SLAC-PUB-12512

RECENT BABAR RESULTS IN CHARM AND CHARMONIUM SPECTROSCOPY

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Recent results related to open charm and charmonium spectroscopy from data collected by the Babar experiment in e^+e^- collisions near $\sqrt{s} = 10.58\,\mathrm{GeV}$ are reviewed. New estimates of the $D_{s0}^*(2317)^+$, $D_{s1}(2460)^+$, and $D_{s1}(2536)^+$ meson properties and the discovery of a new D_s^+ meson at $2.86\,\mathrm{GeV}/c^2$ decaying to DK are presented. New results on the two charmonium candidates $X(3872)$ and $Y(4260)$ are discussed also.

Keywords: Babar; hadron spectroscopy; charm.

1. Open Charm Spectroscopy

The spectrum of known D_s^+ mesons can be summarized as follows: the D_s^+ and D_s^{*+} mesons are assigned to be the lowest mass $q\overline{q}$ S-wave states with spin-parity $J^P = 0^-$ and 1^-, respectively, while the $D_{s0}^*(2317)^+$, $D_{s1}(2460)^+$, $D_{s1}(2536)^+$, and $D_{s2}(2573)^+$ mesons can be interpreted as $q\overline{q}$ P-wave states with $J^P = 0^+, 1^+, 1^+$ and 2^+. For the latter two the spin-parity still needs to be fully established. However, this picture is not universally accepted, because the $D_{s0}^*(2317)^+$ and $D_{s1}(2460)^+$ mass values are considerably lower than predicted by potential models[1]. This has led to speculation that these states are not conventional $c\overline{s}$ mesons but are instead some type of exotic matter[2,3]. In the following, new estimates of $D_{s0}^*(2317)^+$ and $D_{s1}(2460)^+$ properties are summarized. The discovery of a new D_s^+ meson at a mass of $2.86\,\mathrm{GeV}/c^2$ decaying to DK is also presented.

A study[4] of the $D_{s0}^*(2317)^+$ and $D_{s1}(2460)^+$ mesons produced in $e^+e^- \to c\overline{c}$ continuum events has been performed on a data sample corresponding to an integrated luminosity of $232\,\mathrm{fb}^{-1}$. The following final states have been considered: $D_s^+\pi^0$, $D_s^+\gamma$, $D_s^{*+}\pi^0$, $D_{s0}^*(2317)^+\gamma$ (the latter two only for $D_{s1}(2460)^+$), $D_s^+\pi^0\pi^0$, $D_s^+\gamma\gamma$, $D_s^{*+}\gamma$ and $D_s^+\pi^+\pi^-$, with $D_s^+ \to \phi\pi^+$ ($\phi \to K^+K^-$) and $D_s^+ \to \overline{K}^{*0}K^+$ ($\overline{K}^{*0} \to K^-\pi^+$). Charged conjugate states are included implicitly here and throughout. The $D_s^+\pi^+$ and $D_s^+\pi^-$ systems have been examined in search of the partner states of the $D_{s0}^*(2317)^+$ predicted by some four-quark models[2,3].

The $D_{s0}^*(2317)^+$ is observed only in its decay to $D_s^+\pi^0$. The $D_s^+\pi^0$ invariant mass distribution is shown in Fig. 1a. Besides clear D_s^{*+} and $D_{s0}^*(2317)^+$ signals a broad

Contributed to 9th International Workshop on Meson Production, Properties and Interaction (MESON 2006), 6/9/2006-6/13/2006, Cracow, Poland

