ИНСТИТУТ ЯДЕРНОЙ ФИЗИКИ СО АН СССР

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# ON THE BEAUTY-MESON EXCLUSIVE DECAYS INTO BARYONS
## (or can the theory explain ARGUS data on the $B\to\bar{p}p\pi$, $B\to\bar{p}p\pi\pi$ decays?)



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НОВОСИБИРСК

# On the Beauty-Meson Exclusive Decays into Baryons (or can the theory explain ARGUS data on the $B\to\bar p p\pi$, $B\to\bar p p\pi\pi$ decays?)

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ABSTRACT

The decay widths for beauty-meson exclusive decays into various baryonic pairs are calculated. The typical decay widths lie in the intervals ($B$ is the light baryon $B_c$ is the charmed baryon):

a) $\mathrm{Br}(\bar B \longrightarrow \bar B B_c) \simeq \mathrm{Br}(\bar B \longrightarrow \bar B_c B_c) \simeq (0.03\div 0.3)\%$,

b) $\mathrm{Br}(\bar B \longrightarrow \bar B_1 B_2) \simeq (0.5\div 2)10^{-4}|V_{bu}/V_{bc}|^2 \leqslant 10^{-5}$.

All our predictions for various $\bar B \longrightarrow \bar B_1 B_2$ decays are much smaller than the famous ARGUS results for $B^-\to\bar p p\pi^-$ and $B^0\to\bar p p\pi^+\pi^-$ decays. We see no possibilities (within the standard model) to obtain the branching ratios as large as those reported by ARGUS.



**1.** Very interesting results have been published recently by the ARGUS group on the exclusive decays of the beauty-mesons $B^{-,0}$ (5.28) into baryons [1]:

$$\mathrm{Br}(B^-\to\bar p p\pi^-) = (3.7\pm1.3\pm1.4)\cdot10^{-4},$$

$$\mathrm{Br}(B^0\to\bar p p\pi^+\pi^-) = (6.0\pm2.0\pm2.2)\cdot10^{-4}.$$

These results are of great importance, as they are considered to be the first observation of direct $b\to u$ transitions.
The purpose of this paper is to present the results of theoretical calculations of various two-particle baryonic decay widths of beauty-mesons: a) into two light baryons $\bar B_1 B_2(\bar p p, \overline{\Delta^{++}} p$, etc.); b) into one light and one charmed baryon $\bar B B_c(\bar p\Sigma_c$, $\bar p\Lambda_c$, etc.); c) into two charmed baryons $\bar B_c B_c(\bar\Sigma_c\Xi_c$, $\bar\Lambda_c\Xi_c$, ...); d) the $b\to s$ penguin contributions ($\bar p\Sigma^+$, $\bar p\Lambda^0$, etc.).

Below we describe in short the method of calculations and present the typical results obtained for the decay widths. (The detailed description will be published elsewhere).

**2.** The following method has been used for calculations. The beauty-meson is replaced by the local interpolating current, $I_B$, with the momentum $q$, Fig. 1, and the spectral density in $q^2$, $\delta T(q^2)$, is calculated. The «sum rule» is written down then, i. e. the spectral density is integrated with the weight $\exp\{-q^2/M^2\}$ from the threshold $M_b^2$ ($M_b$ is the beauty quark mass, $M_B$ is the beauty meson mass) up to the beginning of the continuum, $S_B$. As a result, the decay amplitude $T$ is:

$$T=f^{-1}\int_{M_b^2}^{S_B} dq^2\,\delta T(q^2)\exp\left\{-\frac{q^2-M_B^2}{M^2}\right\}+(\text{corrections})\,, \qquad (1)$$

where the constant $f$ is: $\langle 0|I_B|B\rangle$. The right hand side in (1) (neglecting corrections) is fitted in $M^2$, and the best fit determines the decay amplitude $T$.

