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CHARMLESS HADRONIC B DECAYS AT *BABAR*

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We present recent results on charmless hadronic B decays using data collected by the *BABAR* detector at the PEP-II asymmetric-energy e^+e^- collider at the Stanford Linear Accelerator Center. We report measurements of branching fractions and charge asymmetries in several charmless two-body, three-body, and quasi-two-body decay modes. We also report measurements of polarization in charmless B decays to exclusive final states with two vector mesons.

1. Introduction

Charmless hadronic B decays are an important probe of the standard model (SM). They can be used to test the Cabibbo-Kobayashi-Maskawa (CKM) mechanism of flavor mixing and CP violation, with sensitivity to the three angles α, β, and γ of the Unitarity Triangle for B decays. Charmless processes are usually dominated by $b \to u$ tree amplitudes and "penguin" decays mediated by $b \to s$ and $b \to d$ processes involving a virtual loop with the emission of a gluon. These transitions are suppressed by CKM factors in the SM, with branching fractions at the $10^{-6} - 10^{-5}$ level. Contributions from supersymmetric particles or other physical effects beyond the SM could induce observable deviations from SM predictions in the measured branching fractions and CP asymmetries.[1]

In these proceedings, I summarize the most recent measurements for this class of decays at the *BABAR* experiment at SLAC. The results include two-body, three-body, and quasi-two-body decay modes. We also report measurements of polarization in modes with two vector mesons in the final state, which are also a sensitive test of SM predictions and the effect of potential non-SM contributions.

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2. Experimental Methods

2.1. *Signal Extraction*

Signal decays are separated from background decays using unbinned extended maximum-likelihood fits to distributions of kinematic and event-shape variables. The primary kinematic variables used to identify a reconstructed signal B candidate are the difference ΔE between its reconstructed energy in the center-of-mass (CM) frame and the beam energy; and a beam-energy substituted mass, $m_{\rm ES} \equiv \sqrt{(s/2 + \mathbf{p}_i \cdot \mathbf{p}_B)^2/E_i^2 - \mathbf{p}_B^2}$, where the B-candidate momentum $\mathbf{p}_B$ and the four-momentum of the initial e^+e^- state $(E_i, \mathbf{p}_i)$ are calculated in the laboratory frame. Event-shape variables are used to suppress the dominant "continuum" $e^+e^- \to q\bar{q}$ $(q = u, d, s, c)$ background further, exploiting angular differences between the jet-like topology of continuum decays and the isotropically distributed decays of $B\overline{B}$ events. Backgrounds from $B\overline{B}$ decays into final states with charm quarks are suppressed by invariant-mass vetoes on charmonium and D mesons, while backgrounds from charmless processes are rejected with selection criteria on ΔE and invariant-mass window selections and mass constraints on composite mesons in the signal decay. Particle-identification information is used to separate charged pion from charged kaon candidates in the $B^+ \to \overline{K}^0 K^+$ and $B^+ \to K^+ K^-$ decays. Angular variables are used for further signal-background discrimination and to identify helicity and polarization information in modes involving vector or tensor mesons.

2.2. *CP Asymmetries*

CP asymmetries in neutral B decays to CP eigenstates are determined from the difference in the time-dependent decay rates for $\overline{B}^0$ and B^0 signal decays. The parameter S describes CP violation in the interference between mixed and unmixed decays into the same final state, while C describes direct CP violation in decay. If no time-dependent measurement is performed, an integrated flavor or charge asymmetry can be measured:

$$\mathcal{A}_{CP} = \left(N_{B^0,B^+} - N_{\overline{B}^0,B^-}\right) / \left(N_{B^0,B^+} + N_{\overline{B}^0,B^-}\right) \tag{1}$$

A non-zero value of this asymmetry signifies the presence of direct CP violation. In the charged B modes, this is the only possible CP measurement.[a]

[a] $\mathcal{A}_{CP} = -C$.

