Measurements of B^0 and $B^\pm$ lifetimes and B^0-$\bar{B}^0$ mixing with fully reconstructed B decays in *BABAR*

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Abstract

Time-dependent $B^0\overline{B}^0$ flavor oscillations and B^0 and B^+ lifetimes are studied in a sample of fully reconstructed B mesons collected with the *BABAR* detector, running at the PEP-II asymmetric e^+e^- B Factory with center-of-mass energies near the $\Upsilon(4S)$ resonance. This is the first time that time-dependent mixing and lifetime measurements have been performed at $\Upsilon(4S)$ energies.

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1 Introduction

Preliminary measurements of time-dependent $B^0\overline{B}^0$ flavor oscillations and B^0 and B^+ lifetimes have been performed with the *BABAR* detector. These analyses exploit the copious production of B meson pairs in $\Upsilon(4S)$ decays, produced by asymmetric e^+e^- collisions at the PEP-II B Factory at SLAC. These measurements can be used to test theoretical models of heavy quark decay and to constrain the Unitarity Triangle (via the sensitivity to the value of the Cabibbo-Kobayashi-Maskawa matrix [1] element V_{td}). The data set, collected from January to June, 2000, has an integrated luminosity of 8.9 fb^{-1} on the $\Upsilon(4S)$ resonance and 0.8 fb^{-1} collected 40 MeV below the $B\overline{B}$ threshold. This corresponds to about $(10.1\pm0.4)\times10^6$ produced $B\overline{B}$ pairs. The resolution function and mistag rates determined from data in the analyses described here are also used in *CP* asymmetry measurements [2].

2 Experimental Method

The *BABAR* detector is described in detail elsewhere [3]. The analyses described here use all the detector capabilities, including high resolution tracking and calorimetry, particle identification and vertexing.

At PEP-II the B meson pairs produced in the decay of the $\Upsilon(4S)$ resonance are moving in the lab frame along the beam axis (z direction) with a Lorentz boost of $\beta_z\gamma = 0.56$. One B (B_{REC}) is fully reconstructed in an all-hadronic ($B^0\to D^{(*)-}\pi^+$, $D^{(*)-}\rho^+$, $D^{(*)-}a_1^+$, $J/\psi K^{*0}$ and $B^-\to D^{(*)0}\pi^-$, $J/\psi K^-$, $\psi(2S)K^-$) or semileptonic decay mode ($B^0 \to D^{*-}\ell^+\nu$) *. A total of about 2600 neutral, and a similar number of charged, B candidates is reconstructed in hadronic decay modes, with an average purity close to 90%. The background is mainly combinatorial. About 7500 B^0's are reconstructed in semileptonic modes, with an average purity of $\sim 84\%$. Backgrounds to the semileptonic mode are due to combinatorics, fake leptons, $c\bar{c}$ events, and charged B decays from $B^- \to D^{*+}(n\pi)l^-\nu$. Fig. 2 shows the beam-energy substituted B mass (m_{ES}) distributions for the hadronic sample (left) and the D^*-D^0 mass distribution for the semileptonic sample (right) [4, 5].

The separation between the two B vertices along the boost direction, $\Delta z = z_{\mathrm{REC}} - z_{\mathrm{TAG}}$, is measured and used to estimate the decay time difference, $\Delta t \approx \Delta z/\beta_z\gamma c$. The B_{TAG} vertex is determined via an inclusive procedure applied to all tracks not associated with the B_{REC} meson [4]. The typical separation between the two vertices is $\Delta z = \beta_z\gamma c\tau_B \approx 260\,\mu$m, to be compared to the experimental resolution $\sim 110\,\mu$m. The Δt resolution is dominated by the precision on the B_{TAG} vertex, and has little dependence on the decay mode of the B_{REC}. An event-by-event Δz resolution is computed and modified to fit the data by convolution with three Gaussians, core, tail and outlier. Most of the events, $\sim 70\%$, are in the core Gaussian, with $\sigma \sim 0.6$ ps.