The eq. (1) without corrections is a kind of «a generalized duality», rather than a genuine QCD sum rule. The reason is that the decay kinematics is essentially Minkowskian and, at present, there is no simple method of calculation of the power corrections in this case. However, the experience with the usual QCD sum rules teaches us that the main power corrections are usually due to the

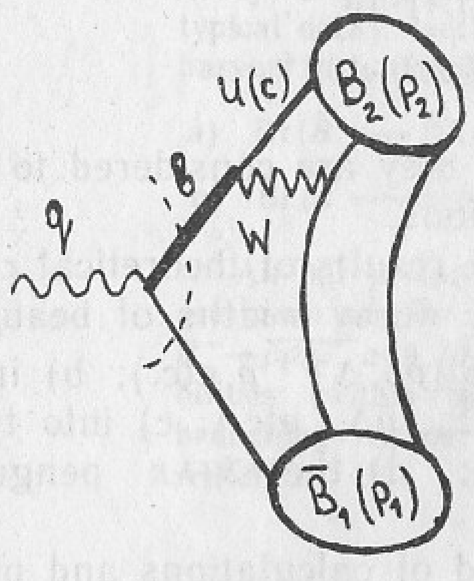


Fig. 1.

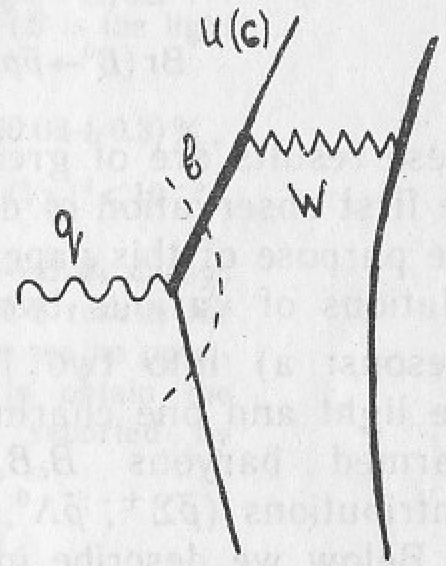


Fig. 2.

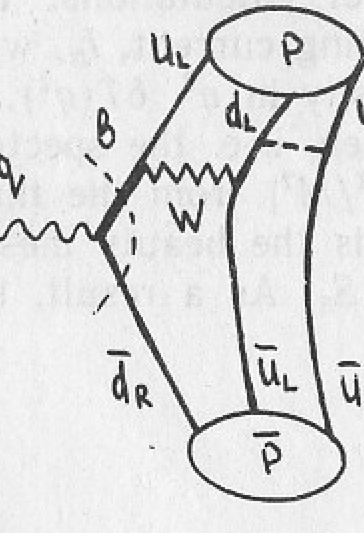


Fig. 3.

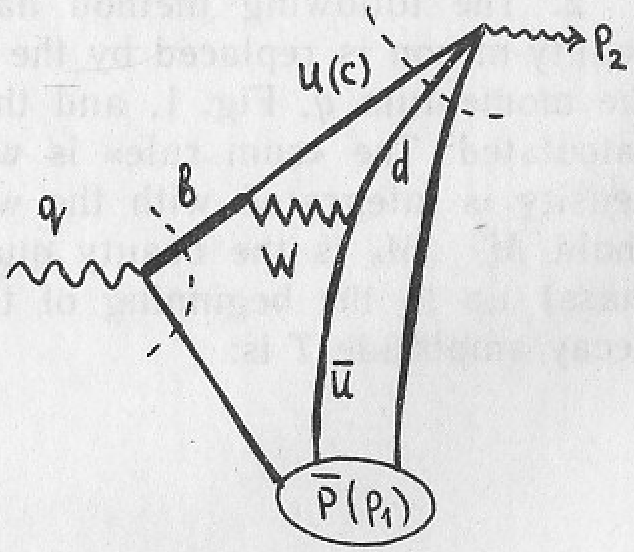


Fig. 4.



quark bilinears $\langle 0|\bar{q}_L q_R|0\rangle$. Therefore, to avoide large corrections, we have used in our calculations only chiral currents, i. e. the currents which contain light quarks with the definite helicity only.

