SLAC-PUB-14688

Quarkonium spectroscopy and search for new states at BaBar

Gianluigi Cibinetto - on behalf of the BaBar Collaboration

Via Saragat 1, 44100, Ferrara, Italy

E-mail: `cibinett@fe.infn.it`

Abstract. The BaBar experiment at the PEP-II B-factory gives excellent opportunities for the quarkonium spectroscopy. Investigation of the properties of new states like the $X(3872)$, $Y(3940)$ and $Y(4260)$ are performed aiming to understand their nature. Recent BaBar results will be presented in this paper.

1. Introduction

At the B-factories charmonium and charmonium-like states are copiously produced via several mechanisms: in B decay (color suppressed $b \to c$ transition), double charmonium production ($e^+e^- \to c\overline{c} + c\overline{c}$), two photons production ($\gamma^*\gamma^* \to c\overline{c}$, where the $c\overline{c}$ state has positive C-parity) and in initial state radiation (ISR) when the $e^{\pm}$ in its initial state emits a photon lowering the effective center of mass energy of the e^+e^- interaction ($e^+e^- \to \gamma_{ISR} + c\overline{c}$, where the charmonium state has the quantum numbers $J^{PC} = 1^{--}$)

Many new states have been recently discovered at the B-factories, BaBar and Belle, above the $D\overline{D}$ threshold in the charmonium energy region. While some of them appear to be consistent with conventional $c\overline{c}$ states others do not fit with any expectation. Several interpretations for these states have been proposed: for some of them the mass values suggest that they could be conventional charmonia, but also other interpretations like $D^0\overline{D}^{*0}$ molecule or diquark-antidiquark states among many other models have been advanced. Reviews can be found in Refs. [1][2]. In all cases the picture is not completely clear.

This situation could be remedied by a coherent search of the decay pattern to $D\overline{D}$, search for production in two-photon fusion and ISR, and of course improving the statistical precision upon the current measurements. The BaBar experiment at the PEP-II asymmetric collider, designed to perform precision measurement of CP violation in the B meson system, has an extensive quarkonium spectroscopy program. Recent BaBar outcomes on the $X(3872)$ and $Y(4260)$ and a new result on the $Y(3940)$ are reported here.

2. The X(3872) state

The $X(3872)$ is the first of the new charmonium-like states observed at the B factories starting a cascade of new discoveries which are reviving the spectroscopy. The $X(3872)$ has been discovered by Belle [3] in B decays and confirmed by BaBar [4], and in hadronic production by CDF [5] and D0 [6]. It's a narrow state (the width is below detector resolution), first observed in $J/\psi\pi^+\pi^-$ final state with a mass of 3872 MeV (very close to the $D^0\overline{D}^{0*}$ threshold).

Work supported in part by US Department of Energy contract DE-AC02-76SF00515.

SLAC National Accelerator Laboratory, Menlo Park, CA 94025

The decays $B^- \to K^- J/\psi\pi^+\pi^-$ and $B^0 \to K^0_s J/\psi\pi^+\pi^-$ have been studied by BaBar with a sample of 232 millions of $B\overline{B}$ pairs (211 fb^{-1}) obtaining respectively 61 ± 15 and 8.3 ± 4.5 $X(3872)$ events with a significance of 6.1σ and 2.5σ [7]. The results include the 90% confidence interval $1.34 \times 10^{-6} < \mathcal{B}(B^0 \to X(3872)K^0, X \to J/\psi\pi^+\pi^-) < 10.3 \times 10^{-6}$ and the branching fraction $\mathcal{B}(B^- \to X(3872)K^-, X \to J/\psi\pi^+\pi^-) = (10.1 \pm 2.5 \pm 1.0) \times 10^{-6}$.

No signal at this mass was seen by BaBar in $B \to X^- K, X^- \to J/\psi\pi^0\pi^-$ [8], which would have implied a charged partner of the $X(3872)$.

In a study of $B^+ \to J/\psi\gamma K^+$ decays, BaBar found evidence for the radiative decay $X(3872) \to J/\psi\gamma$ with a statistical significance of 3.4σ [9]. We measure the product of branching fractions $\mathcal{B}(B^+ \to X(3872)K^+) \times \mathcal{B}(X(3872) \to J/\psi\gamma) = (3.3 \pm 1.0 \pm 0.3) \times 10^{-6}$, where the uncertainties are statistical and systematic, respectively. This provides evidence of the radiative decay $X(3872) \to J/\psi\gamma$ and of charge parity C = + for the $X(3872)$ state.

