TWO BODY NON LEPTONIC DECAYS OF $B$ AND $B_s$ MESONS

A. Deandrea, N. Di Bartolomeo and R. Gatto
Département de Physique Théorique, Univ. de Genève

G. Nardulli
Dipartimento di Fisica, Univ. di Bari
I.N.F.N., Sezione di Bari

UGVA-DPT 1993/07-824
hep-ph/9308210
BARI-TH/155
July 1993

* Partially supported by the Swiss National Science Foundation
We perform an analysis of two-body non leptonic decays of $B$ and $B_s$ mesons in the factorization approximation. We make use of the semileptonic decay amplitudes previously calculated on the basis of an effective lagrangian satisfying chiral and heavy quark symmetries and including spin 1 resonances. Exclusive semileptonic $D$-decay data are used as experimental input. Our results compare favorably with data, whenever they are available and indicate a positive value for the ratio of non leptonic coefficients $a_2/a_1$, similarly to previous studies.
Chiral and heavy quark symmetries \[1, 2\] have been used to construct an effective lagrangian for light and heavy mesons including their effective weak interactions \[3\]. This approach has been extended \[4\] to include the nonet of $1^{-}$ vector meson resonances, coupled through the so-called hidden gauge symmetry, so that one is able to describe the interactions among heavy $Qq_{a}$ mesons ($Q$ heavy quark, $a = 1, 2, 3$ for $u, d, s$), the pseudoscalar and the light vector meson resonances. In reference \[5\], we performed an extensive analysis of heavy meson semileptonic decays into final states containing light mesons. The main result of the analysis was that, using experimental information on $D \to \pi l\nu_{l}$, $D \to K l\nu_{l}$ and $D \to K^{*} l\nu_{l}$ as inputs, together with the hypothesis of a simple pole behaviour of the form factors in the whole region of $q^{2}$, one can make predictions on the form factors describing the semileptonic decays of the $B$ and $B_{s}$ mesons into light mesons.

In the present letter we wish to apply these results to the evaluation of two body nonleptonic decays \[6\] of $B$ and $B_{s}$ within the factorization approximation. Before going into the details of our work, let us discuss the meaning and the possible limits of the approximation.

1 Nonleptonic amplitudes

Let us first write down the weak nonleptonic hamiltonian we shall employ in our calculations. To be specific let us consider $\Delta B = 1$, $\Delta S = \Delta C = 0$ transitions (other relevant cases can be handled similarly). We take \[7\]

$$H_{NL} = \frac{G_{F}}{\sqrt{2}} \sum_{q=u,c} V_{qb} V_{qd}^{*} \left[ C_{1}(\mu)O_{1}^{q} + C_{2}(\mu)O_{2}^{q} \right]$$

(1.1)

where the four local operators $O_{1}^{u}, O_{2}^{u}, O_{1}^{c}$ and $O_{2}^{c}$ are

$$O_{1}^{u} = \bar{u}_{i} \gamma^{\mu}(1 - \gamma_{5})b^{j} \gamma_{\mu}(1 - \gamma_{5})u^{i} \quad \text{(1.2)}$$
$$O_{2}^{u} = \bar{u}_{i} \gamma^{\mu}(1 - \gamma_{5})b^{j} \gamma_{\mu}(1 - \gamma_{5})u^{i} \quad \text{(1.3)}$$

and $O_{1}^{c}$ and $O_{2}^{c}$ are obtained by the change $u \to c$. In \[1\] and \[2\] $i$ and $j$ are colour indices, whereas in \[1\] $C_{1}(\mu)$ and $C_{2}(\mu)$ are QCD coefficients computed at the scale $\mu \approx m_{b}$. We have neglected, in writing eq. \[1\], the contribution of the QCD penguin operators $O_{3}, \ldots O_{6}$ since their Wilson coefficients $C_{3}, \ldots C_{6}$ are numerically very small as compared to $C_{1}$ and $C_{2}$ \[8\]; while these operators could be relevant in some processes where the current-current operators $O_{1}$ and $O_{2}$ are not active or strongly Cabibbo suppressed, in the applications we shall consider here their contribution would never exceed 10% of the result making their neglect reasonable.

The values of the coefficients $C_{1}$ and $C_{2}$ have been computed in \[8\] beyond the leading-log approximation; for $m_{b} = 4.8$ GeV, $m_{t} = 150$ GeV and $\Lambda_{S} = 250$ MeV one finds $C_{1} = 1.133$ and $C_{2} = -0.291$.

