Constraints on the CKM angle $\alpha$ in the $B \rightarrow \rho\rho$ decays

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Using a data sample of 122 million $\Upsilon(4S) \rightarrow B\overline{B}$ decays collected with BABAR detector at the PEP-II asymmetric $B$ factory at SLAC, we measure the time-dependent-asymmetry parameters of the longitudinally polarized component in the $B^0 \rightarrow \rho^+\rho^-$ decay as $C_L = -0.23 \pm 0.24({\text{stat}}) \pm 0.14({\text{syst}})$ and $S_L = -0.19 \pm 0.33({\text{stat}}) \pm 0.11({\text{syst}})$. The $B^0 \rightarrow \rho^0\rho^0$ decay mode is also searched for in a data sample of about 227 million $B\overline{B}$ pairs. No significant signal is observed, and an upper limit of $1.1 \times 10^{-6}$ (90% C.L.) on the branching fraction is set. The penguin contribution to the CKM angle $\alpha$ uncertainty is measured to be $11^o$. All results are preliminary.

Keywords: time-dependent-asymmetry; CKM angle; longitudinal polarization.

1. Introduction

The time-dependent $CP$ asymmetry in a $b \rightarrow u\bar{u}d$ decay of a $B^0$ to a $CP$ eigenstate allows for a measurement of the angle $\alpha = \arg[-V_{td}V^*_{tb}/V_{ud}V^*_{ub}]$ if the decay is dominated by the tree amplitude. The contribution from penguin diagrams gives rise to a correction $\Delta \alpha = \alpha_{\text{eff}} - \alpha$ that can be inferred through an isospin analysis. The recent experimental results indicate a small penguin contributions in $B \rightarrow \rho\rho$. The $CP$ analysis in $B \rightarrow \rho^+\rho^-$ is complicated by the presence of three helicity states. However, the measured polarizations in $\rho^+\rho^-$ and $\rho^0\rho^0$ modes indicate a dominance of the helicity 0 state (longitudinal polarization), that is a $CP = +1$ eigenstate. A measurement of the polarization in $B^0 \rightarrow \rho^0\rho^0$ would complete the isospin triangle, but this mode has not been observed so far. Knowledge of the $B^0 \rightarrow \rho^0\rho^0$ rate is still expected to be limiting factor to the accuracy of the $\alpha$ measurement with $\rho\rho$ decays.

In this paper, we present a time-dependent analysis of $B^0 \rightarrow \rho^+\rho^-$ based on a sample of 122 million $B\overline{B}$ pairs, and a search for the $\rho^0\rho^0$ final state on a sample of 227 million $B\overline{B}$ pairs at BABAR.

2. Analysis Method

We reconstruct $\rho^+\rho^-$ candidates from combinations of two charged tracks and two $\pi^0$ candidates. In the $\rho^0\rho^0$ mode, the $B^0$ candidates are reconstructed from their
decay products $\rho^0 \to \pi^+\pi^-$ with four charged tracks which are required to originate from a single vertex near the interaction point. The $\pi^0$ candidates are formed from pairs of photons that have measured energies greater than 50 MeV. The reconstructed $\pi^0$ mass must satisfy $0.10 < m_{\gamma\gamma} < 0.16$ GeV/c$^2$. The mass of the $\rho$ candidates, $m_{\pi\pi\rho}$, must satisfy $|m_{\pi\pi\rho} - 0.770$ GeV/c$^2| < 0.375$ GeV/c$^2$, and the mass, $m_{\pi^+\pi^-}$, must satisfy $0.55 < m_{\pi^+\pi^-} < 1.0$ GeV/c$^2$. Combinatorial backgrounds dominate near $|\cos\theta_i| = 1$, where $\theta_i$, $i = 1, 2$ is defined for each $\rho$ meson as the angle between the $\pi^0 (\pi^+)$ momentum in the $\rho^0 (\rho^+)$ rest frame and the flight direction of the $B^0$ in this frame. We reduce these backgrounds with the requirement $-0.8 < \cos\theta_i < 0.98$ in $\rho^+\rho^-$ modes and $|\cos\theta_i| < 0.99$ in $\rho^0\rho^0$ mode. Two kinematic variables $\Delta E$ and $m_{\text{ES}}$, allow the discrimination of signal $B$ decays from random combinations of tracks and $\pi^0$ candidates. For $\rho^+\rho^-$ we require that $5.21 < m_{\text{ES}} < 5.29$ GeV/c$^2$ and $-0.12 < \Delta E < 0.15$ GeV/c$^2$. The asymmetric $\Delta E$ window suppresses background from higher-multiplicity $B$ decays. For $\rho^0\rho^0$ we require $m_{\text{ES}} > 5.24$ GeV/c$^2$ and $|\Delta E| < 85$ MeV/c$^2$.

