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Search for the charmed pentaquark candidate $\Theta_c(3100)^0$ in e^+e^- annihilations at $\sqrt{s} = 10.58$ GeV

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We search for the charmed pentaquark candidate reported by the H1 collaboration, the $\Theta_c(3100)^0$, in e^+e^- interactions at a center-of-mass (c.m.) energy of 10.58 GeV, using 124 fb^{-1} of data recorded with the *BABAR* detector at the PEP-II e^+e^- facility at SLAC. We find no evidence for such a state in the same pD^{*-} decay mode reported by H1, and we set limits on its production cross section times branching fraction into pD^{*-} as a function of c.m. momentum. The corresponding limit on its total rate per $e^+e^- \rightarrow q\bar{q}$ event, times branching fraction, is about 3 orders of magnitude lower than rates measured for the charmed Λ_c and Σ_c baryons in such events.

Ten experimental groups have recently reported narrow enhancements near 1540 MeV/c^2 in the invariant mass spectra for nK^+ or pK_S^0 [1]. The minimal quark content of a state that decays strongly to nK^+ is $dduu\bar{s}$; therefore, these mass peaks have been interpreted as a possible pentaquark state, called $\Theta(1540)^+$. The NA49 experiment has reported narrow enhancements near 1862 MeV/c^2 in the invariant mass spectra for $\Xi^-\pi^-$ and $\Xi^-\pi^+$ [2]; the former has minimal quark content $dssd\bar{u}$, and these two mass peaks have also been interpreted as possible pentaquark states, named $\Xi(1860)^{--}$ and $\Xi(1860)^0$ [also known as $\Phi(1860)$], with the latter being a mixture of $ussu\bar{u}$ and $ussd\bar{d}$. The H1 experiment has reported a narrow enhancement at a mass of 3099 ± 6 MeV/c^2 in the mass spectrum for pD^{*-} [3], which has a minimal quark content of $uudd\bar{c}$, making this a possible charmed pentaquark state, named $\Theta_c(3100)^0$. On the other hand, there are numerous experimental searches with negative results [4]: several experiments observe large samples of strange baryons with mass similar to that of the $\Theta(1540)^+$, e.g. $\Lambda(1520) \rightarrow pK^-$, but no evidence for the $\Theta(1540)^+$; several observe large samples of the nonexotic Ξ^- baryon, but not the $\Xi(1860)^{--}$ or $\Xi(1860)^0$ states; and several with large samples of D^{*-} do not observe the $\Theta_c(3100)^0$ state. Our recent search [5] for the $\Theta(1540)^+$ and $\Xi(1860)^{--}$ in e^+e^- annihilations found no evidence for these states, and we set limits on their production rates in $e^+e^- \rightarrow q\bar{q}$ events of factors of eight and four, respectively, below rates expected for ordinary baryons of the same masses.

Here we report the results of an inclusive search for the charmed pentaquark candidate $\Theta_c(3100)^0$ in e^+e^- annihilation data; we expect equal production of the charge conjugate state, and its inclusion is implied throughout this article. The data were recorded with the *BABAR* detector [6] at the PEP-II asymmetric-energy e^+e^- storage rings located at the Stanford Linear Accelerator Center. The data sample represents an integrated luminosity of 124 fb^{-1} collected at an e^+e^- c.m. energy at or just below the mass of the $\Upsilon(4S)$ resonance. We study the same decay mode as in the H1 analysis, $\Theta_c(3100)^0 \rightarrow pD^{*-}$, where the D^{*-} decays to $\bar{D}^0\pi_s^-$ (π_s^- denotes a "slow" pion from the

D^{*-} decay), and the $\bar{D}^0$ decays to $K^+\pi^-$. In addition, we consider the mode in which the $\bar{D}^0$ decays to $K^+\pi^-\pi^+\pi^-$.

The *BABAR* detector is described in detail in Ref. [6]. We use all events accepted by our trigger, which is more than 99% efficient for both $e^+e^- \rightarrow q\bar{q}$ and $e^+e^- \rightarrow \Upsilon(4S)$ events. We use charged tracks reconstructed in the five-layer silicon vertex tracker (SVT) and the 40-layer drift chamber (DCH). The combined momentum resolution, $\sigma(p_T)$, is given by $[\sigma(p_T)/p_T]^2 = [0.0013p_T]^2 + 0.0045^2$, where p_T is the momentum transverse to the beam axis measured in GeV/c. Particles are identified as pions, kaons, or protons with a combination of the energy-loss measured in the two tracking detectors and the Cherenkov angles measured in the detector of internally reflected Cherenkov radiation (DIRC).

