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# MEASUREMENT OF CHARMLESS HADRONIC B DECAYS BRANCHING FRACTION AT BABAR.

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**Abstract**

We present preliminary measurements of the branching fractions for charmless hadronic decays of $B$ mesons into two-body final states with kaons, pions and a $\phi$ resonance. The measurements are based on a data sample of approximately 23 million $B\bar{B}$ pairs collected by the BaBar detector at the PEP-II asymmetric $B$ Factory at SLAC.

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Charmless hadronic final states play an important role in the study of *CP*-violation. In the Standard Model, all *CP*-violating phenomena are a consequence of a single complex phase in the Cabibbo-Kobayashi-Maskawa (CKM) quark-mixing matrix [1]. Measurements of the rates and *CP* asymmetries for $B$ decays into the charmless final states $\pi\pi$ and $K\pi$ can be used to constrain the angles $\alpha$ [2] of the unitarity triangle. Decays containing a $\phi$ meson are interesting since they are dominated by $b \to s(d)\bar{s}s$ peguin diagram, with potential benefits to estimates of direct *CP*-violation effects. They also allow an independent measurement of $\sin 2\beta$.

We present preliminary measurements of the branching fractions for charmless hadronic decays of $B$ mesons in the final states $\pi^+\pi^-$, $K^+\pi^-$, $K^+\pi^0$, $K^0\pi^+$, $K^0\pi^0$, $\phi K^+$, $\phi K^0$, and $\phi K^{*+}(892)$ [3]. The data sample used in these analyses consists of $22.57 \times 10^6$ $B\overline{B}$ pairs, collected at the PEP-II $e^+e^-$ collider (SLAC) with the BaBar detector [4] .

Hadronic events are selected based on track multiplicity and event topology. We use only good quality tracks: tracks are identified as pions or kaons using the Cherenkov angle $\theta_c$ measured by a unique, internally reflecting Cherenkov ring imaging detector (DIRC). Candidate $K^0_S$ mesons are reconstructed from pairs of oppositely charged tracks that form a well-measured vertex and have an invariant mass within 3.5 standard deviations ($\sigma$) of the nominal $K^0_S$ mass [5]. Candidate photons are defined as showers in the EMC that have the expected lateral shape and are not matched to a track. Candidate $\pi^0$ mesons are formed from pairs of photons with an invariant mass within $3\sigma$ of the nominal $\pi^0$ mass. The $\pi^0$ candidates are then kinematically fitted with their mass constrained to the nominal $\pi^0$ mass. All tracks (except $K^0_S$ daughters) are required to have good-quality $\theta_c$ measurements that are inconsistent with the expected value for a proton. Electrons are rejected based on specific ionization ($\mathrm{d}E/\mathrm{d}x$) in the DCH system, shower shape in the EMC, and the ratio of shower energy to track momentum.

Candidate $B$ mesons are reconstructed in the various topologies: $h^+h'^-$, $h^+\pi^0$, $K^0_S h^+$, $K^0_S\pi^0$, $\phi h^+$, $\phi K^0_S$, and $\phi K^{*+}$ where the symbols $h$ and $h'$ refer to $\pi$ or $K$. For $\phi$ candidates, both tracks must be identified as kaons whose invariant mass must lie within a $\pm 30\,\mathrm{MeV}/c^2$ interval centered around $\phi$ mass. The selection of $K^{*+}$ comprises $K^+\pi^0$ and $K^0_S\pi^+$ combinations within a $K\pi$ mass interval of $\pm 150\,\mathrm{MeV}/c^2$. A $K^*$ helicity angle cut effectively requires $\pi^0$ momentum greater than $0.35\,\mathrm{GeV}/c$.

Candidate B mesons are selected exploiting the kinematic constraints provided by the $\Upsilon(4S)$ initial state: we define a energy-substituted mass $m_{\mathrm{ES}}$, where $\sqrt{s}/2$ is substituted for candidate's energy, and the difference $\Delta E$ between the B-candidate energy and $\sqrt{s}/2$. For all modes the $m_{\mathrm{ES}}$ resolution is dominated by the beam energy spread and is approximately $2.5\,\mathrm{MeV}/c^2$, while $\Delta E$ resolution is mode dependent and dominated by momentum resolution. Candidates are selected in the range $5.2 < m_{\mathrm{ES}} < 5.3\,\mathrm{GeV}/c^2$. Candidates are accepted, depending on the decay topology, in various $\Delta E$ ranges, which are restrictive enough to suppress backgrounds due to other types of $B$ decays.