In order to reject the dominated quark-antiquark continuum background, we require $|\cos\theta_T| < 0.8$, where $\theta_T$ is the the angle between the $B$ thrust axis and the thrust axis of the rest of the events (ROE). The other event-shape discriminating variables are combined in a neural network $(N)$. The $N$s for $\rho^+\rho^-$ and $\rho^0\rho^0$ analysis weight the discriminating variables differently, according to training on off-resonance data and the relevant Monte Carlo (MC) simulated signal events.

When multiple $B$ candidates can be formed we select the one that minimizes the sum of the deviations of the reconstructed $\pi^0$ mass in $\rho^+\rho^-$ mode, while, for $\rho^0\rho^0$, one candidate is selected randomly. The selection efficiency is 7% (13%) for the longitudinally (transversely) polarized $\rho^+\rho^+$ signal, and it is 27% (32%) for the $\rho^0\rho^0$ signal. $B$ in the event.

To study the time-dependent asymmetry one needs to measure the proper time difference, $\Delta t$, between the two $B$ decays in the events, and to determine the flavor tag of the other $B$-meson. The time difference between the decays of the two neutral $B$ mesons ($B_{\text{rec}}, B_{\text{tag}}$) is calculated from the measured separation $\Delta z$ between the $B_{\text{rec}}$ and $B_{\text{tag}}$ decay vertices. The flavor of the $B_{\text{tag}}$ is determined with a multivariate technique that has a total effective tagging efficiency of (28.4±0.7)%.

An unbinned likelihood fit is finally performed on the selected event, a probability density function is built from discriminating variables, including the angular distribution and the $\Delta t$-dependence. The signal decay-rate distribution $f_+(f_-)$ for $B_{\text{tag}} = B^0 (\bar{B}^0)$ is given by:

$$f_\pm(\Delta t) = \frac{e^{-|\Delta t|/\tau}}{4\tau} [1 \pm S_L \sin(\Delta m_d \Delta t) \mp C_L \cos(\Delta m_d \Delta t)],$$

(1)

where $\tau$ is the mean $B^0$ lifetime, $\Delta m_d$ is the $B^0 - \bar{B}^0$ mixing frequency, and $S_L$ and $C_L$ are the $CP$ asymmetry parameters for the longitudinal polarized signal.
3. Results

We measure the $CP$ violating asymmetries in the $B^0 \to \rho^+ \rho^−$ longitudinal component decay on 122 million $B^0 \overline{B}^0$ pairs. A detailed analysis of the background due to other $B$ decays is performed. The main systematic uncertainty on the asymmetries is found to be the unknown $CP$ violation in $B$ background events. Our results are $S_L = -0.19 \pm 0.33 \text{(stat)} \pm 0.11 \text{(syst)}$ and $C_L = -0.23 \pm 0.24 \text{(stat)} \pm 0.14 \text{(syst)}$. With a sample of 227 million $B^0 \overline{B}^0$ pairs we have searched for the decay mode $B^0 \to \rho^0 \rho^0$, the measured value for the branching fraction is $(0.54 \pm 0.36 \pm 0.32 \pm 0.19) \times 10^{-6}$ or an upper limit of $1.1 \times 10^{-6}$ at 90% confidence level (C.L.).

Using the Grossman-Quinn bound with the recent results on $B^\pm \to \rho^\pm \rho^0$ we limit $|\alpha_{\text{eff}} - \alpha| < 11^\circ$ (68% C.L.). Ignoring possible non-resonant contributions, and $I = 1$ amplitudes one can relate $CP$ parameters $S_L$ and $C_L$ to $\alpha$, up to a four-fold ambiguity. If we select the solution closest to the CKM best fit central value with the new limit on the $B^0 \to \rho^0 \rho^0$ rate we improve the constraint on $\alpha$ due to the penguin contribution, the measured $CP$ parameters of the longitudinal polarization correspond to $\alpha = (96 \pm 10 \text{(stat)} \pm 4 \text{(syst)} \pm 11 \text{(penguin)})^\circ$. Figure shows the confidence level as a function of $\alpha$ from the isospin analysis.

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