We evaluate the $\Theta_c(3100)^0$ reconstruction efficiency and invariant mass resolution from two simulations. For production in $e^+e^- \rightarrow c\bar{c}$ events, we use the JETSET [7] Monte Carlo generator with the mass and width of the $\Sigma_c(2455)^0$ baryon set to 3099 MeV/c^2 and 1 MeV, respectively, and allow only the pD^{*-} decay mode. We leave all other parameters unchanged, and a momentum spectrum similar to those of nonexotic charmed baryons is produced. The events have a total charm of ± 2, but this has negligible effect on the number and distribution of additional particles in the event, which are the quantities of interest here. We also simulate $\Upsilon(4S)$ decays in which one B decays generically in our standard framework [8] and the other decays into a state containing a $\Sigma_c(2455)^0$ with parameters adjusted in the same way. This gives a much softer momentum spectrum, cut off at the kinematic limit for B meson decays, and a different environment in terms of other particles in the event. We find that the efficiency and resolution depend primarily on the $\Theta_c(3100)^0$ momentum and polar angle in the laboratory frame, and negligibly on other aspects of the production process or event environment. We use large control samples of particles identified in the data to correct small inaccuracies in the performance predicted by the GEANT-based [9] detector simulation.

We choose $\Theta_c(3100)^0$ candidate selection criteria designed for high efficiency and low bias against any pro-

duction mechanism. We use charged tracks reconstructed with at least 12 coordinates measured in the DCH, and select identified pions, kaons and protons. The identification criteria for pions and kaons are fairly loose, having efficiencies better than 99% and misidentification rates below 1% for momenta below 0.5 GeV/c where energy loss in the SVT and DCH provide good separation, and efficiencies of roughly 80% and misidentification rates below 10% for momenta above 0.8 GeV/c where the Cherenkov angles are measured well in the DIRC. The criteria for identified protons are tighter. For momenta below 1 GeV/c and above 1.5 GeV/c the efficiencies are better than 95% and 75%, and the misidentification rates are below 1% and 3%, respectively.

In each event we consider every combination of identified $pK^+\pi^-\pi^-$ and $pK^+\pi^-\pi^+\pi^-\pi^-$ and perform a topological fit to each combination with the hypothesized decay chain $X \to pD^{*-} \to p\bar{D}^0\pi_s^- \to pK^+\pi^-(\pi^+\pi^-)\pi_s^-$. No mass constraints are used in the fit, but the decay products at each stage are required to originate at a single space point. The $\bar{D}^0$ has a finite flight distance, and we require the confidence level of the χ^2 for its decay vertex to exceed 10^{-4}.

We select candidates in which both the reconstructed $\bar{D}^0$ and D^{*-} masses are within 20 MeV/c^2 of the peak value, namely $1843.8 < m_{K^+\pi^-(\pi^+\pi^-)} < 1883.8$ MeV/c^2 and $1989 < m_{K^+\pi^-(\pi^+\pi^-)\pi_s^-} < 2029$ MeV/c^2. In Fig. 1(a) we show the distributions of the differences in reconstructed invariant mass $\Delta m = m_{K^+\pi^-\pi_s^-} - m_{K^+\pi^-}$ and $m_{K^+\pi^-\pi^+\pi^-\pi_s^-} - m_{K^+\pi^-\pi^+\pi^-}$ for these $X \to pK^+\pi^-\pi_s^-$ and $pK^+\pi^-\pi^+\pi^-\pi_s^-$ candidates, respectively. Clear signals for D^{*-} are visible in both cases, with peak positions and widths (~ 0.6 MeV/c^2) consistent with expectations from our simulation. The widths (~ 6 MeV/c^2) of the corresponding $\bar{D}^0$ and D^{*-} peaks (not shown) are underestimated by about 10% in the simulation. We require a

mass difference within 2 MeV/c^2 of the peak value, $143.48 < \Delta m < 147.48$ MeV/c^2.