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

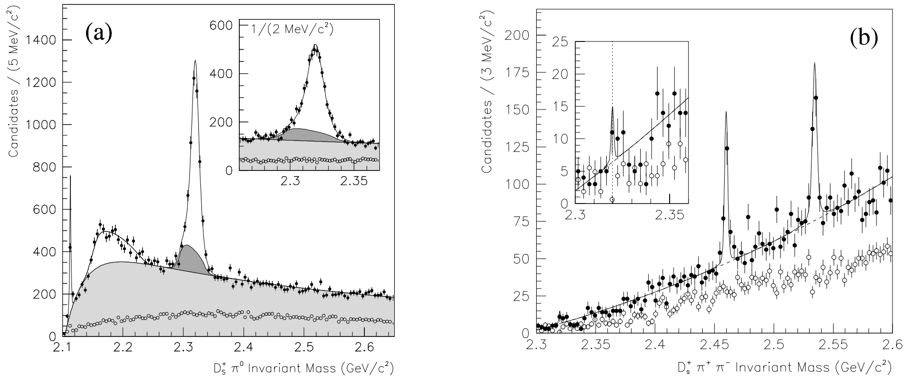

Fig. 1. Invariant mass distributions for **(a)** $D_s^+\pi^0$ and **(b)** $D_s^+\pi^+\pi^-$ candidates selected from D_s^+ signal (solid points) and sideband regions (open points). The solid curves represent the results of the fits described in the text. The insets highlight the $D_{s0}^*(2317)^+$ mass region. In (a) the contributions to the fit due to combinatorial background (light shading) and the reflection from $D_{s1}(2460)^+ \to D_s^{*+}\pi^0$ decays (dark shading) are shown.

distribution peaking at approximately $2.17\,\mathrm{GeV}/c^2$ is apparent. This structure is identified to be a reflection arising from $D_s^{*+} \to D_s^+\gamma$ decays. A second reflection associated with $D_{s1}(2460)^+ \to D_s^{*+}\pi^0$ decays occurs directly under the $D_{s0}^*(2317)^+$ signal. The yield and mean of the $D_{s0}^*(2317)^+$ signal are estimated from an unbinned maximum likelihood (ML) fit accounting for signal, reflections, combinatorial background and a hypothetical $D_{s1}(2460)^+$ contribution. The shapes of the signals and reflections have been derived from Monte Carlo (MC) simulations. The $D_{s1}(2460)^+$ reflection requires special care and its mean and size are adjusted according to the results obtained from the associated analysis of the $D_{s1}(2460)^+ \to D_s^{*+}\pi^0$ decay. Fig. 1a shows the result of the fit, with the individual contributions due to reflections and combinatorial background indicated.

The $D_{s0}^*(2317)^+$ mass is measured to be $m = (2319.6 \pm 0.2 \pm 1.4\,\mathrm{MeV}/c^2)$, where the first uncertainty is statistical and the second systematic (this convention is followed throughout this article). The 95% upper limit on the intrinsic width of the $D_{s0}^*(2317)^+$ meson is estimated to be $\Gamma < 3.8\,\mathrm{MeV}$. No indication has been found for states near the $D_{s0}^*(2317)^+$ mass decaying to $D_s^+\pi^\pm$. The production cross section times branching fraction for such decays relative to $D_{s0}^*(2317)^+$ decay to $D_s^+\pi^0$ is found to be about $60 - 80$ times smaller than predicted for an isospin 1 DK molecule[2], but other four-quark models[2,3] cannot be excluded.

The $D_{s1}(2460)^+$ is observed in its decays to $D_s^{*+}\pi^0$, $D_s^+\gamma$, and $D_s^+\pi^+\pi^-$. For the decay to $D_s^+\pi^0\gamma$ the two subresonant $D_s^{*+}\pi^0$ and $D_{s0}^*(2317)^+\gamma$ decay modes, which overlap in their kinematics and are thus difficult to disentangle, have been considered. The decay to $D_s^+\pi^0\gamma$ is found to be consistent with proceeding entirely through $D_s^{*+}\pi^0$, within error. However, the two modes are included in the analysis and the following ratios of branching fractions have been measured: $\mathcal{B}(D_{s1}(2460)^+ \to D_s^+\gamma)/\mathcal{B}(D_{s1}(2460)^+ \to D_s^+\pi^0\gamma) = (33.7 \pm 3.6 \pm 3.8)\%$ and $\mathcal{B}(D_{s1}(2460)^+ \to D_s^+\pi^+\pi^-)/\mathcal{B}(D_{s1}(2460)^+ \to D_s^+\pi^0\gamma) = (7.7 \pm 1.3 \pm 0.8)\%$. These values may be compared to previous measurements[5] e.g., $\mathcal{B}(D_{s1}(2460)^+ \to D_s^+\gamma)/\mathcal{B}(D_{s1}(2460)^+ \to D_s^{*+}\pi^0)$, although it should be pointed out that the possibility of a $D_{s0}^*(2317)^+\gamma$ decay mode was not explicitly included in that analysis.

