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CHARMLESS B DECAYS TO BARYONS*

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ABSTRACT

We attempt an estimate of $|V_{ub}/V_{cb}|$ from the recent ARGUS observation of $B^{\pm} \to p\bar{p}\pi^{\pm}$ and $B^0 \to p\bar{p}\pi^+\pi^-$ by studying general processes of the type $B \to N\overline{N} + n\pi$ $(n \geq 0)$. The main ingredients of the analysis are the pion multiplicity distribution and a few models for the isospin structure of the final state. It is concluded quite generally that $|V_{ub}/V_{cb}| = 0.25 \pm 0.10$ and $|V_{ub}/V_{cb}| \geq 0.08$. The ratio may become lower only in the event that both the relevant experimental and theoretical quantities obtain the extreme values considered in our study. We also discuss briefly a possible realization of a $\Delta I = 1/2$ rule in these processes.

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1. Introduction

The ARGUS collaboration has recently reported[1] the observation of the following two charmless B decay modes:

$$
\begin{aligned}
B(B^{\pm} \to p\bar{p}\pi^{\pm}) &= (3.7 \pm 1.3 \pm 1.4) \times 10^{-4} \\
B(B^{0} \to p\bar{p}\pi^{+}\pi^{-}) &= (6.0 \pm 2.0 \pm 2.2) \times 10^{-4} \ .
\end{aligned}
\tag{1}
$$

These are the first direct indications for a nonzero value of the Kobayashi-Maskawa matrix element V_{ub}. In this talk[2] I would like to describe a way which leads from the actual measurements to an estimate of the ratio $|V_{ub}/V_{cb}|$. After studying processes of the type $B \to N\overline{N} + (n\pi)$ $(n \geq 0)$ I will indicate how to improve this estimate by further measurements. Such measurements may also shed some light on the dynamics of this type of nonleptonic weak decays. Due to the shortage of time I will not discuss other related topics, such as non-spectator contributions, other charmless decay modes and CP violation in the baryonic modes. A discussion of these subjects may be found in Ref. 2.

Two of the characteristic features of the 32.7 ± 7.7 observed events are the back-to-back nature of the $p\bar{p}$ pairs and their relatively high energies $\langle E_p \rangle \sim 2\ GeV$. The pions are soft and there seems to be a significant signal of Δ's or other low-mass $N\pi$ states. I will refer to these features when applicable.

2. Comparison with Inclusive Decay to Charmed Baryons

To put the branching ratios of Eq. (1) in due perspective let us compare them with the inclusive charmed baryon rates[3]

$$B(B \to \text{charmed baryon} + X) = (7.4 \pm 2.9)\% \tag{2}$$

From $B(B \to e\nu X) = (11.4 \pm 0.5)\%$ and standard phase space factors[4] one obtains in a straightforward manner a total hadronic branching ratio

$$B(B \to \text{hadrons}) \simeq 74\% \tag{3}$$

The small fraction of this rate which corresponds to $b \to u\bar{u}d$ is estimated to be

$$B(u \to u\bar{u}d) = 4.3\% \times \left(\frac{|V_{ub}/V_{cb}|}{0.2}\right)^2 . \tag{4}$$

I have normalized the ratio V_{ub}/V_{cb} by its experimental upper limit of 0.2.[5]

Equations (2) and (3) yield a fraction of charmed baryons from $b \to c$ at the level of $(10 \pm 4)\%$. If the same fraction applies to baryons from $b \to u$, which I will assume from now on, then

$$B(B \to N + X) = (4.3 \pm 1.7) \times 10^{-3} \times \left(\frac{|V_{ub}/V_{cb}|}{0.2}\right)^2 . \tag{5}$$

This inclusive branching ratio should be compared with the two exclusive measurements of Eq. (1). For such a comparison I will study the general processes of the type $B \to N\overline{N} + n\pi$ $(n \geq 0)$. To obtain an estimate for $|V_{ub}/V_{cb}|$ one must analyze two factors:

a. The ratio of the rate of charmless baryonic modes with one or two pions to the total rate of the modes of this type

$$R_{1+2} = \frac{\Gamma(B \to N\overline{N}\pi) + \Gamma(B \to N\overline{N}\pi\pi)}{\sum_{n\geq 0} \Gamma(B \to N\overline{N} + n\pi)} . \tag{6}$$

b. The ratios of the observed rates to the corresponding total rates of the single and double pion modes

$$R_1^{\text{obs}} = \frac{\Gamma(B^+ \to p\bar{p}\pi^+)}{\Gamma(B^+ \to N\overline{N}\pi)} ; \quad R_2^{\text{obs}} = \frac{\Gamma(B^0 \to p\bar{p}\pi^+\pi^-)}{\Gamma(B^0 \to N\overline{N}\pi\pi)} . \tag{7}$$

Estimates of these ratios will be discussed in the subsequent two sections.