About 55 000 $D^{*-} \to K^+\pi^-\pi_s^-$ decays and 73 000 $D^{*-} \to K^+\pi^-\pi^-\pi^+\pi_s^-$ decays are present in the selected data over respective backgrounds of 4000 and 62 000 random combinations. No event in either the data or simulation has more than one surviving pD^{*-} candidate. Without the proton requirement, over 750 000 D^{*-} are seen. Figure 1(b) shows the distribution of the D^{*-} momentum, p^*, in the c.m. frame for the selected data. A characteristic two-peak structure is evident, in which the peak at lower p^* values is due to D^{*-} from decays of B hadrons from $Y(4S)$ decays, and the peak at higher p^* values is due to $e^+e^- \to c\bar{c}$ events. For purposes of illustration, we show the spectra measured [10] from these two sources on Fig. 1(b), scaled by our integrated luminosity, average efficiency and fraction of events with a proton. The shape is modified by the selection criteria; in particular, the proton requirement shifts the edge at the highest p^* values. The background is verified by sideband studies to be concentrated at lower p^* values; it is clear that we are sensitive to $\Theta_c(3100)^0$ production from both of these sources.

We evaluate the $\Theta_c(3100)^0$ reconstruction efficiency for each search mode from the simulation, as a function of p^*. High-mass particles at low p^* are boosted forward in our laboratory frame, so that the probability of losing at least one track outside the acceptance is large, and the efficiencies are low, about 10% and 5% for the $K^+\pi^-$ and $K^+\pi^-\pi^+\pi^-$ modes, respectively. The efficiencies rise with increasing p^* to respective maximum values of 30% and 22% at the kinematic limit. The invariant mass requirements introduce negligible signal loss. The relative systematic uncertainties on the tracking and particle identification efficiencies total 6–8%; at low and high p^* values, there is a contribution of similar size from the statistics of the simulation.

We calculate the $\Theta_c(3100)^0$ candidate invariant mass as $m_{pD^*} \equiv m_{pK^+\pi^-(\pi^+\pi^-)\pi_s^-} - m_{K^+\pi^-(\pi^+\pi^-)\pi_s^-} + m_{D^{*-}}$, where $m_{D^{*-}} = 2010$ MeV/c^2 is the known D^{*-} mass [11]. We take the resolution on this quantity from the simulation, as it is insensitive to the simulated $D^{(*)}$ mass resolution and previous studies involving protons combined with K_S^0 [5] showed the proton contribution to be well simulated. We describe the resolution by a sum of two Gaussian functions with a common center. The width of the core (tail) Gaussian averages 2.5(20) MeV/c^2, almost independent of p^*, and the wider Gaussian contributes between 20% of the total at low p^* and 10% at high p^*. The overall resolution, defined as the FWHM of the resolution function divided by 2.355, averages 2.8 and 3.0 MeV/c^2 for the $K^+\pi^-$ and $K^+\pi^-\pi^+\pi^-$ decay modes, respectively, with a small dependence on p^*.

We show m_{pD^*} distributions for the $\Theta_c(3100)^0$ candidates in the data in Fig. 2 for the two $\bar{D}^0$ decay modes. They show no narrow structure; in particular, they are
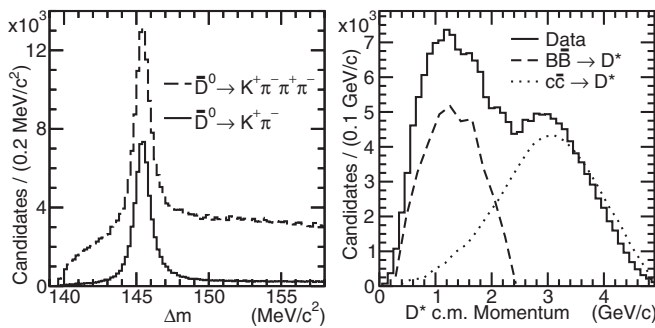
FIG. 1. (a) Distributions of the invariant mass difference between the D^{*-} and $\bar{D}^0$ combinations in $X \to pD^{*-}$ candidates in the data, for the two $\bar{D}^0$ decay modes. (b) Distribution of the reconstructed momentum of the D^{*-} in the e^+e^- c.m. frame for pD^{*-} candidates in the data (histogram); the dashed (dotted) line represents the D^{*-} spectra measured in $Y(4S)$ decays ($e^+e^- \to c\bar{c}$ events) scaled as described in the text.