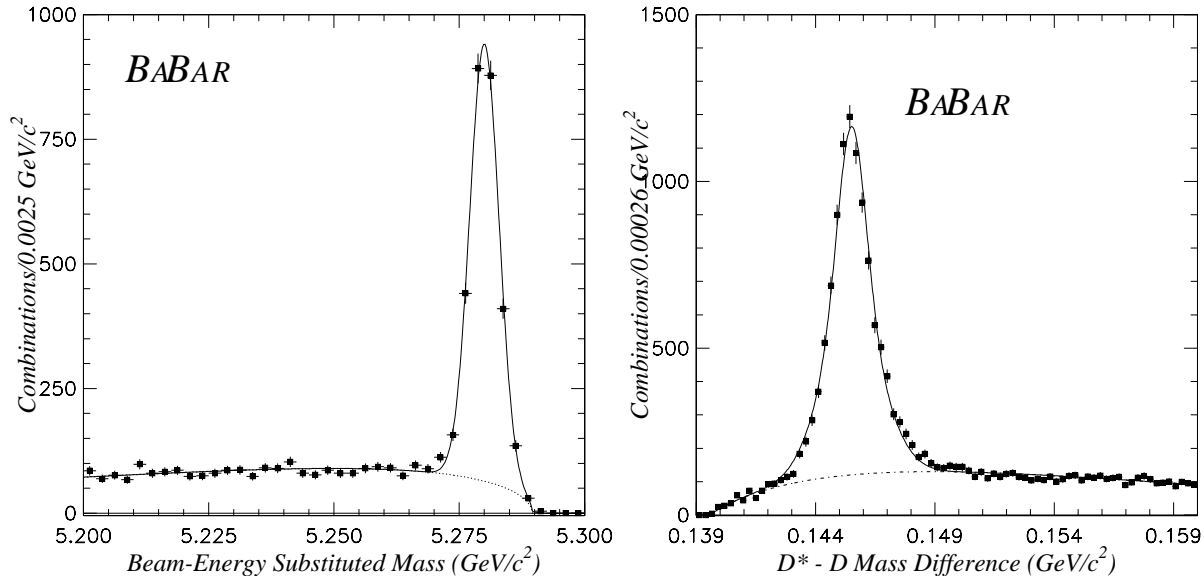*Throughout this paper, conjugate modes are implied.

Figure 1: Left: Beam-energy substituted mass distribution (m_{ES}) for all the hadronic B^0 modes. Right: $D^* - D^0$ mass difference distribution for the $B^0 \to D^{*-}\ell^+\nu$ sample.

3   Lifetime Measurements

The B^0 and B^+ lifetimes are extracted from a simultaneous unbinned maximum likelihood fit to the Δt distributions of the signal candidates, assuming a common resolution function. Only hadronic decays from a subsample of 7.4 fb^{-1} integrated luminosity (on-resonance) have been used. An empirical description of the Δt background shape is assumed, using m_{ES} sidebands with independent parameters for neutral and charged mesons. Fig. 2 shows the Δt distributions with the fit result superimposed. Table 1 summarizes the contributions to the total error (see [4] for details).

4   Time-dependent $B^0\overline{B}^0$ mixing

A time-dependent $B^0\overline{B}^0$ mixing measurement requires the determination of the flavor of both B's. The B_{REC} flavor is known if it has been correctly reconstructed, and the flavor of the B_{TAG} is determined by exploiting the correlation between the flavor of the B_{TAG} meson and the charge of its decay products [5]. If there is an identified lepton its charge is used; otherwise the summed charge of identified kaons provides the tag. An event with no tagging leptons or kaons can still be tagged by use of a neural net that exploits the flavor information carried by other decay products, such as soft leptons from charm semileptonic decays and soft pions from D^* decays.