Recently, Belle showed an excess of events in the $\overline{D}^0 D^0 \pi^0$ invariant mass in the channel $B \to \overline{D}^0 D^0 \pi^0 K$, with a mass of $3875.4 \pm 0.7^{+0.3}_{-1.6} \pm 0.8$ MeV/c^2 [10]. The observed invariant mass is 2σ higher than the world average value of the $X(3872)$ resonance. We have searched for resonances in exclusive decays $B^0/\overline{B^0}$, $B^\pm$ to $\overline{D}^{(*)} D^{(*)} K^\pm$ and $B^0/\overline{B^0}$, $B^\pm$ to $\overline{D}^{(*)} D^{(*)} K^0_S$. Fitting all the 8 final states together we obtain a central value for the mass of $3875.4^{+1.2}_{-2.0} \pm 0.7$ MeV/c^2 which is 2.5σ higher than the world average of the $X(3872)$ state but in good agreement with the Belle's result. An angular distribution analysis by the Belle collaboration favors for the $X(3872)$ $J^{PC} = 1^{++}$ [11]. The mass value and the fact that the $B^\pm \to K^\pm c\overline{c}$ is a typical decay mode of the B meson, suggest the possible charmonium nature of the state. However, its mass is not compatible with any of the existing predictions from the potential model and its likely $J/\psi\rho^0$ decay mode would be forbidden for a charmonium state because of isospin symmetry. More experimental results are needed to discriminate among the different models.

3. The Y(3940)

The $Y(3940)$, discovered by the Belle Collaboration [12] in the decay process $B \to K J/\psi\omega(\omega \to \pi^+\pi^-\pi^0)$, with mass $3943 \pm 11 \pm 13$ MeV/c^2 and a large width, $87 \pm 22 \pm 26$ MeV, appears to be a puzzle, unexpected and unexplained by $q\overline{q}$ quark models of mesons. The mass and width values suggest a radially excited P wave $c\overline{c}$ state. However decay to $J/\psi\omega$ is not readily explained for mass above open-charm threshold [13]. Unconventional explanations for the $Y(3940)$ include hybrid charmonium-gluon bound states, $c\overline{c}g$ [14], charmonium light quark molecules, $c\overline{c}(u\overline{u}+d\overline{d})$ [15], or multi-quark states [16].

We report here a new BaBar results of a study of the decays $B^+ \to J/\psi\omega K^+$ and $B^0 \to J/\psi\omega K^0_S$ using 383 millions $B\overline{B}$ events. Fig. 1 shows the $J/\psi\omega$ mass distribution obtained for B^+ (a) and B^0 (b) decay. Our observation leads to a lower mass and a smaller width than reported in Belle's analysis, we obtain: $M_Y = 3914.3^{+3.8}_{-3.4}(stat) \pm 1.6(syst)$ MeV/c^2 and $\Gamma_Y = 33^{+12}_{-8}(stat) \pm 0.6(syst)$ MeV.

4. The ISR $J/\psi\pi\pi$

Among the new charmonium-like states, the $Y(4260)$ is probably the most intriguing. Its discovery was reported by BaBar in the $J/\psi\pi\pi$ subsystem in the radiative return reaction $e^+e^- \to \gamma_{ISR}\ J/\psi\pi\pi$ [17]. Using 233 fb^{-1} of data, a broad enhancement has been observed at 4260 MeV/c^2, an unbinned fit with a Breit-Wigner signal function and a second order polynomial background yields 125 ± 23 $Y(4260) \to J/\psi\pi^+\pi^-$ events, with a mass $M_Y = 4259 \pm 8(stat)^{+2}_{-6}(syst)$ MeV/c^2 and a width $\Gamma_Y = 88 \pm 23(stat)^{+6}_{-4}(syst)$ MeV.

BaBar searched for the $Y(4260)$ in $e^+e^- \to \gamma_{ISR}\ p\overline{p}$ events. No signal has been found so it's possible to set the upper limit $\mathcal{B}(Y(4260) \to p\overline{p})/\mathcal{B}(Y(4260) \to J/\psi\pi^+\pi^-) < 13\%$ at 90% C.L. [18]. Looking for the $Y(4260)$ in the radiative return process $e^+e^- \to \gamma_{ISR}\ \psi(2S)\pi^+\pi^-$, where

