CERN-TH.4985/88

CHARMLESS B MESON DECAYS AND QUARK-MIXING MATRIX ELEMENTS

L. Łukaszuk^{*)}

CERN - Geneva

and

X.Y. Pham

Laboratoire de Physique Théorique et Hautes Energies
Université Pierre et Marie Curie, Tour 16, 4 Place Jussieu
75252 Paris Cedex 05, France

ABSTRACT

The sensitivity of the ratio $\frac{\text{Br}(B \rightarrow s=1, c=0)}{\text{Br}(B \rightarrow s=0, c=0)}$ (strange versus non-strange inclusive charmless B decays) with respect to V_{bu} (the beauty-up coupling) and ϕ (the CP violation phase) is established. The ratio is shown to be an additional source of information on quark-mixing matrix elements to ε'/ε and $B^0-\bar{B}^0$ mixing data.

^{*)}On leave of absence from University of Szczecin, Wielkopolska 15, 71-061 Szczecin, Poland.

Among the three angles and the phase of the Kobayashi-Maskawa (KM) quark-mixing matrix conveniently parametrized by Maiani-Wolfenstein (MW), the first one, the Cabibbo angle θ , is accurately determined. The second one γ which is identified as the beauty-charm coupling V_{bc} is also well established. Remaining poorly known are the third angle β (closely related to the beauty-up coupling V_{bu}) and the CP violation phase ϕ which were the subject of recent extensive theoretical studies^[1] done in the light of the new experimental results on $B^0_d \bar{B}^0_d$ mixing^[2], ϵ'/ϵ of K^0 meson^[3] and B decays into $p\bar{p} n\pi$ ^[4].

Within the standard model, these measurements provide constraints on the top quark mass in conjunction with the KM angle β and the phase ϕ . However these constraints are not very stringent mostly because of uncertainties in the non perturbative computations of some hadronic matrix elements such as B_K , B_B , f_B , etc. The purpose of this note is to point out that in addition to the data on ϵ'/ϵ and $B^0_d \bar{B}^0_d$ mixing, measurements of charmless B meson decays into strange and non-strange hadrons could provide further information on β and ϕ , quasi independently on the top quark mass. The rare decay processes are in principle sensitive to new physics and consequently the standard model is more vulnerable than before to future experiments.

Let us start by writing the KM matrix following the MW parametrization which is convenient for phenomenological analysis

$$V_{KM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1 - \frac{\lambda^2}{2} & \lambda & A\lambda^3 \rho e^{i\phi} \\ -\lambda & 1 - \frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^2(1 - \rho e^{i\phi}) & -A\lambda^2 & 1 \end{pmatrix}$$

Here $\lambda = \cos \theta = 0.221 \pm 0.002$ and $A = 1.05 \pm 0.17$. This value is fixed by the lifetime of the B meson together with its semileptonic decays. The (not yet) well determined parameters are ρ and ϕ which we discuss.

Prior to the Argus results^[4] that give $\text{Br}(B^0 \rightarrow p\bar{p} \pi^+ \pi^-) = (6. \pm 2. \pm 2.2) 10^{-4}$, $\text{Br}(B^\pm \rightarrow p\bar{p} \pi^\pm) = (3.7 \pm 1.3 \pm 1.4) 10^{-4}$, only the upper limit of $|V_{bu}|$ was known from the electron spectrum of the semileptonic B decay. It corresponds to $0 \leq \rho < 0.9$. These Argus results might be presented as the first evidence for ρ strictly non zero, since a

natural explanation is the inclusive decay $b \rightarrow u d \bar{u}$ of Fig. 1 (its rate is proportional to p^2) among which the exclusive channels $p\bar{p} n\pi$ ($n = 1, 2$) represent some fraction. To translate the Argus results in terms

$$\text{of } p, \text{ a knowledge of the fraction } R = \frac{\Gamma(B \rightarrow p\bar{p} n\pi)}{\Gamma(B \rightarrow C=S=0)} = \frac{\Gamma(B \rightarrow p\bar{p} n\pi)}{\Gamma(b \rightarrow u d \bar{u})}$$

must be assumed and early estimates [5] suggest a few per cent.

