RAPID COMMUNICATIONS

PHYSICAL REVIEW D **71,** 091101(R) (2005)

Search for *CP* violation and a measurement of the relative branching fraction in $D^+ \to K^-K^+\pi^+$ decays

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(Received 1 February 2005; published 5 May 2005)

We report on a search for the *CP* asymmetry in the singly Cabibbo-suppressed decays $D^+ \rightarrow K^- K^+ \pi^+$ and in the resonant decays $D^+ \rightarrow \phi \pi^+$ and $D^+ \rightarrow \overline{K}^{*0} K^+$ based on a data sample of 79.9 fb^{-1} recorded by the *BABAR* detector. We use the Cabibbo-favored $D_s^+ \rightarrow K^- K^+ \pi^+$ branching fraction as normalization in the measurements to reduce systematic uncertainties. The *CP* asymmetries obtained are $A_{CP}(K^- K^+ \pi^\pm) = (1.4 \pm 1.0(\text{stat}) \pm 0.8(\text{syst})) \times 10^{-2}$, $A_{CP}(\phi \pi^\pm) = (0.2 \pm 1.5(\text{stat}) \pm 0.6(\text{syst})) \times 10^{-2}$, and $A_{CP}(\overline{K}^{*0} K^\pm) = (0.9 \pm 1.7(\text{stat}) \pm 0.7(\text{syst})) \times 10^{-2}$. The relative branching fraction $\Gamma(D^+ \rightarrow K^- K^+ \pi^+)/\Gamma(D^+ \rightarrow K^- \pi^+ \pi^+)$ is also measured and is found to be $(10.7 \pm 0.1(\text{stat}) \pm 0.2(\text{syst})) \times 10^{-2}$.

DOI: 10.1103/PhysRevD.71.091101 PACS numbers: 11.30.Er, 13.25.Ft, 14.40.Lb

I. INTRODUCTION

Singly Cabibbo-suppressed (SCS) *D*-meson decays are predicted in the standard model (SM) to exhibit *CP*-violating charge asymmetries of the order of 10^{-3} [1]. Direct *CP* violation in SCS decays could arise from the interference between tree-level [Fig. 1(a)] and penguin [Fig. 1(b)] decay processes. Doubly Cabibbo-suppressed and Cabibbo-favored (CF) decays are expected to be *CP* invariant in the SM because they are dominated by a single weak amplitude. Measurements of *CP* asymmetries in SCS processes greater than $\mathcal{O}(10^{-3})$ would be evidence of physics beyond the standard model [2].

We define the *CP* asymmetry by

$$A_{CP} = \frac{|\mathcal{A}|^2 - |\overline{\mathcal{A}}|^2}{|\mathcal{A}|^2 + |\overline{\mathcal{A}}|^2}, \tag{1}$$

where $\mathcal{A}$ is the total decay amplitude for D^+ decays and $\overline{\mathcal{A}}$ is the amplitude for the charge-conjugate decays. A_{CP} is nonzero only if there are at least two different decay amplitudes with a *CP*-violating relative weak phase and a *CP*-conserving relative strong phase due to final-state interactions. Equation (1) can be expressed as an asymmetry of branching fractions. We assume that the total decay rates for D^+ and D^- are equal (*CPT* invariance). Assuming further that CF decays are invariant under *CP*, we use branching fractions for CF decays as normalization factors to reduce experimental systematics due to particle identification (PID) and tracking:

$$A_{CP} = \frac{\frac{\mathcal{B}(D^+\rightarrow K^+K^-\pi^+)}{\mathcal{B}(D_s^+\rightarrow K^+K^-\pi^+)} - \frac{\mathcal{B}(D^-\rightarrow K^+K^-\pi^-)}{\mathcal{B}(D_s^-\rightarrow K^+K^-\pi^-)}}{\frac{\mathcal{B}(D^+\rightarrow K^+K^-\pi^+)}{\mathcal{B}(D_s^+\rightarrow K^+K^-\pi^+)} + \frac{\mathcal{B}(D^-\rightarrow K^+K^-\pi^-)}{\mathcal{B}(D_s^-\rightarrow K^+K^-\pi^-)}}. \tag{2}$$

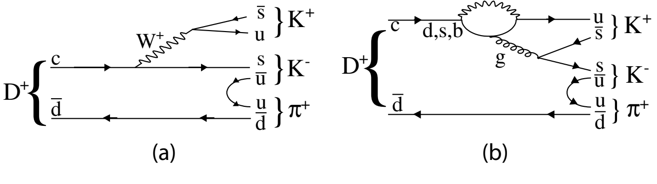

FIG. 1. Parton-level diagrams for $D^+ \rightarrow K^- K^+ \pi^+$ decays: (a) a tree diagram, and (b) a penguin process.