The $D_s^+\pi^+\pi^-$ final state involves only charged particles. Since the performance of the tracking system is well understood a precise measurement of the $D_{s1}(2460)^+$ mass is provided by this decay mode. The invariant $D_s^+\pi^+\pi^-$ mass distribution is shown in Fig. 1b. Clear signals for $D_{s1}(2460)^+$ and $D_{s1}(2536)^+$ production are visible. The signal yields and mean values have been determined from an unbinned ML fit accounting for the two signals, a hypothetical $D_{s0}^*(2317)^+$ contribution and combinatorial background. The signal line shapes have been derived from MC simulations. The result of the fit is shown in Fig. 1b, and the fit yields $D_{s1}(2460)^+$ mass $m = (2460.2 \pm 0.2 \pm 0.8)\,\mathrm{MeV}/c^2$. Combined with the less precise results from the $D_s^{*+}\pi^0$ and $D_s^+\gamma$ decay channels the $D_{s1}(2460)^+$ mass is measured to be $m = (2460.1 \pm 0.2 \pm 0.8)\,\mathrm{MeV}/c^2$. For the $D_{s1}(2460)^+$ intrinsic width a 95% CL upper limit $\Gamma < 3.5\,\mathrm{MeV}$ has been set. In addition the mass and limit on the intrinsic width of the $D_{s1}(2536)^+$ have been estimated from the $D_s^+\pi^+\pi^-$ mode to be $m = (2534.6 \pm 0.3 \pm 0.7)\,\mathrm{MeV}/c^2$ and $\Gamma < 2.5\,\mathrm{MeV}$, respectively.

In a previous Babar analysis[6] exclusive $B \to D_s D^{(*)}$ ($D_s = D_{s0}^*(2317)^+$, $D_{s1}(2460)^+$) decays have been studied and products of branching fractions for the B and successive D_s meson decays have been measured. Absolute B branching fractions can be measured from inclusive $B \to D_s D^{(*)}$ decays in $\Upsilon(4S) \to B\overline{B}$ events, where one $\overline{B}$ meson is fully reconstructed as is the $D^{(*)}$ meson. The missing mass corresponding to the D_s is calculated from the kinematic properties of the e^+e^- initial state and the reconstructed $\overline{B}$ and $D^{(*)}$ candidates. Analyzing a data sample of $210.5\,\mathrm{fb}^{-1}$ signals for $D_{s1}(2460)^+$, but not $D_{s0}^*(2317)^+$, have been found[7]. Combining the measured absolute $B \to D_{s1}(2460)^+ D^{(*)}$ branching fractions and the products of branching fractions from exclusive measurements[6] the absolute $D_{s1}(2460)^+$ branching fractions $\mathcal{B}(D_{s1}(2460)^+ \to D_s^{*+}\pi^0) = (56 \pm 13 \pm 9)\%$ and $\mathcal{B}(D_{s1}(2460)^+ \to D_s^+\gamma) = (16 \pm 4 \pm 3)\%$ are inferred. Along with the ratio $\mathcal{B}(D_{s1}(2460)^+ \to D_s^+\pi^+\pi^-)/\mathcal{B}(D_{s1}(2460)^+ \to D_s^+\pi^0\gamma)$ this yields $\mathcal{B}(D_{s1}(2460)^+ \to D_s^+\pi^+\pi^-) = (4 \pm 1)\%$, where the quoted error represents the combined statistical and systematic uncertainties.

The D^0K^+ ($D^0 \to K^-\pi^+, K^-\pi^+\pi^0$) and $D^+K_S^0$ ($D^+ \to K^-\pi^+\pi^-$, $K_S^0 \to \pi^+\pi^-$) systems have been reconstructed from $240\,\mathrm{fb}^{-1}$ of $e^+e^- \to c\overline{c}$ data in search for new D_s mesons. The invariant mass distributions for the reconstructed DK systems are shown in Fig. 2. All three spectra show four common structures: a reflection at about $2.4\,\mathrm{GeV}/c^2$ coming from $D_{s1}(2536) \to D^*K$ decays, a prominent and narrow $D_{s2}(2573)^+$ signal, a broad structure peaking at approximately $2.7\,\mathrm{GeV}/c^2$ and an enhancement at $2.86\,\mathrm{GeV}/c^2$. No significant structures are present in the distributions obtained for D sideband regions.