The effective flavor tagging efficiency is given by $Q = \sum_i \epsilon_i (1 - 2w_i)^2$ where the sum is over tagging categories, each characterized by a tagging efficiency ϵ_i and a probability to
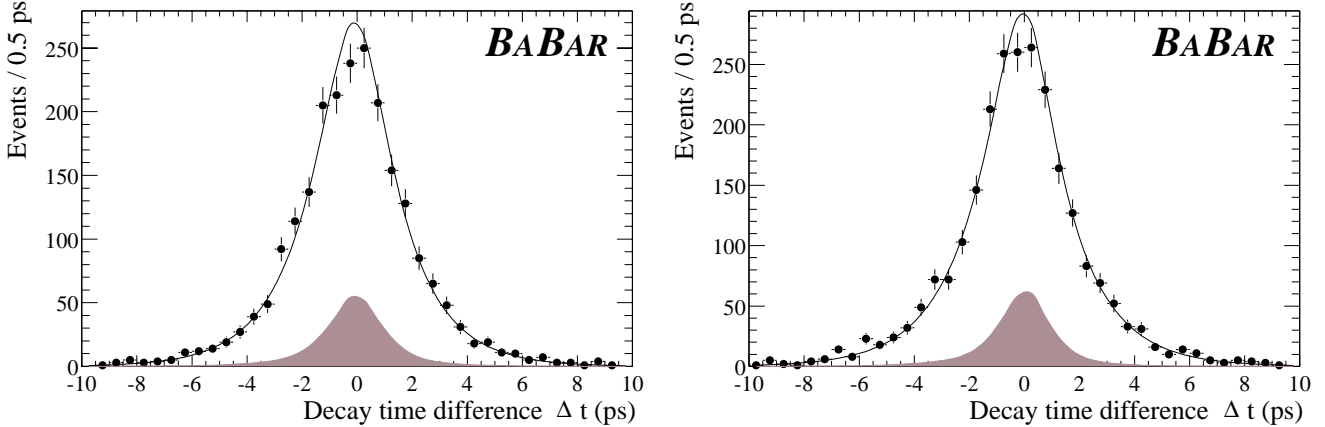
Figure 2: Δt distributions for $B^0/\overline{B}^0$ (left) and B^+/B^- (right) candidates in the signal region ($m_{\mathrm{ES}} > 5.27$ GeV/c^2). The result of the lifetime fit is superimposed. The background is shown by the hatched area.

mis-identify the B flavor, w_i. Q is related to the statistical significance of the measurement ($1/\sigma_{stat}^2 \sim N_{B_{\mathrm{TAG}}} Q$).

From the time-dependent rate of mixed (N_{mix}) and unmixed (N_{unmix}) events, the mixing asymmetry $a(\Delta t) = (N_{unmix} - N_{mix})/(N_{unmix} + N_{mix})$ is calculated as a function of Δt and fit to the expected cosine distribution,

$$a(\Delta t) \propto (1 - 2w) \cos \Delta m_d \Delta t \otimes \mathcal{R}(\Delta t | \hat{a}),$$

where $\hat{a}$ are the parameters of the resolution function [5]. A simultaneous unbinned likelihood fit to all the tagging categories, assuming a common resolution function, allows the determination of both Δm_d and the mistag rates, w_i. An empirical description of the backgrounds is determined by fitting to background control samples taken from data, allowing for the following components: i) zero lifetime, ii) non-zero lifetime with no mixing, iii) non-zero lifetime with mixing (only for semileptonic decays). Fig. 3 shows the $a(\Delta t)$ distributions with the fit result superimposed. Table 2 summarizes all the contributions to the total error (see [5] for details).

5 Results

The preliminary results for the B meson lifetimes are

$$\tau_{B^0} = 1.506 \pm 0.052 \text{ (stat)} \pm 0.029 \text{ (syst) ps,}$$
$$\tau_{B^+} = 1.602 \pm 0.049 \text{ (stat)} \pm 0.035 \text{ (syst) ps}$$

and for their ratio is

$$\tau_{B^+}/\tau_{B^0} = 1.065 \pm 0.044 \text{ (stat)} \pm 0.021 \text{ (syst)}.$$

4

Table 1: Summary of uncertainties for the B Lifetime measurements.

Source	$\sigma(\tau_B^0)$	$\sigma(\tau_B^+)$	$\sigma(\tau_B^+/\tau_B^0)$
Data statistics	0.052	0.049	0.044
MC statistics	0.016	0.014	0.014
Δt resolution	0.007	0.007	0.008
Δz outliers	0.016	0.020	0.005
alignment	-	-	-
z scale	0.015	0.016	-
boost	0.006	0.006	-
signal probability	0.003	0.002	0.005
background	0.005	0.017	0.011
Total systematics	0.029	0.035	0.021

Table 2: Break-down of uncertainties for the B Mixing measurements.