(Throughout this paper we assume that the production of D^+ and D_s^+ mesons is charge symmetric.)

We also measure the *CP* asymmetry in the resonant decays $D^+ \rightarrow \phi \pi^+$ and $D^+ \rightarrow \overline{K}^{*0} K^+$, and determine the relative branching fraction $\Gamma(D^+ \rightarrow K^- K^+ \pi^+)/\Gamma(D^+ \rightarrow K^- \pi^+ \pi^+)$.

II. DETECTOR AND DATA SAMPLE

This analysis is performed with a data sample recorded on and below the $\Upsilon(4S)$ resonance with the *BABAR* detector at the PEP-II asymmetric-energy e^+e^- storage rings at the Stanford Linear Accelerator Center.

The *BABAR* detector is described in detail in Ref. [3]. The silicon vertex tracker (SVT) and the 40-layer cylindrical drift chamber (DCH) embedded in a 1.5-T solenoid measure the momenta and energy loss (dE/dx) of charged particles. A ring-imaging Cherenkov detector (DIRC) is used for charged-particle identification. Photons are detected and electrons identified with a CsI(Tl) electromagnetic calorimeter.

We split the 89.7 fb^{-1} data sample into a randomly selected subsample of 9.8 fb^{-1} to optimize the selection criteria and the remainder (a 79.9 fb^{-1} sample) for the final analysis. This procedure eliminates selection bias. We apply the same selection criteria to the CF and SCS modes whenever possible. We determine selection efficiencies from a sample (145 fb^{-1} equivalent) of Monte Carlo (MC) [4] generated $e^+e^- \rightarrow c\overline{c}$ events. The EVTGEN [5] package was used as the event generator.

III. DATA ANALYSIS

We reconstruct D^+ and D_s^+ [6] decays by selecting events containing at least three charged tracks. Tracks are required to have at least 12 measured DCH coordinates, a minimum transverse momentum of 0.1 GeV/*c*, and to originate within 1.5 cm in *xy* (transverse to the beam) and ±10 cm along the *z* axis (along the e^- beam) of the nominal interaction point. Kaons are identified by a selection on the ratio of likelihood functions derived from dE/dx in the SVT and DCH, and from the Cherenkov angle and number of photons in the DIRC. Pions are identified as tracks that fail a loose kaon identification criterion. The three charged tracks are further constrained to originate at a common vertex, the fit for which is accepted if the χ^2 satisfies $P(\chi^2) > 1\%$. We reject D^+ and D_s^+ mesons from B decays, and thereby reduce backgrounds, by requiring that their momenta in the center-of-mass (c.m.) frame be above 2.4 GeV/c.

In order to reduce the remaining combinatorial background we consider likelihood ratios formed from the probability density functions (PDFs) of the following discriminating variables for the D^+ and D_s^+ decays: c.m. momentum ($p_{\rm c.m.}$), vertex-fit probability with a beam-spot constraint ($P_{\rm BS}(\chi^2)$), and the distance in the xy plane from the interaction point to the D^+ or D_s^+ vertex (d_{xy}). The quantity $P_{\rm BS}(\chi^2)$ is the probability that the decay tracks form a vertex within the beam-spot region. Most of the D^+ mesons decay outside this region, thus the probability $P_{\rm BS}(\chi^2)$ is small for the D^+ signal and is large for combinatorial background. Background distributions are taken from sidebands in the $K^-K^+\pi^+$ mass, while signal distributions are obtained from the signal regions, with the normalized sideband distributions subtracted.

For $D^\pm$ decays, the $m_{KK\pi}$ signal band is defined as $[1.840, 1.896]$ GeV/c^2 and the sideband mass regions as $[1.805, 1.833]$ GeV/c^2 and $[1.903, 1.931]$ GeV/c^2 [see Fig. 2(a)]. Product likelihoods are constructed for the signal, $\mathcal{L}_{\rm sig} = \prod_i \mathcal{L}^i_{\rm sig}(x_i)$, and the background, $\mathcal{L}_{\rm bkg} = \prod_i \mathcal{L}^i_{\rm bkg}(x_i)$, where i runs over two or more of the variables described.

About 16% of the events have more than one D^+ meson candidate. For such events the candidate with the highest likelihood ratio is selected.

