Charmless B decays involving baryons

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Predictions are made for the fraction of B-meson decays involving specific final states of $N\bar{N}+n\pi$ ($n\geq 0$), as functions of (a) decay dynamics, (b) models for multipion production, (c) the isospin of the final state, and (d) the ratio $|V_{bu}/V_{bc}|$ of Kobayashi-Maskawa matrix elements. From recent observations of $B^+\to p\bar{p}\pi^+$(+c.c.) and $B^0\to p\bar{p}\pi^+\pi^-$ by the ARGUS Collaboration, it is concluded that $|V_{bu}/V_{bc}|\gtrsim 0.08$, similar to the ARGUS Collaboration's own estimate of 0.07. However, a more likely value for this ratio is near its present experimental upper limit. Predictions are made for further final states in $N\bar{N}+n\pi$ and in other charmless B decays. We also comment briefly on prospects for observing CP violation in $B\to N\bar{N}+n\pi$.

I. INTRODUCTION

The ARGUS Collaboration[1] has recently presented evidence for the decays $B^{\pm}\to p\bar{p}\pi^{\pm}$, $B^0(\bar{B}^0)\to p\bar{p}\pi^+\pi^-$. These are the first observed decays of B mesons likely to be dominated by the Kobayashi-Maskawa[2] matrix element V_{bu}. In this article we explore some features of the path leading from the experimental results to a determination of V_{bu}. While we can only place a lower limit

$$|V_{bu}/V_{bc}|\gtrsim 0.08\ , \tag{1.1}$$

similar to an estimate by the ARGUS Collaboration of 0.07, we shall argue that this ratio is more likely to be near its present upper bound,[3]

$$|V_{bu}/V_{bc}|\leq 0.16\ . \tag{1.2}$$

We shall point out further modes in which charmless B decays might be observed, both involving $N\bar{N}+$ (pions) and in purely mesonic and semileptonic final states. The decays $B\to N\bar{N}+$ (pions) may be important for studies of CP violation,[4] so that a general overview of expectations for such modes is of possible significance at a fundamental level. More prosaically, however, our suggestions are intended to lead toward a more precise determination of the ratio $|V_{bu}/V_{bc}|$.

This paper is organized as follows. A brief review of the relevant data is presented in Sec. II. We discuss isospin considerations, including relations among amplitudes and the results of statistical models, in Sec. III. The distribution of pion multiplicities in $B\to N\bar{N}+$ (pions) is treated in Sec. IV. The dynamics of baryon production in B decays is the subject of Sec. V. Combining all the above information, we estimate $|V_{bu}/V_{bc}|$ in Sec. VI. Suggestions for further observations which might tighten the bounds (1.1) and (1.2) are made in Sec. VII. Section VIII contains remarks on CP violation, while Sec. IX concludes.

II. EXPERIMENTAL DATA

Two modes involving B decays to baryon-antibaryon pairs + (one or two pions) have been reported so far,[1] with

$$B(B^+\to p\bar{p}\pi^+)=(3.7\pm1.3\pm1.4)\times10^{-4}\ , \tag{2.1}$$

$$B(B^0\to p\bar{p}\pi^+\pi^-)=(6.0\pm2.0\pm2.2)\times10^{-4}\ . \tag{2.2}$$

(We do not distinguish between a B and its charge-conjugate here.) The total number of events in the combined signal for both channels is 32.3±7.7. The p and $\bar{p}$ appear to be produced roughly back to back in the B center of mass; a cut of $-1<\cos\theta_{p\bar{p}}<-0.98$ was applied in order to obtain the observed signal. The pions are soft, and there appears to be significant production of Δ's or other low-mass $N\pi$ states.

The inclusive decays of B's to charmed baryons are estimated to occur with a branching ratio[5]

$$B(B\to\text{charmed baryon}+X)=(7.4\pm2.9)\%$$
$$<11.2\%\ (90\%\ \text{C.L.})\ . \tag{2.3}$$

We shall compare the rates (2.1) and (2.2) with (2.3) in estimating $|V_{bu}/V_{bc}|$. To put Eq. (2.3) in the context of other B decays, we note that the average semileptonic branching ratio[6]

$$B(B\to e\nu X)=(11.4\pm0.5)\% \tag{2.4}$$

should imply (with the help of the phase-space estimates in Ref. 6, listed in Table I)

$$B(B\to(e,\mu,\tau)\nu X)=(26.4\pm1.2)\%\ , \tag{2.5}$$

and the vast majority of the remaining decays ($\approx$74%) should be nonleptonic ones containing one or two charmed quarks. Thus for $|V_{bu}/V_{bc}|=0.16$, we estimate

TABLE I. Phase space times color factors for $b\to uW^-$ and $b\to cW^-$ decays. From Ref. 6.

	$b\to u$	$b\to c$
$W^-\to u\bar{d}$	3.0	1.44
$W^-\to \bar{c}s$	1.44	0.45
$W^-\to e^-\nu$	1.0	0.48
$W^-\to \mu^-\nu$	1.0	0.48
$W^-\to \tau^-\nu$	0.48	0.15
Total	6.92	3.00

$$B(b\to u\bar{u}d)\simeq 2.8\% \ , \tag{2.6a}$$

$$B(b\to u\bar{c}s)\simeq 1.4\% \ , \tag{2.6b}$$

$$B(b\to c\bar{u}d)\simeq 50\% \ , \tag{2.6c}$$

$$B(b\to c\bar{c}s)\simeq 16\% \ , \tag{2.6d}$$

$$B(b\to c\bar{u}s)\simeq 2.6\% \ , \tag{2.6e}$$

$$B(b\to c\bar{c}d)\simeq 0.8\% \tag{2.6f}$$

with the help of phase-space factors tabulated in Ref. 6. Hence, charmed baryons appear in about (10±4)% of nonleptonic final states. If this same ratio were to apply specifically to the noncharmed final state (2.6a), we would expect the branching ratio

$$B(B\to N+X)\simeq(2.8\pm1.1)\times10^{-3} \ , \tag{2.7}$$

for $|V_{bu}/V_{bc}|=0.16$, behaving as the square of this ratio. We wish to estimate whether the branching ratios (2.1) and (2.2) are compatible with the estimate (2.7). The considerations of much of the rest of this article are devoted to such a comparison.

