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Title
Measurement of the Branching Fraction of Y(4S)→B0B̄0

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Measurement of the Branching Fraction of $\Upsilon(4S) \rightarrow B^0\bar{B}^0$

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We report the first measurement of the branching fraction f_{00} for $\Upsilon(4S) \rightarrow B^0\bar{B}^0$. The data sample consists of 81.7 fb^{-1} collected at the $\Upsilon(4S)$ resonance with the *BABAR* detector at the SLAC PEP-II asymmetric-energy e^+e^- storage ring. Using partial reconstruction of the decay $\bar{B}^0 \rightarrow D^{*+}\ell^-\bar{\nu}_\ell$ in which only the charged lepton and the soft pion from the decay $D^{*+} \rightarrow D^0\pi^+$ are reconstructed, we obtain $f_{00} = 0.487 \pm 0.010\text{(stat)} \pm 0.008\text{(syst)}$. Our result does not depend on the branching fractions of $\bar{B}^0 \rightarrow D^{*+}\ell^-\bar{\nu}_\ell$ and $D^{*+} \rightarrow D^0\pi^+$ decays, on the ratio of the charged and neutral B meson lifetimes, nor on the assumption of isospin symmetry.

Isospin violation in the decay $\Upsilon(4S) \rightarrow B\bar{B}^0$ will lead to a difference between the branching fractions $f_{00} \equiv \mathcal{B}(\Upsilon(4S) \rightarrow B^0\bar{B}^0)$ and $f_{+-} \equiv \mathcal{B}(\Upsilon(4S) \rightarrow B^+B^-)$. Predictions for the ratio $R^{+/0} \equiv f_{+-}/f_{00}$ range from 1.03 to 1.25 [1]. Measurements of $R^{+/0}$ [2–6] have been made assuming isospin symmetry in specific decay rates and resulting in an average value of 1.006 ± 0.039 [7], consistent with isospin conservation in $\Upsilon(4S)$ decays to $B\bar{B}$. To date no measurement has been made of either f_{00} or f_{+-}. In this Letter we report the first direct measurement of f_{00}. It is completely independent of the previous measurements of $R^{+/0}$. Independent measurements of f_{00} and $R^{+/0}$ can be used to constrain the $\Upsilon(4S) \rightarrow$ non-$B\bar{B}$ fraction. The f_{00} value is important for measuring absolute $\Upsilon(4S)$ branching fractions and for measuring V_{cb}, the Cabibbo-Kobayashi-Maskawa matrix element.

The data sample used in this analysis consists of 81.7 fb^{-1} collected at the $\Upsilon(4S)$ resonance (on-resonance) and 9.6 fb^{-1} collected 40 MeV below the resonance (off-resonance). The on-resonance data sample has a mean energy of 10.580 GeV and an energy rms spread of 4.6 MeV. Because of the small spread, any plausible energy dependence of f_{00} has a negligible effect on the central value. A simulated sample of $B\bar{B}$ with integrated luminosity equivalent to approximately 3 times the data is used for background studies.

A detailed description of the *BABAR* detector and the algorithms used for track reconstruction and particle identification is provided elsewhere [8]. A brief summary is given here. High-momentum particles are reconstructed by matching hits in the silicon vertex tracker (SVT) with track elements in the drift chamber (DCH). Lower momentum tracks, which do not leave signals on many wires in the DCH due to the bending induced by a magnetic field, are reconstructed in the SVT alone. Electrons are identified by the ratio of the track momentum to the associated energy deposited in the calorimeter (EMC), the transverse profile of the shower, the energy loss in the drift chamber, and information from a Cherenkov detector (DIRC). Muons are identified in the instrumented flux return, composed of resistive plate chambers and layers of iron. Muon candidates are required to have a path length and hit distribution in the instrumented flux return and energy deposition in the EMC consistent with that expected for a minimum-ionizing particle. The *BABAR* detector Monte Carlo simulation is based on GEANT4 [9].

