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Recent results in charmless hadronic B decays with *BABAR*

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We present recent results from the *BABAR* experiment in studies of charmless hadronic B decays. These results were obtained using the full $\Upsilon(4S)$ dataset of approximately 465 million $B\bar{B}$ pairs collected by the *BABAR* detector at the PEP-II asymmetric energy B factory at SLAC. Results include the study of the quasi-two-body decays $B^+ \to \rho^0(770)K^{*+}$ and $B^+ \to f_0(980)K^{*+}$, including a polarization fraction measurement of $B^+ \to \rho^0(770)K^{*+}$, measurements of $B^+ \to \phi\phi K^+$and the first observation of $B^0 \to \phi\phi K^0_S$. Charmless three-body results include the Dalitz plot analysis of $B^0 \to K^+\pi^-\pi^0$ and the first observation of $B^+ \to K^+\pi^0\pi^0$, including measurements of intermediate quasi-two-body resonances such as $B^+ \to K^{*+}(892)\pi^0$.

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1. Introduction

The study of charmless B decays probes the dynamics of weak and strong interactions by measuring the interference between tree level and penguin contributions to the same final state. This interference effect can give rise to direct *CP* violation. Time-dependent measurements and interferences between intermediate states permit measurements of all three angles of the CKM Unitarity Triangle. The presence of loop contributions to these decays also permits searches for the effects of new particles entering the loops, such as enhanced branching fractions and *CP* asymmetries.

2. Analysis Techniques

All the analyses presented below make use of the full BABAR $\Upsilon(4S)$ dataset. This consists of 467 million $B\bar{B}$ pairs collected by the BABAR detector at the PEP-II B factory which collides e^+e^- asymmetric beams at the $\Upsilon(4S)$ resonance. The B meson candidates are characterised using kinematic variables. These take advantage of the fact that the centre-of-mass energy $\sqrt{s}$ is just above the $B\bar{B}$ production threshold to construct a pair of almost uncorrelated variables $m_{\rm ES} = \sqrt{\frac{s}{4} - \vec{p}_B^{*2}}$ and $\Delta E = E_B^* - \frac{\sqrt{s}}{2}$, where $(E_B^*, \vec{p}_B^*)$ is the B meson four-momentum in the centre-of-mass frame. Additionally B meson candidates are distinguished from the lighter $q\bar{q}$ background using topological variables combined in a multivariate analyser (MVA), such as a neural network or a Fisher discriminant, in order to maximise their discriminating power. Both kinematic variables and the output of the MVA can either have selection requirements placed upon them or be supplied as inputs in a maximum likelihood fit.

3. Study of the decays $B^+ \to \rho^0(770)K^{*+}$ and $B^+ \to f_0(980)K^{*+}$

The polarization fraction ($f_{\rm L}$) in $B \to VV$ decays is predicted to be ~ 1.0. However experimental results in penguin dominated $b \to s$ decays have shown that the longitudinal polarization fraction for those decays is $f_{\rm L} \sim 0.5$. The analysis described below presents the first observation of the charmless decay $B^+ \to \rho^0(770)K^{*+}$, including the measurement of its polarization fraction, and measurement of the charmless decay $B^+ \to f_0(980)K^{*+}$. The ρ^0 and f^0 candidates are reconstructed from their decay to $\pi^+\pi^-$ and the K^{*+} candidates from their decays to either $K_S^0\pi^+$ or $K^+\pi^0$. The invariant masses and angular distributions of the $K^+\pi^0(K_S^0\pi^+)$ and $\pi^+\pi^-$ candidates are used as input in the maximum likelihood fit in addition to the kinematic variables, $m_{\rm ES}$ and ΔE, and the output of a neural network. Results are compatible with the previous BABAR upper limit. The first observation of $B^+ \to \rho^0(770)K^{*+}$ is made with a significance of 5.3σ; the branching fraction is measured to be $(4.6 \pm 1.0 \pm 0.4) \times 10^{-6}$. The polarisation fraction in $B^+ \to \rho^0(770)K^{*+}$ is found to be $0.78 \pm 0.12 \pm 0.03$, which is compatible with other experimental results in $b \to s$ decays. The $B^+ \to f_0(980)K^{*+}$ decay is found to have a branching fraction of $(4.2 \pm 0.6 \pm 0.3) \times 10^{-6}$ and a *CP* asymmetry of $-0.15 \pm 0.12 \pm 0.03$ [2].

4. Branching fractions and *CP* asymmetry studies in $B \to \phi\phi K$ decays

The three-body decay $B \to \phi\phi K$ occurs via a "penguin" loop $b \to ss\bar{s}$ transition. This final state can also occur via the intermediate tree level $B \to \eta_c K$ decay, with η_c decaying to $\phi\phi$. In the $\phi\phi$ invariant mass region close to the η_c resonance, the tree and penguin amplitudes may interfere. The Standard Model predicts that these contributions have similar weak phases and therefore no direct *CP* violation is expected. A significant *CP* asymmetry would therefore be a clear sign of New Physics. Both decays of $B^+ \to \phi\phi K^+$ and $B^0 \to \phi\phi K^0_S$ are considered in this analysis. The maximum likelihood fit is constructed from the two ϕ candidates' invariant masses, the kinematic variables $m_{\rm ES}$ and ΔE, and the output of the Fisher discriminant. Below the η_c region, we find the branching fraction of $B^+ \to \phi\phi K^+$ to be consistent with previous measurements [3, 4], with a fitted yield of 178 ± 15 events. We make the first observation of the decay $B^0 \to \phi\phi K^0_S$ at $m_{\phi\phi} < 2.85$ GeV/c^2 with a significance greater than 5σ and a fitted yield of 40 ± 7 events. The branching fraction is found to be $\mathscr{B}\left(B^0 \to \phi\phi K^0_S\right) = (4.5 \pm 0.8 \pm 0.3) \times 10^{-6}$. In the η_c region, the *CP* asymmetry is found to be $A_{CP}\left(m_{\phi\phi} \in [2.94, 3.02]\ \mathrm{GeV}/c^2\right) = -0.09 \pm 0.10 \pm 0.02$ which is consistent with the Standard Model prediction [5].

