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Study of the decay $B^0(\overline{B}^0) \to \rho^+\rho^-$, and constraints on the CKM angle α.

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Using a data sample of 89 million $\Upsilon(4S) \to B\overline{B}$ decays collected with the *BABAR* detector at the PEP-II asymmetric B Factory at SLAC, we measure the $B^0(\overline{B}^0) \to \rho^+\rho^-$ branching fraction as $(30\pm$

4(stat) ± 5(syst)) × 10^{-6} and a longitudinal polarization fraction of $f_L = 0.99 \pm 0.03(\text{stat})\ ^{+0.04}_{-0.03}(\text{syst})$. We measure the time-dependent-asymmetry parameters of the longitudinally polarized component of this decay as $C_L = -0.17 \pm 0.27(\text{stat}) \pm 0.14(\text{syst})$ and $S_L = -0.42 \pm 0.42(\text{stat}) \pm 0.14(\text{syst})$. We present constraints on the CKM angle α.

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The recently observed [1] decay $B^0(\overline{B}^0) \to \rho^+\rho^-$ proceeds mainly through the $b \to u\overline{u}d$ tree diagram. Interference between direct decay and decay after B^0-$\overline{B}^0$ mixing results in a time-dependent decay-rate asymmetry between B^0 and $\overline{B}^0$ that is sensitive to the CKM [2] angle $\alpha \equiv \arg[-V_{td}V^*_{tb}/V_{ud}V^*_{ub}]$. The presence of loop (penguin) contributions introduces additional phases that can shift the experimentally measurable parameter α_{eff} away from the value of α. Recent measurements of the $B^+ \to \rho^+\rho^0$ branching fraction and upper limit for $B^0 \to \rho^0\rho^0$ [3] indicate small penguin contributions in $B \to \rho\rho$, as has been found in some calculations [4]. Here we present a time-dependent analysis of $B^0(\overline{B}^0) \to \rho^+\rho^-$.

The *CP* analysis of B decays to $\rho^+\rho^-$ is complicated by the presence of three helicity states ($h = 0, \pm 1$). The $h = 0$ state corresponds to longitudinal polarization and is *CP*-even, while neither the $h = +1$ nor the $h = -1$ state is an eigenstate of *CP*. The longitudinal polarization fraction f_L is defined as the fraction of the helicity zero state in the decay. The angular distribution is

$$\frac{d^2\Gamma}{\Gamma d\cos\theta_1 d\cos\theta_2} = \frac{9}{4}\left(f_L\cos^2\theta_1\cos^2\theta_2 + \frac{1}{4}(1-f_L)\sin^2\theta_1\sin^2\theta_2\right) \quad (1)$$

where $\theta_i, i = 1, 2$ is defined for each ρ meson as the angle between the π^0 momentum in the ρ rest frame and the flight direction of the B^0 as observed in this frame. We have integrated over the angle between the ρ-decay planes. In the general case a full angular analysis of the decays is needed in order to separate the definite *CP* contributions; if however a single *CP* channel dominates the decay, this is not necessary [5]. The longitudinal polarization dominates this decay [1, 6].

This measurement is based on 89 million $\Upsilon(4S) \to B\overline{B}$ decays collected with the *BABAR* [7] detector at the PEP-II asymmetric B Factory at SLAC. We reconstruct $B^0(\overline{B}^0) \to \rho^+\rho^-$ candidates (B_{rec}) from combinations of two charged tracks and two π^0 candidates. We require that both tracks have particle identification information inconsistent with the electron, kaon, and proton hypotheses. The π^0 candidates are formed from pairs of photons that have measured energies greater than 50 MeV. The reconstructed π^0 mass must satisfy $0.10 < m_{\gamma\gamma} < 0.16$ GeV/c^2. The mass of the ρ candidates, $m_{\pi^\pm\pi^0}$, must satisfy $|m_{\pi^\pm\pi^0} - 0.770 \text{ GeV}/c^2| < 0.375$ GeV/c^2. When multiple B candidates can be formed we select the one that minimizes the sum of the deviations of the reconstructed π^0 masses from the true π^0 mass. Combinatorial backgrounds dominate near $|\cos\theta_i| = 1$, while backgrounds from B decays, like $B^0 \to \rho^+\pi^-$, with an additional low energy π^0 from the rest of the event (ROE), tend to concentrate at negative values of $\cos\theta_i$. We reduce these backgrounds with the requirement $-0.8 < \cos\theta_i < 0.98$.