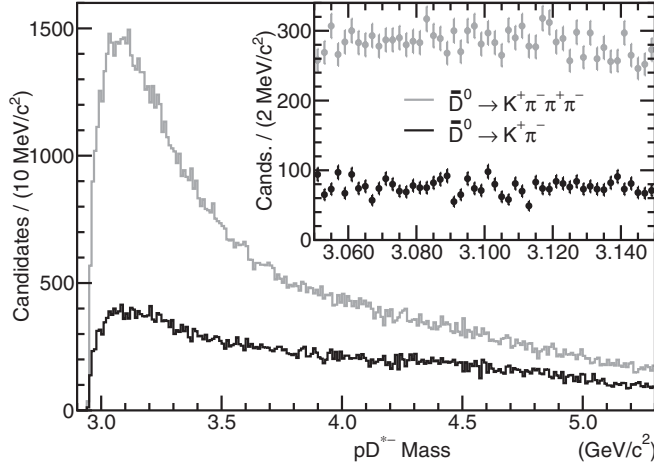FIG. 2.   Invariant mass distributions for $\Theta_c(3100)^0$ candidates in the data in the (black) $K^+\pi^-$ and (gray) $K^+\pi^-\pi^-\pi^+$ decay modes, over a wide mass range and (inset) in the region near 3100 MeV/c^2.

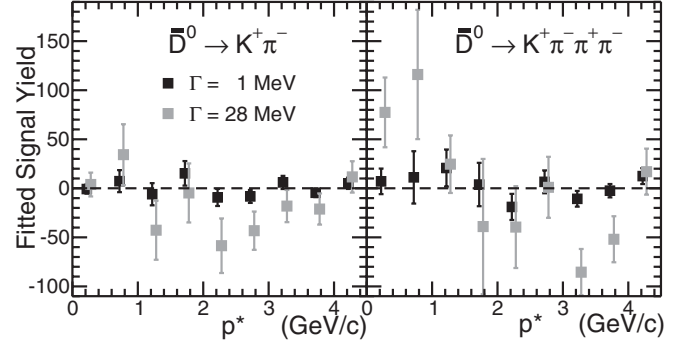FIG. 3. $\Theta_c(3100)^0$ yields from fits to the m_{pD^*} distributions for the (left) $pK^+\pi^-\pi_s^-$ and (right) $pK^+\pi^-\pi^+\pi^-\pi_s^-$ decay modes, assuming a mass of 3099 MeV/c^2 and a natural width of $\Gamma = 1$ MeV (black) or $\Gamma = 28$ MeV (gray).

smooth in the region near 3100 MeV/c^2, shown in the inset, where the bin size is two-thirds of the resolution. Corresponding distributions for sidebands in the $\bar{D}^0$ and D^{*-} masses and the mass differences show overall structure similar to that in the signal region. We consider several variations of the selection criteria that might enhance a pentaquark signal, but in no case do we observe one. To enhance our sensitivity to any production mechanism that gives a p^* spectrum different from that of the background, we divide the data into nine p^* ranges of width 500 MeV/c covering values from 0 to 4.5 GeV/c. The background is lower at high p^*, so we are more sensitive to mechanisms that produce harder spectra. There is no evidence of a pentaquark signal in any p^* range.

We quantify this null result by fitting a signal-plus-background function to the m_{pD^*} distribution in each p^* range. We use a p-wave Breit-Wigner lineshape convolved with the resolution function described above. The RMS width of the reported $\Theta_c(3100)^0$ signal is 12 MeV/c^2 and consistent with the H1 detector resolution [3]. Our mass resolution is considerably better, so we must consider a range of possible natural widths Γ of the $\Theta_c(3100)^0$. We quote results for two assumed widths, $\Gamma = 1$ MeV, corresponding to a very narrow state, and $\Gamma = 28$ MeV, corresponding to the width observed by H1, which we take as an upper limit. For the background we use the function $f(m) = 0$ for $m < m_0$ and $f(m) = \sqrt{1 - (m_0/m)^2}\exp(a[1 - (m_0/m)^2])/m$ for $m > m_0$, where $m_0 = m_p + m_{D^{*-}} = 2948$ MeV/c^2 is the threshold value and a is a free parameter. We fit over the range from threshold to 3300 MeV/c^2, except in the lowest p^* range for the $K^+\pi^-\pi^+\pi^-$ mode. Here the acceptance drops sharply near threshold and the fit range is restricted to the region above 3000 MeV/c^2.

We perform maximum likelihood fits at several fixed $\Theta_c(3100)^0$ mass values in the range 3087–3111 MeV/c^2. In every case we find good fit quality and a signal amplitude consistent with zero. We consider systematic effects in the fitting procedure by varying the signal and background functions and fit range; changes in the signal yield are negligible compared with the statistical uncertainties. The dependence on the assumed mass value is also small compared with the statistical error in each case. Fixing the mass to the reported value of 3099 MeV/c^2, we obtain the event yields shown in Fig. 3. There is no positive trend in the data, and the roughly symmetric scatter of the points about zero indicates little momentum-dependent bias in the background function.

