$B \to p\bar{p}\pi(\pi)$ branching ratios

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The branching ratios for the decays $B^+ \to p\bar{p}\pi^+$ and $B^0 \to p\bar{p}\pi^+\pi^-$ are calculated. The leading diagrams in a $1/N$ expansion are taken into account. The results are compared with those of the ARGUS group and previous theoretical results.

One of the most important problems in high-energy physics today is that of determining the parameters which characterize the mixing of quarks of different generations. The parameter clouded with the greatest uncertainty is the Kobayashi–Maskawa matrix element V_{bu}. There are experimental upper limits on the quantity $|V_{bu}/V_{bc}|$; the most model-independent (found from a calculation of the number of charmed particles in the decays of B mesons) is[1] $|V_{bu}/V_{bc}| < 0.5$, and the most rigorous, but model-dependent, is[1] $|V_{bu}/V_{bc}| < 0.2$; this one was found from the study of the lepton spectra in B decays). The ARGUS group recently reported the existence of decays $B \to p\bar{p}\pi(\pi)$ with branching ratios $Br(B^+ \to p\bar{p}\pi^+) = (5.2 \pm 1.4 \pm 1.9) \times 10^{-4}$ and $Br(B^0 \to p\bar{p}\pi^+\pi^-) = (6.0 \pm 2.0 \pm 2.2) \times 10^{-4}$. They also reported a lower limit on the ratio which we were just discussing[2]: $|V_{bu}/V_{bc}| > 0.07$. More-realistic estimates,[3] however, show that these branching ratios require $|V_{bu}/V_{bc}| > 0.3$. Chernyak and Zhitnitsky[4] assert the result $Br(B \to p\bar{p}\pi(\pi)) \sim 10^{-4}|V_{bu}/V_{bc}|^2$ the experimental results cannot be explained by the standard model.

Let us analyze the probability for the production of $N\bar{N}$ and of mesons in the decays of B mesons under the assumption that these processes are dominated by the diagrams in Fig. 1, a and b. These are the leading diagrams in the limit $N_c \to \infty$ and are distinguished by the hadronization mechanism from the diagram in Fig. 3c, which has been discussed previously in the literature.[2–5] In case c, all of the quarks which are

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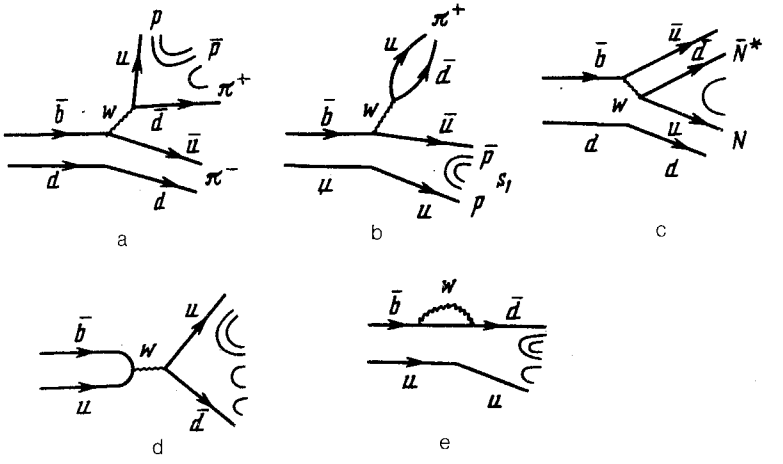

FIG. 1.

produced are part of the final nucleon (isobars); because of the strong interaction, a single $q\bar{q}$ pair is produced. For the mechanism of parts a and b, two white hadron systems ($q\bar{q}$ strings) are typically produced, and the $N\bar{N}$ are created through the production of two $q\bar{q}$ pairs.[1)] We will show that the mechanism which we are discussing here contributes significantly to the exclusive decays of B mesons and that this contribution exceeds that of the diagram in Fig. 1a, which was calculated in Ref. 4.

We start with the part of the weak-interaction Lagrangian in which we are interested, writing the hard-gluon contribution in standard form:

$$\mathcal{L}_w = \frac{G_F}{\sqrt{2}} V_{bu} V_{ud}^* [C_1 (\bar{u}\Gamma_\mu b)(\bar{d}\Gamma_\mu u) + C_2 (\bar{d}\Gamma_\mu b)(\bar{u}\Gamma_\mu u)], \tag{1}$$

where $\bar{q}_1 \Gamma_\mu q_2 = \bar{q}_1^\alpha \gamma_\mu (1+\gamma_5) q_{2\alpha}$, α represents the color indices, and the coefficients C_1 and C_2 are $C_1(m_b) = 1.13$ and $C_2(m_b) = -0.3$ for the b quark. Since we have $c_2^2 \ll C_1^2$, the change in the color structure of the diagrams due to the hard gluons from the structure shown in the figure is inconsequential, and the decay $B^0 \to p\bar{p}\pi^+\pi^-$ is determined primarily by the diagram in Fig. 1a. The decay $B^+ \to p\bar{p}\pi^+$ is determined primarily by the diagram in Fig. 1b. The diagram in Fig. 1b is suppressed in comparison with that in Fig. 1a, since the expectation value of the square of the invariant mass of the lower $q\bar{q}$ system is small, 1.7–2 GeV^2, and the $p\bar{p}$ production results from improbable configurations of light quarks.