To check the above method, we have applied it to the simpler case of beauty-meson decays into two light mesons. Fig. 2, and obtained results close to those obtained in [2] by the different method.

**3.** The diagrams like that shown in Fig. 3, containing the hard gluon exchange, are the dominant ones in the formal limit $M_b\to\infty$. Using the $N$ and $\Delta_{33}$ leading twist wave functions found out in [3], we have calculated these «hard contributions», and they turned out to be anomalously small. For instance,

$$T_{hard}(B^-\to\Delta^{++}\,\overline{p})\simeq(3\cdot 10^{-3}\,\text{GeV}^2)\;G_F V_{bu}(\bar{N}_L N_R)\,,$$

$$\text{Br}\,(B^-\to\overline{\Delta^{++}}\,p)_{hard}\simeq 4\,\text{Br}\,(B^0\to\bar{p}p)_{hard}\simeq 6\cdot 10^{-7}|V_{bu}/V_{bc}|^2. \qquad (2)$$

There are special reasons for such an anomalous smallness of hard contributions in these decays, but we don't touch upon this point here. Let us note only that we also estimated these hard contributions directly, i. e. without introducing the interpolating current instead of the $B$-meson, but using the $B$-meson model wave function. The results are in a reasonable agreement with (2).

**4.** At the real value of the $b$-quark mass the dominant contributions into the decay amplitudes give the «soft contributions», which contain no perturbative gluon exchange, Fig. 4. (In other words, the additional quark pair is created here from the vacuum by non-perturbative forces). These soft contributions, although small parametrically in the formal limit $M_b\to\infty$, are enhanced numerically (there is no loop smallness $\sim\alpha_s/\pi$, etc.).

To calculate these soft contributions, we have used the same method: the baryon $B(p_2)$ was replaced by the suitable interpolating current $\eta$, Fig. 4, and «sum rules» for the double spectral density in $q^2$ and $p_2^2$ were written down.

Let us note that because the final diquark $(u_L C d_L)$ is produced locally and is here in the $\bar{3}$-color state, its isospin is zero. In other words, there is $\Delta I=1/2$ selection rule for $\bar{B}\longrightarrow\bar{B}_1 B_2$ decays. As a result, there are $\bar{B}\longrightarrow\bar{\Delta}N$ decays, but there are no $\bar{B}\longrightarrow\bar{N}\Delta$ decays.

Below we present some results which were obtained with the help of the above described method.

**5.** The decay $B^0 \to \bar{p}p$. When the interpolating current $\eta^\tau = (u_L C d_L) u_L^\tau$ is used for the proton, the result is as follows:

$$T(\bar{B}^0 \to \bar{p}p) \simeq (3.4 \cdot 10^{-2}\ \text{GeV}^2)\ G_F V_{bu} (\bar{N}_L N_R)\,,$$

$$\text{Br}\,(\bar{B}^0 \to \bar{p}p) \simeq 0.8 \cdot 10^{-4} |V_{bu}/V_{bc}|^2. \qquad (3)$$

To check the accuracy of the method used, we have calculated the same amplitude by using other interpolating current: $\eta_\mu^\tau = (u_L C \gamma_\mu d_R) u_L^\tau$. The result is:

$$T(\bar{B}^0 \to \bar{p}p) \simeq (5 \cdot 10^{-2}\ \text{GeV}^2)\ G_F V_{bu} (\bar{N}_L N_R)\,,$$

$$\text{Br}\,(\bar{B}^0 \to \bar{p}p) \simeq 1.6 \cdot 10^{-4} |V_{bu}/V_{bc}|^2. \qquad (4)$$

These two calculations are independent ones, and the comparison of (3) and (4) shows the typical accuracy of the method used. Because our purpose is to obtain the characteristic values of various decay widths, such an accuracy is sufficient for us.