Continuum $e^+e^- \to q\overline{q}$ ($q = u, d, s, c$) events are the dominant background. To discriminate signal from continuum we use a neural network ($\mathcal{N}$) to combine six variables: the two event-shape variables used in the Fisher discriminant of Ref. [8]; the cosine of the angle between the direction of the B and the collision axis (z) in the center-of-mass (CM) frame; the cosine of the angle between the B thrust axis and the z axis; the cosine of the angle between the B thrust axis and the thrust axis of the ROE; the decay angle of the π^0 (defined in the same way as the ρ decay angle, θ_i); the sum of transverse momenta in the ROE relative to the z axis.

Signal events are identified kinematically using two variables, the difference ΔE between the CM energy of the B candidate and $\sqrt{s}/2$, and the beam-energy substituted mass $m_{\text{ES}} = \sqrt{(s/2 + \mathbf{p}_i \cdot \mathbf{p}_B)^2/E_i^2 - \mathbf{p}_B^2}$, where $\sqrt{s}$ is the total CM energy. The B momentum $\mathbf{p}_B$ and four-momentum of the initial state ($E_i, \mathbf{p}_i$) are defined in the laboratory frame. We accept candidates that satisfy $5.21 < m_{\text{ES}} < 5.29$ GeV/c^2 and $-0.12 < \Delta E < 0.15$ GeV. The asymmetric ΔE window suppresses background from higher-multiplicity B decays.

To study the time-dependent asymmetry one needs to measure the proper time difference, Δt, between the two B decays in the event, and to determine the flavor tag of the other B-meson. The time difference between the decays of the two neutral B mesons in the event (B_{rec}, B_{tag}) is calculated from the measured separation Δz between the B_{rec} and B_{tag} decay vertices [9]. We determine the B_{rec} vertex from the two charged-pion tracks in its decay. The B_{tag} decay vertex is obtained by fitting the other tracks in the event, with constraints from the B_{rec} momentum and the beam-spot location. The RMS resolution on Δt is 1.1 ps. We only use events for which the proper time difference between the B_{rec} and B_{tag} decays satisfies $|\Delta t| < 20$ ps and the error on Δt, $\sigma(\Delta t)$, is less than 2.5 ps. The flavor of the B_{tag} meson is determined with a multivariate technique [15] that has a total effective tagging efficiency of $(28.4 \pm 0.7)\%$. The events are assigned to five mutually exclusive taggging categories `Lepton`, `Kaon 1`, `Kaon 2`, `Inclusive`, and `Untagged`, listed in order of decreasing reliability of the tag.

Signal candidates may pass the selection even if one or more of the pions assigned to the $\rho^+\rho^-$ state actually comes from the other B in the event. These self-cross-feed (SCF) candidates comprise 39% (16%) of the accepted signal for $f_L = 1$ ($f_L = 0$) and are included as signal in the fit.

The efficiency of the selection is 7.7% (14.9%) for longitudinally (transversely) polarized signal as determined with Monte Carlo (MC) based on the GEANT4 simulation [10]. We select 24288 events, which are dominated by combinatoric backgrounds: roughly 86% from $q\overline{q}$ and 13% from $B\overline{B}$. We distinguish the following candidate types: (i) correctly reconstructed signal, for $B^0(\overline{B}^0) \to \rho^+\rho^-$ decays where the correct particles are combined to form the $B_{\rm rec}$ candidate; (ii) SCF signal; (iii) charm $B^\pm$ background ($b \to c$); (iv) charm B^0 background ($b \to c$); (v) charmless B backgrounds; (vi) continuum $e^+e^- \to q\overline{q}$ ($q = u, d, s, c$) background. We consider both types (i) and (ii) as signal. The charmless decays $B^\pm \to \rho^\pm\pi^0$, $B^\pm \to \rho^\pm\rho^0$, $B^\pm \to a_1^\pm\pi^0$, and $B^{\pm,0} \to a_1\rho$ are expected to contribute to the final sample. For these decays we assume the following branching fractions: 11.0 ± 2.7 [11], $26.4^{+6.1}_{-6.4}$ [12], 30 ± 15, and 20 ± 20, in units of 10^{-6}, corresponding to 17 ± 4, 16 ± 4, 30 ± 15, and 26 ± 26 events in the data, respectively. The latter two are estimated from the measured branching fractions of related decays. We expect an additional 300 candidates of charmless B decays with more than four mesons in the final state; since most branching fractions for such modes have not been measured yet, we generate them using the JETSET simulation [13]. We expect 1700 (1016) charged (neutral) B decays to final states containing charm mesons. The rest of the background is composed of continuum. Each of these backgrounds is included as an individual component in the fit, where we float the continuum yield.