In describing the hadronization of $q\bar{q}$ systems we use the ideas of the model of quark-gluon strings,[6] which gives a good description of the decays and multiple production of hadrons. Several of the results, however, are model-independent. The branching ratio which can be calculated most reliably is that for the inclusive production of $p(\bar{p})$ in the decays of B mesons through a b–u transition:

$$Br(B_u \to pX) = |V_{bu}/V_{bc}|^2 \gamma_w (q\bar{q} \to pX). \tag{2}$$

The quantity $\gamma \approx r_1 r_2$ incorporates the difference between the phase volumes in the decays $b \to u(q_1 \bar{q}_2)$ and $b \to c(q_1 \bar{q}_2)$ i.e., $r_1 \approx 2$, and the branching ratio for the main decay, $b \to c(\bar{u}d)$, i.e., $r_2 \approx 0.5$. The branching ratio for p production in the hadronization of a $q\bar{q}$ system, $w(q\bar{q} - pX)$ can be estimated from data on e^+e^- annihilation in the region[7] $(2m_p)^2 < Q^2 < m_b^2$. In this Q^2 region, the quantity $w(q\bar{q} - pX)$ varies only slowly and has a value $\approx (3\text{–}4)\%$. The inclusive production of $p(\bar{p})$ in the decays of B mesons which is unrelated to the production of charmed baryons should thus be

$$Br(B_u \to pX) \approx 0.03 \, |V_{bu}/V_{bc}|^2. \tag{3}$$

This quality turns out to be quite large at values of $|V_{bu}/V_{bc}|$ close to the upper limit. However, the switch to exclusive channels, which have been studied by the ARGUS group, sharply reduces the branching ratios for the corresponding processes.

The branching ratio for the decay $B^0 - (p\bar{p}\pi^+)\pi^-$ contains two small factors which are not found in (3): $\beta_1 = w(q\bar{q} - \pi)/w(q\bar{q} - X$, which is a measure of the branching ratio for the transition $B \to \pi$ due to the vector current, and $\beta_2 = w(q\bar{q} - p\bar{p}X)/w(q\bar{q} - pX$. The quantity β_1 has been calculated by several authors (see the review[8]); its values range from 0.03 to 0.2. We calculated β_1 and β_2 in the model of quark-gluon strings, finding $\beta_1 = 0.12\text{–}0.14$ and $\beta_2 = 0.2\text{–}0.3$. The final result for the branching ratio for the decay $B^0 - p\bar{p}\pi^+\pi^-$ is thus

$$Br(B^0 \to p\bar{p}\pi^+\pi^-) = \beta_1\beta_2 \times 3 \times 10^{-2} \, |V_{bu}/V_{bc}|^2 \approx 1 \times 10^{-3} \, |V_{bu}/V_{bc}|^2. \tag{4}$$

This value is an order of magnitude greater than the value calculated in Ref. 4 on the basis of the diagram in Fig. 1a. As we have already mentioned, the branching ratio for the decay $B^+ - p\bar{p}\pi^+$ in this model contains an additional suppression. Incorporating the motion of the u quarks in the B meson and the term C_2 in Lagrangian (1) leads to the estimate

$$Br(B^+ \to p\bar{p}\pi^+) = 2 \times 10^{-4} \, |V_{bu}/V_{bc}|^2. \tag{5}$$

The branching ratio for decays accompanied by the production of an additional π^0 meson is larger by a factor of four to six according to our estimates. This approach has also been used for the decays of B mesons into charmed mesons and π mesons. The results agree with experimental data. We might add that the following limitation, independent of model-based calculations, can be derived on the values of β_1 and β_2:

$$Br(B^0 \to p\bar{p}\pi^+\pi^-) < 0.1 Br(B^0 \to \pi^- l^+ \nu), \quad Br(B^0 \to p\bar{p}\pi^+\pi^-) < Br(B^0 \to \pi^+\pi^-). \tag{6}$$

In deriving relations (6) we made use of the circumstance that the branching ratios for the processes $B \to \pi l \nu$ and $B \to \pi\pi$ are determined by the same combination of unknowns, $\beta_1 |V_{bu}/V_{bc}|^2$, and that we have a value $\beta_2 < 1$. The limitations reported by the CLEO group,[9] $Br(B^0 \to \pi^+\pi^-) < 0.9 \times 10^{-4}$ and relations (6), contradict the results of the ARGUS group on the decay $B^0 \to p\bar{p}\pi^+\pi^-$. The kinematics of the p and $\bar{p}$ for the diagrams in Fig. 1, a and b, does not correspond to that observed in Ref. 2. The CLEO group recently found limitations on the decays[9] $B \to p\bar{p}\pi(\pi)$ which do not agree with the results found by the ARGUS group.

In summary, estimates of the branching ratios for the decays of B mesons resulting in the production of $N\bar{N}$ and π mesons indicate that the diagrams in Fig. 1, a and b, are important. The theoretical values of the corresponding partial widths are smaller than the results found by the ARGUS group,[2] even at the maximum possible values of $|V_{bu}/V_{bc}|$.

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[1]In addition to the mechanisms discussed above, there is the further possibility of a production of hadrons by virtue of the diagrams in Fig. 1, d and e. Estimates show that the contribution of these diagrams is significantly smaller than that of diagrams a-c in the standard model.

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