A study of $B^0\bar{B}^0$ oscillations with full reconstructed $B$ mesons with the BABAR detector

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Abstract

Time–dependent $B^0\bar{B}^0$ flavor oscillations are studied in $e^+e^-$ annihilation data collected with the BABAR detector at center-of-mass energies near the $\Upsilon(4S)$ resonance. We report a preliminary result for the time-dependent $B^0\bar{B}^0$ oscillation frequency, $\Delta m_d = 0.512 \pm 0.017 \pm 0.022 \ h\ ps^{-1}$.

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1 Introduction

We have performed a measurement of time-dependent mixing at the PEP-II asymmetric $e^+e^-$ collider at SLAC, where resonant production of the $\Upsilon(4S)$ provides a copious source of $B^0\bar{B}^0$ pairs. The data set used for this analysis corresponds to an integrated luminosity of $8.9 \text{ fb}^{-1}$ on the $\Upsilon(4S)$ resonance and $0.8 \text{ fb}^{-1}$ collected 40 MeV below the resonance. This corresponds to about $10.1 \times 10^6$ produced $B\bar{B}$ pairs. 

The BABAR detector is described in detail elsewhere [1]. The analysis described here uses all the detector capabilities, including high resolution tracking and calorimetry, particle identification and vertexing.

2 Event Reconstruction

We fully reconstruct one $B$ meson ($B_{\text{REC}}$) in hadronic ($B^0 \to D^{(*)} - \pi^+$, $D^{(*)} - \rho^+$, $D^{(*)} - a_1^+$ and $J/\psi K^{*0}$) or semileptonic ($B^0 \to D^* - \ell^+\nu$) decay mode [3]. A total of 2577 neutral $B$ candidates is reconstructed in hadronic decay modes, with an average purity close to 90%. The main background for these modes is combinatorial. 7517 $B^0$ candidates are reconstructed in the semileptonic mode, with an average purity close to 84%. Backgrounds to the semileptonic mode are due to combinatorial $D^*$ fake leptons, uncorrelated $D^* l$ combinations, $c\bar{c}$ events, and charged $B$ decays from $B^- \to D^{*+}(n\pi)l^-\nu$.

The other two important ingredients for this analysis are the vertex reconstruction and the identification of the flavor of the other $B$ meson ($B_{\text{TAG}}$) in the event. The flavor of the $B_{\text{TAG}}$ is determined from the correlation between the particle types and the charge of its decay products [3]. 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 the use of a neural network that exploits the flavor information carried by other decay products, such as soft leptons from charm semileptonic decays and soft pions from $D^*$ decays.

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 $\beta \gamma = 0.56$. The separation between the two $B$ vertices along the boost direction, $\Delta z = z_{\text{REC}} - z_{\text{TAG}}$, is measured and used to estimate the decay time difference, $\Delta t \approx \Delta z/\beta \gamma c$. The $B_{\text{TAG}}$ vertex is determined via an inclusive procedure applied to all tracks not associated with the $B_{\text{REC}}$ meson [3]. The typical separation between the two vertices is $\Delta z = \beta \gamma c \tau_B \approx 260 \mu\text{m}$, to be compared to the experimental resolution $\sim 100 \mu\text{m}$. The $\Delta t$ resolution is limited by the precision on the $B_{\text{TAG}}$ vertex, and has little dependence on the decay mode of the $B_{\text{REC}}$. The $\Delta t$ resolution function is well described by three Gaussians: core, tail and outlier. We calculate the uncertainty on $\Delta t$ by using a globally-fitted rescaling of the event-by-event vertex separation errors. Most of the events, $\sim 70\%$, are in the core Gaussian, with $\sigma \sim 0.6 \text{ ps}$.

3 Likelihood Fit method

The time-dependent asymmetry between same sign $B^0\bar{B}^0/\bar{B}^0\bar{B}^0$ (unmixed) and opposite sign $B^0\bar{B}^0$ (mixed) events, $A(\Delta t) = (N_{\text{unmix}} - N_{\text{mix}})/(N_{\text{unmix}} + N_{\text{mix}})$ is calculated as a function of $\Delta t$ and is given by

\footnote{Throughout this paper, charge conjugate modes are implied.}
\[ A(\Delta t) \approx (1 - 2w) \cos \Delta m_d \Delta t \otimes R(\Delta t|\hat{a}), \]

where \( \hat{a} \) are the parameters of the \( \Delta t \) resolution function and \( w \) is the probability of incorrect tagging (mistag fraction). A simultaneous unbinned likelihood fit to the \( \Delta t \) distribution of mixed and unmixed events in all tagging categories, assuming a common resolution function, allows the simultaneous determination of both \( \Delta m_d \) and the mistag fractions, \( w_i \). An empirical description of the \( \Delta t \) structure of the backgrounds is determined from a fit to background control samples taken from data, allowing for the following components: zero lifetime, non-zero lifetime with no mixing, non-zero lifetime with mixing.

4 Results and Conclusions

We measure the \( B^0 \overline{B}^0 \) oscillation frequency to be \( \Delta m_d = 0.516 \pm 0.031 \text{ (stat)} \pm 0.018 \text{ (syst)} \text{ hps}^{-1} \) in the hadronic sample and \( \Delta m_d = 0.508 \pm 0.020 \text{ (stat)} \pm 0.022 \text{ (syst)} \text{ hps}^{-1} \) in the \( D^*-\ell^+\nu \) sample. Figure 1 shows the asymmetry \( A(\Delta t) \) distributions for each sample with the fit result superimposed.

The systematic errors include uncertainty due to Monte Carlo statistics, \( \Delta t \) resolution function, background \( \Delta t \) shape, fraction of background events, \( B^0 \) lifetime, \( z \) scale and the boost. In addition, we have looked at the uncertainty due to feeddown from \( B^- \rightarrow D^{*-}(n\pi)\ell^-\nu \) in the semileptonic sample. The dominant contribution in the hadronic sample comes from the \( \Delta t \) resolution function, while the semileptonic sample is dominated by the uncertainty on the fraction of background events (see [2] for details).

Figure 1: 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 \( B \rightarrow D^*\ell\nu \) candidates.

Combining the two \( \Delta m_d \) results, we obtain the preliminary result:

\[ \Delta m_d = 0.512 \pm 0.017 \text{ (stat)} \pm 0.022 \text{ (syst)} \text{ hps}^{-1}. \]

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 \( \epsilon_i \) and a mistag fraction \( w_i \). \( Q \) is related to the statistical significance of the measurement \( 1/\sigma_{stat}^2 \sim N_{B_{TAG}} Q \) and is found to be \( (27.9 \pm 1.6)\% \). The mistag fractions and the \( \Delta t \) resolution function parameters are used in the \( CP \) asymmetry measurement [3].
The results for $\Delta m_d$ are consistent with previous measurements [4] and are of similar precision. They are also compatible with other BABAR measurements [5, 6]. Significant improvements are expected in the near future with the accumulation of more data and further systematic studies.

References

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