III. ISOSPIN CONSIDERATIONS

A. General remarks

The free-quark decay $\bar{b}\to\bar{u}\,\bar{d}u$ leads to both $\Delta I=\frac{1}{2}$ and $\Delta I=\frac{3}{2}$ transitions. Thus, the noncharmed, nonstrange decay products of a $B^+(=\bar{b}u)$ can have ($I=1$ or 2, $I_3=1$), while those of a $B^0(=\bar{b}d)$ can have ($I=0$, 1, or 2, $I_3=0$).

Specific selection rules follow from other operators or dynamical effects. Thus, in a B^+, the annihilation transition $\bar{b}u\to\bar{d}u$ leads only to $I=1$, while the exchange process in B^0, $\bar{b}d\to\bar{u}u$, leads to a coherent superposition of $I=0$ and $I=1$ states. Both these processes are expected to be unimportant for charmless B decays in comparison with the free-quark transitions. So is the penguin transition $b\to d+$gluon(s), which is a $\Delta I=\frac{1}{2}$ operator.

A modest enhancement of the $\Delta I=\frac{1}{2}$ piece of the $\bar{b}\to\bar{u}\,\bar{d}u$ operator follows from short-distance QCD. If one writes the final state as a combination of the piece symmetric ($I=1$) and antisymmetric ($I=0$) in the flavor of the antiquarks $\bar{u}$ and $\bar{d}$, the antisymmetric piece (in a color **3***) is favored in the amplitude by a factor of about 1.9 over the symmetric one (in a color **6**).[7] The correlation between isospin and color of the $\bar{u}\bar{d}$ pair arises because these antiquarks are in a spin-antisymmetric $S=0$ state as a result of the four-fermion interaction.[8] We shall discuss a further possible dynamical source of a $\Delta I=\frac{1}{2}$ rule in Sec. V.

B. Relations among isospin amplitudes

Tests of the $\Delta I=\frac{1}{2}$ rule for B decays to low-multiplicity mesonic states would roughly parallel those for kaons. Thus, the decay $B^+\to\pi^+\pi^0$ should be highly suppressed in comparison with $B^0\to\pi^+\pi^-$. The possibility of resonance dominance (as in $B\to\pi\rho$) is a new and possibly simplifying feature. The relation $\Gamma(B^+\to\pi^+\omega)=2\Gamma(B^0\to\pi^0\omega)$ follows from the $\Delta I=\frac{1}{2}$ rule but does not hold, in general, in the presence of $\Delta I=\frac{3}{2}$ contributions.

Turning more specifically to states involving $N\bar{N}+$ (possible pions), a $\Delta I=\frac{1}{2}$ rule would imply separate relations

$$A(B^+\to p\bar{n})=A(B^0\to p\bar{p})-A(B^0\to n\bar{n}) \tag{3.1}$$

in ${}^1S_0$ and ${}^3P_0$ channels. The possibility of coherence between $I=0$ and $I=1$ amplitudes in $B^0\to N\bar{N}$ means that in general one cannot expect $\Gamma(B^0\to p\bar{p})=\Gamma(B^0\to n\bar{n})$. Such an equality *will* hold if only one isospin amplitude ($I=0$ or 1) is present in the final state, however.

A simple example involving pions occurs for the process $B\to\Delta\bar{N}$. If $\Delta I=\frac{1}{2}$, both charged and neutral B's must decay to the $I=1$ final state, and one expects

$$A(B^+\to\Delta^{++}\bar{p})=\sqrt{3/4}A_1 \ , \tag{3.2a}$$

$$A(B^+\to\Delta^{+}\bar{n})=-\sqrt{1/4}A_1 \ , \tag{3.2b}$$

$$A(B^0\to\Delta^{+}\bar{p})=A_1/2 \ , \tag{3.2c}$$

$$A(B^0\to\Delta^{0}\bar{n})=-A_1/2 \tag{3.2d}$$

or, defining $\Gamma_1\equiv\Gamma(B^+\to(N\bar{N}\pi)^+)$,

$$\Gamma(B^+\to p\bar{p}\pi^+)=\tfrac{3}{4}\Gamma_1^+ \ , \tag{3.3a}$$

$$\Gamma(B^+\to n\bar{n}\pi^+)=\tfrac{1}{12}\Gamma_1^+ \ , \tag{3.3b}$$

$$\Gamma(B^+\to p\bar{n}\pi^0)=\tfrac{1}{6}\Gamma_1^+ \ , \tag{3.3c}$$

$$\Gamma(B^0\to p\bar{p}\pi^0)=\Gamma(B^0\to n\bar{n}\pi^0)=\tfrac{1}{6}\Gamma_1^+ \ , \tag{3.3d}$$

$$\Gamma(B^0\to n\bar{p}\pi^+)=\Gamma(B^0\to p\bar{n}\pi^-)=\tfrac{1}{12}\Gamma_1^+ \ . \tag{3.3e}$$

Note that $\Gamma_1^0\equiv\Gamma(B^0\to(N\bar{N}\pi)^0)=\frac{1}{2}\Gamma(B^+\to(N\bar{N}\pi)^+)=\frac{1}{2}\Gamma_1^+$ in this specific instance. Thus, decays to a given multiplicity of pions need not proceed at the same rate for the charged and neutral B's.

Dynamical models lead to curious selection rules associated with isospin.[9] A model to which we shall refer subsequently for quasi-two-body decay of B's into baryon-antibaryon pairs is illustrated in Fig. 1. In such a model, the B^0 cannot decay to $\Delta^{++}\bar{\Delta}^{--}$, implying a coherence among amplitudes for total (final) isospins 0,

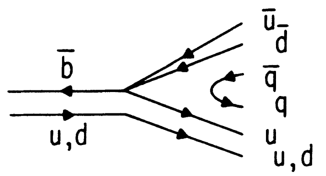

FIG. 1. Model for quasi-two-body decays of B's into baryon-antibaryon pairs.

1, and 2 (in general) or between $I=0$ and $I=1$ amplitudes when the $\Delta I=\frac{1}{2}$ rule is valid.

C. A statistical model

The assumption that multiparticle production amplitudes for different isospins of subsystems are equal and incoherent leads to a unique set of predictions for the charge states associated with each multiplicity.[10,11] Thus, for example, one would then expect

$$\Gamma(B^0\to p\bar{p})=\Gamma(B^0\to n\bar{n}) \quad (3.4)$$

for *either* $I=0$ or $I=1$ in the final state.

