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

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We report the first measurement of the absolute branching fraction $e^+e^- \to B^0\bar{B}^0$ 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 $\bar{B}^0 \to D^{*+}\ell^+\bar{\nu}_\ell$, 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 $e^+e^- \to B^0\bar{B}^0 = 0.486 \pm 0.010(\text{stat.}) \pm 0.009(\text{sys.})$. Our result does not depend on branching fractions of the $\bar{B}^0$ 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 $e^+e^- \to B\bar{B}$ at the $\Upsilon(4S)$ resonance results in a difference between the branching fractions $f_{00} \equiv B(e^+e^- \to B^0\bar{B}^0)$ and $f_{+-} \equiv B(e^+e^- \to B^+\bar{B}^-)$. The experimental value of $R^{+/0} \equiv f_{+-}/f_{00}$ measured by BABAR is $1.006 \pm 0.036 \pm 0.031 \pm 1.10 \pm 0.06 \pm 0.05$, by Belle is $1.01 \pm 0.03 \pm 0.09$, and by CLEO is $1.058 \pm 0.084 \pm 0.136$ and $1.04 \pm 0.07 \pm 0.04$. Theoretical predictions for $R^{+/0}$ range from 1.03 to 1.25. 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 $\bar{B}^0 \to D^{*+}\ell^-\bar{\nu}_\ell$. The sample of events in which at least one $\bar{B}^0 \to D^{*+}\ell^-\bar{\nu}_\ell$ candidate decay is found is labeled as “single-tag sample”. The number of signal events in such decays is

$$N_s = 2N_{\text{BB}}f_{00}\epsilon_sB(\bar{B}^0 \to D^{*+}\ell^-\bar{\nu}_\ell),$$

(1)

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aThe inclusion of charge-conjugate states is implied throughout this paper.
where \( N_{\bar{B}\bar{B}} = (88726 \pm 23) \times 10^3 \) is the total number of \( B\bar{B} \) events in the data sample and \( \epsilon_s \) is the reconstruction efficiency of the decay \( \bar{B}^0 \to D^{*+}\ell^-\bar{\nu}_\ell \). The technique for measuring \( N_{\bar{B}\bar{B}} \) is described elsewhere.\(^8\) The number of signal events in which two \( \bar{B}^0 \to D^{*+}\ell^-\bar{\nu}_\ell \) candidates are found is labeled as “double-tag sample”:

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

(2)

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

\[
f_{00} = \frac{CN^2}{4N_dN_{\bar{B}\bar{B}}}.
\]

(3)

2. Data and Analysis Technique

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

The decays \( \bar{B}^0 \to D^{*+}\ell^-\bar{\nu}_\ell \) 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 GeV/c and 2.5 GeV/c (60 MeV/c and 200 MeV/c) in the \( e^+e^- \) center-of-mass (CM) frame. The neutrino invariant mass squared is calculated by

\[
\mathcal{M}^2 \equiv (E_{\text{beam}} - E_{D^*} - E_\ell)^2 - (p_{D^*} + p_\ell)^2,
\]

(4)

where \( E_{\text{beam}} \) is the beam energy and \( E_\ell \) \( (E_{D^*}) \) and \( p_\ell \) \( (p_{D^*}) \) are the CM energy and momentum of the lepton (the \( D^* \) meson).

In what follows, we use the symbol \( \mathcal{M}_2 \) 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 \( \bar{B}^0 \to D^{*+}\ell^-\bar{\nu}_\ell \) candidates as “first” and the other as “second”. Their \( \mathcal{M}^2 \) values are labeled \( \mathcal{M}_2^1 \) and \( \mathcal{M}_2^2 \), respectively. We define a signal region \( \mathcal{M}^2 > -2 \text{ GeV}^2/c^4 \) and a sideband \(-8 < \mathcal{M}^2 < -4 \text{ GeV}^2/c^4 \). 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.\(^1^2\)

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 \( B\bar{B} \) 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 \( B \).\(^1^3\) The peaking \( B\bar{B} \) background is composed of \( \bar{B} \to D^*(n\pi)\ell\bar{\nu}_\ell \) decays with or without an excited charmed resonance \( D^{**} \).\(^1^4\)

The \( \mathcal{M}_2^1 \) 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.
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>
<thead>
<tr>
<th>Source</th>
<th>$\delta(f_{00})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mathcal{M}_2^2$-combinatorial</td>
<td>0.0005</td>
</tr>
<tr>
<td>$\mathcal{M}_2^2$-peaking</td>
<td>0.0005</td>
</tr>
<tr>
<td>Monte Carlo statistics</td>
<td>0.002</td>
</tr>
<tr>
<td>Same-charged events</td>
<td>0.0025</td>
</tr>
<tr>
<td>$\Upsilon(4S) \to$ non-$B\bar{B}$</td>
<td>0.0025</td>
</tr>
<tr>
<td>Peaking background</td>
<td>0.004</td>
</tr>
<tr>
<td>Efficiency correlation</td>
<td>0.004</td>
</tr>
<tr>
<td>$B$-meson counting</td>
<td>0.0055</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>0.009</strong></td>
</tr>
</tbody>
</table>

(1) The systematic uncertainty from the $\mathcal{M}_2^2$-combinatorial contribution subtraction in the $\mathcal{M}_2^2$ histogram is 0.0005. The error is obtained by varying the total $\mathcal{M}_2^2$-combinatorial background by its statistical error.

(2) An error of 0.0005 is estimated due to the subtraction of the $\mathcal{M}_2^2$-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-$B\bar{B}$ is 4%
at 95% confidence level. 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 $N_{BG}$ 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 $\bar{B}^0 \to D^{*+}\ell^-\nu_\ell$ to
obtain a preliminary result of

\[ f_{00} = 0.486 \pm 0.010(\text{stat.}) \pm 0.009(\text{sys.}). \]  (5)

This result does not depend on branching fractions of the $\bar{B}^0$ 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.

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