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Charm and charmonium spectroscopy in BaBar

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The BaBar experiment at the PEP-II B-factory offers excellent opportunities in charm and charmonium spectroscopy. The recent observation of new states in the D_s and in the charmonium mass regions revived the interest in this field. Recent BaBar results are presented.

1. INTRODUCTION

The D_s ($c\bar{s}$ bound states) and charmonium ($c\bar{c}$ bound states) mass spectra were reasonably well described by potential models up to recent years, when several new states that have been observed at the B-factories did not match the theoretical expectations. Several interpretations for these states exist in the literature [1]. More experimental results are needed in order to test the theoretical predictions and discriminate between the models.

The BaBar experiment [2] is located at the PEP-II B-factory, an asymmetric e^+e^- collider with center of mass energy in the region of the mass of the $Y(4S)$ resonance. It is designed to perform precision measurements of CP violation in the B meson system but has a much broader physics reach and an extensive program of meson spectroscopy. In the following we will present some recent BaBar result about the spectroscopy of these new states.

2. D_s SPECTROSCOPY

Two narrow states were recently discovered in the decays $D^*_{sJ}(2317)^+ \rightarrow D_s^+\pi^0$ [3] and $D_{sJ}(2460)^+ \rightarrow D_s^{*+}\pi^0$ [4] by BaBar and CLEO, respectively. Their masses are considerably lower than the potential models predictions for D_s states and the $D_s^{(*)+}\pi^0$ decay is isospin violating. For this reason, other interpretations like tetraquark or molecular states have been suggested.

A detailed study of the $D^*_{sJ}(2317)^+$ and the $D_{sJ}(2460)^+$ has been performed by BaBar, using a data sample corresponding to 232 fb^{-1} of integrated luminosity [5]. The decay modes considered in the analysis are: $D_s^+\pi^0$, $D_s^+\gamma$, $D_s^+\pi^0\gamma$, $D_s^+\pi^0\pi^0$, $D_s^+\gamma\gamma$, and $D_s^+\pi^+\pi^-$. The results for the mass and width measurements are summarized in Table 1, together with the observed decay modes.

2.1. Inclusive D_s production in two body B decays

An inclusive study of the $D_{(s)}$ mesons has been performed in $B \rightarrow D_{meas}D_X$, where D_{meas} is a fully reconstructed $D^{(*)}_{(s)}$ meson. D_X is not reconstructed and its mass is inferred from the mass recoiling against the $D_{(s)}$ [6]. This technique allows the observation of D_X states independently of their decay mode and the measurement of the branching fractions products $\mathcal{B}(B \rightarrow D_{meas}D_X) \times \mathcal{B}(D_{meas} \rightarrow f)$, where f is the decay mode in which the D_{meas} is reconstructed, which does not depend on any D_X branching fraction.

Production of the $D_{sJ}(2460)^+$ meson is clearly observed. Combining the results of this study with previous exclusive measurements, it is possible to obtain:

$$\mathcal{B}(D_{sJ}(2460)^+ \rightarrow D_s^*(2112)^+\pi^0) = 0.56 \pm 0.16, \quad (1)$$
$$\mathcal{B}(D_{sJ}(2460)^+ \rightarrow D_s^+\gamma) = 0.16 \pm 0.05, \quad (2)$$
$$\mathcal{B}(D_{sJ}(2460)^+ \rightarrow D_s^+\pi^+\pi^-) = 0.04 \pm 0.01, \quad (3)$$

determining that the $D_{sJ}(2460)^+$ meson decays mainly ($76 \pm 17\%$) into final states containing a $D_s^{(*)+}$.

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Table 1
Summary of $D_{sJ}^{*}(2317)^{+}$, $D_{sJ}(2460)^{+}$, and $D_{s1}(2536)^{+}$ mass (m) and width (Γ) measurements and observed decay modes.