We select the decays $\bar{B}^0 \rightarrow D^{*+}\ell^-\bar{\nu}_\ell$, $D^{*+} \rightarrow D^0\pi^+$ ($\ell = e, \mu$). The inclusion of charge-conjugate reactions is implied throughout this Letter. The sample of events in which at least one $\bar{B}^0 \rightarrow D^{*+}\ell^-\bar{\nu}_\ell$ candidate decay is found is labeled the "single-tag sample." The number of signal decays in this sample is

$$N_s = 2N_{B\bar{B}}f_{00}\varepsilon_s\mathcal{B}(\bar{B}^0 \rightarrow D^{*+}\ell^-\bar{\nu}_\ell), \qquad (1)$$

where $N_{B\bar{B}}$ is the total number of $B\bar{B}$ events in the data sample and ε_s is the reconstruction efficiency for $\bar{B}^0 \rightarrow D^{*+}\ell^-\bar{\nu}_\ell$. We determine $N_{B\bar{B}} = 88.7$ million events by counting the number of hadronic decays in the on-resonance data and subtracting the $e^+e^- \rightarrow q\bar{q}$ ($q = u, d, s,$ or c quark) component using off-resonance data, as described in detail in Ref. [10]. The error in $N_{B\bar{B}}$ is 1.1% and is dominated by systematic uncertainties. We attribute all $B\bar{B}$ pairs to $\Upsilon(4S)$ decays.

The number of signal events in the subset in which two $\bar{B}^0 \rightarrow D^{*+}\ell^-\bar{\nu}_\ell$ candidates are found is labeled the "double-tag sample." The number of such events is

$$N_d = N_{B\bar{B}}f_{00}\varepsilon_d[\mathcal{B}(\bar{B}^0 \rightarrow D^{*+}\ell^-\bar{\nu}_\ell)]^2, \qquad (2)$$

where ε_d is the efficiency to reconstruct two $\bar{B}^0 \rightarrow D^{*+}\ell^-\bar{\nu}_\ell$ decays in the same event. From Eqs. (1) and (2), f_{00} is given by

$$f_{00} = \frac{CN_s^2}{4N_dN_{B\bar{B}}}, \qquad (3)$$

where we have defined $C \equiv \varepsilon_d/\varepsilon_s^2$. The value of C is 1 if the efficiencies for detecting each B meson are uncorrelated in double-tag events, which, given the pseudoscalar nature of B mesons and the proximity of the $\Upsilon(4S)$ to the $B\bar{B}$ threshold, is expected. Using the Monte Carlo simulation we determine $C = 0.995 \pm 0.008$, where the error is due to the finite size of the simulated sample.

We select the decays $\bar{B}^0 \rightarrow D^{*+}\ell^-\bar{\nu}_\ell$ with a partial reconstruction technique [4,11–13]. In this technique, only the lepton from the decay $\bar{B}^0 \rightarrow D^{*+}\ell^-\bar{\nu}_\ell$ and the soft pion from the decay $D^{*+} \rightarrow D^0\pi^+$ are reconstructed. No attempt is made to reconstruct the D^0, resulting in a high reconstruction efficiency.

The $\bar{B}^0$ decay point is determined from a vertex fit of the soft-pion and lepton tracks, with the vertex constrained to the beam spot position in the x-y plane. We only use events

with vertex-fit probability, $\mathcal{P}_V$, greater than 0.1% to optimize a signal-to-background ratio.

We select hadronic events by requiring at least four charged particle tracks reconstructed in the SVT and the DCH. To reduce non-$B\bar{B}$ background, the ratio of the second to the zeroth Fox-Wolfram moments [14], $R_2 = H_2/H_0$, is required to be less than 0.5.