**6.** For other decay widths we have obtained:

$$\text{Br}\,(B^- \to \overline{\Delta^{++}}\ p) \simeq 0.25\,\text{Br}\,(\bar{B}^0 \to \bar{p}p)\,,$$

$$\text{Br}\,(\bar{B}^0 \to \overline{\Delta^{+}}\ p) \simeq 10^{-5} |V_{bu}/V_{bc}|^2, \qquad (5)$$

$$\text{Br}\,(B^- \to \bar{p}n) \simeq 0.6\,\text{Br}\,(\bar{B}^0 \to \bar{p}p) \simeq 2\,\text{Br}\,(\bar{B}^0 \to \bar{n}n)\,,$$

$$\text{Br}\,(\bar{B}^0 \to \bar{p}\overset{*}{N}{}^+(1440)) \simeq 1.5\,\text{Br}\,(\bar{B}^0 \to \bar{p}p) \simeq 1.5\,\text{Br}\,(B^- \to \bar{p}\overset{*}{N}{}^0(1440))\,.$$

In summary, our main result concerning the decays into two lightest baryons in the following. The typical decay widths lie in the interval:

$$\text{Br}\,(\bar{B} \longrightarrow \bar{B}_1 B_2) \simeq (0.5 \div 2\,) \cdot 10^{-4} |V_{bu}/V_{bc}|^2.$$

At $|V_{bu}/V_{bc}| \leqslant 0.2$ these numbers are 40—100 times smaller than the ARGUS values (1).*) **We see no possibilities (within the standard model) to obtain so large values as those reported by ARGUS [1].**

**7.** Using the same method we have calculated also the $\bar{B} \longrightarrow \bar{B}B_c$ decay widths (Fig. 4 with the $u$-quark replaced by the $c$-quark). Some typical numbers are:

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*) There are the arguments and estimates showing that $\text{Br}\,(B^- \to \bar{p}p\pi^-) \leqslant \text{Br}\,(B^0 \to \bar{p}p)$ for a non-resonant pion and that $\text{Br}\,(B^- \to \bar{p}p\pi^-) \leqslant$ few $\text{Br}\,(B^0 \to \bar{p}p)$ on the whole.



$$\text{Br}\,(\bar{B}^0 \to \bar{p}\Sigma_c^{+}) \simeq 3 \cdot 10^{-3}, \quad \text{Br}\,(\bar{B}^0 \to \bar{p}\Lambda_c^{+}) \simeq 4 \cdot 10^{-4},$$

$$\text{Br}\,(B^- \to \overline{\Delta^{++}}\ \Sigma_c^{+}) \simeq 1 \cdot 10^{-3}, \quad \text{Br}\,(B^- \to \overline{\Delta^{++}}\ \Lambda_c^{+}) \simeq 1.5 \cdot 10^{-4}, \qquad (7)$$

$$\text{Br}\,(B^- \to \bar{p}\Sigma_c^0) \simeq 3 \cdot 10^{-3}.$$

Therefore, the typical widths for the $\bar{B} \longrightarrow \bar{B}B_c$ decays lie in the interval:

$$\text{Br}\,(\bar{B} \longrightarrow \bar{B}B_c) \simeq (0.03 \div 0.3)\,\%\,. \qquad (8)$$

