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Studies of Rare Hadronic B Decays with *BABAR*

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We present a selection of recent results from studies of rare hadronic B decays based on a sample of 232 million $B\overline{B}$ pairs, corresponding to an integrated luminosity of 211 fb^{-1}, which were recorded with the *BABAR* detector at the PEP-II asymmetric-energy e^+e^- storage ring.

1 Introduction

The study of rare hadronic B decays provides valuable insight into various aspects of particle interactions. The large *BABAR* data set makes it possible to probe branching fractions (BF) down to $\mathcal{O}(10^{-6})$. Within the standard model of particle physics (SM), these measurements test descriptions of specific decay mechanisms as well as more fundamental concepts such as QCD factorization. Meaningful constraints can be obtained for theories beyond the SM using processes where the SM predictions are significantly lower than current experimental sensitivity. Another important aspect is to probe our understanding of the CKM description of quark mixing and CP violation; this, however, is covered in a different contribution to this conference.[1]

2 Experimental strategy

The *BABAR* detector is described elsewhere.[2] Key selection quantities are the missing energy $\Delta E \equiv E_B^* - E_{\rm beam}^*$ and the beam-energy-substituted mass $m_{\rm ES} \equiv \sqrt{E_{\rm beam}^{*2} - \vec{p}_B^{\,*2}}$, where $E_{\rm beam}^*$ denotes the center-of-mass (CM) beam energy; E_B^* and $\vec{p}_B^{\,*}$ are the reconstructed B mass and momentum in the CM frame. After reducing the large backgrounds, for example by applying event shape requirements to discriminate between the jet-like continuum background ($e^+e^- \to q\bar{q}$, where $q = u, d, s, c$) and the more spherically-symmetric signal events, the signal is extracted using extended maximum-likelihood fits to the data.

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Table 1: Measured $B \to D^{(*)}\overline{D}^{(*)}$ branching fractions.

Mode	$B^0 \to D^0\overline{D}^0$	$B^0 \to D^{*0}\overline{D}^0$	$B^0 \to D^{*0}\overline{D}^{*0}$	$B^0 \to D^+D^-$	$B^0 \to D^{*+}D^-$
BF/10^{-4}	< 0.59	< 2.92	< 0.92	$2.81 \pm 0.43 \pm 0.45$	$5.72 \pm 0.64 \pm 0.71$
Mode	$B^0 \to D^{*+}D^{*-}$	$B^- \to D^-\overline{D}^0$	$B^- \to D^-\overline{D}^{*0}$	$B^- \to D^{*-}\overline{D}^{*0}$	$B^- \to D^{*-}\overline{D}^{*0}$
BF/10^{-4}	$8.11 \pm 0.57 \pm 0.99$	$3.76 \pm 0.57 \pm 0.45$	$3.56 \pm 0.52 \pm 0.40$	$6.30 \pm 1.32 \pm 0.95$	$8.14 \pm 1.17 \pm 1.21$

3 Decays to open-charm mesons

B-meson decays to double-charm final states $D^{(*)}\overline{D}^{(*)}$ are a good example for the wide range of questions which can be addressed through the experimental study of rare hadronic B decays. In addition to constraining the SM CKM triangle, measurements of these processes provide a test of QCD heavy-heavy factorization as well as information on the decay mechanism and final-state interactions. The measured BF from a recent analysis [3] are summarized in Table 1. These include BF limits from a first search for the color-suppressed $B^0 \to D^0\overline{D}^0$, which – if observed – would provide evidence of W-exchange or annihilation contributions.

The W-exchange contribution to $B^0 \to D^{*+}D^{*-}$ decays could be estimated from a measurement of the relative rate with respect to the decays $B \to D_s^{(*)-}\overline{D}_s^{(*)+}$, which in the SM are dominated by W-exchange. These have been searched for [4] for the first time, without observing a significant signal. The resulting 90% C.L. upper BF limits, 1.0×10^{-4} ($D_s\overline{D}_s$), 1.3×10^{-4} ($D_s^{*-}\overline{D}_s$), and 2.4×10^{-4} ($D_s^*\overline{D}_s^*$), are close to the expectation from perturbative QCD calculations and are already excluding certain alternative models.