The largest source of background is from random combinations of tracks and neutrals produced in the $e^+e^- \to q\overline{q}$ continuum (where $q = u$, $d$, $s$ or $c$). In the CM frame this background typically exhibits a two-jet structure. In contrast, the low momentum and pseudoscalar nature of $B$ mesons in the decay $\Upsilon(4\mathrm{S}) \to B\overline{B}$ leads to a more spherically symmetric event. This topology difference is exploited using two event-shape quantities: the angle $\theta_S$ [6] between the sphericity axes, evaluated in the CM frame, of the $B$ candidate and the remaining tracks and photons in the event. The distribution of the absolute value of $\cos\theta_S$ is strongly peaked near 1 for continuum events and is approximately uniform for $B\overline{B}$ events. We require $|\cos\theta_S| < 0.9$

The second quantity used in the analyses is a Fisher discriminant $\mathcal{F}$ which consists of a linear

combination of several variables that distinguish signal from background [7]. The experimental observables used in the definition of $\mathcal{F}$ are the scalar sum of the momenta of all tracks and photons (excluding the $B$ candidate daughters) flowing into nine concentric cones centered on the thrust axis of the $B$ candidate, in the CM frame. Each cone subtends an angle of 10° and is folded to combine the forward and backward intervals.

The global detection efficiencies, which include the intermediate particle branching fractions, are listed in Table 1.

Table 1: Summary of results for detection efficiencies ($\epsilon$), numbers of fitted signal yields ($N_S$), statistical significances, and measured branching fractions ($\mathcal{B}$). ( 90% confidence level upper limits). The efficiencies include the branching fractions for $K^0 \to K^0_S \to \pi^+\pi^-$, $\pi^0 \to \gamma\gamma$, $\phi \to K^+K^-$. Equal branching fractions for $\Upsilon(4S) \to B^0\overline{B}^0$ and $B^+B^-$ are assumed.

| Mode | $\epsilon$ (%) | $N_S$ | Stat. Sig. ($\sigma$) | $\mathcal{B}(10^{-6})$ |
|---|---|---|---|---|
| $\pi^+\pi^-$ | 45 | $41 \pm 10$ | 4.7 | $4.1 \pm 1.0 \pm 0.7$ |
| $K^+\pi^-$ | 45 | $169 \pm 17$ | 15.8 | $16.7 \pm 1.6 \pm 1.3$ |
| $K^+K^-$ | 43 | $8.2^{+7.8}_{-6.4}$ | 1.3 | $< 2.5$ |
| $\pi^+\pi^0$ | 32 | $37 \pm 14$ | 3.4 | $< 9.6$ |
| $K^+\pi^0$ | 31 | $75 \pm 14$ | 8.0 | $10.8^{+2.1}_{-1.9} \pm 1.0$ |
| $K^0\pi^+$ | 14 | $59^{+11}_{-10}$ | 9.8 | $18.2^{+3.3}_{-3.0} \pm 1.7$ |
| $\overline{K}^0K^+$ | 14 | $0.0^{+2.4}_{-0}$ | 0 | $< 2.5$ |
| $K^0\pi^0$ | 9.6 | $17.9^{+6.8}_{-5.8}$ | 4.5 | $8.2^{+3.1}_{-2.7} \pm 1.1$ |
| $\phi K^+$ | 18 | $31.4^{+6.7}_{-5.9}$ | 10.5 | $7.7^{+1.6}_{-1.4} \pm 0.8$ |
| $\phi\pi^+$ | 19 | $0.9^{+2.1}_{-0.9}$ | 0.6 | $< 1.4$ |
| $\phi K^0$ | 6 | $10.8^{+4.1}_{-3.3}$ | 6.4 | $8.1^{+3.1}_{-2.5} \pm 0.8$ |
| $\phi K^{*+}$ | 5 | | 4.5 | $9.7^{+4.2}_{-3.4} \pm 1.7$ |
| $\phi K^{*+}_{K^+}$ | 2.5 | $7.1^{+4.3}_{-3.4}$ | 2.7 | $12.8^{+7.7}_{-6.1} \pm 3.2$ |
| $\phi K^{*+}_{K^0}$ | 2.4 | $4.4^{+2.7}_{-2.0}$ | 3.6 | $8.0^{+5.0}_{-3.7} \pm 1.3$ |

Signal yields are determined from an unbinned maximum likelihood fit using $m_{\rm ES}$, $\Delta E$, $\mathcal{F}$, $\theta_c$, $\phi$ mass, and $K^{*+}$ mass (where applicable). In each of the fits, the likelihood for a given candidate $j$ is obtained by summing the product of event yield $n_k$ and probability $\mathcal{P}_k$ over all possible signal and background hypotheses $k$. The $n_k$ are determined by maximizing the extended likelihood function $\mathcal{L}$:

$$\mathcal{L} = \exp\left(-\sum_{i=1}^{M} n_i\right) \prod_{j=1}^{N} \left[\sum_{k=1}^{M} n_k \mathcal{P}_k\left(\vec{x}_j; \vec{\alpha}_k\right)\right] . \tag{1}$$