To suppress leptons from charm decays, all lepton candidates are required to have momenta between 1.5 GeV/c and 2.5 GeV/c in the e^+e^- center-of-mass frame. Soft-pion candidates are required to have center-of-mass momenta between 60 MeV/c and 200 MeV/c. As a consequence of the limited phase space available in the D^{*+} decay, the soft pion is emitted nearly at rest in the D^{*+} rest frame. The D^{*+} four momentum can therefore be computed by approximating its direction as that of the soft pion, and parametrizing its momentum as a linear function of the soft-pion momentum, with parameters obtained from a Monte Carlo simulation. The presence of an undetected neutrino is inferred from conservation of momentum and energy. The neutrino invariant mass squared is calculated as

$$\mathcal{M}^2 \equiv (E_{\text{beam}} - E_{D^*} - E_\ell)^2 - (\mathbf{p}_{D^*} + \mathbf{p}_\ell)^2, \quad (4)$$

where E_{beam} is half the center-of-mass energy and $E_\ell (E_{D^*})$ and $\mathbf{p}_\ell (\mathbf{p}_{D^*})$ are the center-of-mass energy and momentum of the lepton (the D^* meson). We set $\mathbf{p}_B = 0$, which introduces a negligible spread in $\mathcal{M}^2$ compared with the approximation of the D^* momentum based on the soft pion. For signal decays that are properly reconstructed, the $\mathcal{M}^2$ distribution peaks near zero. Background events, however, are spread over a wide range of $\mathcal{M}^2$ values. We define a signal region ($\mathcal{M}^2 > -2$ GeV^2/c^4) and a side-band region ($-8 < \mathcal{M}^2 < -4$ GeV^2/c^4).

We use the symbol $\mathcal{M}_s^2$ to denote $\mathcal{M}^2$ for any candidate in the single-tag sample. In the double-tag sample, we randomly choose one of the two reconstructed $\bar{B}^0 \rightarrow D^{*+}\ell^-\bar{\nu}_\ell$ candidates as "first" and the other as "second." Their $\mathcal{M}^2$ values are labeled $\mathcal{M}_1^2$ and $\mathcal{M}_2^2$, respectively. We require that $\mathcal{M}_1^2$ fall in the signal region.

The single-tag and double-tag samples have several types of background: continuum, combinatorial $B\bar{B}$, and peaking $B\bar{B}$. The combinatorial $B\bar{B}$ background originates from random combinations of reconstructed leptons and soft pions. The peaking $B\bar{B}$ background is composed of $\bar{B} \rightarrow D^*\pi\ell\bar{\nu}_\ell$ decays with or without an excited charmed resonance D^{**} [15], where the reconstructed soft pion comes from the decay $D^{*+} \rightarrow D^0\pi^+$, leading to an accumulation of these events at high values of $\mathcal{M}^2$. The peaking $B\bar{B}$ background is suppressed by the requirement $p_\ell > 1.5$ GeV/c on the lepton center-of-mass momentum. Such events have an $\mathcal{M}^2$ distribution that is different from the signal, allowing us to extract their contribution in the signal region.

The double-tag sample contains two additional types of background: events in which the first candidate is combinatorial background and the second is signal (called $\mathcal{M}_1^2$-combinatorial background) and events in which the first candidate is peaking background and the second is signal (called $\mathcal{M}_1^2$-peaking background).

To determine N_s and N_d, we perform binned χ^2 fits to one-dimensional histograms of the $\mathcal{M}_s^2$ and $\mathcal{M}_2^2$ distributions of on-resonance data events, ranging from -8 to 2 GeV^2/c^4. Before fitting, we subtract the continuum background contribution from the histograms. This is determined using the $\mathcal{M}_s^2$ and $\mathcal{M}_2^2$ distributions of off-resonance data, scaled to account for the ratio of on-resonance to off-resonance luminosities and the center-of-mass energy dependence of the continuum production cross-section. In addition, the contributions of the $\mathcal{M}_1^2$-combinatorial (3%) and $\mathcal{M}_1^2$-peaking (1%) backgrounds are subtracted from the $\mathcal{M}_2^2$ histogram before doing the fit. The contribution of the $\mathcal{M}_1^2$-combinatorial background is determined from sideband data. The $\mathcal{M}_1^2$-peaking background is determined with simulated events.

