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

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We report the first measurement of the absolute branching fraction $e^+e^- \rightarrow B^0\overline{B}^0$ 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 $\overline{B}^0 \rightarrow D^{*+}\ell^-\bar{\nu}_\ell$, 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 $e^+e^- \rightarrow B^0\overline{B}^0 = 0.486 \pm 0.010(stat.) \pm 0.009(sys.)$. Our result does not depend on branching fractions of the $\overline{B}^0$ and the D^{*+} decay chains, on the individual simulated reconstruction efficiencies, on the ratio of the charged and neutral B meson lifetimes, or on the assumption of isospin symmetry.

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1 Introduction

Isospin violation in decays of $e^+e^- \rightarrow B\overline{B}$ at the $\Upsilon(4S)$ resonance results in a difference between the branching fractions $f_{00} \equiv \mathcal{B}(e^+e^- \rightarrow B^0\overline{B}^0)$ and $f_{+-} \equiv \mathcal{B}(e^+e^- \rightarrow B^+B^-)$. 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], 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 $\overline{B}^0 \rightarrow D^{*+}\ell^-\bar{\nu}_\ell$.[2] The sample of events in which at least one $\overline{B}^0 \rightarrow D^{*+}\ell^-\bar{\nu}_\ell$ candidate decay is found is labeled as "single-tag sample". The number of signal events in such decays is

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

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 ϵ_s is the reconstruction efficiency of the decay $\overline{B}^0 \rightarrow D^{*+}\ell^-\bar{\nu}_\ell$. The technique for measuring $N_{B\overline{B}}$ is described elsewhere [8]. The number of signal events in which two $\overline{B}^0 \rightarrow D^{*+}\ell^-\bar{\nu}_\ell$ candidates are found is labeled as "double-tag sample":

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

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

$$f_{00} = \frac{CN_s^2}{4N_dN_{B\overline{B}}}. \tag{3}$$

2 Dataset 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 $\overline{B}^0 \rightarrow D^{*+}\ell^-\bar{\nu}_\ell$ 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_{beam} is the beam energy and E_ℓ (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 $\overline{B}^0 \rightarrow D^{*+}\ell^-\nu_l$ 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

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

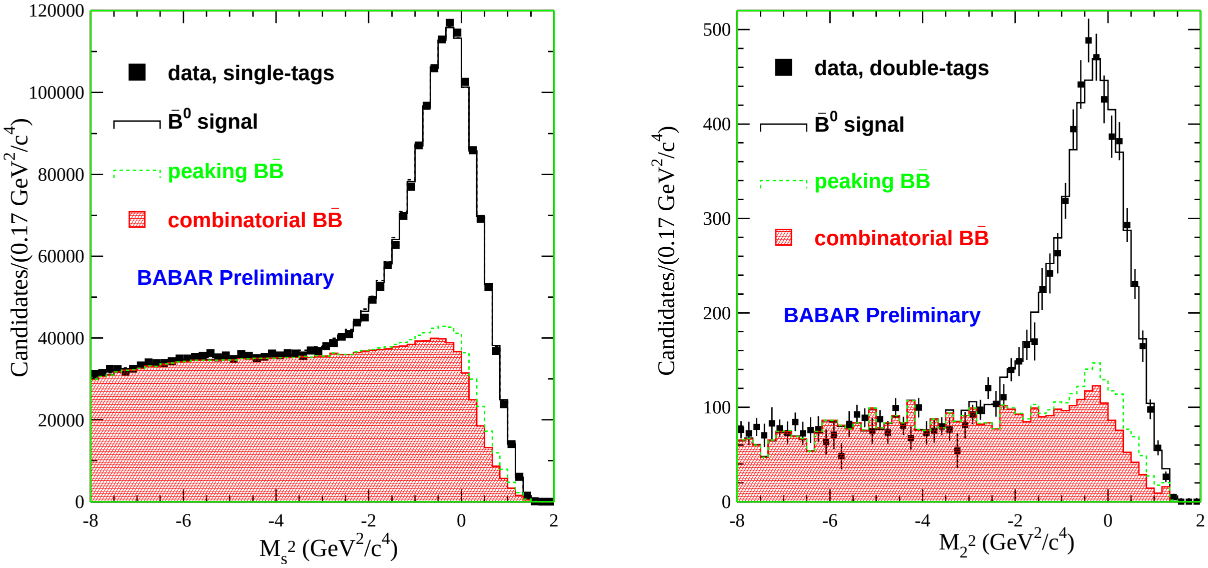

Figure 1: The $\mathcal{M}_s^2$ (left) and $\mathcal{M}_2^2$ (right) distributions of the on-resonance samples. The continuum background has been subtracted from the $\mathcal{M}_s^2$ and $\mathcal{M}_2^2$ distributions. For the $\mathcal{M}_2^2$ distribution, the $\mathcal{M}_1^2$-combinatorial, and 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.

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 D mesons and their associated pions either the same B or the other [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 χ^2 binned fits yield 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.

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.

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.

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
$\Upsilon(4S) \rightarrow$ non-$B\overline{B}$	0.0025
Peaking background	0.004
Efficiency correlation	0.004
B-meson counting	0.0055
Total	0.009

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 $\overline{B}^0 \rightarrow D^{*+}\ell^-\nu_l$ 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^{*+} decay chains, on the individual simulated reconstruction efficiencies, on the ratio of the charged and neutral B meson lifetimes, or on the assumptions of isospin symmetry.

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