BABAR also performed a search [5] for the annihilation processes $B^- \to D_s^{(*)-}\phi$, see Figure 1(a), yielding upper BF limits of 1.9×10^{-6} and 1.2×10^{-5} for $B^- \to D_s^-\phi$ and $B^- \to D_s^{*-}\phi$ respectively. Although still about a factor of ten larger the SM expectation, this constitutes an improvement of previous limits by two orders of magnitude and makes it possible to set competitive limits on parameters in the type II Two-Higgs-Doublet Model and the MSSM with R-parity violation.

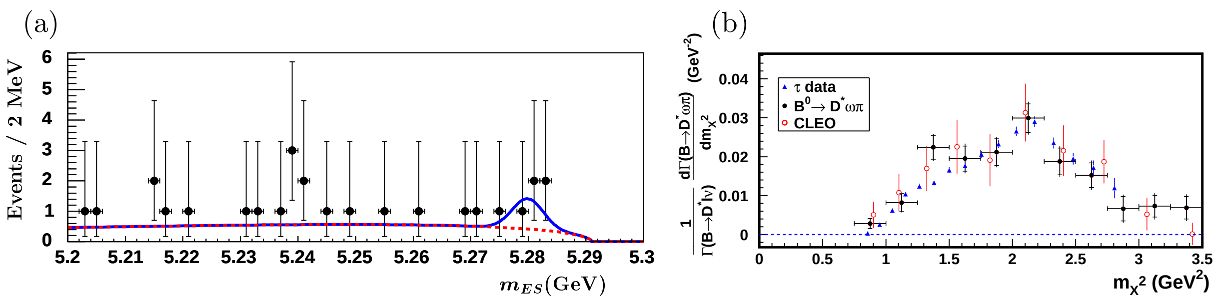

Figure 1: (a) $m_{\rm ES}$ distribution for $B^- \to D_s^{*-}\phi$ candidates in the ΔE signal region; (b) m_X^2 distribution for $B \to D^*\omega\pi$ candidates, normalized to the semi-leptonic width $\Gamma(\overline{B}^0 \to D^{*+}l^-\bar{\nu})$, compared to other measurements.

An elegant test of factorization is provided in the context of a study of $B \to D^*\omega\pi$ decays [6], where the invariant mass spectrum of the $\omega\pi$ system is found to be in agreement with theoretical expectations based on τ decay data, cf. Figure 1(b). In addition, the longitudinal polarization fraction is measured from a D^* angular analysis and found to be consistent with heavy-quark effective theory predictions assuming factorization and using results from semi-leptonic B decays.

4 Inclusive decays to open charm

An inclusive picture of B decays to open charm is provided by a preliminary measurement [7] of D^0X, D^+X, D_s^+X, Λ_c^+X final states and their charge conjugates, which is performed separately for flavor-correlated and anti-correlated b to c transitions. Events are selected by completely reconstructing one B and searching for a reconstructed charm particle in the rest of the event.

The measured branching fractions include $\mathrm{BF}(B^- \to D_s^+ X) = 1.1^{+0.4}_{-0.3} \pm 0.1^{+0.2}_{-0.1}$, which is the first evidence of D_s^+ production in B^- decays. The sum of all correlated charm branching fractions is found to be compatible with 1. The numbers of charm particles per B^- decay ($n_c^- = 1.202 \pm 0.023 \pm 0.040^{+0.035}_{-0.029}$) and per $\bar{B}$ decay ($n_c^0 = 1.193 \pm 0.030 \pm 0.034^{+0.044}_{-0.035}$) are consistent with previous measurements and theoretical expectations. Charm momentum distributions in the B rest frame are measured as well; two examples are shown in Figs. 2(a) and (b).