Comparing the $\bar{B} \longrightarrow \bar{B}B_c$ decays (see (7), Fig. 4) with the two-meson decays (Fig. 2) one sees that the decay widths are approximately the same, i. e. the amplitude for picking up the light-quark pair from the vacuum is $\sim O(1)$ for $\bar{B} \longrightarrow \bar{B}B_c$. On the other hand, this amplitude is $\sim O(1/10)$ for $\bar{B} \longrightarrow \bar{B}_1 B_2$ decays. The reason is that the light quark carries only a small, $\sim O(M_0/M_c)$, fraction of the $B_c$-momentum, and it is much more easily to pick up softer quark from the vacuum. At the same time, there is no additional parametrical enhancement when the second light baryon ($\bar{B}$ in Fig. 4) is replaced by the charmed one. So, the hierarchy of amplitudes has, roughly, the form:

$$T(\bar{B} \longrightarrow \bar{B}B_c) \simeq T(\bar{B} \longrightarrow \bar{B}_c B_c) \simeq (5 \div 10)\,\frac{V_{bc}}{V_{bu}}\ T(\bar{B} \longrightarrow \bar{B}_1 B_2)\,. \qquad (9)$$

**8.** Since the charmed baryon wave functions are unknown at present, to obtain the characteristic values of the $\bar{B} \longrightarrow \bar{B}_c B_c$ decay widths we have used the Fig. 5 diagrams, i. e. we have replaced all hadrons by suitable interpolating currents. We have obtained:

$$T(\bar{B}^0 \to \overline{\Sigma_c^0}\ \Xi_c^0) = [\,A\,\overline{\Xi_c^L}\ \Sigma_c^R + B\,\overline{\Xi_c^R}\ \Sigma_c^L\,]\,,$$

$$A \simeq (0.37\,\text{GeV})\ G_F V_{bc}, \qquad B \simeq (-0.23\,\text{GeV})\ G_F V_{bc},$$

$$\text{Br}\,(\bar{B}^0 \to \overline{\Sigma_c^0}\ \Xi_c^0) \simeq 0.4\% \simeq \text{Br}\,(B^- \to \overline{\Sigma_c^{++}}\ \Xi_c^{+})\,, \qquad (10)$$

$$\text{Br}\,(\bar{B}^0 \to \overline{\Sigma_c^{+}}\ \Xi_c^{+}) \simeq \text{Br}\,(B^- \to \overline{\Sigma_c^{+}}\ \Xi_c^0) \simeq 0.2\%\,,$$

$$\text{Br}\,(B^- \to \overline{\Lambda_c^{+}}\ \Xi_c^0) \simeq 0.1\%\,.$$

Therefore, the characteristic values of the $\bar{B} \longrightarrow \bar{B}_c B_c$ decay widths lie in the interval: $(0.1 \div 0.5)\,\%$. The number of such modes is, however, very limited due to a small phase space.

**9.** The inclusive yeld of charmed baryons is known experimentally [4]:

$$\mathrm{Br}(\bar{B}\to B_c+X)=(7.4\pm2.9)\,\%. \qquad (11)$$

Comparing (7) — (10) with (11) we see that a given exclusive mode constitute $(0.5\div5.)\,\%$ of the inclusive baryonic yield. Therefore, one should expect that there are ∼20 — 30 exclusive baryonic modes which constitute in a sum a bulk of the inclusive yield (11). Moreover, the $\bar{B}\to\bar{B}_cB_c$ modes constitutes a sizeable part of the inclusive yield (11).

From our point of view, these are the reasonable numbers, and they don't look as being underestimated. (The typical two-meson