To take a less trivial example, let us assume that $B^+\to(N\bar{N}\pi)^+$ proceeds via an $I=1$ final state. We may decompose the decay amplitudes $A_{I_{N\bar{N}}}$ according to the isospin of the final $N\bar{N}$ state, and find

$$A(B^+\to p\bar{p}\pi^+)=A_0/\sqrt{2}+A_1/2\ , \quad (3.5a)$$

$$A(B^+\to n\bar{n}\pi^+)=A_0/\sqrt{2}-A_1/2\ , \quad (3.5b)$$

$$A(B^+\to p\bar{n}\pi^0)=-A_1/\sqrt{2} \quad (3.5c)$$

or (up to overall factors), if the amplitudes are incoherent,

$$\Gamma(B^+\to p\bar{p}\pi^+)=\Gamma(B^+\to n\bar{n}\pi^+) = |A_0|^2/2+|A_1|^2/4\ , \quad (3.6a)$$

$$\Gamma(B^+\to p\bar{n}\pi^0)=|A_1|^2/2\ , \quad (3.6b)$$

$$\Gamma_1^+\equiv\Gamma(B^+\to(N\bar{N}\pi)^+)=|A_0|^2+|A_1|^2\ . \quad (3.6c)$$

Then, if $|A_0|^2=|A_1|^2$, we find

$$\Gamma(B^+\to p\bar{p}\pi^+)=\Gamma(B^+\to n\bar{n}\pi^+)=\tfrac{3}{8}\Gamma_1^+\ , \quad (3.7a)$$

$$\Gamma(B^+\to p\bar{n}\pi^0)=\tfrac{1}{4}\Gamma_1^+\ . \quad (3.7b)$$

The beauty of this approach is that results do not depend on the particular isospin decomposition adopted.

In Table II we summarize some predictions of the statistical model for specific isospins of final states. There are several points to note.

(1) The $p\bar{p}\pi^+$ final state is only $\frac{3}{8}$ of $(N\bar{N}\pi)^+$ for $I=1$ and $\frac{1}{4}$ of $(N\bar{N}\pi)^+$ for $I=2$, to be contrasted with $\frac{3}{4}$ of $(N\bar{N}\pi)^+$ in the specific model leading to Eq. (3.3a).

(2) The states involving all charged particles are most prominent for the lowest total isospins. Thus, $p\bar{p}\pi^+\pi^-$ is $(\frac{1}{4},\frac{9}{40},\frac{1}{6})$ of $(N\bar{N}\pi\pi)^0$ for $I=(0,1,2)$, while $p\bar{p}\pi^+\pi^+\pi^-$ is $(\frac{1}{6},\frac{15}{112})$ of $(N\bar{N}\pi\pi\pi)^+$ for $I=(1,2)$.

(3) The $p\bar{p}\pi^+\pi^+\pi^-$ channel is a significant fraction of $(N\bar{N}\pi\pi\pi)^+$, at least for $I=1$.

(4) Final states involving neutrons and antineutrons are important; the roles of charged and neutral nucleons are of course exactly equivalent for neutral final states, whatever the total isospin.

(5) The statistical model on the average tends to favor final states in which the number of identical particles is a minimum. A crude estimate of the fraction of $(N\bar{N}\pi\pi)^0$ decays involving $p\bar{p}\pi^+\pi^-$ could have been obtained by assigning each charge state without identical pions a relative weight 1 and each charge state with two identical pions $(\pi^0\pi^0)$ a relative weight $\frac{1}{2}$. Thus, one would esti-

TABLE II. Predictions of statistical model for charge states of $N\bar{N}$+(pions) in states of final isospins 0, 1, and 2, as fractions of total for a given pion multiplicity.

Charge 0		$I=0$	$I=1$	$I=2$
$N\bar{N}$	$p\bar{p}$	$\frac{1}{2}$	$\frac{1}{2}$	
	$n\bar{n}$	$\frac{1}{2}$	$\frac{1}{2}$	
$N\bar{N}\pi$	$p\bar{p}\pi^0$	$\frac{1}{6}$	$\frac{1}{4}$	$\frac{1}{3}$
	$n\bar{n}\pi^0$	$\frac{1}{6}$	$\frac{1}{4}$	$\frac{1}{3}$
	$p\bar{n}\pi^-$	$\frac{1}{3}$	$\frac{1}{4}$	$\frac{1}{6}$
	$n\bar{p}\pi^+$	$\frac{1}{3}$	$\frac{1}{4}$	$\frac{1}{6}$
$N\bar{N}\pi\pi$	$p\bar{p}\pi^+\pi^-$	$\frac{1}{4}$	$\frac{9}{40}$	$\frac{1}{6}$
	$n\bar{n}\pi^+\pi^-$	$\frac{1}{4}$	$\frac{9}{40}$	$\frac{1}{6}$
	$p\bar{p}\pi^0\pi^0$	$\frac{1}{12}$	$\frac{3}{40}$	$\frac{1}{9}$
	$n\bar{n}\pi^0\pi^0$	$\frac{1}{12}$	$\frac{3}{40}$	$\frac{1}{9}$
	$p\bar{n}\pi^-\pi^0$	$\frac{1}{6}$	$\frac{1}{5}$	$\frac{2}{9}$
	$n\bar{p}\pi^+\pi^0$	$\frac{1}{6}$	$\frac{1}{5}$	$\frac{2}{9}$
Charge 1		$I=1$	$I=2$	
$N\bar{N}$	$p\bar{n}$	1		
$N\bar{N}\pi$	$p\bar{p}\pi^+$	$\frac{3}{8}$	$\frac{1}{4}$	
	$n\bar{n}\pi^+$	$\frac{3}{8}$	$\frac{1}{4}$	
	$p\bar{n}\pi^0$	$\frac{1}{4}$	$\frac{1}{2}$	
$N\bar{N}\pi\pi$	$p\bar{p}\pi^+\pi^0$	$\frac{9}{40}$	$\frac{5}{18}$	
	$n\bar{n}\pi^+\pi^0$	$\frac{9}{40}$	$\frac{5}{18}$	
	$p\bar{n}\pi^+\pi^-$	$\frac{3}{10}$	$\frac{2}{9}$	
	$p\bar{n}\pi^0\pi^0$	$\frac{1}{10}$	$\frac{1}{9}$	
	$n\bar{p}\pi^+\pi^+$	$\frac{3}{20}$	$\frac{1}{9}$	
$N\bar{N}\pi\pi\pi$	$p\bar{p}\pi^+\pi^+\pi^-$	$\frac{1}{6}$	$\frac{15}{112}$	
	$n\bar{n}\pi^+\pi^+\pi^-$	$\frac{1}{6}$	$\frac{15}{112}$	
	$p\bar{p}\pi^+\pi^0\pi^0$	$\frac{7}{60}$	$\frac{29}{224}$	
	$n\bar{n}\pi^+\pi^0\pi^0$	$\frac{7}{60}$	$\frac{29}{224}$	
	$p\bar{n}\pi^+\pi^0\pi^-$	$\frac{4}{15}$	$\frac{2}{7}$	
	$p\bar{n}\pi^0\pi^0\pi^0$	$\frac{1}{30}$	$\frac{5}{112}$	
	$n\bar{p}\pi^+\pi^+\pi^0$	$\frac{2}{15}$	$\frac{1}{7}$	