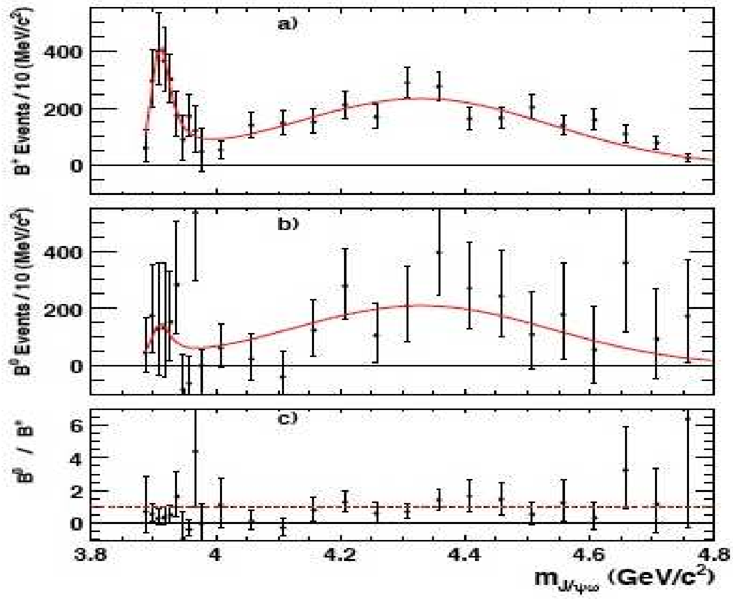

Figure 1. The $J/\psi\omega$ mass distribution for (a) B^+ and (b) B^0 decay. The solid curves result from the fit. (c) The B^0/B^+ ratio; the dashed line corresponds to isospin conservation.

$\psi(2S) \to J/\psi\pi^+\pi^-$, BaBar observed a broad structure near 4.32 GeV, that is not consistent with the $\psi(4415) \to J/\psi\pi^+\pi^-$. A fit to the mass spectrum with a single resonance yields a mass of 4324 ± 23 MeV/c^2 and a width of 172 ± 33 MeV (where the errors are statistical only). This structure has a mass that differs somewhat from the reported for the $Y(4260)$, however, the possibility that it represents evidence for a new decay mode for the $Y(4260)$ cannot be ruled out at this time.

The $Y(4260)$ therefore represents an overpopulation of the expected 1^{--} states in the mass region above the $D\overline{D}$ threshold. The absence of open charm production also argues against it being a conventional $c\bar{c}$ state. The observation of other decay modes may help in understanding the nature of this state.

References

[1] E. Swanson, *Conf. on the Intersections of Particle and Nuclear Physics (CIPANP 2006*, AIP Conf. Proc. **870**.
[2] S. Godfrey, *Proceedings of 4^{th} Int. Conf. of Flavor Physics and CP Violation 06*, eConf **C060409**, 221(2006).
[3] S. K. Choi *et al.* [Belle Collaboration], Phys. Rev. Lett. **91**, 262001 (2003).
[4] B. Aubert *et al.* [BaBar Collaboration], Phys. Rev. D **71**, 071103 (2005).
[5] D. Acosta *et al.* [CDF II Collaboration], Phys. Rev. Lett. **93**, 072001 (2004).
[6] V. M. Abazov *et al.* [D0 Collaboration], Phys. Rev. Lett. **93**, 162002 (2004).
[7] B. Aubert *et al.* [BaBar Collaboration], Phys. Rev. D **73**, 011101 (2006).
[8] B. Aubert *et al.* [BaBar Collaboration], Phys. Rev. D **71**, 031501 (2005).
[9] B. Aubert *et al.* [BaBar Collaboration], Phys. Rev. D **74**, 071101 (2006).
[10] Belle Collaboration, Phys. Rev. Lett. **97**, 162002 (2006).
[11] K. Abe *et al.* [Belle Collaboration], arXiv:hep-ex/0505038, paper no. LP-2005-176.
[12] K. Abe *et al.* [Belle Collaboration], Phys. Rev. Lett. **94**, 182002 (2005).
[13] E. Eichten *et al.* (hep-ph/0701208), (2007).
[14] F. E. Close and P. R. Page, Phys. Lett. B**628**, 215 (2005).
[15] N. A. Tornqvist, Phys. Lett. B**590**, 209 (2004).
[16] L. Maiani et al., Phys. Rev. D**71**, 014028 (2005).
[17] B. Aubert *et al.* [BaBar Collaboration], Phys. Rev. Lett. **95**, 142001 (2005).
[18] B. Aubert *et al.* [BaBar Collaboration], Phys. Rev. D **73**, 012005 (2006).