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Measurement of CP-Violating Asymmetries in $B^0 \to (\rho\pi)^0$ Using a Time-Dependent Dalitz Plot Analysis

ATTILA MIHALYI*

Department of Physics, University of Wisconsin, Madison, 53706, USA†

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We present the preliminary measurement of CP-violating asymmetries in $B^0 \to (\rho\pi)^0 \to \pi^+\pi^-\pi^0$ decays using a time-dependent Dalitz plot analysis. The results are obtained from a data sample of 213 million $\Upsilon(4S) \to B^0\overline{B}^0$ decays, collected by the BaBar detector at the PEPII asymmetric-energy B-Factory at SLAC. We measure 16 coefficients of the bilinear form factor terms occurring in the time-dependent decay rate of the B^0 meson with the use of a maximum-likelihood fit. The physically relevant CP parameters are derived from these coefficients.

1. Introduction

In the Standard Model, CP-violation arises from a single phase in the three generation CKM quark mixing matrix. The goal of the analysis is the simultaneous extraction of the strong transition amplitudes and the weak interaction phase $\alpha \equiv \arg\left[-V_{td}V_{tb}^*/V_{ud}V_{ub}^*\right]$ of the Unitarity Triangle where V_{ij} are elements of the CKM matrix [1].

It has been pointed out that by explicitly including the variation of the strong phases of the interfering ρ resonances in the Dalitz plot one can constrain α without ambiguities. These regions were removed for the earlier $B^0 \to \rho^\pm\pi^\mp$ analysis[2], but for this analysis, in order to constrain α, we include the entire Dalitz plot that contains the neutral and charge ρ resonances and their interference[4].

2. Analysis Method

The differential decay width to the three pion final state can be written as,

$$d\Gamma(B^0 \to \pi^+\pi^-\pi^0) = \frac{1}{(2\pi)^3}\frac{|\mathcal{A}_{3\pi}|^2}{8m_{B^0}^3}\,ds_+ds_- \,, \tag{1}$$

where $s_\pm$ are the Mandelstam variables and $\mathcal{A}_{3\pi}$ is the Lorentz- invariant decay amplitude. The amplitude can be expanded as $\mathcal{A}_{3\pi} = f_+A^+ + f_-A^- + f_0A^0$ where

*Representing the BaBar collaboration.
†Department of Physics, 1150 University Ave., Madison, WI 53706, USA

$f_{+,-,0}$ are functions of the Dalitz plot and incorporate the dynamical properties of the B^0 decay into a $\rho^{+,-,0}$ resonance (including the ground state $\rho(770)$ and the excitations $\rho(1450)$, $\rho(1700)$). $A^{+,-,0}$ are complex amplitudes that may comprise weak and strong transition phases and that are independent of the Dalitz variables. With $\Delta t \equiv t_{3\pi} - t_{\rm tag}$ defined as the proper time interval between the decay of the fully reconstructed $B^0_{3\pi}$ and that of the other meson $B^0_{\rm tag}$, the time-dependent decay rate $|\mathcal{A}^+_{3\pi}(\Delta t)|^2$ ($|\mathcal{A}^-_{3\pi}(\Delta t)|^2$) when the tagging meson is a B^0 ($\overline{B}^0$) is given by[4]

$$|\mathcal{A}^{\pm}_{3\pi}(\Delta t)|^2 = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}}\Big[|\mathcal{A}_{3\pi}|^2 + |\overline{\mathcal{A}}_{3\pi}|^2 \mp \left(|\mathcal{A}_{3\pi}|^2 - |\overline{\mathcal{A}}_{3\pi}|^2\right)\cos(\Delta m_d \Delta t) \pm 2Im\left[\overline{\mathcal{A}}_{3\pi}\mathcal{A}^*_{3\pi}\right]\sin(\Delta m_d\Delta t)\Big], \quad (2)$$

where τ_{B^0} is the mean B^0 lifetime, Δm_d is the $B^0\overline{B}^0$ oscillation frequency, and where we have assumed that CP violation in $B^0\overline{B}^0$ mixing is absent ($|q/p| = 1$), $\Delta\Gamma_{B_d} = 0$ and CPT is conserved. The amplitude coefficients in Eq. (2) can be re-written in terms of real-valued parameters that multiply the $f_{+,-,0}$ bilinears[5]. It results in 27 coefficients that are the observables determined from a maximum likelihood fit to the data. The coefficients of the sine and cosine terms for the $\rho^0\pi^0$ signal are set to zero due to the low branching ratio of this mode[6]. We furthermore perform a transformation of the DP into what we denote the Square Dalitz plot (SDP). This step is taken to enable a better background parametrization for the likelihood fit and also to ease the correction of efficiency and resolution effects, both of which depend on the DP. The new coordinates are