where $\mathcal{P}_k(\vec{x}_j; \vec{\alpha}_k)$ is the probability for candidate $j$ to belong to category $k$ (of $M$ total categories), based on its characterizing variables $\vec{x}_j$ and parameters $\vec{\alpha_k}$ that describe the expected distributions of these variables. The probabilities $\mathcal{P}_k(\vec{x}_j; \vec{\alpha}_k)$ are evaluated as the product of probability density functions (PDFs) for each of the independent variables $\vec{x}_j$, given the set of parameters $\vec{\alpha}_k$. Monte Carlo simulated data is used to validate the assumption that the fit variables are uncorrelated. The exponential factor in $\mathcal{L}$ accounts for Poisson fluctuations in the total number of observed events $N$.

The probabilities for each possible signal and background hypotheses are evaluated as the product of probability density functions (PDFs) for each of the independent variables. The parameters of $m_{\rm ES}$, $\Delta E$, and $\mathcal{F}$ PDFs are determined from data, and are cross-checked with Monte Carlo

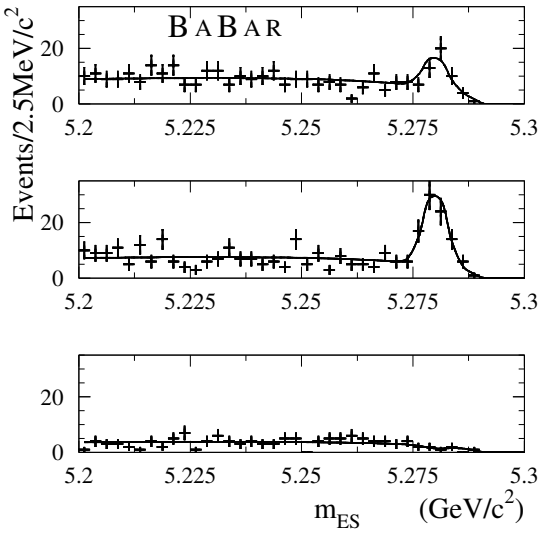


Figure 1: The $m_{\rm ES}$ distributions for candidates which are (from top to bottom) $\pi^+\pi^-$-like, $K^+\pi^-$-like, $K^+K^-$-like The curves represent fits to the distributions

simulation. In particular, a sample of $D^*$-tagged $D^0 \to K^-\pi^+$ decays is used to parametrize the $\theta_C$ distribution for pion and kaon tracks as a function of momentum. The results of the fits for the various topologies are summarized in Table 1. We find evidence for the decay $B^+ \to \pi^+\pi^0$ and measure a branching fraction of $\mathcal{B}(B^+ \to \pi^+\pi^0) = (5.1^{+2.0}_{-1.8} \pm 0.8) \times 10^{-6}$. However, the signal significance is insufficient to claim observation. A 90% confidence level upper limit is computed for this mode, as well as for $B^0 \to K^+K^-$ $B^+ \to \overline{K}^0K^+$, and $B^+ \to \phi\pi^+$ in the following manner. The upper limit on the signal yield for mode $k$ is given by the value of $n_k^0$ for which $\int_0^{n_k^0} \mathcal{L}_{\rm max}\, {\rm d}n_k / \int_0^\infty \mathcal{L}_{\rm max}\, {\rm d}n_k = 0.90$, where $\mathcal{L}_{\rm max}$ is the likelihood as a function of $n_k$, maximized with respect to the remaining fit parameters.

The result is then increased by the total systematic error. The detection efficiency is reduced by its systematic uncertainty in calculating the branching fraction upper limit. The statistical significance of a given channel is determined by fixing the yield to zero, repeating the fit, and recording the change in $-2\ln\mathcal{L}$.

Figure 1 shows the distributions in $m_{\rm ES}$ for events passing the selection criteria, as well as requirements on Fisher value, which are used to increase the relative fraction of signal events of a given type. Fits to these distributions are overlaid.

Imperfect knowledge of the PDF shapes and of the detection efficiencies are the main sources of systematic uncertainties on the branching ratio measurements. Uncertainties in the PDF parameterizations are estimated either by varying the PDF parameters within $1\sigma$ of their measured uncertainties or by substituting alternative PDF from independent control samples, and recording the variations in the fit results.

In summary, we have measured branching fractions for the rare charmless decays $B^0 \to \pi^+\pi^-$, $B^0 \to K^+\pi^-$, $B^+ \to K^+\pi^0$, $B^+ \to K^0\pi^+$, $B^0 \to K^0\pi^0$, $\phi K^+$, $\phi K^0$, and $\phi K^{*+}$ and set upper limits on $B^0 \to K^+K^-$, $B^+ \to \pi^+\pi^0$, $B^+ \to \overline{K}^0K^+$, and $\phi\pi^+$.

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