mate the $p\bar{p}\pi^+\pi^-$ final state to be $\frac{1}{5}$ of the total. This is exactly what one would obtain if one considered a statistical admixture of $I=0$, 1, 2, and 3 final states (weighted by the total number of amplitudes, which is 2, 4, 3, and 1). The absence of the $I=3$ amplitude (for which $p\bar{p}\pi^+\pi^-$ would be $\frac{1}{10}$ of the total) suggests that $p\bar{p}\pi^+\pi^-$ should be *at least* $\frac{1}{5}$ of $(N\bar{N}\pi\pi)$, if a statistical average of the remaining $I=0$, 1, 2 amplitudes were approximately valid. Such a statistical average gives

$$\Gamma((p\bar{p}\pi^+\pi^-))/\Gamma((N\bar{N}2\pi)^0)=[2(\tfrac{1}{4})+4(\tfrac{9}{40})+3(\tfrac{1}{6})]/9 = \tfrac{19}{90}\simeq 0.21 \ . \quad (3.8)$$

D. Statistical models with isobars

The ARGUS Collaboration has reported significant Δ production in the $p\bar{p}\pi^+$ and $p\bar{p}\pi^+\pi^-$ final states. To see the effect Δ production might have on the basis of a statistical model, we consider the decays $B\to N\bar{N}+n\pi$ to be dominated by $B\to\Delta\bar{N}+(n-1)\pi$. Many other assumptions could have been made instead: for example, that $\bar{\Delta}$ production was dominant. [The statistical models for $B^0\to\Delta\bar{N}+(n-1)\pi$ and $\bar{\Delta}N+(n-1)\pi$ are equivalent, but not for the corresponding B^+ decays.] Our purpose is primarily to exhibit one case in which the observed final states can be enhanced with respect to the total.

The results are presented in Table III, where we have allowed each Δ to decay. We draw attention to the results for $p\bar{p}\pi^+\pi^-$, where the $\Delta\bar{N}\pi$ model leads to predictions of (0.278,0.83,0.167) for $I=(0,1,2)$, to be compared with (0.25,0.225,0.167) in the pure statistical model. The enhancements due to the Δ are relatively modest. On the other hand, we have already noted that for $p\bar{p}\pi^+$, the enhancement in the $I=1$ channel due to the Δ was a factor of 2. The enhancements due to Δ for $p\bar{p}\pi^+\pi^+\pi^-$ are also worth noting.

TABLE III. Predictions of statistical model for charge states arising from $\Delta\bar{N}+$ (pions) in states of final isospin 0, 1, and 2, as fractions of total for a given pion multiplicity.

Charge 0		$I=0$	$I=1$	$I=2$
$N\bar{N}\pi$	$p\bar{p}\pi^0$		$\frac{1}{3}$	$\frac{1}{3}$
	$n\bar{n}\pi^0$		$\frac{1}{3}$	$\frac{1}{3}$
	$p\bar{n}\pi^-$		$\frac{1}{6}$	$\frac{1}{6}$
	$n\bar{p}\pi^+$		$\frac{1}{6}$	$\frac{1}{6}$
$N\bar{N}\pi\pi$	$p\bar{p}\pi^+\pi^-$	$\frac{5}{18}$	$\frac{17}{60}$	$\frac{1}{6}$
	$n\bar{n}\pi^+\pi^-$	$\frac{5}{18}$	$\frac{17}{60}$	$\frac{1}{6}$
	$p\bar{p}\pi^0\pi^0$	$\frac{1}{9}$	$\frac{1}{15}$	$\frac{1}{9}$
	$n\bar{n}\pi^0\pi^0$	$\frac{1}{9}$	$\frac{1}{15}$	$\frac{1}{9}$
	$p\bar{n}\pi^-\pi^0$	$\frac{1}{9}$	$\frac{3}{10}$	$\frac{2}{9}$
	$n\bar{p}\pi^+\pi^0$	$\frac{1}{9}$	$\frac{3}{10}$	$\frac{3}{9}$
Charge 1		$I=1$	$I=2$	
$N\bar{N}\pi$	$p\bar{p}\pi^+$	$\frac{3}{4}$	$\frac{1}{4}$	
	$n\bar{n}\pi^+$	$\frac{1}{12}$	$\frac{1}{4}$	
	$p\bar{n}\pi^0$	$\frac{1}{6}$	$\frac{1}{2}$	
$N\bar{N}\pi\pi$	$p\bar{p}\pi^+\pi^0$	$\frac{13}{40}$	$\frac{3}{8}$	
	$n\bar{n}\pi^+\pi^0$	$\frac{19}{120}$	$\frac{5}{24}$	
	$p\bar{n}\pi^+\pi^-$	$\frac{7}{20}$	$\frac{1}{4}$	
	$p\bar{n}\pi^0\pi^0$	$\frac{7}{60}$	$\frac{1}{12}$	
	$n\bar{p}\pi^+\pi^+$	$\frac{1}{20}$	$\frac{1}{12}$	
$N\bar{N}\pi\pi\pi$	$p\bar{p}p^+\pi^+\pi^-$	$\frac{11}{50}$	$\frac{107}{630}$	
	$n\bar{n}\pi^+\pi^+\pi^-$	$\frac{7}{50}$	$\frac{79}{630}$	
	$p\bar{p}\pi^+\pi^0\pi^0$	$\frac{3}{20}$	$\frac{191}{1260}$	
	$n\bar{n}\pi^+\pi^0\pi^0$	$\frac{29}{300}$	$\frac{3}{28}$	
	$p\bar{n}\pi^+\pi^0\pi^-$	$\frac{7}{25}$	$\frac{19}{63}$	
	$p\bar{n}\pi^0\pi^0\pi^0$	$\frac{1}{30}$	$\frac{31}{630}$	
	$n\bar{p}\pi^+\pi^+\pi^0$	$\frac{1}{15}$	$\frac{2}{21}$	

IV. MULTIPION PRODUCTION

A. Poisson distribution

One may assume the probability for a B decay to $N\bar{N}+(n\pi)$ approximately follows a distribution[12,13]

$$P_{\bar{n}}(n)=\bar{n}^n e^{-\bar{n}}/n! \ , \quad (4.1)$$

which appears to describe the decays $J/\psi\to$hadrons[14] and $D\to\bar{K}\pi+(n\pi)$ satisfactorily. In the latter process $\bar{n}$ appears to be slightly larger than 2. For $B\to N\bar{N}+n\pi$, we would expect $\bar{n}$ to be at least as large.

