightarrow J/\psi\omega)$  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),  $\Gamma_{\gamma\gamma}[X(3872)] \times \mathcal{B}(X(3872) \rightarrow J/\psi\omega) < 1.7$  eV, assuming  $J=2$ .

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

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<sup>-1</sup>. The  $\eta_c$  was reconstructed via its decay to  $K_S^0 K^+ \pi^-$ , with  $K_S^0 \rightarrow \pi^+ \pi^-$ . The signal yield for each X resonance is extracted from a two-dimensional fit to  $m(K_S^0 K^+ \pi^-)$  and  $m(K_S^0 K^+ \pi^- \pi^+ \pi^-)$ . 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  $\mathcal{B}(\eta_c(2S) \rightarrow \eta_c\pi^+\pi^-) < 7.4\%$  and  $\mathcal{B}(\chi_{c2}(1P) \rightarrow \eta_c\pi^+\pi^-) < 2.2\%$  at 90% CL.

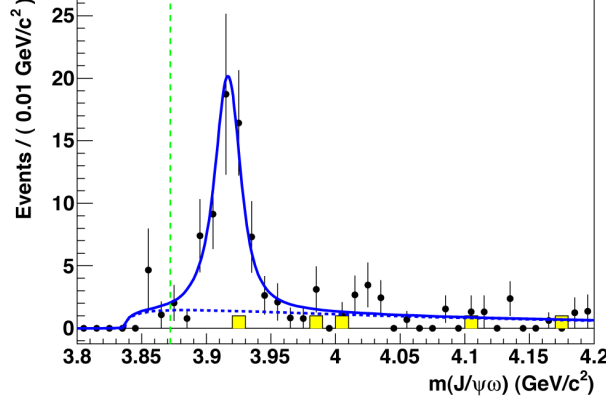


Figure 1: The efficiency-corrected invariant mass distribution for the  $J/\psi\omega$  final state. The vertical dashed line is placed at the  $X(3872)$  mass.

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

Table 1: Results of the  $\gamma\gamma \rightarrow \eta_c\pi^+\pi^-$  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  $X \rightarrow \eta_c\pi\pi$  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  $\bar{B}^0 \rightarrow \chi_{c1}K^-\pi^+$ , 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  $\bar{B}^0 \rightarrow \chi_{c1}K^-\pi^+$  and  $B^+ \rightarrow K_S^0\chi_{c1}\pi^+$  where  $\chi_{c1} \rightarrow J/\psi\gamma$ , using a data sample of 429 fb<sup>-1</sup>. 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<sup>2</sup>/c<sup>4</sup> 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  $2\sigma$ . The ULs on the 90% CL on the branching fractions are:  $\mathcal{B}(\bar{B}^0 \rightarrow Z_1(4050)^+K^-) \times \mathcal{B}(Z_1(4050)^+ \rightarrow \chi_{c1}\pi^+) < 1.8 \times 10^{-5}$ ;  $\mathcal{B}(\bar{B}^0 \rightarrow Z_2(4250)^+K^-) \times \mathcal{B}(Z_2(4250)^+ \rightarrow \chi_{c1}\pi^+) < 4.0 \times 10^{-5}$  and  $\mathcal{B}(\bar{B}^0 \rightarrow Z^+K^-) \times \mathcal{B}(Z^+ \rightarrow \chi_{c1}\pi^+) < 4.7 \times 10^{-5}$ .

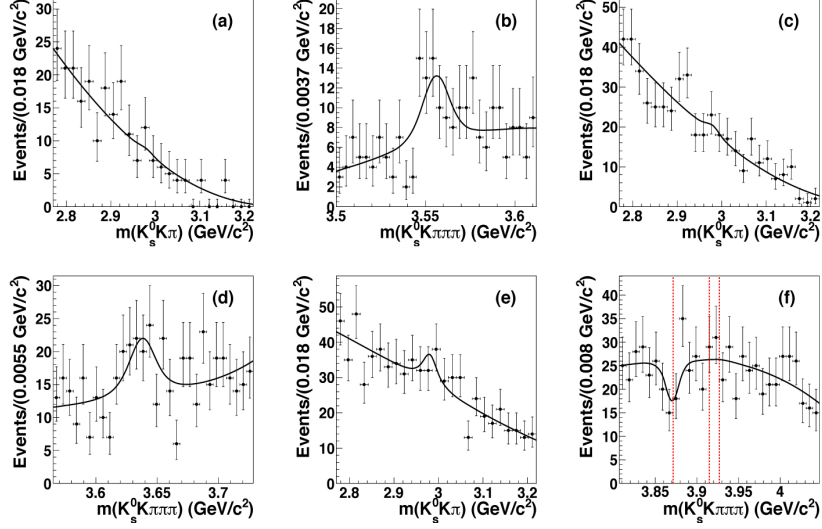


Figure 2: Distributions of (a,c,e)  $m(K_S^0 K^+ \pi^-)$  and (b,d,f)  $m(K_S^0 K^+ \pi^- \pi^+ \pi^-)$  with the fit function overlaid for the fit regions of the (a,b)  $\chi_{c2}(1P)$ , (c,d)  $\eta_c(2S)$ , and (e,f) X(3872), X(3915) and  $\chi_{c2}(2P)$ . The vertical dashed lines in (f) indicates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

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

Table 2: Results of the  $\chi_{c1}\pi$  fits.  $N_\sigma$  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<sup>2</sup> 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<sup>-1</sup>.