The sensitivity $S/\Delta S$, where S and ΔS refer to the signal yield and its uncertainty, is optimized as a function of the product likelihood ratio $r \equiv \mathcal{L}_{\rm sig}/\mathcal{L}_{\rm bkg}$ formed using $p_{\rm c.m.}$ and $P_{\rm BS}(\chi^2)$; the optimal selection is found to be $r \geq 4.3$. This criterion is applied to both CF and SCS decays. When we use the analogous ratio r_1 obtained by including the PDF for d_{xy} in $\mathcal{L}_{\rm sig}$ and $\mathcal{L}_{\rm bkg}$, the sensitivity is nearly as good [d_{xy} is highly correlated with $P_{\rm BS}(\chi^2)$]. The results we find using r_1 provide a measure of systematic uncertainty.

The subsamples for the decays $D^+ \to \phi\pi^+$ and $D^+ \to \overline{K}^{*0}K^+$ are selected by requiring that the invariant mass of the resonant decays be within 10 and 50 MeV/c^2 of the nominal ϕ and $\overline{K}^{*0}$ masses, respectively [7]. In addition, the resonant signal samples are enhanced by a selection on the cosine of the helicity angle ($\cos\theta_H$). In the $D^+ \to \phi\pi^+$ decay mode, the helicity angle is defined as the angle between the K^- and the π^+ in the ϕ rest frame. In the $D^+ \to \overline{K}^{*0}K^+$ decay mode, the helicity angle is defined as the angle between the K^- and the K^+ in the $\overline{K}^{*0}$ rest frame. Maximum sensitivity is obtained when $|\cos\theta_H| \geq 0.2$ and $|\cos\theta_H| \geq 0.3$ for $D^+ \to \phi\pi^+$ and for $D^+ \to \overline{K}^{*0}K^+$, respectively.

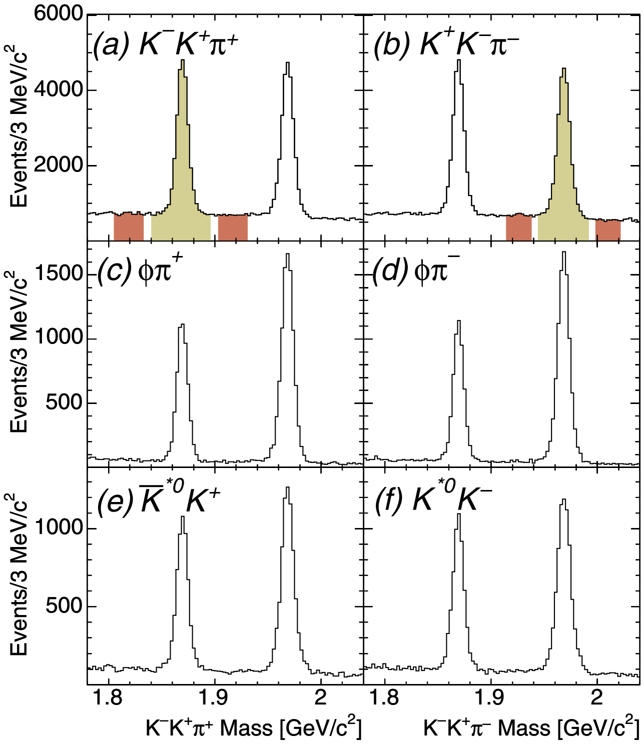

FIG. 2 (color online). $KK\pi$ mass distributions for positively charged (left panels) and negatively charged (right panels) D and D_s candidates for events satisfying the requirement $r \geq 4.3$. (a),(b) are for all $KK\pi$ candidates, while (c), (d) are for $\phi\pi$ candidates, and (e),(f) for $\overline{K}^{*0}K$ candidates. Signal (yellow or light shaded) and sidebands (red or darker shaded) regions are shown for D^+ and D_s^+ decays in (a) and (b), respectively.

