International Journal of Modern Physics A


# First Measurement of the Branching Fraction of $e^+e^- \to B^0\overline{B}^0$

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Received 22 October 2004

We report the first measurement of the absolute branching fraction $e^+e^- \to B^0\overline{B}^0$ at the $\Upsilon(4S)$ resonance using data collected with the *BABAR* detector at the PEP-II asymmetric-energy $e^+e^-$ storage ring. The analysis is performed with partial reconstruction of the decay $\overline{B}^0 \to D^{*+}\ell^-\bar{\nu}_\ell$, where the presence of a signal decay is determined using only the lepton and the soft pion from the $D^*$ decay. By reconstructing events with one or two signal decays, we obtain a preliminary result of $e^+e^- \to B^0\overline{B}^0 = 0.486 \pm 0.010(stat.) \pm 0.009(sys.)$. Our result does not depend on branching fractions of the $\overline{B}^0$ and the $D^{*+}$ decays, on the individual simulated reconstruction efficiencies, on the ratio of the charged and neutral $B$ meson lifetimes, or on the assumption of isospin symmetry.

*Keywords*: $f_{00}$, $\Upsilon(4S)$ Resonance, Isospin Violation at $\Upsilon(4S)$.

## 1. Introduction

Isospin violation in decays of $e^+e^- \to B\overline{B}$ at the $\Upsilon(4S)$ resonance results in a difference between the branching fractions $f_{00} \equiv \mathcal{B}(e^+e^- \to B^0\overline{B}^0)$ and $f_{+-} \equiv \mathcal{B}(e^+e^- \to B^+B^-)$. The experimental value of $R^{+/0} \equiv f_{+-}/f_{00}$ measured by *BABAR* is $1.006 \pm 0.036 \pm 0.031$ [1] and $1.10 \pm 0.06 \pm 0.05$ [2], by Belle is $1.01 \pm 0.03 \pm 0.09$ [3], and by CLEO is $1.058 \pm 0.084 \pm 0.136$ [4] and $1.04 \pm 0.07 \pm 0.04$.[5] Theoretical predictions for $R^{+/0}$ range from 1.03 to 1.25.[6] A precision measurement of $f_{00}$ or $f_{+-}$ can be used to re-normalize all $B$ meson branching fractions, eliminating the usual assumption that $f_{00} = f_{+-} = 50\%$, and will bring us closer to an understanding of the isospin violation in the $\Upsilon(4S)$ decays.

This first direct measurement of $f_{00}$ is based on partial reconstruction of the decay $\overline{B}^0 \to D^{*+}\ell^-\bar{\nu}_\ell$.[a] The sample of events in which at least one $\overline{B}^0 \to D^{*+}\ell^-\bar{\nu}_\ell$ candidate decay is found is labeled as "single-tag sample". The number of signal events in such decays is

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

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[a]The inclusion of charge-conjugate states is implied throughout this paper.

where $N_{B\overline{B}} = (88726 \pm 23) \times 10^3$ is the total number of $B\overline{B}$ events in the data sample and $\epsilon_s$ is the reconstruction efficiency of the decay $\overline{B}^0 \to D^{*+}\ell^-\bar{\nu}_\ell$. The technique for measuring $N_{B\overline{B}}$ is described elsewhere.[8] The number of signal events in which two $\overline{B}^0 \to D^{*+}\ell^-\bar{\nu}_\ell$ candidates are found is labeled as "double-tag sample":

$$N_d = N_{B\overline{B}}\, f_{00}\, \epsilon_d\, [\mathcal{B}(\overline{B}^0 \to D^{*+}\ell^-\bar{\nu}_\ell)]^2, \tag{2}$$

where $\epsilon_d$ is the efficiency to reconstruct two $\overline{B}^0 \to D^{*+}\ell^-\bar{\nu}_\ell$ decays in the same event. Using Eq. (1), (2) and defining $C \equiv \epsilon_d/\epsilon_s^2$, $f_{00}$ is given by

$$f_{00} = \frac{C N_s^2}{4 N_d N_{B\overline{B}}}. \tag{3}$$

## 2. Data and Analysis Technique

The *BABAR* data sample used in this paper consists of $81.7\,\mathrm{fb}^{-1}$ collected at the $\Upsilon(4S)$ resonance and $9.6\,\mathrm{fb}^{-1}$ collected 40 MeV below the resonance. A detailed description of the *BABAR* detector is provided elsewhere.[9]

The decays $\overline{B}^0 \to D^{*+}\ell^-\bar{\nu}_\ell$ are partially reconstructed. This technique has been widely used.[4,10,11] All lepton (soft pion) candidates are required to have momenta between $1.5\,\mathrm{GeV}/c$ and $2.5\,\mathrm{GeV}/c$ ($60\,\mathrm{MeV}/c$ and $200\,\mathrm{MeV}/c$) in the $e^+e^-$ center-of-mass (CM) frame. The neutrino invariant mass squared is calculated by

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

where $E_{\mathrm{beam}}$ is the beam energy and $E_\ell$ ($E_{D^*}$) and $\mathbf{p}_\ell$ ($\mathbf{p}_{D^*}$) are the CM energy and momentum of the lepton (the $D^*$ meson).