The  $J/\psi\pi^+\pi^-$  mass region below  $\sim 4$  GeV/c<sup>2</sup> 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 possibility of a contribution from a  $J/\psi\pi^+\pi^-$  continuum cross section in this region. From this study we obtain the cross section value  $14.05 \pm 0.26$  (stat) pb for radiative return to the  $\psi(2S)$  and the measurement of the width  $\Gamma(\psi(2S) \rightarrow e^+e^-) = 2.31 \pm 0.05$  (stat) keV. Figure

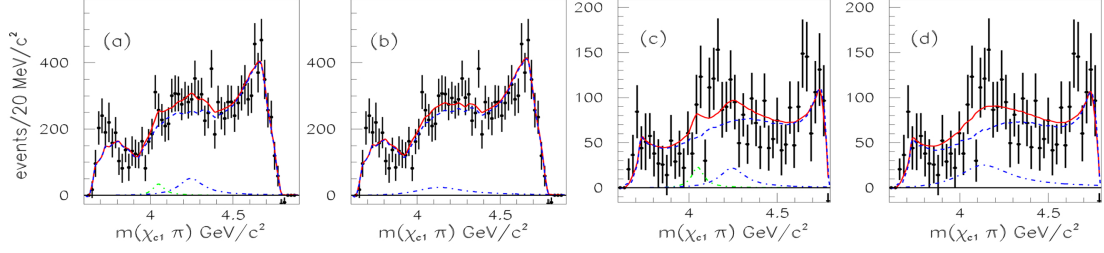


Figure 3: Fit on the background-subtracted and efficiency-corrected  $\chi_{c1}\pi$  mass distribution. See text for more details.

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  $m[Y(4260)] = 4244 \pm 5 \pm 4 \text{ MeV}/c^2$ ,  $\Gamma[Y(4260)] = 114^{+16}_{-15} \pm 7 \text{ MeV}$  and  $\Gamma_{ee} \times \mathcal{B}(J/\psi\pi^+\pi^-) = 9.2 \pm 0.8 \text{ (stat)} \pm 0.7 \text{ (syst)} \text{ eV}$ . No evidence for the state at  $\sim 4 \text{ GeV}/c^2$  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  $0.17 \pm 0.13 \text{ (stat)}$ . The fit to the dipion invariant mass distribution is shown in Figure 4(b).

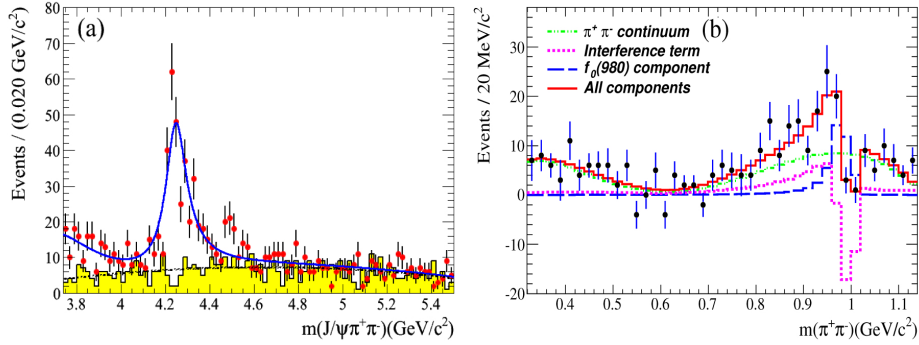


Figure 4: Figure (a) shows the fit to the  $J/\psi\pi^+\pi^-$  invariant mass distribution. The Figure (b) shows the fit to the dipion invariant mass distribution.

## References

- [1] S. Uehara *et al.* (Belle Collaboration), Phys. Rev. Lett. **104**, 092001 (2010).
- [2] P. del Amo Sanchez *et al.* (BABAR Collaboration), Phys. Rev. D. **82**, 011101(R) (2010).
- [3] R. Mizuk *et al.* (Belle Collaboration), Phys. Rev. D **78**, 072004 (2008).
- [4] J. P. Lees *et al.* (BABAR Collaboration), Phys. Rev. D **85**, 052003 (2012).
- [5] B. Aubert *et al.* (BABAR Collaboration), Phys. Rev. Lett. **95**, 142001 (2005).
- [6] C. Z. Yuan *et al.* (Belle Collaboration), Phys. Rev. Lett. **99**, 182004 (2007).
- [7] BABAR Collaboration, hep-ex/1204.2158v1