The CF $D_s^+ \to K^-K^+\pi^+$ decays are selected by a procedure identical to that for the SCS $D^+ \to K^-K^+\pi^+$ decays. We choose the signal $m_{KK\pi}$ region to be $[1.944, 1.992]$ GeV/c^2, while the sidebands are chosen to be $[1.914, 1.938]$ and $[1.998, 2.022]$ GeV/c^2, respectively [see Fig. 2(b)]. In addition, contamination from $D^+ \to K^-\pi^+\pi^+$ decays is removed as follows: for all $KK\pi$ candidates, the kaon with the same charge as the pion is treated as a pion and then the $K\pi\pi$ invariant mass is calculated. We observe a D^+ peak, indicating that part of the D_s^+ signal is composed of misidentified D^+ candidates. Events in the region $1.855 \leq m_{K\pi\pi} \leq 1.883$ GeV/c^2 are removed from the D_s^+ sample. Contamination from $D^{*+} \to D^0(\to K^-\pi^+, K^-K^+)\pi^+$ decays is removed by eliminating events for which $m_{K^-h^+} \geq 1.84$ GeV/c^2. Candidates for $D^+ \to K^-\pi^+\pi^+$ are eliminated if either $K\pi$ combination satisfies this requirement on $m_{K^-\pi^+}$. Partially reconstructed $D^{*+} \to D^0(\to K^-\pi^+\pi^0)\pi^+$ decays can also be misidentified as $K^-K^+\pi^+$ candidates if the π^0 is missed and the charged pion is misidentified as a kaon. Most of these decays are eliminated by assigning a pion mass to kaon tracks and removing candidates for which the mass difference $(m_{K^-\pi^+\pi^+} - m_{K^-\pi^+})$ lies in the range $[0.139, 0.150]$ GeV/c^2.

Figure 2 shows the mass distributions obtained after all selection criteria are applied. The yields, listed in Table I,

TABLE I. Yields of background subtracted events, separately for each charge.

Parent charge	+	−
$D^\pm \to K^-K^+\pi^\pm$	21 632 ± 228	20 940 ± 226
$D^\pm \to \phi\pi^\pm$	5452 ± 87	5327 ± 86
$D^\pm \to K^{*0}K^\pm$	5247 ± 96	5113 ± 96
$D_s^\pm \to K^-K^+\pi^\pm$	23 066 ± 217	22 928 ± 214

TABLE II. Efficiencies for positively (ε^+) and negatively (ε^-) charged D and D_s meson decays. Efficiencies are in percent. The stated uncertainties are due to MC statistics only.

Decay	ε^+	ε^-
$D^\pm \to K^-K^+\pi^\pm$	8.20 ± 0.04	8.26 ± 0.04
$D^\pm \to \phi\pi^\pm$	7.67 ± 0.07	7.63 ± 0.07
$D^\pm \to K^{*0}K^\pm$	5.88 ± 0.07	5.90 ± 0.07
$D_s^\pm \to K^-K^+\pi^\pm$	3.77 ± 0.02	3.79 ± 0.02

TABLE III. Results of the CP-asymmetry measurements, A_{CP}. Also listed are the values for $A_{CP}^{(2)}$, the asymmetry computed without the normalization mode.

Decay	A_{CP} $[10^{-2}]$	$A_{CP}^{(2)}$ $[10^{-2}]$
$K^-K^+\pi^\pm$	+1.36 ± 1.01	+2.07 ± 0.84
$\phi\pi^\pm$	+0.24 ± 1.45	+0.94 ± 1.33
$\overline{K}^{*0}K^\pm$	+0.88 ± 1.67	+1.58 ± 1.57

are computed by subtracting from the number of events in the signal region a scaled background estimate, obtained from the sideband mass region.

The efficiencies needed for the A_{CP} calculation are obtained from a sample of MC generated $c\bar{c}$ events to which the same selection criteria are applied. The efficiencies for each decay mode are shown in Table II.

We obtain A_{CP} using Eq. (2) and replacing branching fractions with efficiency-corrected yields. The results are shown in Table III. We also studied the CP asymmetry in 16 bins of the $D^+ \to K^-K^+\pi^+$ Dalitz plot and found that the asymmetry is consistent with being constant (with a probability of 51%) and zero.

We use the CF sample of $D^+ \to K^-\pi^+\pi^+$ decays, obtained using selection criteria identical to the SCS case, to determine the relative branching fraction $\Gamma(D^+ \to K^-K^+\pi^+)/\Gamma(D^+ \to K^-\pi^+\pi^+)$ as follows. The CF and SCS Dalitz plots are first divided into equally populated bins (16 bins for the SCS mode, 64 for the CF mode). Next, the signal and normalization yields and efficiencies are calculated bin by bin. The efficiency-corrected yields are then summed and divided to obtain the ratio. Figure 3 shows the mass distribution in the CF $D^\pm \to K^\mp\pi^\pm\pi^\pm$ mode, for which the average efficiency is $10.03 \pm 0.01(\mathrm{stat})\%$. We obtain a relative branching fraction of $(10.7 \pm 0.1(\mathrm{stat})) \times 10^{-2}$. The difference in the relative branching fractions measured separately for D^+ and D^- mesons is consistent with the CP asymmetry reported above.