In order to discuss the factorization approximation let us be specific and consider, e.g., the decay $\bar{B}^{0} \to \pi^{+}\pi^{-}$. To compute $< \pi^{+}\pi^{-} | H_{NL} | \bar{B}^{0} >$ we have to consider the two hadronic matrix elements $< \pi^{+}\pi^{-} | O_{1} | \bar{B}^{0} >$ and $< \pi^{+}\pi^{-} | O_{2} | \bar{B}^{0} >$. As for the first one, the factorization procedure amounts to write $(\Gamma_{\mu} = \gamma_{\mu}(1 - \gamma_{5}))$:

$$< \pi^{+}\pi^{-} | O_{1} | \bar{B}^{0} > = < \pi^{+} | \bar{u}_{i} \Gamma_{\mu} b | \bar{B}^{0} > < \pi^{-} | d\Gamma^{\mu} u | 0 > \quad \text{(1.4)}$$
This approximation can be given some theoretical justification on the basis of $1/N_c$ expansion\cite{footnote1} or color transparency \cite{footnote2}. Moreover, from a phenomenological point of view there are indications that in the realm of B physics, factorization roughly works satisfactorily\cite{footnote3}. As to the second operator, we can write

$$<\pi^+\pi^-|O_2|B^0>=<\pi^+\pi^-|\frac{1}{N_c}O_1+\tilde{O}_2|B^0>$$

with

$$\tilde{O}_2 = \bar{u}\Gamma^\mu T^a b\bar{d}\Gamma^\mu T^a u$$

In \cite{footnote1} $T^a$ ($a = 1,\ldots,8$) are colour matrices, normalized according to $TrT^aT^b = \frac{1}{2}\delta^{ab}$ and the sum over repeated indices is understood. In the naive factorization, inserting the vacuum, one finds that the $\tilde{O}_2$ operator, which contains coloured currents, does not contribute and therefore the contribution of $H_{NL}$ to the amplitude will be given only by the $O_1$ operator with a multiplicative coefficient $a_1 = C_1 + \frac{1}{N_c}C_2$. However, as discussed in \cite{footnote12} and \cite{footnote13}, the rule of discarding the operators with coloured currents while applying the vacuum saturation is ambiguous and unjustified. This is already one reason, among many others, to make the choice \cite{footnote14} $a_1$ and the analogous parameter $a_2$, multiplying $O_2$ in the naive factorization approximation, $a_2 = C_2 + C_1/N_c$, as free parameters. This will be our attitude in this letter as well.

Let us recall that the analysis of $D$ non leptonic decays leads to the empirical finding $a_1 \approx C_1, a_2 \approx C_2$ \cite{footnote12}. There has been some recent theoretical effort to understand the empirical rule of “discarding the $1/N_c$ term ”, which has shown that, at least in some channels (e.g. $B^0 \rightarrow D^+\pi^-$) and within a certain kinematical approximation (i.e. $M_B, M_D \rightarrow \infty$ while their difference is kept fixed) there is a tendency to cancellation between the two terms appearing in 1.5 \cite{footnote15}. Since these analyses are far from having reached a definite conclusion, we are justified in our choice, especially because from our analysis, as we shall discuss below, a positive value of $a_2$ appears favourite, a result that seems general \cite{footnote16} and would indicate that the positive $1/N_c$ term cannot be neglected.

In such a type of calculation one has to be aware of the many uncertainties and incompleteness heavily bearing down at practically all the levels of the procedure. Such uncertainties and incompleteness are unfortunately in a way or in another common to all calculations of such complex phenomenon as non leptonic decays, and like everybody else we cannot avoid them.

The standard approach to non leptonic decays consists, as we have already described, in incorporating short distance effects into an effective hamiltonian constructed through operator product expansion and use of renormalization group, while leaving long distance QCD effects within the hadronic matrix elements. Already the construction of the effective hamiltonian contains uncertainties, particularly in cases where many different scales are present, such as for transitions from $b$ to $c$. One has to add to this the general impossibility of obtaining a scale independent result when the matrix elements of the scale-dependent effective hamiltonian are taken within some hadronic model with usually unrelated scale dependence. One can only hope that, within a class of processes, one may choose a suitable scale at which this procedure approximately applies.