After the subtraction, the $\mathcal{M}_s^2$ and $\mathcal{M}_2^2$ histograms are fit separately, to a function whose value for bin j of the histogram is

$$f_j = \sum_t N^t P_j^t, \quad (5)$$

where N^t is the number of events of type t ($t =$ signal, combinatorial, peaking) populating the histogram, and P_j^t is the bin j value of a discrete probability density function obtained from simulated events of type t, normalized such that $\Sigma_j P_j^t = 1$. The fit determines the parameters N^t by minimizing

$$\chi^2 = \sum_j \frac{(H_j - f_j)^2}{\sigma_{H_j}^2 + \sigma_{f_j}^2}, \quad (6)$$

where H_j is the number of entries in bin j of the data histogram being fit; σ_{H_j} is the statistical error on H_j, including uncertainties due to the background subtractions described above; and σ_{f_j} is the error on f_j, determined from the errors on P_j^t, which are due to the finite size of the simulated sample.

The results of the fits are presented in Table I. The $\mathcal{M}_s^2$ and $\mathcal{M}_2^2$ distributions are shown in Fig. 1. The fits yield $N_s = 786200 \pm 1900$ [Confidence Level (C.L.) = 11%] and $N_d = 3560 \pm 70$ (C.L. = 82%). Equation (3) then gives $f_{00} = 0.487 \pm 0.010$, where the error is due to data statistics.

To determine how well the simulation reproduces the $\mathcal{M}_s^2$ and $\mathcal{M}_2^2$ distributions for the combinatorial background in the data, we study the distributions for a sample of same-charge candidates, in which the lepton and soft pion have the same electric charge. We fit the continuum-subtracted $\mathcal{M}_s^2$ and $\mathcal{M}_2^2$ histograms of the same-charge

TABLE I.   Numbers of entries of different types in the $\mathcal{M}_s^2$ and $\mathcal{M}_2^2$ histograms in the signal region.

Source	$\mathcal{M}_s^2$	$\mathcal{M}_2^2$
Signal	$786\,200 \pm 1900$	3560 ± 70
Combinatorial $B\bar{B}$	$558\,080 \pm 470$	1510 ± 20
Peaking $B\bar{B}$	$68\,170 \pm 260$	300 ± 20
Continuum	$240\,600 \pm 1400$	160 ± 40
$\mathcal{M}_1^2$-combinatorial	$\cdots$	180 ± 20
$\mathcal{M}_1^2$-peaking	$\cdots$	60 ± 10