5 Baryonic decays

Two-body decays to charm baryons provide a way to test various theoretical models for exclusive baryonic B decays. In particular, there is theoretical interest in the suppression of the two-body baryonic decay rates compared to three-body rates and the possible connection to the mechanisms for baryon production in B decays. Figure 2(c) shows the m_{ES} projection of of selected $\overline{B}^0 \to \Lambda_c \bar{p}$ signal events. The corresponding BF is measured to be $(2.15 \pm 0.36 \pm 0.13 \pm 0.56) \times 10^{-5}$, where the third uncertainty is associated with the $\Lambda_c \to pK^-\pi^+$ BF.

Charmless two-body baryonic B decays have not yet been seen but several observation of three-body decays have been reported. A recent example is the *BABAR* measurement of the $B^0 \to \bar{\Lambda} p \pi^-$ BF yielding $(3.34 \pm 0.54 \pm 0.31) \times 10^{-6}$. The efficiency-corrected distribution of the di-baryon invariant mass $m(\Lambda p)$, see Figure 2(d), shows a near-threshold enhancement already seen in several other baryonic B decays.

All these results, which are preliminary, are consistent with previous measurements by the Belle collaboration.

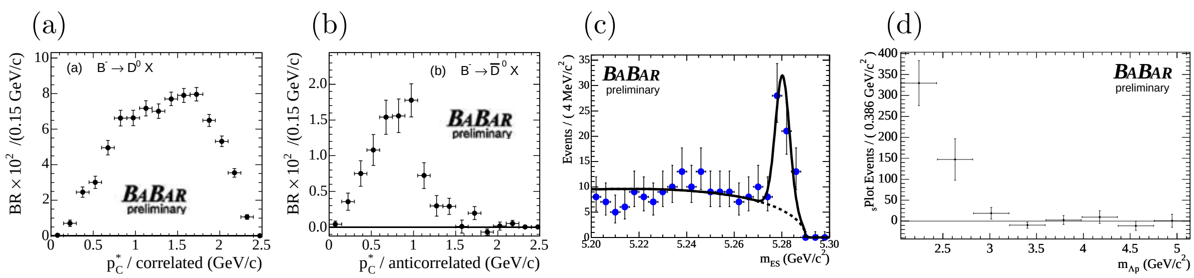

Figure 2: Charm momentum distributions in the B rest frame for (a) $B^- \to D^0 X$ and (b) $B^- \to \overline{D}^0 X$ decays; (c) m_{ES} distribution for selected $\overline{B}^0 \to \Lambda_c \bar{p}$ candidates; (d) $m(\Lambda p)$ distribution for $B^0 \to \bar{\Lambda} p \pi^-$ candidates.

6 Decays to charmless mesons

Tables 2(a) and (b) summarize recent results of searches for B decays to charmless mesons. The study of such processes is a rich field and a comprehensive review is far beyond the scope of this note. One of various motivations arises from potential differences ΔS between the measurements of the CKM parameter $\sin 2\beta$ from tree and penguin-dominated processes respectively. [a] Leading order SM calculations give $\Delta S = 0$ and significant non-zero values could be a signal for physics beyond the SM. There are, however, also contributions from sub-leading SM amplitudes, often referred to as SM pollution, which involve the CKM matrix element V_{ub} and are currently not well known.

Using SU(3) flavor symmetry, a SM constraint on $\Delta S_{\phi K^0}$, i.e. the SM pollution for the decay $B^0 \to \phi K^0$, can be obtained from the BF of eleven different B^0 decays.[8] Experimental limits for nine of these BF were previously available; a recent *BABAR* search [9] for $B^0 \to K^{*0} K_S$

[a] Although below most of the results will be discussed in the context of SM constraints on ΔS, it should be noted that these measurements are very interesting in their own rights; see the references for details.

Table 2: Recent results of searches for B decays to charmless mesons. Results marked † are preliminary.