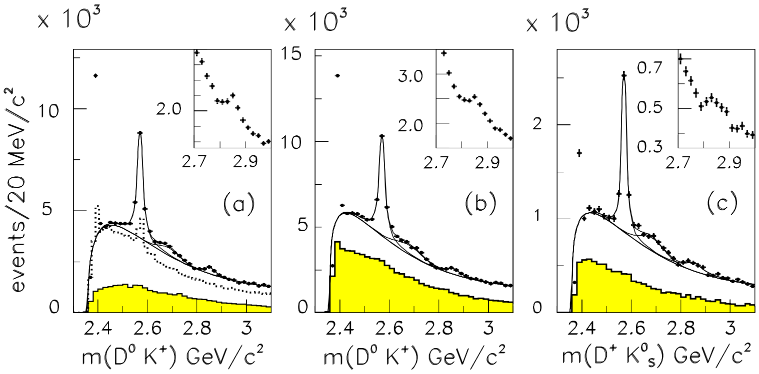

Fig. 2. Invariant mass distributions for DK candidates selected from D signal (solid points) and sideband regions (shaded) for the **(a)** D^0K^+ ($D^0 \to K^+\pi^-$), **(b)** D^0K^+ ($D^0 \to K^+\pi^-\pi^0$) and **(c)** $D^+K^0_S$ ($D^+ \to K^-\pi^+\pi^+$) systems. Overlaid is the result of the fit (solid line) described in the text. The insets highlight the $2.86\,\mathrm{GeV}/c^2$ region. The dotted histogram in a), derived from MC simulation accounting for all previously known charm states, is arbitrarily scaled to data.

The structure at $2.86\,\mathrm{GeV}/c^2$ is interpreted as evidence for a new state, denoted as $D^*_{sJ}(2860)^+$. The possibility that the signal results from reflections from D^* decays or misidentification of kaons and pions has been investigated carefully and excluded. Possible reflections from other charm particle decays can be ruled out as the source of the signal, as is apparent in the invariant D^0K^+ ($D^0 \to K^-\pi^+$) mass distribution derived from MC simulation of $e^+e^- \to c\bar{c}$ events including all known charm particles and decays (dotted histogram in Fig. 2a). The possibility that the broad structure at $2.7\,\mathrm{GeV}/c^2$ results from kinematic reflections cannot be excluded entirely, and further investigation is required. In the following this structure is labelled tentatively as the $X(2690)^+$.

The $D^*_{sJ}(2860)^+$ mass and width are derived from a fit to the sum of the three mass spectra shown in Fig. 2. The fit accounts for the $D_{s2}(2573)^+$ and $D^*_{sJ}(2860)^+$ signals, the $X(2690)^+$ structure and combinatorial background. The $D_{s2}(2573)^+$ and $D^*_{sJ}(2860)^+$ signals are parameterized by relativistic Breit-Wigner functions for spin 2 and 0, respectively. The result was found to be insensitive to the assumed $D^*_{sJ}(2860)^+$ spin. The $X(2690)^+$ structure can be best described by a Gaussian. The fit yields $D^*_{sJ}(2860)^+$ mass $m = (2856.6 \pm 1.5 \pm 5.0)\,\mathrm{MeV}/c^2$ and width $\Gamma = (47 \pm 7 \pm 10)\,\mathrm{MeV}$. The corresponding values for the $D_{s2}(2573)^+$ are $m = (2572.2 \pm 0.3 \pm 1.0)\,\mathrm{MeV}/c^2$ and $\Gamma = (27.1 \pm 0.6 \pm 5.6)\,\mathrm{MeV}$. Consistent results are obtained when the fit is applied to the individual DK mass spectra. The results of these fits are shown in Fig. 2. The corresponding invariant mass distributions for the $D_s^+\eta$ and D^*K systems have been investigated also, but no evidence for a $D^*_{sJ}(2860)^+$ signal has been found in these modes.