3. The ratio R_{1+2}

A simple approach which leads to an estimate of this ratio is to consider the multiplicity distribution for $B \to N\overline{N} + (n\pi)$. There are various ways to estimate the average multiplicity of pions. Applying an old model of Fermi[6] to count the number of degrees of freedom in a hadronic state initially confined within radius $\hbar c/E_0$ (at temperature T), one finds for $B \to N\overline{N} + (n\pi)$

$$\overline{n} = 0.53 \left(\frac{M_B - 2E_N}{E_0} \right)^{3/4} \tag{8}$$

where $E_0 = 0.2\ GeV$ is a typical hadron energy scale. This scheme describes adequately the average pion multiplicity in $D \to K\pi + (n\pi)$. Equation (8) yields $n \simeq 4$ for $E_N = M_N$ and $n \simeq 2$ for $E_N = 2\ GeV$, which is about the average energy measured for the proton (and antiprotons) in the observed events. I quite safely conclude that

$$2 \leq \overline{n} \leq 4 \ . \tag{9}$$

The average pion multiplicity in pp and (non-annihilation) $\bar{p}p$ collision at $\sqrt{s} = M_B$ is a bit larger than three and supports our estimate. The relatively high momentum protons and antiprotons in the observed events seem to indicate a value close to the lower value of Eq. (9).

The multiplicity distribution will be assumed to be Poisson-like or somewhat narrower, as motivated by current- algebra.[7] Such a distribution describes adequately the decays $\psi \to$ hadrons and $D \to K\pi + (n\pi)$. This distribution with Eq. (9) imply that[2]

$$R_{1+2} = 0.45 \pm 0.25 \ . \tag{10}$$

4. $R_{1,2}^{\rm obs}$ and an Estimate of $|V_{ub}/V_{cb}|$.

The ratios $R_{1,2}^{\rm obs}$ depend on the isospin structure of the final states. The free quark decay $b \to u\bar{u}d$ is a mixture of $I = 1/2$ and $I = 3/2$ transitions. In B^- decays it leads to $I = 1, 2$ states, whereas the final state in B^0 decay is made of $I = 0, 1, 2$.

In a simple statistical model one may assume that the multiparticle decay amplitudes into a given isospin state are independent of the isospins of subsystems and add up incoherently.[8] In another model one may adopt $\Delta I = 1/2$ dominance (see discussion in the next section) and finally, one may assume that the multiparticle states are dominated by $B^{0,-} \to \overline{\Delta} N + (n-1)\pi$. The detailed predictions of these schemes are given in Ref. 2. The overall range allowed for $R_{1,2}^{\rm obs}$ may be summarized as follows:

$$R_1^{\rm obs} = 0.5 \pm 0.25 \ ; \qquad R_2^{\rm obs} = 0.25 \pm 0.05 \ . \tag{11}$$

Combining Eqs. (1), (5), (10), and(11) one finds

$$\begin{aligned} &B(B \to N\overline{N}\pi) + B(B \to N\overline{N}\pi\pi) \\ &\quad = (3.1 \pm 1.4) \times 10^{-3} = (0.45 \pm 0.25)\,(4.3 \pm 1.7) \times 10^{-3} \times \left(\frac{|V_{ub}/V_{cb}|}{0.2}\right)^2 \ . \end{aligned} \tag{12}$$

errors are added in quadrature. This implies

$$|V_{ub}/V_{cb}| = 0.25 \pm 0.10 \ . \tag{13}$$

Allowing a $1.64\,\sigma$ deviation from the central value we obtain a "90% c.l." limit

$$|V_{ub}/V_{cb}| \geq 0.08 \ . \tag{14}$$

Since part of the uncertainty in Eq. (13) is theoretical, this lower value should not be considered to have a 90% c.l. in a statistical sense. It rather represents our own judgement.