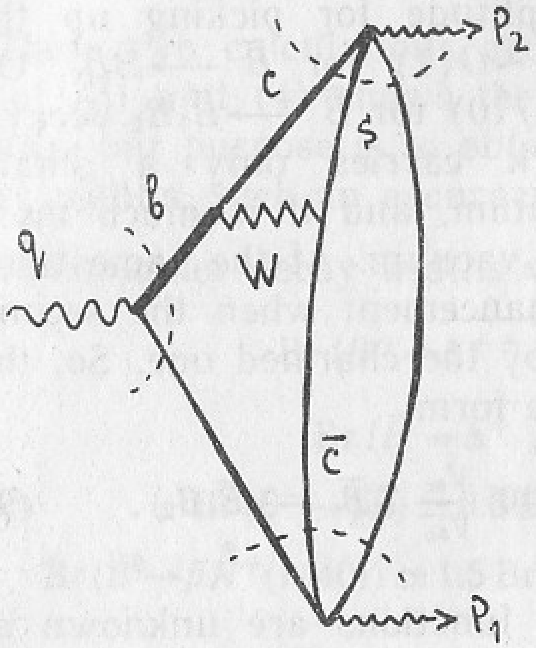


*Fig. 5,*

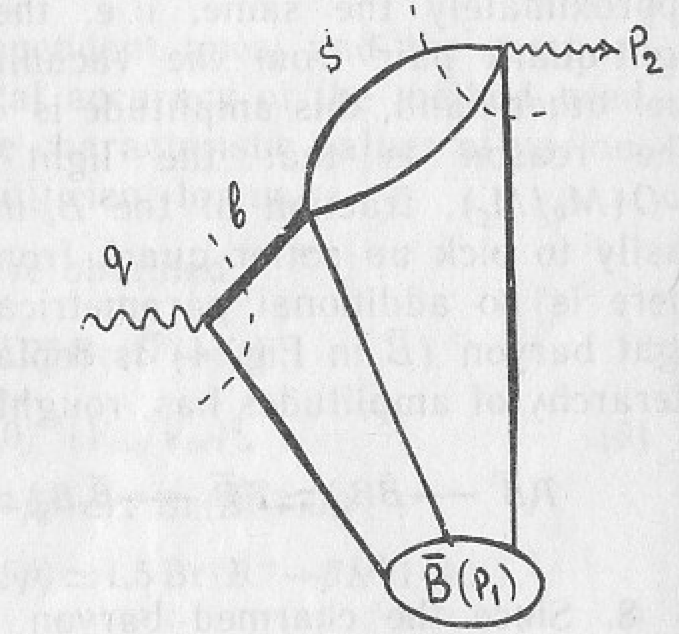


*Fig. 6.*

branching ratios also lie in this interval. One should remember also that although baryons are heavier than mesons, their spectrum is much more dense). The above results (7) — (10) are of importance for us, as they indicate that the $\bar{B}\to\bar{B}_1B_2$ decay widths (3) — (6), obtained by the same method, are also not underestimated.

**10.** We have calculated also the typical exclusive decay widths induced by the $b\to s$ penguin contributions Fig. 6 (the $b\to d$ penguin contributions are negligible):

$$\mathrm{Br}(\bar{B}^0\to\bar{p}\Sigma^+)\simeq2\,\mathrm{Br}(B^-\to\bar{p}\Sigma^0)\simeq\mathrm{Br}(B^-\to\overline{\Delta^{++}}\,\Sigma^+)\simeq$$
$$\simeq\mathrm{Br}(\bar{B}^0\to\overline{\Delta^-}\,\Sigma^-)\simeq3\,\mathrm{Br}(B^-\to\overline{\Delta^0}\,\Sigma^-)\simeq0.6\cdot10^{-5}, \qquad (12)$$
$$\mathrm{Br}(B^-\to\bar{p}\Sigma^0)\gg\mathrm{Br}(B^-\to\bar{p}\Lambda_0)\,.$$



It is seen from (12) that these widths are small.

**11.** The main conclusion which follows from all the above results is that the typical exclusive branching ratios for the beauty-meson decays into two light baryons are*):

$$\mathrm{Br}(\bar{B}\longrightarrow\bar{B}_1B_2)\simeq(0.5\div2.)\cdot10^{-4}|V_{bu}/V_{bc}|^2,$$

and these numbers are much smaller than the ARGUS values $\simeq3\cdot10^{-4}$. We see no possibilities to obtain (within the standard model) the branching ratios as large as those reported by ARGUS.

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*) See the footnote after the formula (6).

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**Об эксклюзивных распадах**
**прелестных мезонов на барионы**

Ответственный за выпуск С.Г.Попов

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