Particle	m (MeV/c^2)	Γ (MeV)	Decay modes
$D_{sJ}^{*}(2317)^{+}$	$2319.6 \pm 0.2 \pm 1.4$	< 3.8 (95 %CL)	$D_s^+\pi^0$
$D_{sJ}(2460)^{+}$	$2460.1 \pm 0.2 \pm 0.8$	< 3.5 (95 %CL)	$D_s^+\gamma$, $D_s^+\pi^0\gamma$, $D_s^+\pi^+\pi^-$
$D_{s1}(2536)^{+}$	$2534.6 \pm 0.3 \pm 0.7$	< 2.5 (95 %CL)	$D_s^+\pi^+\pi^-$

2.2. Observation of the $D_{sJ}(2860)^{+}$

A new state has been recently observed in the D^0K^+ and D^+K_s decays by BaBar in the analysis of 240 fb^{-1} of data [7]. Three inclusive processes are reconstructed:

$$e^+e^- \to D^0K^+X\ (D^0 \to K^-\pi^+), \quad (4)$$
$$e^+e^- \to D^0K^+X\ (D^0 \to K^-\pi^+\pi^0), \quad (5)$$
$$e^+e^- \to D^+K_sX\ (D^+ \to K^-\pi^+\pi^+). \quad (6)$$

The charged tracks are required to originate from a common vertex located in the e^+e^- interaction region and the momentum in the e^+e^- center of mass system of the DK candidate is required to be larger than 3.5 GeV/c to reduce background from continuum and B meson decays.

All the three channels show an enhancement in the DK mass distribution around 2.86 GeV/c^2, as shown in Figure 1. The background has been parameterized with a threshold function, $(m - m_{th})^{\alpha}e^{-\beta m-\gamma m^2-\delta m^3}$, where $m_{th} = m_D + m_K$, which provides a good description of the Monte Carlo background distribution, while for resonant peaks relativistic Breit-Wigner are used. A simultaneous fit of the three mass spectra distributions yields a mass and a width of the new state:

$$m(D_{sJ}(2860)^+) = 2856.6 \pm 1.5 \pm 5.0\text{MeV}/c^2, \quad (7)$$
$$\Gamma(D_{sJ}(2860)^+) = 48 \pm 7 \pm 10\text{MeV}/c^2. \quad (8)$$

The threshold function itself does not provide a good background description for the data; an additional broad structure centered around 2.7 GeV/c^2 is needed. If a Breit-Wigner function is assumed, the additional structure corresponds to a mass $m(X(2690)^+) = 2688 \pm 4 \pm 2$ MeV/c^2 and a width $\Gamma(X(2690)^+) = 112 \pm 7 \pm 36$ MeV/c^2.

3. CHARMONIUM SPECTROSCOPY

Several states have been recently discovered at the B-factories. Among them, the $X(3872)$ and $Y(4260)$ have been observed by more than one experiment and show properties that are not expected for conventional charmonia.

The $X(3872)$, have been discovered by the Belle collaboration in the decay $B^{\pm} \to K^{\pm}J/\psi\pi^+\pi^-$. A narrow signal in the $J/\psi\pi^+\pi^-$ invariant mass is observed at 3872 MeV/c^2 [8]. The observation was then confirmed by CDF [9], D0 [10] and BaBar [11].

The $Y(4260)$ was discovered by BaBar in initial state radiation (ISR) events [12], where a photon (γ_{ISR}) is emitted by the $e^{\pm}$ in the initial state, by studying the process $e^+e^- \to \gamma_{ISR}J/\psi\pi^+\pi^-$. The structure has been recently confirmed by CLEO-III (also in ISR production) [13] and by CLEO-c (through e^+e^- energy scan), with the additional observation of the $J/\psi\pi^0\pi^0$ decay [14].

3.1. Study of $X(3872) \to J/\psi\gamma$

An analysis of the decay $B^+ \to J/\psi\gamma K^+$ has been performed by BaBar using 260 fb^{-1} of data taken at the $Y(4S)$ [15]. The $J/\psi\gamma$ invariant mass distribution is shown in Figure 2, where 19.2 ± 5.7 events correspond to $X(3872)$ production. We obtain the product of the branching ratios $\mathcal{B}(B^+ \to X(3872)K^+) \times \mathcal{B}(X(3872) \to J/\psi\gamma) = (3.4 \pm 1.0 \pm 0.3) \times 10^{-6}$, with a statistical significance of 3.4 σ, confirming a previous result by Belle [16].

The observation of the $X(3872) \to J/\psi\gamma$ decay implies even C-parity and isospin $I = 1$ for the dipion in the $J/\psi\pi^+\pi^-$ decay. $X(3872)$ decays to $J/\psi\pi^0\pi^0$, $J/\psi\pi^0$, and $J/\psi\eta$ are therefore expected to be forbidden.