Each candidate is described with the eight $B_{\rm rec}$ kinematic variables $m_{\rm ES}$ and ΔE, the $m_{\pi^\pm\pi^0}$ and $\cos\theta_i$ values of the two ρ mesons, Δt, and $\mathcal{N}$. For each different candidate-type considered, we construct a probability density function (PDF) that is the product of PDFs in each of these variables, assuming that they are uncorrelated. These combined PDFs are used in the fit to the data sample.

The continuum-background $m_{\rm ES}$, ΔE, $\cos\theta_i$, and $\mathcal{N}$ PDF parameters are floated in the final fit to the data. The distribution of the continuum as a function of $m_{\pi^\pm\pi^0}$ is described by a non-parametric PDF [14] derived from $m_{\rm ES}$ and ΔE data sidebands. For all other types these distributions are extracted from high-statistics MC samples. The $\cos\theta_i$ distributions for the background are described by a non-parametric PDF derived from the MC, as the detector acceptance and selection criteria modify the known vector-meson decay distribution. The signal distribution is given by Eq. (1) multiplied by an acceptance function determined from signal MC. We take into account known differences between data and the MC.

The signal Δt distribution is described by an exponential (B lifetime) multiplied by a CP violating term, convoluted with three Gaussians (core, tail, outliers) and takes into account $\sigma(\Delta t)$ from the vertex fit. The resolution is parameterized using a large sample of fully reconstructed hadronic B decays [9]. The nominal Δt distribution for the B backgrounds is a non-parametric representation of the MC; in the study of systematic errors we replace this model with the one used for signal. The continuum background is described by the sum of three Gaussian distributions whose parameters are determined by fitting the data.

The signal decay-rate distribution $f_+ (f_-)$ for $B_{\rm tag}$= B^0 ($\overline{B}^0$) is given by:

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

where τ is the mean B^0 lifetime, Δm_d is the B^0-$\overline{B}^0$ mixing frequency, and S= S_L or S_T and C= C_L or C_T are the CP asymmetry parameters for the longitudinal and transversely polarized signal. The fitting function takes into account mistag dilution and is convoluted with the Δt resolution function described above. Since the data indicate nearly complete longitudinal polarization, the fit has no sensitivity to either S_T or C_T. We set these parameters to zero.

We perform an unbinned extended maximum likelihood (ML) fit that assumes the event types mentioned previously. The results of the fit are 246 ± 29 signal events with $f_L = 0.99 \pm 0.03$, $S_L = -0.42 \pm 0.42$ and $C_L = -0.17 \pm 0.27$. There is a bias on the yield coming from the fit (six events) and B-background modeling (16 events). The former is estimated using toy MC and the latter is dominated by the change in signal yield when allowing the $a_1\rho$ component to float in a fit to the data. The signal yield remains stable when floating other background types. The corrected signal yield is 224 ± 29 events. Figure 1 shows distributions of $m_{\rm ES}$, $\cos\theta_i$ and $m_{\pi^\pm\pi^0}$ for `Lepton` and `Kaon 1` tagged events, enhanced in signal content by cuts on the signal-to-background likelihood ratios of the discriminating variables not projected. The additional cuts retain $\mathcal{O}(15\%)$ of the signal events in the analysis sample. For $m_{\rm ES}$ and ΔE we show a projection of the data for all tag categories; in these plots we retain $\mathcal{O}(60\%)$ of the signal events in the analysis sample. Figure 2 shows the raw Δt distribution for B^0 and $\overline{B}^0$ tagged events. The time-dependent decay-rate asymmetry $A = (R(\Delta t) - \overline{R}(\Delta t))/(R(\Delta t) + \overline{R}(\Delta t))$ is also shown, where $R(\overline{R})$ is the decay-rate for B^0 ($\overline{B}^0$) tagged events.

The nominal fit does not account for non-resonant background. If we add a non-resonant component of $B \to \rho\pi\pi^0$ events to the likelihood, the fitted signal yield changes by less than 11% (90% C.L.). Any possible $B \to 4\pi$ component would be significantly smaller. We ignore non-resonant contributions in the following discussion. The dominant systematic uncertainties in the