Source	$\sigma(\Delta m_d)$ hadronic	$\sigma(\Delta m_d)$ semileptonic
Data statistics	0.031	0.020
MC statistics	0.011	0.009
Δt resolution	0.011	0.012
background Δt	0.002	0.002
background dilutions	-	0.006
background fractions	0.004	0.006
B^+ background	-	0.010
B^0 Lifetime	0.005	0.006
z scale	0.005	0.005
boost	0.003	0.003
Total systematics	0.018	0.022

From the hadronic B^0 sample we measure the $B^0\overline{B}^0$ oscillation frequency:

$$\Delta m_d = 0.516 \pm 0.031 \text{ (stat)} \pm 0.018 \text{(syst)} \ \hbar\text{ps}^{-1}$$

and from the $D^{*-}\ell^+\nu$ sample the result is

$$\Delta m_d = 0.508 \pm 0.020 \text{ (stat)} \pm 0.022 \text{(syst)} \ \hbar\text{ps}^{-1}.$$

Combining the two Δm_d results, we obtain the preliminary result:

$$\Delta m_d = 0.512 \pm 0.017 \text{(stat)} \pm 0.022 \text{(syst)} \ \hbar\text{ps}^{-1}.$$

The mistag rates and Δt resolution function extracted from these fits are used in the *BABAR* *CP* violation asymmetry analysis [2]. The effective flavor tagging efficiency is found to be $Q \approx 28\%$.
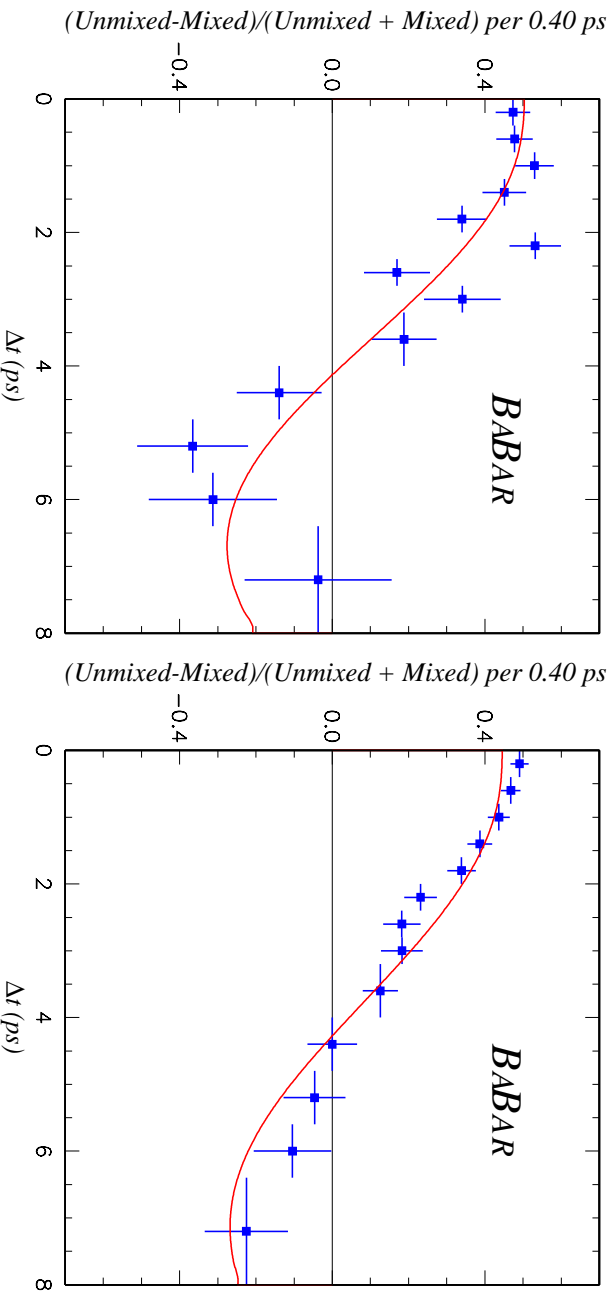
Figure 3: Time-dependent asymmetry $a(\Delta t)$ between unmixed and mixed events for (left) hadronic B candidates with $m_{ES} > 5.27 \; \text{GeV}/c^2$ and (right) for $B \to D^*\ell\nu$ candidates.

The above results are consistent with previous measurements [6] and are of similar precision. They are also compatible with other BABAR measurements [7, 8]. Significant improvements are expected in the near future with the accumulation of more data and further systematic studies.

References

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