However as pointed out recently [6], the extraction of the lower bound of p using only the $p\bar{p} n\pi$ modes must be done with caution since whatever p is (in particular even $p = 0$), the Penguin mechanism of Fig. 2 simulating $b \rightarrow d u \bar{u}$ and $b \rightarrow d d \bar{d}$ constitutes inevitably a source of background. The Penguin contribution to the inclusive branching ratio $\text{Br}(b \rightarrow d u \bar{u} + d d \bar{d})$ was estimated to be $(1.5 - 2)10^{-3}$, which is large enough to cover the observed exclusive channels $p\bar{p} n\pi$. Therefore both diagrams 1 and 2 must be considered on the same footing in the computation of the $b \rightarrow d q \bar{q}$ rate (q stands for u and d quarks).

Enlarging the analyses with the strange quark, i.e. considering both $b \rightarrow d q \bar{q}$ and $b \rightarrow s q \bar{q}$, we find out that due to the interplay between the two diagrams (to be specific, their relative strengths and their

$$\text{interferences), the ratio } \frac{\text{Br}(B \rightarrow S=1, C=0)}{\text{Br}(B \rightarrow S=0, C=0)} \equiv \frac{\Gamma(b \rightarrow s)}{\Gamma(b \rightarrow d)} \text{ happens}$$

to be sensitive to the KM parameters p and φ , which in turn could be exploited to obtain information on them.

Indeed, the amplitude $b \rightarrow u d \bar{u}$ of Fig. 1 is given by

$$\frac{G_F}{\sqrt{2}} V_{ub} V_{ud} \left\{ \frac{C_+ + C_-}{2} (\bar{u}b)_L (\bar{d}u)_L + \frac{C_+ - C_-}{2} (\bar{u}u)_L (\bar{d}b)_L \right\} \quad (1)$$

with the short hand notation $(\bar{u}b)_L = \bar{u} \gamma_\mu (1 - \gamma_5) b$ and C_+ , C_- are the QCD corrected coefficients which are reduced to one when these corrections are neglected. Numerically $C_+ \approx 0.8$, $C_- \approx 1.5$

On the other hand, the effective loop amplitude $b \rightarrow d q \bar{q}$ of Fig. 2 can be written as [6]:

$$\frac{\alpha_s}{\pi} \frac{G_F}{\sqrt{2}} V_{cb} V_{cd} \left\{ (\bar{d} T^a \Gamma_\mu b) (\bar{q} T^a \gamma_\mu q) \right\} \quad (2)$$

$$\text{where } \Gamma_\mu = \frac{1}{2} F_1(q^2) \gamma_\mu (1 - \gamma_5) - \frac{i F_2(q^2) M \sigma_{\mu\nu} q^\nu}{2 q^2} (1 + \gamma_5)$$

$$\text{and } F_{1,2}(q^2) = f_{1,2}(x_c, q^2) - f_{1,2}(x_t, q^2) - p e^{i\varphi} [f_{1,2}(x_u, q^2) - f_{1,2}(x_t, q^2)] \quad (3)$$

$x_j = m_j^2 / M_w^2$ and q^2 is the squared momentum of the virtual gluon.

The expressions for $f_{1,2}(x, q^2 = 0)$ have been calculated by Inami and Lim [7].

$$f_1(x, 0) = \frac{x}{12} \left[\frac{1}{x-1} + \frac{13}{(x-1)^2} - \frac{6}{(x-1)^3} \right] + \left\{ \frac{4}{x-1} - x \left[\frac{4}{(x-1)^2} + \frac{5}{(x-1)^3} - \frac{3}{(x-1)^4} \right] \right\} \frac{\ell_n x}{6}$$

$$f_2(x, 0) = \frac{x}{4} \left[\frac{1}{x-1} - \frac{3}{(x-1)^2} - \frac{6}{(x-1)^3} \right] + \frac{3x^2 \ell_n x}{2(x-1)^4}$$

The q^2 dependence of $f_{1,2}$ has complicated expressions and an approximation has been previously used [6]

We remark that the amplitude $b \rightarrow d u \bar{u}$ from the Penguin diagram Fig. 2 can interfere with the one $b \rightarrow u d \bar{u}$ of the tree graph Fig. 1, once an appropriate Fierz type transformation into color states has been done.