B. Estimates of $\bar{n}$

A multipion distribution may be constructed by assuming that a hadronic state is initially confined within a radius R_0 at some temperature T, and calculating both the total energy and the number of degrees of freedom as functions of T (Refs. 12 and 15). One then finds the average number $\bar{n}$ of pions in $B\to N\bar{N}+(n\pi)$ final states to be

$$\bar{n}=0.528\left[\frac{M_B-2m_N}{E_0}\right]^{3/4} , \quad (4.2)$$

where $E_0\equiv\hbar c/R_0$ is a typical hadron energy scale, of order 0.2 GeV. On the basis of such an expression, one would estimate $\bar{n}$ to be slightly greater than 4. This is an upper limit, since no account has been taken of the longitudinal energy carried off by the nucleons. In experiment,[1] these are observed to be almost back to back, and rather energetic: $\langle E_N\rangle\simeq 2$ GeV. Using the data as a guide for the average energy of N and $\bar{N}$, one estimates $\bar{n}$ to be closer to 2. The average pion multiplicity in pp and (nonannihilation) $\bar{p}p$ interactions at $\sqrt{s}=M_B$ is a bit larger than 3,[16] though the mechanism of hadron production could differ in such interactions from that in B decays.

A further estimate of the pion multiplicity can be made by considering the kinematics of the free-quark decay $\bar{b}\to\bar{u}\bar{d}u$ in the presence of a light spectator quark, as illustrated in Fig. 1. The energy distribution of u in the b rest frame, in units of its maximum value $m_b/2$, is

$$\frac{dN}{dx}\sim x^2(1-x)\ , \tag{4.3}$$

where $x\equiv 2E_u/m_b$, $0\le x\le 1$. The corresponding effective mass of the $\bar{u}\bar{d}$ subsystem is

$$m^2_{\bar{u}\bar{d}}=m_b^2(1-x)\ , \tag{4.4}$$

and thus is expected to be rather high on the average:[17]

$$\langle m^2_{\bar{u}\bar{d}}\rangle^{1/2}=\sqrt{2/5}m_b\sim 3\text{ GeV}\ . \tag{4.5}$$

The effective mass of the ud subsystem, on the other hand, is expected to be rather low, of order a GeV or less. One can estimate that the lower "baryon" cluster in Fig. 1 fragments to at most one additional pion, the rapidity gap between the "baryon" and "antibaryon" could fill in with a pion, and the upper "antibaryon" cluster could decay to as many as three pions.

We shall thus estimate

$$2\le\bar{n}\le 4 \tag{4.6}$$

as a rough guess for the average number of pions in $B\to N\bar{N}+n\pi$. We shall see in Sec. VII that the data themselves favor $\bar{n}\ge 2$.

C. Estimates of width of distribution

The Poisson distribution predicts the width of the distribution to be $\sigma_{\bar{n}}=\sqrt{\bar{n}}$. Somewhat narrower distributions are predicted in a model motivated by current algebra,[12,13,18] with a matrix element for $N\bar{N}(n+1)\pi$ related to that for $N\bar{N}n\pi$ by a constant with dimensions F_π^{-1}. Thus, whereas Poisson statistics predicts (for example)

$$\begin{aligned}
&P_2(0)=0.135,\quad P_3(0)=0.050,\quad P_4(0)=0.018\ ,\\
&P_2(1)=0.271,\quad P_3(1)=0.149,\quad P_4(1)=0.073\ ,\\
&P_2(2)=0.271,\quad P_3(2)=0.224,\quad P_4(2)=0.147\ ,\\
&P_2(3)=0.180,\quad P_3(3)=0.224,\quad P_4(3)=0.195\ ,
\end{aligned} \tag{4.7}$$

and thus between 54% and 22% of $N\bar{N}n\pi$ in $n=1$ and 2 modes (for $2\le\bar{n}\le 4$), it is conceivable that a somewhat larger fraction of decays could be concentrated in these low multiplicities. One would be surprised not to be able to observe $n=0$ or $n=3$ modes at some reasonable level, however.

V. DYNAMICAL MECHANISMS

A. QCD and the $\Delta I=\frac{1}{2}$ rule

The lowest-order QCD-corrected weak Hamiltonian describing the process $b\to u\bar{u}d$ is[7]

$$H=-V^*_{ub}V_{ud}\frac{G_F}{2\sqrt{2}}\{c_+[(\bar{u}b)_L(\bar{d}u)_L+(\bar{d}b)_L(\bar{u}u)_L]+c_-[(\bar{u}b)_L(\bar{d}u)_L-(\bar{d}b)_L(\bar{u}u)_L]\}\ , \tag{5.1}$$

where

$$(\bar{q}_1q_2)_L=\bar{q}_{1\alpha}\gamma_\mu(1-\gamma_5)q_{2\alpha}\ . \tag{5.2}$$

Summation over color indices α is implied. For the bottom quark[7] $c_-\sim 1.5$, $c_+\sim 0.8$, which implies an enhancement of the coefficient of the antisymmetric operator by a factor of 1.9 with respect to the symmetric one. Since the former is a pure $\Delta I=\frac{1}{2}$ operator, whereas the latter contains both $\Delta I=\frac{1}{2}$ and $\Delta I=\frac{3}{2}$, QCD is expected to lead to some $\Delta I=\frac{1}{2}$ enhancement in these processes. The actual enhancement in a given process depends of course on the ratio of matrix elements of the above two operators, for which one may only use oversimplified schemes.