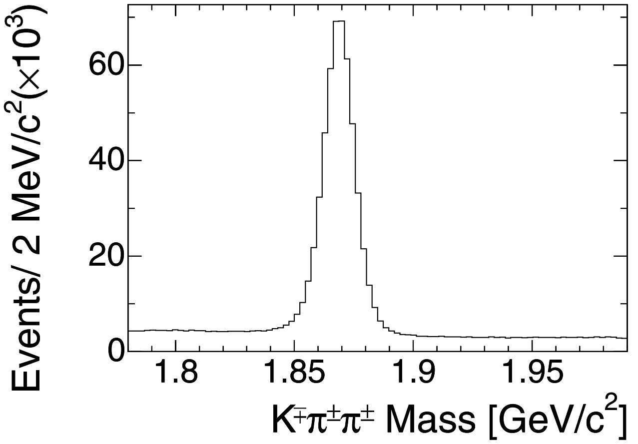

FIG. 3. Mass distribution for $D^\pm \to K^\mp\pi^\pm\pi^\pm$ decays.

IV. SYSTEMATIC UNCERTAINTIES AND CROSS-CHECKS

The only difference between the final states from $D_s^\pm$ and $D^\pm$ decays considered here is a slightly harder momentum spectrum for the $D_s^\pm$ decay products. In turn, these small differences are corrected for by the efficiencies which come from MC. Any charge asymmetry in the detection of pions thus cancels when $D_s^\pm \to K^-K^+\pi^\pm$ decays are used as normalization, as in Eq. (2). We estimate the systematic uncertainty on the CP asymmetries by combining estimates of the contributions from various identified sources listed in Table IV.

The uncertainty due to small differences in momentum spectra of π, K from D^+ and D_s^+ decays, 0.06%, is conservatively estimated as 3 times the maximum difference in π, K asymmetries in the efficiencies from tracks from D^+ vs those from D_s^+ decays. We evaluate an uncertainty for the background subtraction by increasing by 50% the widths of the sideband mass regions. The uncertainty is taken to be the resulting difference in the central value of A_{CP}. The uncertainties in the likelihood-ratio technique are estimated with two variants: (i) tightening the likelihood ratio to produce a 10% change in the yields, and (ii) using the likelihood ratio r_1 (described above) in place of r. The systematic uncertainty is chosen to be the larger of the two

TABLE IV. Systematic uncertainties for the CP asymmetries.

Source	$K^-K^+\pi^\pm$ A_{CP} $[10^{-2}]$	$\phi\pi^\pm$ A_{CP} $[10^{-2}]$	$\overline{K}^{*0}K^\pm$ A_{CP} $[10^{-2}]$
MC simulation	0.06	0.06	0.06
Background estimate	0.63	0.32	0.49
Selection criteria	0.46	0.54	0.54
Total	0.78	0.63	0.73

TABLE V. Systematic uncertainties for the relative branching fraction.

Source	Uncertainty $[10^{-2}]$
PID + tracking	0.22
Background estimate	0.05
Selection criteria	0.02
Total	0.23

changes. Table IV summarizes these systematic uncertainties for the observed *CP* asymmetries.

We performed two cross-checks on our measurement of A_{CP}. First, we calculated an alternative measure of *CP* asymmetry without using $D_s^+ \to K^- K^+ \pi^+$ decays as normalization, which we labeled $A_{CP}^{(2)}$ in Table III. We find its values to be consistent with our measurements of A_{CP}. Second, we measured the *CP* asymmetry for a control sample: the CF decays $D_s^+ \to K^- K^+ \pi^+$ (nonresonant as well as resonant). This asymmetry is expected to be zero within the SM. In $D_s^+ \to K^- K^+ \pi^+$ decays, both the D_s^+ and the D_s^- decay to two oppositely charged kaons and only the pion charge differs in particle and antiparticle decays. Thus, any detector-induced asymmetry would arise only from a charge asymmetry in pion tracking and is expected to be very small. Indeed the measured value is $(+0.6 \pm 0.8) \times 10^{-2}$.

As a final cross-check, the *CP* asymmetry has also been studied as a function of the D^+ laboratory momentum, as well as by the run period. The momentum distributions in data and MC agree very well and no significant dependence on momentum or detector operation conditions is observed.