Now, when the down quark is replaced by the strange quark in both diagram 1 and diagram 2, the couplings V_{ud} and V_{cd} of Eqs. (1) and (2) are respectively substituted by V_{us} and V_{cs} while the last term ($-p e^{i\varphi}$) of Eq. (3) is replaced by $(+\lambda^2 p e^{i\varphi})$. The amplitude for $b \rightarrow s$ can then be written like $P_s + (\lambda^2 p e^{i\varphi}) L_s$ while the one for $b \rightarrow d$ has the form $-\lambda P_d + (\lambda p e^{i\varphi}) L_d$ where L and P correspond respectively to the graphs 1 and 2. In fact L_s and L_d are nearly equal in magnitude and the same thing holds for P_s and P_d . We recognize that when only the tree graph

contributes ($P = 0$), the ratio $\frac{\Gamma(\ell \rightarrow s)}{\Gamma(\ell \rightarrow d)} = \lambda^2$ while if only the Penguin graph intervenes ($L = 0$), the ratio becomes $\frac{1}{\lambda^2}$ as previously noted [6].

We have $\lambda^2 \leq \frac{\Gamma(\ell \rightarrow s)}{\Gamma(\ell \rightarrow d)} \leq \frac{1}{\lambda^2}$. Also, we remark that the interferences (between L and P amplitudes) in $\Gamma(b \rightarrow s)$ and $\Gamma(b \rightarrow d)$ have opposite sign.

All these features make the ratio $\frac{\Gamma(\ell \rightarrow s)}{\Gamma(\ell \rightarrow d)}$ sensitive to the parameters

p and φ .

A technical discussion is now in order. The m_U^2 dependence in the logarithms of $f_1(x_U)$ reflecting the GIM cancellation should be replaced, as usual, by μ^2 i.e. the scale appropriate to the processes considered here. We will put $\mu^2 = m_C^2$. Also the dominant term of $\frac{\alpha_s}{\pi} [f_1(x_C, q^2) - f_1(x_t, q^2)]$ in Eq. 3 which is $\frac{2\alpha_s}{3\pi} \ln \frac{m_t^2}{m_c^2}$ can be large so that the whole series of leading logarithms must be resummed by the standard procedure. Following Ref. [8] we replace $\frac{\alpha_s}{8\pi} [f_1(x_C, q^2) - f_1(x_t, q^2)] = \frac{\alpha_s}{12\pi} \ln \frac{m_t^2}{m_c^2} + \text{smaller terms}$ by $C_T = 0.085 \pm 0.035$ corresponding to the resummation. Then we get :

$$\frac{\Gamma(\ell \rightarrow s)}{\Gamma(\ell \rightarrow d)} = \frac{\lambda^2 N}{D}$$

with $N = p^2 + 2dp \cos \varphi + \frac{9}{2} d^2$

$$D = p^2[(1 + \lambda^2 d)^2 + \frac{23}{4} (\lambda^2 d)^2] - 2 d p \cos \varphi \lambda^2 (1 + \lambda^2 d) + \frac{27}{4} (\lambda^2 d)^2$$

$$\text{and } d = \frac{\alpha_s}{9\pi\lambda^2} [f_1(x_C, q^2) - f_1(x_t, q^2)] \rightarrow \frac{8}{9} \frac{C_T}{\lambda^2}$$

Some numerical values of the ratio $\frac{\Gamma(\ell \rightarrow s)}{\Gamma(\ell \rightarrow d)}$ as function of p and φ are given in Table 1 (within a large range of d).