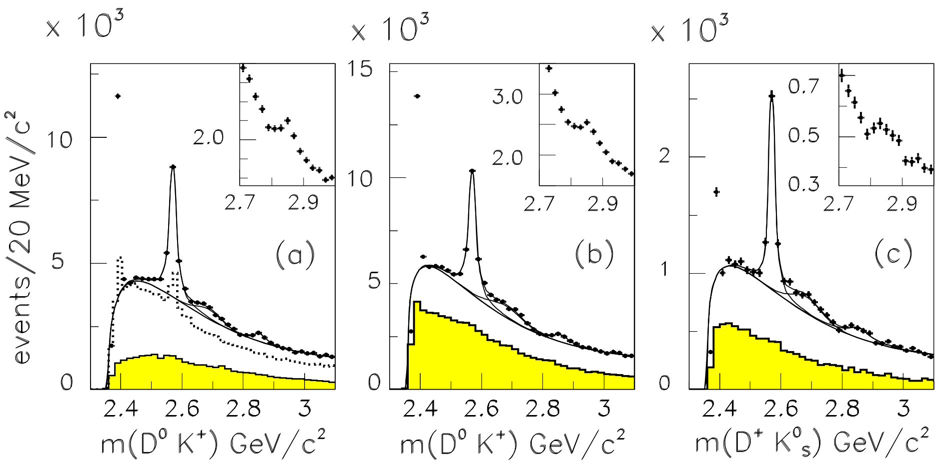

Figure 1. Invariant mass distribution for the DK candidate for (a) D^0K^+ ($D^0 \to K^+\pi^-$), (b) D^0K^+ ($D^0 \to K^+\pi^-\pi^0$), and (c) D^+K_s ($D^+ \to K^-\pi^+\pi^+$) for the D signal (points) and D side-band (shaded) regions. The result of the fit, as described in the text, is represented as a solid line. The dotted histogram in (a) is the DK mass distribution obtained from Monte Carlo simulation, containing all the previously known charm states.

3.2. Inclusive charmonia production in two body B decays

The inclusive study of charmonia states produced in two body B decays $B \to KX_{c\bar{c}}$ has been performed by measuring the mass spectra recoiling against a K [17]. This technique allows to observe charmonia states independently from their decay mode and to perform the measurement of absolute branching fractions $\mathcal{B}(B \to KX_{c\bar{c}})$.

No $B^\pm \to K^\pm X(3872)$ signal is observed, entailing an upper limit $\mathcal{B}(B^\pm \to K^\pm X(3872)) < 3.2\times10^{-4}$ at 90% CL. Using the average of Belle and BaBar results [8,11] $\mathcal{B}(B^\pm \to K^\pm X(3872)) \cdot \mathcal{B}(X(3872) \to J/\psi\pi^+\pi^-) = (13.3\pm2.5)\cdot10^{-6}$ it is possible to extract the lower limit $\mathcal{B}(X(3872) \to J/\psi\pi^+\pi^-) > 4.2\%$ at 90% CL.

3.3. Study of the $Y(4260)$

The study of the process $e^+e^- \to \gamma_{ISR}J/\psi\pi^+\pi^-$, shows a broad structure at 4260 MeV/c^2, shown in Figure 3, the natural quantum number assignment is $J^{PC} = 1^{--}$ [12].

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 $m_Y = 4259 \pm 8(\text{stat})^{+2}_{-6}(\text{syst})$ MeV/c^2 and a width $\Gamma_Y = 88 \pm 23(\text{stat})^{+6}_{-4}(\text{syst})$ MeV.

Differently from the other $J^{PC} = 1^{--}$ charmonium states, the $Y(4260)$ is not observed in inclusive $e^+e^- \to hadrons$. To investigate its nature, other hadronic final states ($\phi\pi^+\pi^-$, $D\bar{D}$, $p\bar{p}$) have been studied in ISR processes, but no indication of $Y(4260)$ decay to these final states is observed. The following upper limits are determined (preliminary results and [18]):

$$\Gamma(Y(4260) \to e^+e^-) \times \mathcal{B}(Y(4260) \to \phi\pi^+\pi^-) < 0.4 \text{ eV (90\%C.L.)}, \quad (9)$$

$$\mathcal{B}(Y(4260) \to D\bar{D})/\mathcal{B}(Y(4260) \to J/\psi\pi^+\pi^-) < 7.6 \text{ (95\%C.L.)}, \quad (10)$$