The decay of the $D^*_{sJ}(2860)^+$ meson to DK implies that it has natural-spin parity. It has been suggested that this state could be a radial excitation of the $D^*_{s0}(2317)^+$ meson[8], but other interpretations cannot be excluded.

2. Charmonium Spectroscopy and New States

As for the charm meson sector, potential models have had success in describing the charmonium spectrum[9]. However, the discovery of the $X(3872)$ and $Y(4260)$ resonances, with mass values in the $c\bar{c}$ mass region above the $\psi(3770)$, has complicated the situation. It is difficult to interpret these resonances as conventional charmonium states, and alternative scenarios[11] have been proposed, including suggestions that these two states are exotic matter. In the following recent experimental results, which provide experimental tests for some of the proposed scenarios, are summarized.

The $X(3872)$ was discovered in $B^+ \to X(3872)K^+$ decays, with $X(3872) \to J/\psi\pi^+\pi^-$. Its narrow width, mass very close to the $D^0\overline{D}^{*0}$ threshold and small radiative transition rate to $\chi_c\gamma$ have made it difficult to identify the $X(3872)$ with a conventional charmonium state. Numerous exotic interpretations have been suggested, including the S-wave $D^0\overline{D}^{*0}$ molecule model of Ref. 10 and diquark-antidiquark model of Ref. 12. The molecule model considers the $X(3872)$ to be a loosely bound S-wave $D^0\overline{D}^{*0}$ system with $J^{PC} = 1^{++}$ produced in $B \to D^0\overline{D}^{*0}K$ decays. It is predicted that the decay $B^0 \to X(3872)K^0_S$ is suppressed by more than an order of magnitude with respect to $B^+ \to X(3872)K^+$ decay. The diquark-antidiquark model predicts two neutral states in the mass range of the $X(3872)$ with $J^{PC} = 1^{++}$ and a quark content of $X_u = [\overline{cu}][cu]$ and $X_d = [\overline{cd}][cd]$, which can mix. It is expected that one of the two mixed states is produced predominantly in charged B meson decay, while the other is produced predominantly in neutral B decay at the same rate. A mass difference of $(7 \pm 2)\,\mathrm{MeV}/c^2$ is expected between the two states. In addition charged partner states are predicted by the model at a level which could not be excluded by a previous Babar analysis[13].

To investigate the predictions made by the two models exclusive $B^+ \to X(3872)K^+$ and $B^0 \to X(3872)K^0_S$ ($X(3872) \to J/\psi\pi^+\pi^-$) decays have been reconstructed[14] from a data sample of $211\,\mathrm{fb}^{-1}$. Signals for the $X(3872)$ from the B^+ and B^0 decay modes are observed with a significance of 6.1σ and 2.5σ, respectively. The mass difference obtained, $\Delta m = (2.7 \pm 1.3 \pm 0.2)\,\mathrm{MeV}/c^2$, is consistent both with zero and with the prediction of the diquark-antidiquark model within two standard deviations of the combined statistical and systematic uncertainties. For these decays the values of the product branching fractions are found to be $\mathcal{B}^+ = \mathcal{B}(B^+ \to X(3872)K^+) \cdot \mathcal{B}(X(3872)J/\psi\pi^+\pi^-) = (10.1 \pm 2.5 \pm 1.0) \times 10^{-6}$ and $\mathcal{B}^0 = \mathcal{B}(B^+ \to X(3872)K^0_S) \cdot \mathcal{B}(X(3872)J/\psi\pi^+\pi^-) = (5.1 \pm 2.8 \pm 0.7) \times 10^{-6}$. The 90% CL interval for the ratio of branching fractions $R = \mathcal{B}^0/\mathcal{B}^+$ is estimated to be $0.13 < R < 1.10$. This is consistent with isospin conserving decays (where $R = 1$ is expected) but does not entirely exclude the molecule model ($R < 0.1$).