5. Dalitz plot analysis of $B^0 \to K^+\pi^-\pi^0$

Amplitudes of $B \to K^*\pi$ decays are sensitive to the angle γ of the Unitarity Triangle at tree level. Tree level contributions are however Cabibbo suppressed with respect to QCD and electroweak (EWP) penguin amplitudes. QCD penguin contributions can be eliminated by forming isospin triangles from the amplitudes of the decays $B^0 \to K^{*+}\pi^-$ and $B^0 \to K^{*0}\pi^0$given by:

$$A_{\frac{3}{2}}(K^{*+}\pi^0) = \frac{1}{\sqrt{2}}A(B^0 \to K^{*+}\pi^-) + A(B^0 \to K^{*0}\pi^0), \tag{5.1}$$

where $A_{\frac{3}{2}}$ is the isospin $\frac{3}{2}$ weak decay amplitude. These amplitudes are measured from their interferences with other contributions to the final state $B^0 \to K^+\pi^-\pi^0$. The phase difference between $B^0 \to K^{*+}\pi^-$ and $\bar{B}^0 \to K^{*-}\pi^+$ is measured from the Dalitz plot analysis of the final state $B^0 \to K^0_S\pi^+\pi^-$ [6, 7]. Both *BABAR* and Belle have made measurements of this phase in $B^0 \to K^0_S\pi^+\pi^-$, however, the results presented here are from a combination of the *BABAR* analyses of $B^0 \to K^+\pi^-\pi^0$ and $B^0 \to K^0_S\pi^+\pi^-$, which yields the weak phase of $A_{\frac{3}{2}}$, given by $\Phi_{\frac{3}{2}} = -\frac{1}{2}Arg\left(\bar{A}_{\frac{3}{2}}/A_{\frac{3}{2}}\right)$. This phase is equal to the CKM angle γ in the absence of electroweak penguins. A maximum likelihood fit is formed from the kinematic variables, output of the neural network and the Dalitz plot parameters. The overall branching fraction for the three-body decay is found to be $\mathscr{B}(B^0 \to K^+\pi^-\pi^0) = (38.5 \pm 1.0 \pm 3.9) \times 10^{-6}$. A 3.1σ evidence of direct *CP* violation is observed as $A\left(B^0 \to K^{*+}\pi^-\right) = -0.29 \pm 0.11 \pm 0.02$. There is poor sensitivity to $\Phi_{\frac{3}{2}}$ due to $\bar{A}_{\frac{3}{2}}$ being close to zero. $B^0 \to \rho K$ decays also allow the measurement of an analogous amplitude via the amplitudes of $B^0 \to \rho^- K^+$ and $B^0 \to \rho^0 K^0$. These decays do not contribute to a common final state but do interfere with the $B^0 \to K^{*+}\pi^-$ amplitude in their decays to $B^0 \to K^+\pi^-\pi^0$ and $B^0 \to K^0_S\pi^+\pi^-$. We find $\Phi_{\frac{3}{2}}(\rho K) = \left(-10^{+10+7}_{-20-22}\right)^\circ$ [8].

6. Search for $B^+ \to K^+\pi^0\pi^0$

Recent measurements of rates and asymmetries in $B \to K\pi$ decays have generated considerable interest because of possible hints of new physics contributions. $B \to K^*\pi$ decays are predicted to have larger *CP* asymmetries and hence provide useful additional information. To this purpose an improved measurement of $K^{*+}\pi^0$ is needed and is measured through the final state of $B^+ \to K^+\pi^0\pi^0$. We construct a maximum likelihood fit to two variables, $m_{\rm ES}$ and the output of a neural network of event-shape variables. Results include the first observation of $B^+ \to K^+\pi^0\pi^0$ with a branching fraction of $\mathscr{B}\left(B^+ \to K^+\pi^0\pi^0\right) = (16.2 \pm 1.2 \pm 1.5) \times 10^{-6}$ and a significance greater than 10σ. A Dalitz plot analysis of this mode is not possible due to the large fraction of misreconstructed signal events, hence branching fractions and *CP* asymmetries for the resonances are measured by selecting signal regions in the invariant mass distributions reproduced from $_s$Weights [9]. Background yields in the signal regions are estimated using normalised averages of two sidebands on either side of the signal regions and subtracted from the signal yield. We find a product branching fraction for $B^+ \to f_0(980)\left(\to \pi^0\pi^0\right)K^+$ of $(2.79 \pm 0.57 \pm 0.51) \times 10^{-6}$. The result for $K^{*+}(892)\pi^0$ supercedes the previous *BABAR* result with an overall branching fraction of $\mathscr{B} = (8.2 \pm 1.5 \pm 1.1) \times 10^{-6}$ and $A_{CP} = (-6 \pm 24 \pm 4)\%$ [10].

7. Conclusion

BABAR continues to produce many new physics results in charmless *B* decays. Most of these results agree with the Standard Model predictions but puzzles such as the polarisation problem and "$K\pi$" puzzle still remain unsolved. To ascertain if these discrepancies are indeed a sign of New Physics, larger statistics from current experiments, *e.g.* LHCb, and future experiments, such as SuperB and BelleII is needed.

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