A summary of the systematic uncertainties for the relative branching fraction $\Gamma(D^+ \to K^- K^+ \pi^+)/\Gamma(D^+ \to K^- \pi^+ \pi^+)$ is given in Table V. The fractional uncertainty due to PID and tracking has been estimated as 2.1%, computed as the sum in quadrature of 1.1% for PID and 1.8% for tracking [8]. The PID uncertainty is estimated from a comparison of PID efficiencies in data and MC. The tracking uncertainty, which is the uncertainty on the K/π efficiency ratio, is conservatively estimated as 3 times its value obtained using MC.

TABLE VI. Results of the *CP*-asymmetry (A_{CP}) measurements for $D^\pm$ decays.

Decay	A_{CP} $[10^{-2}]$
$K^- K^+ \pi^\pm$	$+1.4 \pm 1.0(\text{stat}) \pm 0.8(\text{syst})$
$\phi\pi^\pm$	$+0.2 \pm 1.5(\text{stat}) \pm 0.6(\text{syst})$
$\overline{K}^{*0} K^\pm$	$+0.9 \pm 1.7(\text{stat}) \pm 0.7(\text{syst})$

V. SUMMARY

We have searched for a *CP* asymmetry in $D^+ \to K^- K^+ \pi^+$, $D^+ \to \phi\pi^+$, and $D^+ \to \overline{K}^{*0} K^+$ decays and measured the relative branching fraction of $D^+ \to K^- K^+ \pi^+$ decays, with a data sample of 79.9 fb^{-1} collected by the *BABAR* experiment.

The measurements of the *CP* asymmetries are summarized in Table VI. These results are in agreement with previous published results [9], with our results in the resonant modes having significantly smaller uncertainties.

Further, we obtain a branching fraction for $D^+ \to K^- K^+ \pi^+$ decays relative to that for $D^+ \to K^- \pi^+ \pi^+$ decays of $(10.7 \pm 0.1(\text{stat}) \pm 0.2(\text{syst})) \times 10^{-2}$. This result is a significant improvement over previous measurements [10].

ACKNOWLEDGMENTS

We are grateful for the excellent luminosity and machine conditions provided by our PEP-II colleagues, and for the substantial dedicated effort from the computing organizations that support *BABAR*. The collaborating institutions wish to thank SLAC for its support and kind hospitality. This work is supported by DOE and NSF (USA), NSERC (Canada), IHEP (China), CEA and CNRS-IN2P3 (France), BMBF and DFG (Germany), INFN (Italy), FOM (The Netherlands), NFR (Norway), MIST (Russia), and PPARC (United Kingdom). Individuals have received support from CONACyT (Mexico), A. P. Sloan Foundation, Research Corporation, and Alexander von Humboldt Foundation.

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[1] F. Buccella, M. Lusignoli, G. Mangano, G. Miele, A. Pugliese, and P. Santorelli, Phys. Lett. B **302**, 319 (1993); F. Buccella, M. Lusignoli, G. Miele, A. Pugliese, and P. Santorelli, Phys. Rev. D **51**, 3478 (1995); M. Golden and B. Grinstein, Phys. Lett. B **222**, 501 (1989).

[2] S. Bianco, F. L. Fabbri, D. Benson, and I. Bigi, Riv. Nuovo Cimento **26N7-8**, 1 (2003); A. Le Yaouanc, L. Oliver, and J. C. Raynal, Phys. Lett. B **292**, 353 (1992).

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

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

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

[6] Charge conjugation is assumed throughout the selection unless otherwise indicated.

[7] S. Eidelman *et al.*, Phys. Lett. B **592**, 1 (2004).

[8] Estimates of tracking and PID systematics are discussed in more detail in *BABAR* Collaboration, B. Aubert *et al.*, Phys. Rev. D **69**, 071101 (2004) and in *BABAR* Collaboration, B. Aubert *et al.*, Phys. Rev. Lett. **92**, 241802 (2004).

[9] FOCUS Collaboration, J. M. Link *et al.*, Phys. Lett. B **491**, 232 (2000); **495**, 443(E) (2000); E791 Collaboration, E. M. Aitala *et al.*, Phys. Lett. B **403**, 377 (1997); E687 Collaboration, P. L. Frabetti *et al.*, Phys. Rev. D **50**, R2953 (1994).

[10] E687 Collaboration, P. L. Frabetti *et al.*, Phys. Lett. B **351**, 591 (1995); SELEX Collaboration, S. Y. Jun *et al.*, Phys. Rev. Lett. **84**, 1857 (2000).