In each p^* range we divide the sum of the two signal yields by the sum of the two products of reconstruction efficiency and $\bar{D}^0 \to K^+\pi^-$ or $\bar{D}^0 \to K^+\pi^-\pi^+\pi^-$ branching fraction, the $D^{*-} \to \bar{D}^0\pi_s^-$ branching fraction, the integrated luminosity, and the p^* range. This gives the product of the unknown $\Theta_c(3100)^0 \to pD^{*-}$ branching fraction, $\mathcal{B}$, and the differential production cross section, $d\sigma/dp^*$. The resulting values of $\mathcal{B} \cdot d\sigma/dp^*$ for $\Gamma = 1$ MeV and $\Gamma = 28$ MeV are shown in Fig. 4. We derive an upper limit on the value in each p^* range under the assumption that it cannot be negative: a Gaussian function centered at the measured value with RMS equal to the total uncertainty is integrated from zero to infinity, and the point at which the integral reaches 95% of this total is taken as the limit. These 95% confidence level (CL) upper limits are also shown in Fig. 4.

We integrate $\mathcal{B} \cdot d\sigma/dp^*$ over the full p^* range from 0–4.5 GeV/c, taking into account the correlation in the systematic uncertainty, to derive a total production cross section times branching fraction, $\mathcal{B} \cdot \sigma$, for each of the two assumed Γ values, and calculate corresponding upper limits. These limits are model independent; any postulated production spectrum can be folded with the measured differential cross section to obtain a smaller limit. We calculate corresponding limits on the number of
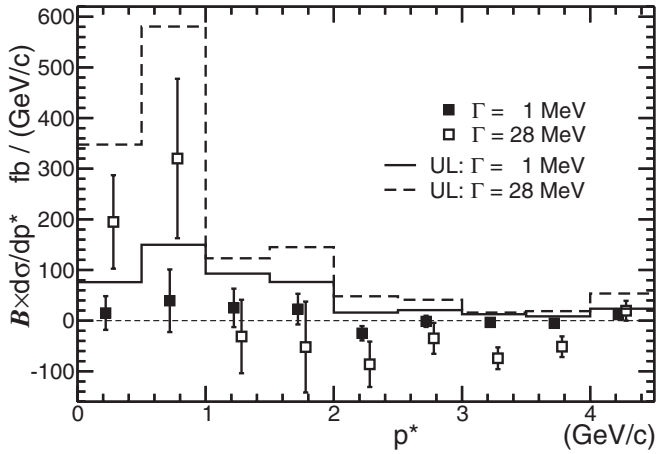
FIG. 4. Product of the $\Theta_c(3100)^0$ differential production cross section and its branching fraction to pD^{*-} (symbols) and corresponding 95% CL upper limits (lines), assuming natural widths of $\Gamma = 1$ MeV (solid) and $\Gamma = 28$ MeV (open/dashed), as functions of c.m. momentum.

$\Theta_c(3100)^0$ produced per $q\bar{q}$ ($q = udsc$) event and per $c\bar{c}$ event by dividing by the respective cross sections for these types of events; we also calculate a limit per $\Upsilon(4S)$ decay by integrating $\mathcal{B} \cdot d\sigma/dp^*$ over the range $p^* < 2$ GeV/c (the kinematic limit for B meson decays is 1.8 GeV/c) and dividing by our effective cross section for $e^+e^- \rightarrow \Upsilon(4S)$. These central values and limits are given in Table I.

In summary, we perform a search in e^+e^- annihilations at $\sqrt{s} = 10.58$ GeV for the pentaquark candidate state $\Theta_c(3100)^0$ reported by the H1 collaboration. We use the same decay mode as H1, $\Theta_c(3100)^0 \rightarrow pD^{*-}$, and find no evidence for the production of this state in a sample of over 125 000 pD^{*-} combinations. The components of this sample from c-quark fragmentation and $B^0/\bar{B}^0 + B^{\pm}$ decays are both at least 100 times larger than the sample used by H1, implying that neither hard charm quarks nor B mesons produced in deep inelastic scattering can be the source of the H1 signal. We set upper limits on the product of the inclusive $\Theta_c(3100)^0$ production cross section times branching fraction to this mode for two assumptions as to its natural width, which are valid for any state in the vicinity of 3100 MeV/c^2. It would be interesting to compare these limits with the rate expected for an ordinary