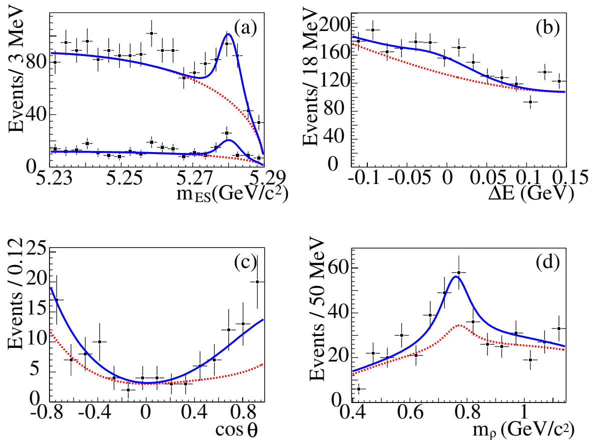

FIG. 1: The distributions for a sample of events enriched in signal for the variables (a) $m_{\rm ES}$, (b) ΔE, (c) cosine of the ρ helicity angle and (d) $m_{\pi^\pm\pi^0}$. The dotted line is the projection of the sum of backgrounds and the solid line is the projection of the full likelihood. For $m_{\rm ES}$ we show the projections for (top line) all and (bottom line) `Lepton` and `Kaon 1` tagged events.

yield arise from the assumed B-background branching fractions (20 events) and the uncertainty on the fraction of SCF events (14 events). The uncertainty on the estimated fraction of misreconstructed events is extrapolated from a control sample of fully reconstructed $B^0 \to D^-\rho^+$ decays [16]. The dominant systematic error on f_L is from the uncertainty in PDF parameterization (± 0.03). The main systematic uncertainty on the *CP* results is from possible *CP*-violation in the B background: charged B decays can violate *CP* directly and we vary S and C of

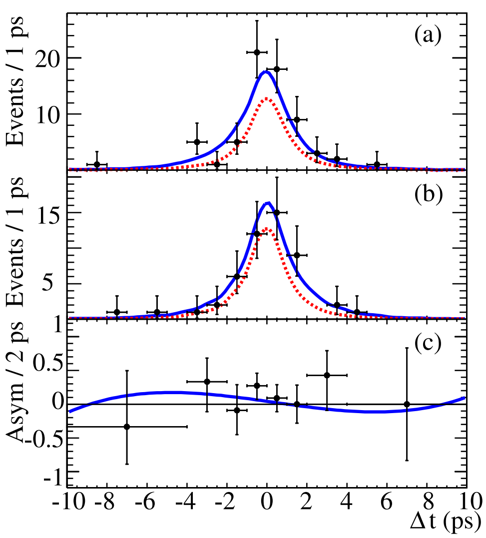

FIG. 2: The Δt distribution for a sample of events enriched in signal for (a) B^0 and (b) $\overline{B}^0$ tagged events. The dashed line represents the sum of backgrounds and the solid line represents the sum of signal and backgrounds. The time-dependent *CP* asymmetry A (see text) is shown in (c), where the curve represents the asymmetry.

background neutral B decays within reasonable limits. For B-meson decays to final states with charm, we allow the direct *CP*-violating asymmetry (charged B decay) and both S and C (neutral B decay) to vary between ± 0.5, as no large *CP*-violation is expected in these decays. For the other B backgrounds we vary these parameters between -1 and $+1$. This gives a systematic uncertainty of 0.08 (0.11) on S_L (C_L). Uncertainty in the vertex-detector alignment contributes an error of 0.06 (0.04) on S_L (C_L). In half of the SCF events the misreconstructed signal contains at least one wrong track; the difference in resolution function for these events corresponds to an uncertainty of 0.03 (0.01) on S_L (C_L). The uncertainty in the parametrization of the likelihood contributes an error of 0.05 (0.02) on S_L (C_L). The uncertainty from possible *CP*-violation in the doubly-Cabibbo-suppressed decays on the tag side of the event [17] is assumed to be of a similar magnitude to that ascribed in the case of $B^0(\overline{B}^0) \to \pi^+\pi^-$: 0.012 (0.037) for S_L (C_L). We also apply a correction to account for possible dilution from B-background (5%) and SCF (3%) events.

Our results are

$$\begin{aligned} BR(B^0 \to \rho\rho) &= (33 \pm 4({\rm stat}) \pm 5({\rm syst})) \times 10^{-6} \\ f_L &= 0.99 \pm 0.03({\rm stat})\ ^{+0.04}_{-0.03}({\rm syst}) \\ C_L &= -0.17 \pm 0.27({\rm stat}) \pm 0.14({\rm syst}) \\ S_L &= -0.42 \pm 0.42({\rm stat}) \pm 0.14({\rm syst}) \end{aligned}$$

The correlation coefficient between S_L and C_L is -0.016. The measured branching fraction and polarization are in agreement with the earlier *BABAR* result presented in Ref. [1]. We average these branching fractions, taking into account correlations where appropriate [12], to obtain the final value of $(30 \pm 4 \pm 5) \times 10^{-6}$. This measurement supersedes the previous *BABAR* result.