sample using the function $f_j' = NP_j'$, where P_j' is the bin j value of the probability density function of same-charge simulated $B\bar{B}$ events, normalized such that $\Sigma_j P_j' = 1$, and the parameter N is determined by the fit. The histograms, overlaid with the fit function, are shown in Fig. 2. The accumulated differences $D \equiv \Sigma_j (H_j' - f_j')$ between the
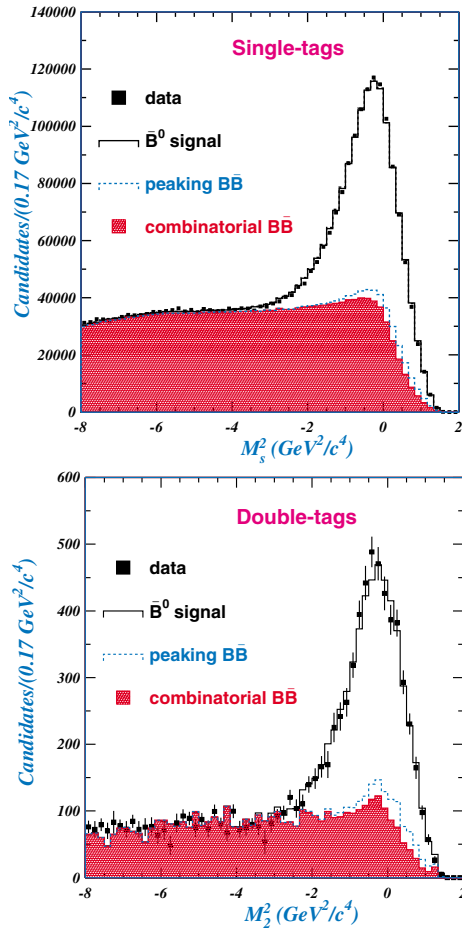
FIG. 1 (color).   The $\mathcal{M}_s^2$ (top) and $\mathcal{M}_2^2$ (bottom) distributions for the on-resonance sample. The continuum background has been subtracted from the distributions. In addition, the $\mathcal{M}_1^2$-combinatorial and the $\mathcal{M}_1^2$-peaking backgrounds have been subtracted from the $\mathcal{M}_2^2$ distribution. The levels of the simulated signal, peaking $B\bar{B}$, and combinatorial $B\bar{B}$ background contributions are obtained from the fit.
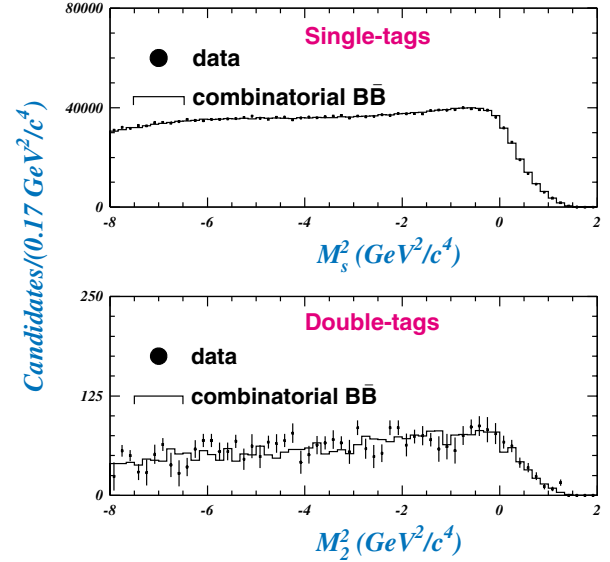

FIG. 2 (color).   The $\mathcal{M}_s^2$ (top) and $\mathcal{M}_2^2$ (bottom) distributions for the same-charge on-resonance sample. The continuum background has been subtracted from the distributions. The $\mathcal{M}_1^2$-combinatorial and the $\mathcal{M}_1^2$-peaking backgrounds have been subtracted from the $\mathcal{M}_2^2$ distribution. The level of the simulated combinatorial $B\bar{B}$ background is obtained from the fit.

same-charge data histograms H_j' and the fit functions are summarized in Table II. Their consistency with zero indicates that the distributions of simulated combinatorial $B\bar{B}$ background events do not lead to significant fake signal yields. Nevertheless, we evaluate a systematic uncertainty on the modeling of the combinatorial background based on the observed difference in the like-sign sample.

We evaluate the absolute systematic uncertainties in f_{00} due to the $\mathcal{M}_1^2$-combinatorial subtraction (0.0005), the $\mathcal{M}_1^2$-peaking background (0.0005), the value of C due to the track multiplicity dependence of the efficiency (0.0015), the finite size of the simulated sample (0.002), the same-charge sample (0.0025), the impact of a possible contribution of non-$B\bar{B}$ decays of the $\Upsilon(4S)$ [16] (0.0025), the peaking background composition (0.004), and the total number of $B\bar{B}$, $N_{B\bar{B}}$ (0.0055).

The dominant contribution to the systematic error comes from a 1.1% systematic uncertainty in $N_{B\bar{B}}$, due mainly to the uncertainty in the tracking efficiency. The peaking $B\bar{B}$

TABLE II.   The difference $D \equiv \Sigma_j (H_j' - f_j')$ between the same-charge data histogram and the fit function, summed over the signal region or over the whole region of the $\mathcal{M}_s^2$ and $\mathcal{M}_2^2$ distributions.