Taking the preliminary experiment [4] $\frac{Br(B \rightarrow \Lambda \bar{p} \pi^+(\pi))}{Br(B \rightarrow p \bar{p} \pi^+(\pi))} < 0.5$ as a

firm result and assuming that the ratio of these exclusive modes is the same as the inclusive ratio $\frac{\Gamma(\ell \rightarrow s)}{\Gamma(\ell \rightarrow d)}$, we are tempted to anticipate

that p and φ cannot be small : p nearly 0.6 and φ in the second quadrant ($\frac{2\pi}{3} < \varphi < \pi$) are preferred. If it is correct, then the pure leptonic mode $B^\pm \rightarrow \tau^\pm \nu$ could be soon observed, its branching ratio, as given by

$$Br(B \rightarrow \tau \nu) = \lambda^2 p^2 24\pi^2 \left(\frac{f_B}{M}\right)^2 \left(\frac{m_\tau}{M}\right)^2 \left(\frac{0.78}{0.48}\right) Br(B \rightarrow e \nu \dots), \text{ is around } 10^{-4} \text{ (the last coefficient } \frac{0.78}{0.48} \text{ representing phase space factor).}$$

Acknowledgements :

We would like to thank Prof. A. Martin and Prof. G. Altarelli for fruitful discussions. One of us (L.L.) would like to thank the Theory Division of CERN for its hospitality and to acknowledge support in part by grant n° CPBP 01-03 of the Polish Ministry of National Education.

Table 1

ρ d		0.3	0.6	0.9
0.9	$\varphi = 0$	2.68	0.69	0.35
	$\varphi = \frac{2\pi}{3}$	1.39	0.40	0.16
	$\varphi = \pi$	1.16	0.32	0.10
1.5	$\varphi = 0$	6.61	1.65	0.75
	$\varphi = \frac{2\pi}{3}$	3.53	0.92	0.41
	$\varphi = \pi$	3.03	0.76	0.33
2.2	$\varphi = 0$	13.5	2.61	1.59
	$\varphi = \frac{2\pi}{3}$	4.6	1.67	0.80
	$\varphi = \pi$	4.	1.41	0.67

The ratio $\frac{\Gamma(b \rightarrow s)}{\Gamma(b \rightarrow d)}$ as a function of the KM matrix elements ρ

and φ for different values of the parameter d characterizing the Penguin strength.

References :

- [1] J. Ellis, J.S. Hagelin, S. Rudaz - Phys. Lett. 192 B (1987) 201
 G. Altarelli and P. Franzini - CERN preprint TH 4745/87 (1987).
 S. Bertolini, F. Borzumati and A. Masiero - Phys. Lett. 194 B (1987) 545.
 I. Bigi and A. Sanda - Phys. Lett. 194 B (1987) 307.
 H. Harari and Y. Nir - Phys. Lett. 195 B (1987) 586.
 J. Maalampi and M. Roos - Phys. Lett. 195 B (1987) 489.
 V. Barger, T. Han, D. Nanopoulos and R.J.N. Phillips - Phys. Lett. 194 B (1987) 312.
 J.R. Cudell, F. Halzen, X.G. He and S. Pakvasa - Phys. Lett. 196 B (1987) 227.
- [2] H. Albrecht et al. - Phys. Lett. 192 B (1987) 245.
 C. Albajar et al. - Phys. Lett. 186 B (1987) 247.
- [3] I. Mannelli, Proceedings of the 1987 Int. Symp. on Lepton and Photon Interactions at High Energies, Hamburg (1987).
- [4] W. Schmidt - Parzefall - ibidem.
- [5] M. Gronau, SLAC Pub 4407 (1987).
 N. Paver and Riazuddin - Phys. Lett. 201 B (1988) 279
- [6] L. Łukaszuk, X.Y. Pham and C. Vu Xuan - Paris preprint 87-55 (Phys. Lett. B to be published)
- [7] T. Inami and C.S. Lim - Prog. Theo. Phys. 65 (1981) 207 and 1772 (E).
- [8] G. Altarelli and P. Franzini - CERN preprint TH 4914/87 (December 1987).

Figure 1

Figure 2