The idea behind the factorization approximation is that hadronization appears only after the amplitude takes the form of a product of matrix elements of quark currents which are singlets in color, thus allowing for approximate deductions from semileptonic processes.
Different kinematical situations may suggest that factorization may apply better to some non-leptonic processes rather than to others. For instance one intuitively expects that it may work better when a color singlet current directly produces an energetic meson easily escaping interaction with the other quarks. Independent of this, various other effects such as more or less strong role of long-distance contributions, including final state interactions effects, of small annihilation terms, more or less sensitivity to choice of the scale, etc., may suggest that the uniform simultaneous application of the factorization approximation to different processes must be subject to detailed qualifications and may at the end turn out to be incorrect. Unfortunately at the present stage of the subject one is forced to first collect informations by comparing an admittedly very rough procedure to the data available.

We also note that the effective lagrangian approach can be used to write down the non-leptonic hamiltonian in terms of the heavy and light meson fields \[16\], however in this way one can make prediction only for a small region of the phase space where the light mesons are soft.

According to what already said, in the factorization approximation, two body non-leptonic decays of \(B\) and \(B_s\) mesons are obtained by the semileptonic matrix elements of the weak currents between different mesons. A suitable form is

\[
<P (p') | V^\mu | B(p) > = [(p + p')^\mu + \frac{M_P^2 - M_B^2}{q^2}q^\mu]F_1(q^2) - \frac{M_P^2 - M_B^2}{q^2}q^\mu F_0(q^2) \tag{1.7}
\]

\[
<V (\epsilon, p') | (V^\mu - A^\mu) | B(p) > = \frac{2V(q^2)}{M_B + M_V} \epsilon^{\mu\nu\alpha\beta} \epsilon_{\nu} p^\alpha p_{\beta} + i(M_B + M_V) \left[ \epsilon_{\mu} - \frac{\epsilon^{\mu} \cdot q}{q^2} q_{\mu} \right] A_1(q^2) - i\frac{\epsilon^* \cdot q}{(M_B + M_V)} \left[ (p + p')_{\mu} - \frac{M_B^2 - M_V^2}{q^2} q_{\mu} \right] A_2(q^2) + i\epsilon^* \cdot \frac{2M_V}{q^2} q_{\mu} A_0(q^2) \tag{1.8}
\]

where \(P\) is a light pseudoscalar meson and \(V\) a light vector meson, \(q = p - p'\),

\[
A_0(0) = \frac{M_V - M_B}{2M_V} A_2(0) + \frac{M_V + M_B}{2M_V} A_1(0) \tag{1.9}
\]

and \(F_1(0) = F_0(0)\).

For the \(q^2\) dependence of all the form factors we have assumed a simple pole formula \(F(q^2) = F(0)/(1 - q^2/M_P^2)\) with the pole mass \(M_P\) given by the lowest lying meson with the appropriate quantum numbers (\(J^P = 0^+\) for \(F_0\), 1\(-\) for \(F_1\) and \(V\), 1\(+\) for \(A_1\) and \(A_2\), 0\(-\) for \(A_0\)).

The values of the form factors at \(q^2 = 0\), as given by the study of the semileptonic decays as performed in [5], are reported in Table I. The errors in the Table follow from the experimental semileptonic exclusive \(D\) decays, that we used as inputs. In Table II we report the values of the pole masses we employ. Let us explicitly stress that the values reported in Table I were obtained in the leading order of the \(1/M_Q\) expansion of the heavy chiral current. In [5] we reported also the results of a fit obtained introducing
mass corrections to the leptonic decay constant ratio $f_B/f_D = \sqrt{M_D/M_B}$ (modulo logs) predicted by the heavy quark effective theory. However, as discussed below (see also [18]), a few non leptonic $B$ decays seem to disagree with this latter solution and therefore we choose to work everywhere at the leading order in $1/M_Q$ expansion.

As for the current matrix elements between a pseudoscalar meson $P$ or vector meson $V$ we take:

$$<0|A^\mu|P(p)> = i f_P p^\mu$$
$$<0|V^\mu|V(p,\epsilon)> = f_V M_V \epsilon^\mu$$ (1.10)

In Table III we present the values of $f_P$ and $f_V$ used in computing the rates. We observe that recent CLEO data on the decay $D_s \to \mu \nu$ point to a rather large value of $f_{D_s}$: $f_{D_s} = 315 \pm 46$ MeV [17]. On the other hand all theoretical approaches indicate for $f_D$ and $f_{D_s}$ smaller values; for example QCD sum rules [19] give $f_D = 223 \pm 27$ MeV and $f_{D_s} = 277 \pm 13$ MeV; a recent QCD sum rules analysis for the ratio $f_{D_s}/f_D$ gives the value $\approx 1.1$ [20] and similar results are obtained from Lattice QCD or potential models (for a review see [21]). In view of these results we have assumed for $f_D$ and $f_{D_s}$ the values reported in Table III that are compatible with both CLEO data and theoretical expectations.