TABLE I. Total production cross section of the $\Theta_c(3100)^0$ pentaquark candidate times its branching fraction to pD^{*-}, $\mathcal{B} \cdot \sigma$, in e^+e^- annihilations at $\sqrt{s} = 10.58$ GeV, for two assumed values of the natural width. The corresponding 95% CL upper limits on $\mathcal{B} \cdot \sigma$ and on $\mathcal{B}$ times the yields per $e^+e^- \rightarrow q\bar{q}$ event, $e^+e^- \rightarrow c\bar{c}$ event, and $\Upsilon(4S)$ decay.

	$\Gamma = 1$ MeV	$\Gamma = 28$ MeV
$\mathcal{B} \cdot \sigma$ (fb)	40 ± 44	102 ± 111
	<117	<297
$\mathcal{B} \times$ yield $\times 10^{-5}$per		
$e^+e^- \rightarrow q\bar{q}$ event	<3.4	<8.8
$e^+e^- \rightarrow c\bar{c}$ event	<8.5	<22
$\Upsilon(4S)$ decay	<12	<37

charmed baryon of mass ~ 3100 MeV/c^2. However rates have been measured for only two charmed baryons, the $\Lambda_c^+(2285)$ [10,11] and $\Sigma_c(2455)$ [11], with precision that does not allow a meaningful estimate of the mass dependence. The mass dependence observed [11] for non-charmed baryons in e^+e^- annihilations would predict a rate for a 3100 MeV/c^2 baryon about 1000 times smaller than that of the $\Lambda_c^+(2285)$. Our limits for a narrow state in both $e^+e^- \rightarrow c\bar{c}$ and $\Upsilon(4S)$ events are roughly 1000 and 500 times below the measured $\Lambda_c^+(2285)$ and $\Sigma_c(2455)$ rates, respectively. As a result the existence of an ordinary charmed baryon with this mass and decay mode cannot be excluded.

[1] T. Nakano *et al.* (LEPS Collaboration), Phys. Rev. Lett. **91**, 012002 (2003); J. Barth *et al.* (SAPHIR Collaboration), Phys. Lett. B **572**, 127 (2003); S. Stepanyan *et al.* (CLAS Collaboration), Phys. Rev. Lett. **91**, 252001 (2003); V. Kubarovsky *et al.* (CLAS Collaboration), Phys. Rev. Lett. **92**, 032001 (2004); **92**, 049902(E) (2004); V. V. Barmin *et al.* (DIANA Collaboration), Phys. At. Nucl. **66**, 1715 (2003); A. Aleev *et al.* (SVD Collaboration), Yad. Fiz. **68**, 1012 (2005); A. Airapetian *et al.* (HERMES Collaboration), Phys. Lett. B **585**, 213 (2004); A. E. Asratyan, A. G. Dolgolenko, and M. A. Kubantsev, Phys. At. Nucl. **67**, 682 (2004); M. Abdel-Bary *et al.* (COSY-TOF Collaboration), Phys. Lett. B **595**, 127 (2004); S.

Chekanov *et al.* (ZEUS Collaboration), Phys. Lett. B **591**, 7 (2004).

[2] C. Alt *et al.* (NA49 Collaboration), Phys. Rev. Lett. **92**, 042003 (2004).

[3] A. Aktas *et al.* (H1 Collaboration), Phys. Lett. B **588**, 17 (2004).

[4] See, e.g., A. R. Dzierba, C. A. Meyer, and A. P. Szczepaniak, J. Phys.: Conf. Ser. **9**, 192 (2005), and references therein.

[5] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. Lett. **95**, 042002 (2005).

[6] B. Aubert *et al.* (*BABAR* Collaboration), Nucl. Instrum. Methods Phys. Res., Sect. A **479**, 1 (2002).

[7] T. Sjostrand, Comput. Phys. Commun. **82**, 74 (1994).

[8] D. J. Lange, Nucl. Instrum. Methods Phys. Res., Sect. A **462**, 152 (2001).

[9] S. Agostinelli *et al.* (GEANT4 Collaboration), Nucl. Instrum. Methods Phys. Res., Sect. A **506**, 250 (2003).

[10] R. Seuster, *et al.* (Belle Collaboration), Phys. Rev. D **73**, 032002 (2006).

[11] S. Eidelman *et al.* (Particle Data Group), Phys. Lett. B **592**, 1 (2004).