In a complementary approach[15] absolute branching fractions of inclusive two-body $B \to c\bar{c}K$ decays have been measured, where $c\bar{c}$ denotes any charmonium state or the $X(3872)$. Just as for the measurements of absolute $B \to D_sD^{(*)}$ branching fractions mentioned previously, the kinematic properties of $B \to c\bar{c}K$ decays in

$\Upsilon(4S) \to B\overline{B}$ events with one fully-reconstructed $\overline{B}$ meson are exploited to measure the momentum of the other B meson. The K momentum measured in the rest frame of this recoil B meson defines the invariant mass of the $c\overline{c}$ system. Inspecting the K momentum distribution, significant signals are found for J/ψ, η_c, χ_{c1} and $\psi(2S)$, but not for $X(3872)$. The 90% CL upper limit of the branching fraction is estimated to be $\mathcal{B}(B^+ \to X(3872)K^+) < 3.2 \cdot 10^{-4}$. Combined with the product of branching fractions $\mathcal{B}^+$ a 90% CL lower limit $\mathcal{B}(X(3872) \to J/\psi\pi^+\pi^-) > 4.2\%$ is derived.

The existence of radiative $X(3872) \to J/\psi\gamma$ decays is crucial for the nature of the $X(3872)$, since the presence of this decay mode would imply positive C-parity for the $X(3872)$. From a data sample of $260\,\text{fb}^{-1}$ the exclusive decay chain $B^+ \to c\overline{c}K^+$ with $c\overline{c} \to J/\psi\gamma$ has been reconstructed[16], where $c\overline{c}$ denotes any state of positive C-parity, for which decay to $J/\psi\gamma$ is allowed. The number of reconstructed B decays is extracted as a function of the invariant mass $m(J/\psi\gamma)$ of the $c\overline{c}$ candidates by a series of unbinned ML fits in $10\,\text{MeV}/c^2$ intervals of $m(J/\psi\gamma)$. Fig. 3 shows the number of signal events as a function of $m(J/\psi\gamma)$ in the $X(3872)$ mass region. An enhancement at about $3.87\,\text{GeV}/c^2$ is clearly visible. The number of signal events $N = 19.2 \pm 5.7$ is estimated from a fit to this distribution, where the line shape and position of the $X(3872)$ signal have been derived from MC simulations and only the signal yield is allowed to vary. The statistical significance is determined to be 3.4σ. The product branching fraction is measured to be $\mathcal{B}(B^+ \to X(3872)K^+) \cdot \mathcal{B}(X(3872)J/\psi\gamma) = (3.3 \pm 1.0 \pm 0.3) \times 10^{-6}$. A relative branching fraction value $\mathcal{B}(X(3872)J/\psi\gamma)/\mathcal{B}(X(3872)J/\psi\pi^+\pi^-) = 0.34 \pm 0.14$ is inferred from this result and the value $\mathcal{B}^+$ dicussed previously.

To establish clearly the existence of the decay $X(3872) \to J/\psi\gamma$, significantly more data are required. A recent Belle analysis[17], which combines angular distributions and kinematic properties of the $\pi^+\pi^-$ system in $X(3872) \to J/\psi\pi^+\pi^-$ decays favors $J^{PC} = 1^{++}$ for the $X(3872)$, in agreement with $C = +1$. If confirmed, this greatly restricts the possible charmonium state assignments, but remains compatible with the diquark-antidiquark and molecule interpretations.

In a recent analysis[18] the initial state radiation (ISR) process $e^+e^- \to \gamma_{\text{ISR}}J/\psi\pi^+\pi^-$ has been investigated using a data sample of $233\,\text{fb}^{-1}$. The invariant $J/\psi\pi^+\pi^-$ mass distribution (Fig. 4a) has been inspected over the charmonium mass range. In addition to a clear $\psi(2S)$ signal (see inset in Fig. 4a) a broad structure at about $4.26\,\text{GeV}/c^2$ is evident. Treating the structure as a resonance described by a relativistic Breit-Wigner function a fit to the data yields mass $m = (4259 \pm 8^{+8}_{-6})\,\text{MeV}/c^2$ and intrinsic width $\Gamma = (88 \pm 23^{+6}_{-4})\,\text{MeV}$. With the observed statistics, the presence of two interfering resonances cannot be excluded as a source of the structure at $4.26\,\text{GeV}/c^2$. The significance of the structure is estimated to be approximately 8σ. The partial width times branching fraction of the $Y(4260)$ is measured to be $\Gamma(Y(4260) \to e^+e^-) \cdot \mathcal{B}(Y(4260) \to J/\psi\pi^+\pi^-) = (5.5 \pm 1.0^{+0.8}_{-0.7})\,\text{eV}$.