5. $\Delta I = 1/2$ and Dynamics of $B \rightarrow N\overline{N} + (n\pi)$

The effective weak Hamiltonian for $b \rightarrow u\bar{u}d$, which includes short-distance QCD corrections, is[9]

$$H = -V_{ub}^{*}V_{ud}\,\frac{G_F}{2\sqrt{2}}\sum_{i=1}^{2} c_i\left[(\bar{u}b)_L(\bar{d}u)_L + (-1)^i(\bar{d}b)_L(\bar{u}u)_L\right] \tag{15}$$

where $c_1/c_2 = 1.5 - 2$ for the bottom quark mass scale. This implies some $\Delta I =$ 1/2 enhancement, since the operator which is antisymmetric in $\bar{u} \leftrightarrow \bar{d}$ is a pure $\Delta I = 1/2$ operator, while the symmetric one leads to both $\Delta I = 1/2$ and 3/2 transitions. The actual enhancement depends also on the relative strength of the matrix elements of the two operators in a particular process. In the baryonic decay modes of B there seems to be an additional relative enhancement coming from the matrix elements.

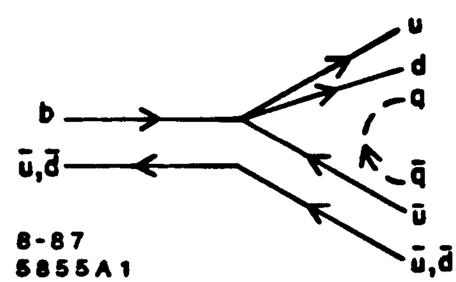

Figure 1

Consider the diagram of Fig. 1, in which the ud pair of quarks turns into a baryon by picking up a quark q from a flactuated $q\bar{q}$ pair and similarly the pair of antiquarks turns to an antibaryon. These states may subsequently emit pions. Such a scheme was proposed by Bigi[10] to lead to a sizeable baryonic decay rate for the B mesons. An old argument,[11] applied originally to hyperon decays, used the V-A current-current structure to conclude that the baryon-to-baryon matrix elements obey a $\Delta I = 1/2$ rule. The same argument may be applied here. The ud pair is in a state symmetric in $(flavor) \times (color)$. If embedded directly in a baryon it must be in a color 3^* and is an isospin singlet state. This implies that the transition is pure $\Delta I = 1/2$. There is, of course, the possibility that the ud pair was created by the weak interactions in a color 6 state. One of the quarks emits a gluon, which subsequently radiates the $q\bar{q}$ pair to make a baryon. In this case the $\Delta I = 1/2$ rule would not apply. Some arguments[12] seem to indicate that the first mechanism, in which the ud pair is directly embedded in a baryon with no color and spin flip, should prevail. A test of this mechanism is the absence of Δ in contrast to the existence of $\overline{\Delta}$ in the decays of B mesons containing a b (and not $\bar{b}$) quark.

At this point I wish to make two remarks in passing about the model-dependence of $R_{1,2}^{\rm obs}$ discussed in Section 4. It is straightforward to show[2] that if $B^- \to N\overline{N}\pi$ is dominated by $N\overline{\Delta}$, with $\Delta I = 1/2$, then $R_1^{\rm obs} = 3/4$. This should be compared with the value of 1/3 obtained in a statistical isospin model and explains the relatively large range of values in the first of Eqs. (11). This model does not enhance $R_2^{\rm obs}$. Furthermore, the $N\overline{\Delta}$ $\Delta I = 1/2$ scheme leads to[2]

$$\Gamma(B^- \to N\overline{N}\pi) = 2\Gamma(B^0 \to N\overline{N}\pi) \tag{16}$$

which illustrates the possibility that decays of B^- and B^0 to a given multiplicity may not occur at the same rate.

6. Conclusions.

Our analysis of the ARGUS data leads to $|V_{ub}/V_{cb}| = 0.25 \pm 0.10$ and we feel quite confident with $|V_{ub}/V_{cb}| \geq 0.08$, similar to ARGUS' own estimate[1] of 0.07. A more precise value can be obtained by further experimental studies which may help specify the shape of the multiplicity distribution. Measurements of $B^0 \to p\bar{p}$, $B^+ \to p\bar{p}\,\pi^+\pi^+\pi^-$ or obtaining useful bounds for these modes beyond the existing one may serve such a goal. Detection of neutrals may reduce the uncertainty discussed in Section 4. An alternative way to approach the problem, which is easier to study theoretically, is to search for a corresponding charmful baryonic decay mode such as $B \to \Lambda_c \bar{p} \pi^+$. Signal-to-background ratio is expected to be worse than in the charmless modes, since one is looking for the decay products of Λ_c, but the expected rates are not hopelessly small. Finally, as we have illustrated in our discussion of $\Delta I = 1/2$ enhancement, baryonic decay modes of B mesons offer an interesting field for studies of the dynamics of nonleptonic weak decays.

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