$$\mathcal{B}(Y(4260) \to p\bar{p})/\mathcal{B}(Y(4260) \to J/\psi\pi^+\pi^-)$$

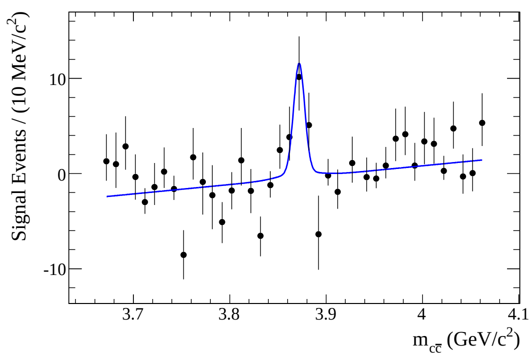

Figure 2. $J/\psi\gamma$ invariant mass distribution for $B^+ \to J/\psi\gamma K^+$ decays around the $X(3872)$ region. The solid curve represents the fit to the data.

$$< 0.13\ (90\%\text{C.L.}). \quad (11)$$

The decay $B^{\pm} \to J/\psi\pi^+\pi^-K^{\pm}$, studied by BaBar using 211 fb^{-1} of data collected at the $\Upsilon(4S)$, indicates a 3σ excess of events in the $Y(4260) \to J/\psi\pi^+\pi^-$ region [19]. More data is needed to confirm this production mechanism.

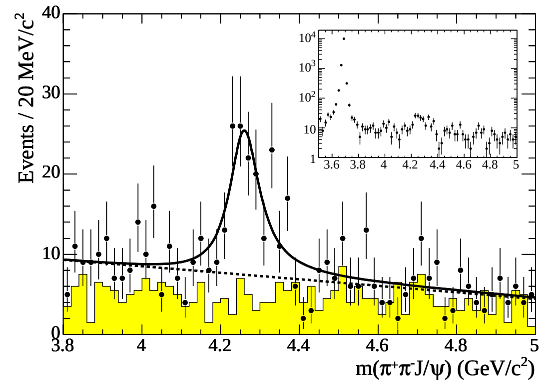

Figure 3. Invariant mass distribution for ISR $J/\psi\pi^+\pi^-$ events in the region 3.8-5 GeV/c^2. The inset shows a larger region, where the ψ' peak is clearly visible. The solid line is the fit of the distribution with a relativistic Breit-Wigner and a second order polynomial background (dashed line). The histogram represents the background estimated from the J/ψ sideband regions.

REFERENCES

1. See for example: N. A. Tornqvist, Phys. Lett. B **590**, 209 (2004); L. Maiani, F. Piccinini, A. D. Polosa and V. Riquer, Phys. Rev. D **71**, 014028 (2005).
2. B. Aubert *et al.* [BABAR Collaboration], Nucl. Instrum. Meth. A **479**, 1 (2002).
3. B. Aubert *et al.* [BABAR Collaboration], Phys. Rev. Lett. **90**, 242001 (2003).
4. D. Besson *et al.* [CLEO Collaboration], Phys. Rev. D **68**, 032002 (2003).
5. B. Aubert *et al.* [BABAR Collaboration], Phys. Rev. D **74**, 032007 (2006).
6. B. Aubert *et al.* [BABAR Collaboration], Phys. Rev. D **74**, 031103 (2006).
7. B. Aubert [BABAR Collaboration], arXiv:hep-ex/0607082.
8. S. K. Choi *et al.* [Belle Collaboration], Phys. Rev. Lett. **91**, 262001 (2003).
9. D. Acosta *et al.* [CDF II Collaboration], Phys. Rev. Lett. **93**, 072001 (2004).
10. V. M. Abazov *et al.* [D0 Collaboration], Phys. Rev. Lett. **93**, 162002 (2004).
11. B. Aubert *et al.* [BABAR Collaboration], Phys. Rev. D **71**, 071103 (2005).
12. B. Aubert *et al.* [BABAR Collaboration], Phys. Rev. Lett. **95**, 142001 (2005).
13. R. Poling, eConf **C060409**, 005 (2006) [arXiv:hep-ex/0606016].
14. T. E. Coan *et al.* [CLEO Collaboration], Phys. Rev. Lett. **96**, 162003 (2006).
15. B. Aubert [BABAR Collaboration], arXiv:hep-ex/0607050.
16. K. Abe *et al.*, arXiv:hep-ex/0505037.
17. B. Aubert *et al.* [BABAR Collaboration], Phys. Rev. Lett. **96**, 052002 (2006).
18. B. Aubert *et al.* [BABAR Collaboration], Phys. Rev. D **73**, 012005 (2006).
19. B. Aubert *et al.* [BABAR Collaboration], Phys. Rev. D **73**, 011101 (2006).