$$m' \equiv \frac{1}{\pi}\arccos\left(2\frac{m_0 - m_0^{\rm min}}{m_0^{\rm max} - m_0^{\rm min}} - 1\right), \quad \text{and} \quad \theta' \equiv \frac{1}{\pi}\theta_0, \quad (3)$$

where m_0 is the invariant mass between the charged tracks, $m_0^{\rm max} = m_{B^0} - m_{\pi^0}$ and $m_0^{\rm min} = 2m_{\pi^+}$ are the kinematic limits of m_0, θ_0 is the ρ^0 helicity angle.

The event yield and the coefficients entering the SDP parametrization are determined from a maximum likelihood fit. The cross-feed from B-background modes is estimated from Monte Carlo (MC) simulation. Over 100 such modes have been considered and 36 of them are retained in the likelihood model. Dominant modes are $B \to \rho\rho$ and $B^+ \to (\rho\pi)^+$. Non-resonant events are bound at the upper limit of 1.4×10^{-6} at 90% C.L. and we also searched for $B^0 \to f_0(980)\pi^0$ without finding evidence for a signal.

We use MC simulation to parametrize the discriminating variables entering the fit. Most of the continuum parameters are floated while all the B-background shapes are fixed.

3. Systematic Uncertainties

The most important contribution to the systematic uncertainty stems from the signal modeling of the Dalitz plot dynamics. We vary the mass and width of the $\rho(770)$

and $\rho(1450)$ within ranges that exceed twice the errors found for these parameters in the fits to τ and e^+e^- data[7]. The phase and fraction of $\rho(1450)$ is however floated in the fit. The systematic uncertainty due to the $\rho(1700)$ amplitude parameters is determined from a separate fit to data. Another major source of uncertainty is the B-background model. For these modes we vary the expected yields and their CP-parameters within the measured or estimated ranges. The systematic errors for the parameters that measure interference effects are dominated by the uncertainty in the signal model, mainly the tail description of the ρ resonance. For the other parameters, the uncertainty on the fit bias and the B-background contamination are important.

4. Results

The DP averaged, resonant $B^0 \to \pi^+\pi^-\pi^0$ efficiency is 24% and we fit $1184 \pm 58(stat)$ events. The signal is dominated by $B^0 \to \rho^\pm\pi^\mp$ decays. We observe an excess of $\rho^0\pi^0$ events, which is in agreement with our previous upper limit of 2.9×10^{-6} at 90% C.L.[6]. The result for the $\rho(1450)$ amplitude is in agreement with the findings in τ and e^+e^- decays[7]. For the relative strong phase between the $\rho(770)$ and the $\rho(1450)$ amplitudes we find $(199^{+13}_{-17})^\circ$ (statistical error only), which is compatible with published results[7].

From the fitted coefficients that multiply the $f_{+,-,0}$ bilinears we can determine the physically more intuitive direct CP-violation parameters, $\mathcal{A}_{\rho\pi}^{+-}$ and $\mathcal{A}_{\rho\pi}^{-+}$[2]. They are proportional to the asymmetry between the possible $\rho^\pm\pi^\mp$ decay rates of B^0 and $\overline{B}^0$ mesons. We find $\mathcal{A}_{\rho\pi}^{+-} = -0.21 \pm 0.11 \pm 0.04$, and $\mathcal{A}_{\rho\pi}^{-+} = -0.47^{+0.14}_{-0.15} \pm 0.06$ which imply direct CP violation at the 2.9σ level. The measurement of the resonance interference also allows us to determine the relative phase between the the amplitudes of the decays $B^0 \to \rho^-\pi^+$ and $B^0 \to \rho^+\pi^-$. The solution favored by the fit is, $\delta_{+-} = (-67^{+28}_{-31} \pm 7)^\circ$, with only a marginal constraint for $C.L. < 0.05$.

Furthermore we derive a constraint on α from the measured coefficients. Ignoring the mirror solution at $\alpha{+}180^\circ$, we find $\alpha = (113^{+27}_{-17} \pm 6)^\circ$, where the systematic error is dominated by the uncertainties in the signal model. Only a marginal constraint on α is obtained for C.L. < 0.05.

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