B. Additional symmetry argument for $\Delta I=\frac{1}{2}$

The nonleptonic decays of B mesons appear to lead to charmed baryons around 10% of the time, as mentioned in Sec. II. The prominence of the $p\bar{p}\pi^+$ and $p\bar{p}\pi^+\pi^-$ modes will be seen to suggest that the corresponding ratio is at least this high for noncharmed final states. It is not clear whether 10% is a large number on the scale of decays of a 5-GeV object. One possible source of baryons that has been mentioned in the present context[1,17] is the diagram of Fig. 1, in which the fundamental vertex $\bar{b}\to\bar{u}\bar{d}u$ gives rise to a $u+(u$ or $d)$ pair in a baryon, and a $\bar{u}\bar{d}$ pair in an antibaryon. These states may subsequently decay to others with the emission of pions.

As mentioned earlier, the structure of the $V-A$ current implies that the final $\bar{u}\bar{d}$ is in a state symmetric in (flavor)×(color).[8] Thus, if it is in a color **3**, it has $I=0$, while if it is in a **6***, it has $I=1$. If $I_{\bar{u}\bar{d}}=0$, the effective operator satisfies a $\Delta I=\frac{1}{2}$ rule.

Now, if the final $\bar{u}\,\bar{d}$ pair is in a color **3**, it can be incorporated immediately into a color-singlet baryonic state by being "dressed" by a single antiquark. This mechanism, which starts with the $\bar{u}\bar{d}$ in $I=0$, gives rise to $\bar{N}$ and $\bar{N}^*$ but not to $\bar{\Delta}$. (This argument has been used by Stech in Ref. 9.) Testing this feature may help one understand the dynamics of these decays. More specifically, the structure of the weak interaction guarantees that the final $\bar{u}\bar{d}$ pair will have total spin equal to zero. If these antiquarks end up in an antibaryon without any spin flip, that antibaryon cannot be a $\bar{\Delta}$, for which every pair of antiquarks has total spin 1. A $\bar{\Delta}$ can be produced only if at least one of the $\bar{u}$,$\bar{d}$ flips its spin or annihilates with some other quark. Thus the presence of $\bar{\Delta}$ in $B\to N\bar{\Delta}$ (recall that B contains a $\bar{b}$ quark, by convention) could indicate that simple arguments based on quark helicities are not valid for nonleptonic decays, both here and more generally.

On the other hand, if the $\bar{u}\bar{d}$ pair is in a **6***, it must be "dressed" by at least two quarks to end up as a color singlet, and this will not be a baryonic state at all. A **6*** can, of course, always emit a gluon to become a **3**. The gluon then can give rise to the extra $q\bar{q}$ needed to form a baryon-antibaryon pair in the final state. Thus, if $\bar{u}\bar{d}$ is in a **3**, Fig. 1 provides some advantage to the final state

$N\bar{N}+$(pions), while if $\bar{u}\bar{d}$ is in a **6***, we expect it to provide no special enhancement to baryon-antibaryon production. The fact that the first charmless B decay appears to have shown up in $N\bar{N}+$ (pions) indicates that at least for this channel, an approximate $\Delta I=\frac{1}{2}$ rule may be satisfied. We have seen earlier that the states populated if such a rule is valid have slightly higher probability of decaying to purely charged nucleons and pions than the $I=2$ states, which can be reached only via $\Delta I=\frac{3}{2}$ transitions.

C. Annihilation and penguin contributions

The effects of exchange graphs can lead to differences in B^+ and B^0 lifetimes: $1.4 \le \tau_{B^+}/\tau_{B^0} \le 1.8$ in one estimate.[19] Thus, they are not considered to be the dominant contributions to $\bar{b}d \to \bar{c}u$ transitions, but they could play a noticeable role in comparison with the free-quark decay $\bar{b}\to\bar{c}\bar{d}u$.

The $\bar{b}d\to\bar{u}u$ transition, by contrast, should be much more subject to helicity suppression arguments (if such arguments are at all valid), since only light quarks are present in the final state. On the other hand, whereas $\bar{b}u$ annihilations in $B^+=\bar{b}u$ decays are expected to be totally negligible in comparison with the dominant $\bar{b}u\to\bar{c}\bar{d}uu$ transitions, they might not play such a small role in comparison with $\bar{b}u\to\bar{u}\bar{d}uu$. The annihilation graph describing $\bar{b}u\to\bar{d}u$ has three possible colors of final quarks, and thus an advantage of three in rate over the exchange graph for $\bar{b}d\to\bar{u}u$. The main argument in favor of the smallness of an annihilation contribution in B decays comes from a similar process for charm: $D_s^+=c\bar{s}$ is seen to decay to $\pi^+\pi^+\pi^-$, but only at the level of about 1%, and the decay into $\rho\pi$ seems to have even a smaller rate.[20] If annihilation is unimportant for $\bar{b}u\to\bar{d}u$, then *a fortiori* we expect exchange to be even less so for $\bar{b}d\to\bar{u}u$.

As mentioned, both annihilation and exchange lead to a $\Delta I=\frac{1}{2}$ rule for B decays to charmless final states.

Penguin diagrams for $b\to d$, involving the products $V_{ub}V_{ud}^*$, $V_{cb}V_{cd}^*$, and $V_{tb}V_{td}^*$, are all of order θ^3, where θ is the Cabibbo angle, assuming[21] that

$$V=\begin{bmatrix} 1-\frac{\theta^2}{2} & \theta & A\theta^3(\rho-i\eta) \\ -\theta & 1-\frac{\theta^2}{2} & A\theta^2 \\ A\theta^3(1-\rho-i\eta) & -A\theta^2 & 1 \end{bmatrix} \quad (5.3)$$

and that A,ρ,η are parameters of order 1. There is a large dynamical suppression $[\alpha_s(m_c^2)/(12\pi)]\ln m_t^2/m_c^2$ associated with such contributions.[22] The corresponding contributions to $b\to s$ involve $V_{ub}V_{us}^*$ ($\sim\theta^4$), $V_{cb}V_{cs}^*$ ($\sim\theta^2$), and $V_{tb}V_{ts}^*$ ($\sim\theta^2$), and so should be about 4 or 5 times larger in amplitude. Charmless baryon-antibaryon final states of B's do not seem to have any Λ's in them.[1] Thus, the effects of penguin diagrams, inferred both from theory and from experiment, are very small for the observed $N\bar{N}+(n\pi)$ modes.