3. Experimental Results

3.1. *Two-Body Modes with Only Kaons and Pions in the Final State*

The $\pi\pi$ modes are important for the extraction of the angle α,[2] while direct CP violation has been observed in the $B^0 \to K^+\pi^-$ and $B^0 \to \pi^+\pi^-$ modes. In addition, several relations between branching fractions and charge asymmetries in the $B \to K\pi$ modes can be used to test SM predictions. No significant deviations between experiment and theory is observed in the recent results, relaxing the so-called "$K\pi$ Puzzle" tension.[3] *BABAR* has also observed the $b \to d$ penguin-dominated modes $B^0 \to K^0\overline{K}^0$ and $B^+ \to \overline{K}K^+$, and measured the time-dependent CP-violating asymmetries in the former for the first time, utilizing a beam-constrained technique to vertex the signal B meson in the absence of prompt charged tracks. The $B^0 \to K^+K^-$ mode is the last mode left to be observed in this class of decays. Table 1 summarizes the most recent *BABAR* results.[4]

Table 1. Branching fractions and CP asymmetries for two-body modes with only kaons and pions in the final state.

Mode	$\mathcal{B}$, 10^{-6}	$\mathcal{A}_{CP}$ or $-C$	S
$B^0 \to \pi^+\pi^-$	$5.5 \pm 0.4 \pm 0.3$	$0.21 \pm 0.09 \pm 0.02$	$-0.60 \pm 0.11 \pm 0.03$
$B^+ \to \pi^+\pi^0$	$5.1 \pm 0.5 \pm 0.3$	$-0.02 \pm 0.09 \pm 0.01$	–
$B^0 \to \pi^0\pi^0$	$1.48 \pm 0.26 \pm 0.12$	$0.33 \pm 0.36 \pm 0.08$	–
$B^0 \to K^+\pi^-$	$19.1 \pm 0.6 \pm 0.6$	$-0.107 \pm 0.018^{+0.007}_{-0.004}$	–
$B^+ \to K^+\pi^0$	$13.3 \pm 0.6 \pm 0.6$	$0.016 \pm 0.041 \pm 0.012$	–
$B^+ \to K^0\pi^+$	$23.9 \pm 1.1 \pm 1.0$	$-0.029 \pm 0.039 \pm 0.010$	–
$B^0 \to K^0\pi^0$	$10.5 \pm 0.7 \pm 0.5$	$-0.20 \pm 0.16 \pm 0.03$	$0.33 \pm 0.26 \pm 0.04$
$B^0 \to K^0\overline{K}^0$	$1.08 \pm 0.28 \pm 0.11$	$0.40 \pm 0.41 \pm 0.06$	$-1.28^{+0.80}_{-0.73}{}^{+0.11}_{-0.16}$
$B^+ \to \overline{K}^0K^+$	$1.61 \pm 0.44 \pm 0.09$	$0.10 \pm 0.26 \pm 0.03$	–
$B^0 \to K^+K^-$	< 0.5 (90% C.L.)	–	–

3.2. *Vector-Pseudoscalar Decays*

BABAR reports the first observation, at the level of 7.9σ (including systematic uncertainties), of the $b \to s$ penguin-dominated decay $B^+ \to \rho^+K^0$. The branching fraction is in agreement with the SM prediction $p'_V = -p'_P$, which is a relation between amplitudes where the spectator quark is present in the vector and pseudoscalar meson, respectively. The charge asymmetry is consistent with zero and the SM expectation. *BABAR* also presents an updated upper limit on the branching fraction of the $b \to d$ penguin-dominated decay $B^+ \to \overline{K}^{*0}K^+$. Using the technique described in Ref. [5], an improved upper limit is placed on the difference between $\sin(2\beta_{\rm eff})$ and

Table 2. Branching fractions and CP asymmetries in vector-pseudoscalar modes.

Mode	$\mathcal{B},\ 10^{-6}$	$\mathcal{A}_{CP}$
$B^+ \to \rho^+ K^0$	$8.0^{+1.4}_{-1.3} \pm 0.5$	$-0.122 \pm 0.166 \pm 0.020$
$B^+ \to \overline{K}^{*0} K^+$	< 1.1 (90% C.L.)	–
$B^+ \to \overline{K}^{*0}_0(1430) K^+$	< 2.2 (90% C.L.)	–

$\sin(2\beta)$ in the $B^0 \to \phi K^0$ decay mode: $|\Delta S_{\phi K^0}| < 0.11$. The results are summarized in Table 2.[6]

3.3. *Vector-Vector Modes*

As B mesons are pseudoscalars, their decays to vector-vector final states are polarized. Using the quark spin-flip argument based on the left-handed nature of the charged weak current, we expect the following hierarchy to hold in modes dominated by $b \to u$ tree and $b \to s$ penguin amplitudes:

$$A_0 \sim 1 \gg A_+ \sim \frac{m_{\rm V}}{m_B} \gg A_- \sim \frac{m_{\rm V}^2}{m_B^2}, \qquad (2)$$

where $A_{\rm h}$ is the amplitude of helicity h and $m_{\rm V}$ and m_B are the masses of the vector and B mesons, respectively.[7] This translates into the prediction that the fraction of longitudinal polarization $f_{\rm L}$ in the decay should be close to 1. Other amplitudes from SM and non-SM processes could alter this expectation. The prediction has been verified in the tree-dominated $B \to \rho\rho$ and $B \to \rho\omega$ decays, with measured $f_{\rm L}$ in the range $0.8 - 1.0$.