Fit parameter	Signal region		Whole region	
	$\mathcal{M}_s^2$	$\mathcal{M}_2^2$	$\mathcal{M}_s^2$	$\mathcal{M}_2^2$
D	-1300 ± 2100	-80 ± 80	700 ± 3000	70 ± 80
C.L. (%)	57	78	94	98

background is estimated from the simulated sample containing all D^{**} resonances and nonresonant events. We vary the ratio of the branching fraction of the resonant and the nonresonant production such that the variation of this ratio is wide enough to include poorly known decays. We repeat the analysis procedure to determine N_s and N_d. The uncertainties due to the lepton and soft-pion momentum spectra are negligible. We combine the uncertainties given above in quadrature to determine an absolute systematic error of 0.008 for f_{00}.

In summary, we use a partial reconstruction of the decay $\bar{B}^0 \to D^{*+}\ell^-\bar{\nu}_\ell$ to obtain the result

$$f_{00} = 0.487 \pm 0.010(\text{stat}) \pm 0.008(\text{syst}), \qquad (7)$$

where the first error is statistical and the second is systematic. This result is the first, precise, and direct measurement of f_{00}. Since this measurement is made by comparing the numbers of events with one and two reconstructed $\bar{B}^0 \to D^{*+}\ell^-\bar{\nu}_\ell$ decays, it does not depend on branching fractions of $\bar{B}^0 \to D^{*+}\ell^-\bar{\nu}_\ell$ and $D^{*+} \to D^0\pi^+$ decays, on the ratio of the charged and neutral B meson lifetimes, nor on the assumption of isospin symmetry. By combining our f_{00} result with the world average of $R^{+/0}$ noted in the introduction, we add the errors quadratically to obtain $f_{+-} = 0.490 \pm 0.023$. Thus we find the fraction of $\Upsilon(4S) \to$ non-$B\bar{B}$ to be $1 - f_{00} - f_{+-} = 0.023 \pm 0.032$. If $f_{00} + f_{+-} = 1$, our f_{00} result can be averaged with $R^{+/0}$ [7] to yield $f_{00} = 0.494 \pm 0.008$, $f_{+-} = 0.506 \pm 0.008$, and $f_{+-}/f_{00} = 1.023 \pm 0.032$. This value of f_{+-}/f_{00} is in good agreement with isospin conservation in $\Upsilon(4S) \to B\bar{B}$ within errors.

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[1] E. Eichten *et al.*, Phys. Rev. D **21**, 203 (1980); D. Atwood *et al.*, Phys. Rev. D **41**, 1736 (1990); N. Byers *et al.*, Phys. Rev. D **42**, 3885 (1990); G. P. Lepage, Phys. Rev. D **42**, 3251 (1990); M. B. Voloshin, Mod. Phys. Lett. A **18**, 1783 (2003); R. Kaiser *et al.*, Phys. Rev. Lett. **90**, 142001 (2003); Soo-hyeon Nam, Mod. Phys. Lett. A **20**, 95 (2005).

[2] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. D **69**, 071101 (2004).

[3] N. C. Hastings *et al.* (Belle Collaboration), Phys. Rev. D **67**, 052004 (2003).

[4] S. B. Athar *et al.* (CLEO Collaboration), Phys. Rev. D **66**, 052003 (2002).

[5] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. D **65**, 032001 (2002).

[6] J. P. Alexander *et al.* (CLEO Collaboration), Phys. Rev. Lett. **86**, 2737 (2001).

[7] J. P. Alexander *et al.* [Heavy Flavor Averaging Group (HFAG)], hep-ex/0412073 (2004); O. Schneider (private communication).

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

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

[10] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. D **67**, 032002 (2003).

[11] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. Lett. **89**, 011802 (2002).

[12] P. Abreu *et al.* (DELPHI Collaboration), Z. Phys. C **74**, 19 (1997).

[13] H. Albrecht *et al.* (ARGUS Collaboration), Phys. Lett. B **324**, 249 (1994).

[14] G. C. Fox and S. Wolfram, Phys. Rev. Lett. **41**, 1581 (1978).

[15] J. C. Anjos *et al.* (E691 Collaboration), Phys. Rev. Lett. **62**, 1717 (1989).

[16] B. Barish *et al.* (CLEO Collaboration), Phys. Rev. Lett. **76**, 1570 (1996).