The observation of the $Y(4260)$ structure has been confirmed[19] by the CLEO collaboration in direct $e^+e^- \to Y(4260)$ reactions, with $Y(4260) \to$

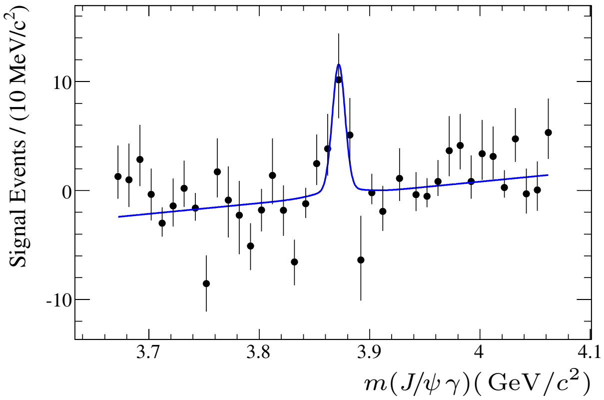

Fig. 3. Number of extracted $B^+ \to J/\psi\gamma K^+$ signal events versus the invariant mass $m(J/\psi\gamma)$ in the region of the $X(3872)$ mass. The solid line represents the result of the fit explained in the text.

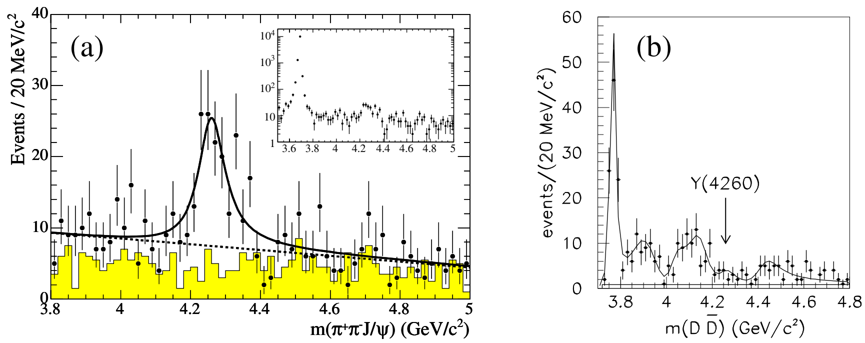

Fig. 4. **(a)** Invariant mass distribution of $J/\psi\pi^+\pi^-$ candidates selected from J/ψ signal (points with error bars) and sideband (shaded histogram) regions. The solid line represents the result of the fit, and the dashed line the background component. In the inset the spectrum is extended to include the $\psi(2S)$ mass region. **(b)** Invariant mass spectrum of the $D\overline{D}$ system overlaid by the result of the fit (solid line) described in the text.

$J/\psi\pi^+\pi^-$, $J/\psi\pi^0\pi^0$. Due to the production mechanism the $Y(4260)$ is constrained to be a $J^{PC} = 1^{--}$ state, while the presence of the $J/\psi\pi^0\pi^0$ decay mode indicates isospin 0, as expected for a charmonium state. In contrast to these observations the total e^+e^- hadronic cross section exhibits a local minimum at the $Y(4260)$ mass[20]. This is in contradiction with expectations for a conventional charmonium state and has led to speculation that the $Y(4260)$ is an exotic object[11].