In what follows, 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 $\overline{B}^0 \to D^{*+}\ell^-\nu_l$ 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 define a signal region $\mathcal{M}^2 > -2\ \mathrm{GeV}^2/c^4$ and a sideband $-8 < \mathcal{M}^2 < -4\ \mathrm{GeV}^2/c^4$. We also require that the first candidate has to fall into the signal region. This selection increases the ratio of signal to background as much as a factor of 2 in statistics compared to that without the selection.[12]

The continuum background events are non-resonant decays of $e^+e^- \to \gamma^* \to q\bar{q}$ where $q = u, d, s, c$. The combinatorial $B\overline{B}$ background is formed from random combinations of reconstructed leptons and soft pions. This background can also be due to the low-momentum soft pions not coming from a $D^*$, produced by production correlation between a $D$ meson and an associated pion from either $B$.[13] The peaking $B\overline{B}$ background is composed of $\overline{B} \to D^*(n\pi)\ell\bar{\nu}_\ell$ decays with or without an excited charmed resonance $D^{**}$.[14]

The $\mathcal{M}_s^2$ and $\mathcal{M}_2^2$ distributions are shown in Fig.1. A binned $\chi^2$ fit yields the values $N_s = 786300 \pm 2000$ and $N_d = 3560 \pm 80$. Using the simulation we determine $C = 0.9946 \pm 0.0078$, where the error is due to the finite size of the sample.

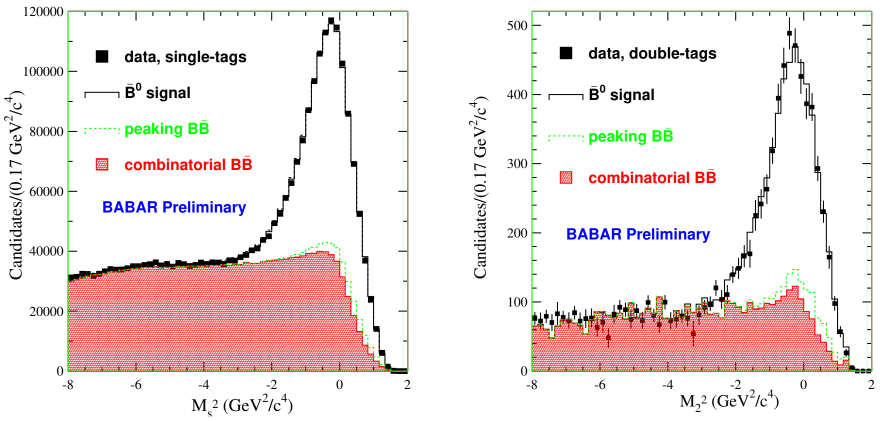


Fig. 1. The $\mathcal{M}_s^2$ (left) and $\mathcal{M}_2^2$ (right) distributions of the on-resonance samples. The continuum background has been subtracted from the $\mathcal{M}_s^2$ and $\mathcal{M}_2^2$ distributions. For the $\mathcal{M}_2^2$ distribution, also the $\mathcal{M}_1^2$-combinatorial, and the $\mathcal{M}_1^2$-peaking have been subtracted. The levels of the simulated signal, peaking $B\overline{B}$ and combinatorial $B\overline{B}$ background contributions are obtained from the fit.

## 3. Systematic Studies

We consider several sources of systematic uncertainties in $f_{00}$. All estimated errors are absolute systematic uncertainties in $f_{00}$ and summarized in Table 1.

Table 1. Summary of the absolute systematic errors for $f_{00}$.

| Source | $\delta(f_{00})$ |
|---|---|
| $\mathcal{M}_1^2$-combinatorial | 0.0005 |
| $\mathcal{M}_1^2$-peaking | 0.0005 |
| Monte Carlo statistics | 0.002 |
| Same-charged events | 0.0025 |
| $\Upsilon(4S) \to$ non-$B\overline{B}$ | 0.0025 |
| Peaking background | 0.004 |
| Efficiency correlation | 0.004 |
| $B$-meson counting | 0.0055 |
| Total | 0.009 |

(1) The systematic uncertainty from the $\mathcal{M}_1^2$-combinatorial contribution subtraction in the $\mathcal{M}_2^2$ histogram is 0.0005. The error is obtained by varying the total $\mathcal{M}_1^2$-combinatorial background by its statistical error.
(2) An error of 0.0005 is estimated due to the subtraction of the $\mathcal{M}_1^2$-peaking contribution in the $\mathcal{M}_2^2$ histogram.
(3) An error of 0.002 is due to the finite size of the simulated sample.
(4) The same-charged events lead to an error of 0.0025 on $f_{00}$.
(5) The upper limit for the branching fraction of $\Upsilon(4S)$ decays into non-$B\overline{B}$ is 4%

at 95% confidence level.[15] The error due to such decays is 0.0025.

(6) The systematic uncertainty of the peaking background is 0.004 on $f_{00}$.

(7) The systematic uncertainty due to the efficiency correlation is estimated from the Monte Carlo simulation to be 0.004.

(8) The error due to the uncertainty in $N_{B\overline{B}}$ is 0.0055.

We combine the uncertainties given above in quadrature to determine an absolute systematic error of 0.009 in $f_{00}$. For more details see Ref. 16.

## 4. Summary

In summary, we have used partial reconstruction of the decay $\overline{B}^0 \to D^{*+}\ell^-\nu_l$ to obtain a preliminary result of

$$f_{00} = 0.486 \pm 0.010(stat.) \pm 0.009(sys.). \tag{5}$$

This result does not depend on branching fractions of the $\overline{B}^0$ and the $D^{*+}$ decays, on the individual simulated reconstruction efficiencies, on the ratio of the charged and neutral $B$ meson lifetimes, or on the assumptions of isospin symmetry.

## 5. Acknowledgments

The author would like to thank all members of the *BABAR* collaboration. This work was supported in part by the U.S. Department of Energy contracts DE-AC03-76SF00515 and DE-FG05-91ER40622.

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