(a)

Mode	BF/10^{-6}	Limit (90% C.L.)
$B^0 \to K^{*0} K_S{}^\dagger$ ($\overline{K}^{*0}K^0 + K^{*0}\overline{K}^0$)	$0.2^{+0.9+0.1}_{-0.8-0.3}$	$< 1.9 \times 10^{-6}$
$B^0 \to \phi\pi^0$	0.12 ± 0.13	$< 0.28 \times 10^{-6}$
$B^+ \to \phi\pi^+$	-0.04 ± 0.17	$< 0.24 \times 10^{-6}$
$B^0 \to \eta'\eta$	$0.2^{+0.7+0.4}_{-0.5-0.4}$	$< 1.7 \times 10^{-6}$
$B^0 \to \eta\pi^0$	$0.6^{+0.5+0.1}_{-0.4-0.1}$	$< 1.3 \times 10^{-6}$
$B^0 \to \eta'\pi^0$	$0.8^{+0.5+0.1}_{-0.4-0.1}$	$< 2.1 \times 10^{-6}$

(b)

Mode	BF/10^{-6}	Limit (90% C.L.)
$B^0 \to K_S^0 K_S^0 K_L^0{}^\dagger$	$2.4^{+2.7+0.6}_{-2.5-0.6}$	$< 6.4 \times 10^{-6}$
$B^0 \to \eta' K^{*0}$ $\dagger$	$3.8^{+1.1+0.5}_{-1.1-0.5}$	–
$B^+ \to \eta' K^{*+}$ $\dagger$	$4.9^{+1.9+0.8}_{-1.7-0.8}$	$< 7.9 \times 10^{-6}$
$B^0 \to \eta' \rho^0$ $\dagger$	$0.4^{+1.2+1.6}_{-0.9-0.6}$	$< 3.7 \times 10^{-6}$
$B^+ \to \eta' \rho^+$ $\dagger$	$6.8^{+3.2+3.9}_{-2.9-1.3}$	$< 14 \times 10^{-6}$
$B^0 \to \eta' f_0$ $\dagger$ ($f_0 \to \pi^+\pi^-$)	$0.1^{+0.6+0.9}_{-0.4-0.4}$	$< 1.5 \times 10^{-6}$

completes the set. The resulting limit for the sum of branching fractions BF($B^0 \to \overline{K}^{*0} K^0$)+ BF($B^0 \to K^{*0}\overline{K}^0$), see Table 2(a), makes it possible to set a 90% C.L. upper bound on $\Delta S_{\phi K^0}$ of 0.43. Recently improved BF limits [10] for the decay $B^0 \to \phi\pi^0$, which is also relevant for constraining $\Delta S_{\phi K^0}$, and its charged counterpart $B^+ \to \phi\pi^+$ are included in Table 2(a) as well.

The contribution from SM pollution to the process $B^0 \to \eta' K_S$ can be constrained in a similar way[8]. New BF limits [11] for three of the relevant decays ($B^0 \to \eta'\eta$, $B^0 \to \eta\pi^0$, and $B^0 \to \eta'\pi^0$), as listed in Table 2(a), represent two to three-fold improvements over previous measurements. The corresponding reduction in the theoretical uncertainty on $\Delta S_{\eta' K_S}$ is estimated to be 20%.

B^0 decays to the CP eigenstate $K_S^0 K_S^0 K_L^0$ are pure $b \to s\bar{s}s$ penguin transitions. $b \to u$ decay amplitudes enter only through rescattering, which reduces the corresponding SM CP asymmetry uncertainty. In a first search [12] for these decays, *BABAR* finds no significant signal and obtains the results listed in Table 2(b). Here, the central BF value is determined assuming a uniform 3-body phase space and excluding the ϕ resonance; the upper limit is single-sided Bayesian and based on a uniform prior probability for physical values.

In addition, *BABAR* studied the decays of charged and neutral B mesons to $\eta' K^*$ and $\eta'\rho$, resulting in the observation of $B^0 \to \eta' K^{*0}$, evidence for $B^+ \to \eta' K^{*+}$, and significantly improved limits for the other modes, see Table 2(b).

Acknowledgments

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