Using the Grossman-Quinn bound [1, 19] with the recent results on $B \to \rho^\pm\rho^0, \rho^0\rho^0$ from [3] we limit $|\alpha_{\rm eff} - \alpha| < 13^\circ$ (68% C.L.). Ignoring possible non-resonant contributions, interference with $\rho\pi\pi^0$, $\pi\pi^0\pi\pi^0$, or $a_1\pi$, and $I = 1$ amplitudes one can relate the *CP* parameters S_L and C_L to α, up to a four-fold ambiguity [18]. If we select the solution closest to the CKM best fit average [20], the measured *CP* parameters of the longitudinal polarization correspond to $\alpha = 102^{+16}_{-12}({\rm stat})^{+5}_{-4}({\rm syst}) \pm 13({\rm penguin})^\circ$. Figure 3 shows the confidence level as a function of $\alpha_{eff} = \arcsin(S_L/\sqrt{1-C_L^2})/2$ for this result, (dotted) taking into account systematic uncertainties and (solid) also including the penguin contribution. We exclude values of α between 19° and 71° (90% C.L.).

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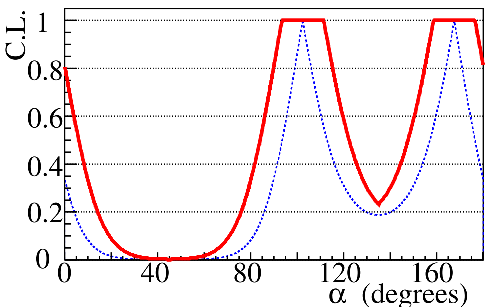

FIG. 3: A plot of (dotted) α_{eff} and (solid) α as a function of confidence level for this result.

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[1] *BABAR* Collaboration, B. Aubert *et al.*, Phys. Rev. D **69**, 031102 (2004).
[2] N. Cabibbo, Phys. Rev. Lett. **10**, 531 (1963); M. Kobayashi and T. Maskawa, Prog. Th. Phys. **49**, 652 (1973).
[3] *BABAR* Collaboration, B. Aubert *et al.*, Phys. Rev. Lett. **91**, 171802 (2003). Belle Collaboration, J. Zhang *et al.*, Phys. Rev. Lett. **91**, 221801 (2003);
[4] R. Aleksan *et al.*, Phys. Lett. B **356**, 95 (1995).
[5] I. Dunietz *et al.*, Phys. Rev. D **43**, 2193 (1991).
[6] G. Kramer and W. Palmer, Phys. Rev. D **45**, 193 (1992); D. Ebert *et al.*, Phys. Rev. D **56**, 312 (1997); A. Ali *et al.*, Phys. Rev. D **58**, 094009 (1998); Y.-H. Chen *et al.*, Phys. Rev. D **60**, 094014 (1999); H.-Y. Cheng and K.-C. Yang, Phys. Lett. B **511**, 40 (2001). M. Suzuki, Phys. Rev. D **66**, 054018 (2002);
[7] *BABAR* Collaboration, B. Aubert *et al.*, Nucl. Instr. Meth. A **479**, 1 (2002).
[8] *BABAR* Collaboration, B. Aubert *et al.*, Phys. Rev. Lett. **89**, 281802 (2002).
[9] *BABAR* Collaboration, B. Aubert *et al.*, Phys. Rev. D **65**, 091104 (2002).
[10] S. Agostinelli *et al.* [GEANT4 Collaboration], Nucl. Instr. Meth. A **506**, 250 (2003).
[11] *BABAR* Collaboration, B. Aubert *et al.*, hep-ex/0311049.
[12] The Heavy Flavor Averaging Group, http://www.slac.stanford.edu/xorg/hfag/.
[13] T. Sjöstrand *et al.*, Comput. Phys. Commun. **135**, 238 (2001).
[14] Cranmer, K. S., Comput. Phys. Commun. **136**, 198 (2001).
[15] *BABAR* Collaboration, B. Aubert *et al.*, Phys. Rev. Lett. **89**, 201802 (2002).
[16] *BABAR* Collaboration, B. Aubert *et al.*, Phys. Rev. Lett. **91**, 201802 (2003).
[17] O. Long *et al.*, Phys. Rev. D **68**, 034010 (2003).
[18] A. Falk *et al.*, Phys. Rev. D **69**, 011502 (2004).
[19] M. Gronau, D. London, Phys. Rev. Lett. **65**, 3381 (1990); Y. Grossman and H. Quinn, Phys. Rev. D **58**, 017504 (1998).
[20] K. Hagiwara *et al.*, Phys. Rev. D **66**, 010001 (2002).