In search for the $D\overline{D}$ decay mode of the $Y(4260)$ a study[21] of exclusive production of the $D\overline{D}$ system in ISR processes has been performed exploiting a data sample of $288.5\,\text{fb}^{-1}$. The three $D^0\overline{D}^0$ systems with $D^0 \to K^-\pi^+$, $D^0 \to K^-\pi^+\pi^0$, $D^0 \to K^-\pi^+\pi^+\pi^-$ and $\overline{D}^0 \to K^+\pi^-$ as well as the D^+D^- system with $D^+ \to K^-\pi^+\pi^+$ and $D^- \to K^+\pi^-\pi^-$ have been investigated. The invariant $D\overline{D}$ mass spectrum for the complete sample is shown in Fig. 4b. A clear $\psi(3770)$ signal is visible, and there are enhancements in the $\psi(4040)$, $\psi(4160)$ and $\psi(4415)$ mass regions. The broad structure at $3.9\,\mathrm{GeV}/c^2$ is found to be consistent with predictions from coupled-channel models. An unbinned ML fit is applied to extract a possible $Y(4260)$ contribution. The fit accounts for ψ and $Y(4260)$ contributions and includes a Gaussian function to describe the structure at $3.9\,\mathrm{GeV}/c^2$ and a constant background. The ψ, $Y(4260)$ and Gaussian functions are allowed to interfere. The mass and width of the Breit-Wigner term describing the $Y(4260)$ contribution are fixed to values observed from the $J/\psi\pi^+\pi^-$ decay mode. The fit result is shown in Fig. 4b. A $Y(4260)$ contribution of $7 \pm 13 \pm 8$ events is obtained, yielding a 95% CL upper limit $\mathcal{B}(Y(4260) \to D\overline{D})/\mathcal{B}(Y(4260) \to J/\psi\pi^+\pi^-) < 7.6$. This value is at least one order of magnitude smaller than the value found for $\psi(3770)$, which might indicate that the $Y(4260)$ is not a conventional $c\overline{c}$ meson.

References

1. S. Godfrey, N. Isgur, *Phys. Rev.* **D32**, 189 (1985);
   S. Godfrey, R. Kokoski, *Phys. Rev.* **D43**, 1679 (1991);
   N. Isgur, M.B. Wise, *Phys. Rev. Lett.* **66**, 1130 (1991);
   M. Di Pierro, E. Eichten, *Phys. Rev.* **D64**, 114004 (2001).
2. T. Barnes, F.E. Close, H.J. Lipkin, *Phys. Rev.* **D68**, 054006 (2003).
3. H.J. Lipkin, *Phys. Lett.* **B580**, 50 (2004).
4. B. Aubert *et al.* [Babar Collaboration], *ArXiv:hep-ex/0604030*;
   accepted by *Phys. Rev. D.*
5. K. Abe *et al.* [Belle Collaboration], *Phys. Rev. Lett.* **92**, 012002 (2004).
6. B. Aubert *et al.* [Babar Collaboration], *Phys. Rev. Lett.* **93**, 181801 (2004).
7. B. Aubert *et al.* [Babar Collaboration], *ArXiv:hep-ex/0605036.*
8. E. van Beveren, G. Rupp, *ArXiv:hep-ph/0606110.*
9. E.J. Eichten, K. Lane, C. Quigg, *Phys. Rev. Lett.* **89**, 1620002 (2002);
   E.J. Eichten, K. Lane, C. Quigg, *Phys. Rev.* **D69**, 094019 (2004);
   T. Barnes, S. Godfrey, *Phys. Rev.* **D69**, 054008 (2004).
10. E. Braaten, M. Kusonoki, *Phys. Rev.* **D71**, 074005 (2005).
11. E.S. Swanson, *Phys. Rept.* **429**, 243 (2006), and references therein.
12. L. Maiani, F. Piccinini, A.D. Polosa, V. Riquer, *Phys. Rev.* **D71**, 014028 (2005).
13. B. Aubert *et al.* [Babar Collaboration], *Phys. Rev.* **D71**, 052001 (2005).
14. B. Aubert *et al.* [Babar Collaboration], *Phys. Rev.* **D73**, 011101 (2006).
15. B. Aubert *et al.* [Babar Collaboration], *Phys. Rev. Lett.* **96**, 052002 (2006).
16. B. Aubert *et al.* [Babar Collaboration], *ArXiv:hep-ex/0607050.*
17. K. Abe *et al.* [Belle Collaboration], *ArXiv:hep-ex/0505038.*
18. B. Aubert *et al.* [Babar Collaboration], *Phys. Rev. Lett.* **95**, 142001 (2005).
19. T. E. Coan *et al.* [CLEO Collaboration], *Phys. Rev. Lett.* **96**, 162003 (2006).
20. J.Z. Bai *et al.* [BES Collaboration], *Phys. Lett.* **88**, 101802 (2002).
21. B. Aubert *et al.* [Babar Collaboration], *ArXiv:hep-ex/0607083.*