BABAR reports branching-fraction, charge-asymmetry, and polarization measurements in the $B \to \phi K^{*0}$ and $B \to \rho K^*$ decays,[8] which are thought to be dominated by $b \to s$ penguin amplitudes. The results are summarized in Table 3. The observed longitudinal-polarization fractions are approximately $f_{\rm L} \sim 0.5$ for the vector-vector modes, while the measured transverse-polarization fractions are $f_\perp(B^0 \to \phi K^*(892)^0) = 0.227 \pm 0.038 \pm 0.013$ and $f_\perp(B^0 \to \phi K_2^*(1430)^0 = 0.045^{+0.049}_{-0.040} \pm 0.013$, implying the amplitude hierarchy $|A_0| \approx |A_{+1}| \gg |A_{-1}|$. This suggests the presence of additional contributions to the total amplitude of these decays.[7] These can come from SM sources, such as annihilation amplitudes, electromagnetic or charming penguins, and long-distance rescattering effects; or from non-SM sources such as right-handed supersymmetric mass insertions or tensor Z''. Whatever their source, the additional contributions are not interfering with the nominal amplitudes to produce sizeable CP asymmetries, as the measurements are consistent with the SM prediction of zero or very small CP violation. Thus, they must occupy a peculiar corner of phase space. It is

Table 3. Branching fractions, CP asymmetries, and fractions of longitudinal polarization in vector-vector and vector-tensor modes. Upper limits on branching fractions at 90% C.L. are given for modes with less than 3σ significance, while both central values and upper limits are given for modes with significance between 3σ and 5σ.

Mode	$\mathcal{B}$, 10^{-6}	$\mathcal{A}_{CP}$	$f_{\rm L}$
$B^0 \to \phi K^*(892)^0$	$9.2 \pm 0.7 \pm 0.6$	$-0.03 \pm 0.07 \pm 0.03$	$0.506 \pm 0.040 \pm 0.015$
$B^0 \to \phi K_2^*(1430)^0$	$7.8 \pm 1.1 \pm 0.6$	$-0.12 \pm 0.14 \pm 0.04$	$0.853^{+0.061}_{-0.069} \pm 0.036$
$B^0 \to \phi(K\pi)_0^{*0}$	$5.0 \pm 0.8 \pm 0.3$	$0.17 \pm 0.15 \pm 0.03$	–
$B^+ \to \rho^0 K^{*+}$	< 6.1 (90% C.L.)	–	–
$B^+ \to \rho^+ K^{*0}$	$9.6 \pm 1.7 \pm 1.5$	$-0.01 \pm 0.16 \pm 0.02$	$0.52 \pm 0.10 \pm 0.04$
$B^0 \to \rho^- K^{*+}$	< 12.0 (90% C.L.)	–	–
$B^0 \to \rho^0 K^{*0}$	$5.6 \pm 0.9 \pm 1.3$	$0.09 \pm 0.19 \pm 0.02$	$0.57 \pm 0.09 \pm 0.08$
$B^+ \to f_0(980) K^{*+}$	$5.2 \pm 1.2 \pm 0.5$	$-0.34 \pm 0.21 \pm 0.03$	–
$B^0 \to f_0(980) K^{*0}$	$2.6 \pm 0.6 \pm 0.09$ (< 4.3)	$-0.17 \pm 0.28 \pm 0.02$	–

also interesting to note that these amplitudes have a different or no effect on tensor-vector modes, as $f_{\rm L}$ is close to unity for $B^0 \to \phi K_2^*(1430)^0$.

4. Conclusion

BABAR reports measurements of branching fractions, CP asymmetries, and polarization fractions in charmless hadronic B decays. While disagreements from SM predictions are no longer apparent in two-body decays with kaons and pions, hints of previously unconsidered amplitudes from SM or non-SM contributions have been observed in vector-vector polarization measurements. More data and further theoretical work will shed more light on this issue in the future.

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