VI. AN ESTIMATE OF V_{bu}

We are now ready to put the ingredients together into an estimate of V_{bu}. This estimate is not very different from that presented by the ARGUS Collaboration itself,[1] but we wish to point out where further experiments could reduce some of the uncertainties.

In Sec. II we estimated $B(B\to N+X)=(2.8\pm1.1)\times10^{-3}$ for $|V_{bu}/V_{bc}|=0.16$. This estimate was based on the assumption, which we shall continue to make, that baryon production is equally probable in $b\to u$ transitions and in $b\to c$ transitions. We shall now draw upon the results of Sec. IV to conclude that it is unlikely that more than 70% of the $N+X$ final states occur in $N\bar{N}\pi+N\bar{N}\pi\pi$. The maximum of $P_{\bar{n}}(1)+P_{\bar{n}}(2)$ for a Poisson distribution (4.1) occurs at $\bar{n}=\sqrt{2}$ and is 58.7%. For this value of $\bar{n}$, $P_{\bar{n}}(0)=P_{\bar{n}}(2)=24.3\%$; $P_{\bar{n}}(1)=34.4\%$. We have estimated in Sec. IV that a value of $\bar{n}$ as small as $\sqrt{2}$ is unlikely. In view of the possibility that the distribution is narrower than the Poisson distribution, we therefore take $P_{\bar{n}}(1)+P_{\bar{n}}(2)\le 70\%$.

A *lower* limit on the fraction of $N+X$ final states in $N\bar{N}\pi+N\bar{N}\pi\pi$ is risky at this point. Taking a Poisson distribution with $2\le\bar{n}\le4$, we found $54\%\ge P_{\bar{n}}(1)+P_{\bar{n}}(2)\ge22\%$ in Sec. IV. We shall thus estimate, for $|V_{bu}/V_{bc}|=0.16$,

$$B(B\to N\bar{N}\pi)+B(B\to N\bar{N}\pi\pi) =(2.8\pm1.1)\times10^{-3}\times(45\pm25)\% =(1.26\pm0.86)\times10^{-3}\,, \quad (6.1)$$

where errors have been added in quadrature. Expressing Eq. (6.1) as a general function of $|V_{bu}/V_{bc}|^2$, we find

$$B(B\to N\bar{N}\pi)+B(B\to N\bar{N}\pi\pi) =(4.9\pm3.4)\times10^{-2}\,|V_{bu}/V_{bc}|^2\,. \quad (6.2)$$

We now take the experimental branching ratios, divided by the appropriate statistical isospin factors, to estimate the experimental branching ratio corresponding to Eq. (6.1).

We assume the isospin statistical factor in $B^+\to p\bar{p}\pi^+$ is 0.5 ± 0.25 and that for $B^0\to p\bar{p}\pi^+\pi^-$ is 0.25 ± 0.05. Then

$$B(B^+\to(N\bar{N}\pi)^+)=(7.4\pm5.3)\times10^{-4}\,, \quad (6.3)$$

$$B(B^0\to(N\bar{N}2\pi)^0)=(2.4\pm1.3)\times10^{-3}\,. \quad (6.4)$$

Now, we argued in Sec. III that it was not necessarily true that $B(B^0\to(N\bar{N}\pi)^0)=B(B^+\to(N\bar{N}\pi)^+)$, but let us assume this relation in any case. Then

$$B(B\to N\bar{N}\pi)+B(B\to N\bar{N}\pi\pi)=(3.1\pm1.4)\times10^{-3}\,. \quad (6.5)$$

We now take the quotient of Eqs. (6.2) and (6.5) to find

$$|V_{bu}/V_{bc}|^2=(6.3\pm5.2)\times10^{-2}\,, \quad (6.6)$$

$$|V_{bu}/V_{bc}|=0.25\pm0.10\,. \quad (6.7)$$

At the 90%-confidence-level limit (1.64σ) this implies

$$|V_{bu}/V_{bc}| \geq 0.08 \ . \quad (6.8)$$

On the other hand, the ARGUS result[1] is much more comfortably understood if $|V_{bu}/V_{bc}|$ is near its present upper limit of 0.16. In the next section we suggest how this factor-of-2 uncertainty in $|V_{bu}/V_{bc}|$ may be reduced.

VII. OTHER DETECTABLE MODES

A. Other modes of $N\bar{N}$+(pions)

Let us take the ratio of Eqs. (6.3) and (6.4) (bearing in mind previous cautionary remarks), to estimate

$$\frac{B(B \to N\bar{N}2\pi)}{B(B \to N\bar{N}\pi)} = 3.2 \pm 2.9 \ . \quad (7.1)$$

For a Poisson distribution, this ratio would be $P_{\bar{n}}(2)/P_{\bar{n}}(1) = \bar{n}/2$. While Eq. (7.1) is clearly useless for estimating $\bar{n}$ as it stands, it would be much more helpful if the error were reduced by a factor of 2. This can be done by reducing the statistical errors on the existing data, and by elucidating the isospin content of the $N\bar{N}\pi$ and $N\bar{N}\pi\pi$ states. Detection of final states involving at least one π^0 (e.g., $B^0 \to p\bar{p}\pi^0$ or $B^+ \to p\bar{p}\pi^+\pi^0$) would be extremely helpful in both respects.

Only upper limits exist for the decay $B^0 \to p\bar{p}$:[6]

$$B(B^0 \to p\bar{p}) < 2 \times 10^{-4} \ (90\% \ \text{C.L.}) \ . \quad (7.2)$$

On the basis of the statistical model, one converts this result to

$$B(B^0 \to N\bar{N}) < 4 \times 10^{-4} \ . \quad (7.3)$$

This result is to be compared with Eqs. (6.3) and (6.4). We estimate

$$\frac{B(B^0 \to N\bar{N}2\pi)}{B(B^0 \to N\bar{N})} \gtrsim 2 \ , \quad (7.4)$$

which is enough (for a Poisson distribution) to imply $\bar{n} \geq 2$, since $P_{\bar{n}}(2)/P_{\bar{n}}(0) = \bar{n}^2/2$. Improvements on the bound (7.2) then can either place better lower bounds on $\bar{n}$, or strengthen the case for a distribution narrower than Poisson.

If $\bar{n}$ increases, the $B^+ \to p\bar{p}\pi^+\pi^+\pi^-$ mode becomes more favorable for observation. Since $P_{\bar{n}}(3)/P_{\bar{n}}(2) = \bar{n}/3 \geq \frac{2}{3}$, we expect (on the basis of isospin factors $\sim \frac{1}{4}$ for $p\bar{p}\pi^+\pi^-$ and $\sim \frac{1}{6}$ for $p\bar{p}\pi^+\pi^+\pi^-$) that

$$B(B^+ \to p\bar{p}\pi^+\pi^+\pi^-) \geq \frac{2}{3}\frac{1/6}{1/4}B(B^0 \to p\bar{p}\pi^+\pi^-)$$
$$= (2.7 \pm 1.3) \times 10^{-4} \ . \quad (7.5)$$

Failure to observe $B^+ \to p\bar{p}\pi^+\pi^+\pi^-$ at the level of $B = 10^{-4}$ would indicate, at the very least, that the distribution was narrower than Poisson.

B. Other nonleptonic decays

Present 90%-C.L. upper limits on B-decay modes to charmless final states involving mesons alone include[6]

$$B(B^0 \to \pi^+\pi^-) \leq 3 \times 10^{-4} \ , \quad (7.6)$$

$$B(B^+ \to \pi^+\rho^0) \leq 2 \times 10^{-4} \ , \quad (7.7)$$

$$B(B^0 \to \rho^0\rho^0) \leq 4 \times 10^{-4} \ , \quad (7.8)$$

and hence are comparable to values for those models observed in $N\bar{N}$+pions. There is much more energy available in B decay for multipion production when an $N\bar{N}$ pair is not produced, however. When the nucleons are fast in the B center-of-mass system (c.m.s.), as appears to be true experimentally, there is even less energy remaining for multipion production. A statistical estimate along the lines of Sec. IV implies that we could expect as many as an average of eight pions in charmless B decays involving pions alone. The probability for two-pion decays will then be very small, and very sensitive to the shape of the multiplicity distribution. In one specific model for two-body decays,[23] it is estimated that the present experimental upper bound on $B^0 \to \pi^+\pi^-$ corresponds only to $|V_{bu}/V_{bc}| \lesssim \frac{1}{2}$. One expects useful information on V_{bu} to begin coming from nonleptonic decays involving pions if B branching ratios can be measured at the level of several parts in 10^5.

C. Semileptonic decays

The present limit on $|V_{bu}/V_{bc}|$ came from the study of inclusive semileptonic decays, $\bar{b} \to l^+\nu_l\bar{u}$ (Ref. 3). There are predictions for exclusive final states,[24] such as

$$B^0 \to l^+\nu_l\rho^- \quad (7.9)$$

which indicate that such processes could account for as much as $\frac{1}{5}$ of the total charmless semileptonic rate. In fact, the experimental upper limit[6]

$$B(B^+ \to l^+\nu_l\rho^0) \leq 0.21\% \quad (7.10)$$

implies a value of $|V_{bu}/V_{bc}| \lesssim 0.2$ on the basis of such a calculation, not far from the present upper limit based on the inclusive final state.

We regard as particularly promising the final states in (7.9), (7.10), and also $B^+ \to l^+\nu_l\omega$, for which a simple quark-model argument leads us to expect

$$B(B^+ \to l^+\nu_l\omega) = B(B^+ \to l^+\nu_l\rho^0) \ . \quad (7.11)$$

We also expect on quite general grounds

$$\Gamma(B^+ \to l^+\nu_l\rho^0) = \tfrac{1}{2}\Gamma(B^0 \to l^+\nu_l\rho^-) \ , \quad (7.12)$$

a relation which could be used to measure the lifetime ratio of B^+ and B^0 in a manner very similar to that suggested for D^+ and D^0 (Ref. 25). The $l^+\nu_l\omega$ final state may be less subject to combinatorial background than $l^+\nu_l\rho$, because of the narrowness of the ω.

VIII. CP VIOLATION

The observation of noncharmed decay modes of B^0 at levels of several parts in 10^4 is an extremely favorable situation for the observation of CP-violating effects, especially since mixing in the B^0-$\bar{B}^0$ system[26] seems to be more prominent than anticipated. One makes use of standard interference between mixing and decay amplitudes[27] to show that in general there will be substantial asymmetries between the rates for such processes as $B^0 \to p\bar{p}\pi^+\pi^-$ and $\bar{B}^0 \to p\bar{p}\pi^+\pi^-$, where by B^0 and $\bar{B}^0$ we mean the states as produced at times $t=0$.

The general rule of thumb which makes CP violation a challenging phenomenon to study in B systems is that large asymmetries only are expected to occur for processes with small branching ratios. It was estimated in Ref. 27 that at least 6×10^7 $B\bar{B}$ pairs were needed to begin studying CP violation in charmless B^0 systems, for a branching ratio to exclusive $\bar{b}\to\bar{u}\bar{d}u$ final states of 10^{-4}, and for $(\Delta m/\Gamma)_{B^0}=0.1$. Since branching ratios and the value of $(\Delta m/\Gamma)_{B^0}$ both seem at least 5 times as large, it may require fewer than 10^7 $B\bar{B}$ pairs to make a serious study of CP violation in charmless final states involving baryons. Such experiments may be within the capabilities of present e^+e^- experiments, with suitably upgraded machines.

IX. CONCLUSIONS

We have presented some steps along the way to an estimate of $|V_{bu}/V_{bc}|$ from present data[1] on charmless B decays involving baryons. The ingredients of this estimate were (a) the observation of inclusive charmed-baryon production in about 10% of all nonleptonic B decays, (b) an estimate that in $B\to N\bar{N}+n\pi$, $\bar{n}=3\pm1$, and (c) a statistical isospin model for estimating the frequency of states containing only charged particles. Our result is $|V_{bu}/V_{bc}|=0.25\pm0.10$, or $|V_{bu}/V_{bc}| \geq 0.08$ (90% C.L.), in accord with a similar estimate of ≥ 0.07 presented by the ARGUS Collaboration. The present bounds from inclusive semileptonic decays[3] constrain $|V_{bu}/V_{bc}|\leq 0.16$. Our result favors a value close to this upper bound. If so, at least some of the decays $B^0\to p\bar{p}$, $B^+\to p\bar{p}\pi^+\pi^+\pi^-$, $B^0\to\rho^- l^+\nu_l$, $B^+\to(\rho^0$ or $\omega)l^+\nu_l$ should be appearing soon. The final states $N\bar{N}+n\pi$ may be an ideal place in which to begin the study of CP violation in B decays, if only because of all charmless B decays, they have the virtue of being the first discovered.

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