## 2 Numerical results

Let us begin our numerical analysis by discussing a class of decays that depend only on the parameter $a_2$. Recent data from CLEO Collaboration [17] allow for a determination of this parameter. From $BR(B \to K J/\psi) = (0.10 \pm 0.016) \times 10^{-2}$, $BR(B \to K^* J/\psi) = (0.19 \pm 0.036) \times 10^{-2}$ and $BR(B \to K \psi(2s)) = (0.10 \pm 0.036) \times 10^{-2}$ we obtain

$$|a_2| \simeq 0.27$$ (2.1)

Using this value we can compute the results of Table IVa that contain two body non leptonic $B^0$ decays depending only on $a_2$ and on current matrix elements between $B$ and light mesons. We have used the recent determination for $V_{ub}$ arising from the CLEO analysis of the end-point of lepton spectrum in semileptonic inclusive $B$ decays [22]: $V_{ub}/V_{cb} = 0.075$. We take $V_{cb} = 0.040$.

Let us now study the coefficient $a_1$. The best way to determine it is to consider $B^0$ decays into $D^{*+} \pi^-$, $D^{*+} \rho^-$, $D^{+} \pi^-$, $D^{+} \rho^-$ final states. In order to use the experimental data we need an input for current matrix elements between $B$ and $D, D^*$ states.

In [4] we did not consider $B \to D$ and $B \to D^*$ transitions in the heavy quark effective theory; this subject has been recently actively investigated by several authors and we rely on their work to compute the corresponding non leptonic decay rates. The relevant matrix elements at leading order in $1/M_Q$ are [2]

$$<D(v')|V^\mu(0)|B(v)> = \sqrt{M_B M_D} \xi(w)[v + v']^\mu$$ (2.2)

$$<D^*(v, v')|(V^\mu - A^\mu)|B(v)> =$$

$$\sqrt{M_B M_D} \xi(w) \left[-\epsilon^\mu \epsilon^\nu \epsilon^\rho \epsilon^\tau v_\nu v_\tau' + i(1 + v \cdot v')\epsilon'^\mu - i(\epsilon^* \cdot v)v'^\mu \right]$$ (2.3)
where \( w = v \cdot v' = (M_B^2 + M_D^2 - q^2)/2M_BM_D \), \( v \) and \( v' \) are the meson velocities, and \( \xi(w) \) is the Isgur-Wise form factor. \( \xi(w) \) has been computed by QCD sum rules [23], potential models, and estimated phenomenologically [14]. We shall take for it the expression [24]

\[
\xi(w) = \left( \frac{2}{1 + w} \right) \exp \left[ - (2\rho^2 - 1) \frac{w - 1}{w + 1} \right] \tag{2.4}
\]

which reproduces rather well the semileptonic data [24] with \( \rho \simeq 1.19, V_{cb} = 0.04, \tau_B = 1.4ps \). We stress once again that we have chosen to work at the leading order in \( 1/M_Q \), which is why we have not introduced the non leading form factors discussed e.g. in [27].

From the new CLEO data [14] \( BR(\bar{B}^0 \to D^+\pi^-) = (2.2 \pm 0.5) \times 10^{-3}, BR(\bar{B}^0 \to D^{\ast+}\pi^-) = (2.7 \pm 0.6) \times 10^{-3}, BR(B^0 \to D^+\rho^-) = (6.2 \pm 1.4) \times 10^{-3} \) and \( BR(B^0 \to D^{\ast+}\rho^-) = (7.4 \pm 1.8) \times 10^{-3} \) one gets

\[ |a_1| \simeq 1.0 \tag{2.5} \]

For completeness we have reported in Table IVb the results for non leptonic decays depending only on \( a_1 \) and on the Isgur-Wise form factor \( \xi(w) \).

In Table IVc we use the fitted value of \( a_1 \) together with the weak matrix elements computed in our model to compute additional two body decays depending on \( a_1 \). We observe explicitly that the recent CLEO result [24] \( BR(B^0 \to \pi^+\pi^-) = (1.3^{+0.8}_{-0.6} \pm 0.2) \times 10^{-5} \) is in agreement with our outcome. We stress that this agreement depends on our choice of the "scaling" solution for the semileptonic matrix elements, according to our previous discussion. The other solution discussed in ref. [5] appears to be excluded by the present data for this decay channel.

In Table V we consider \( B^- \) decays. Let us observe that they depend on the relative sign between \( a_1 \) and \( a_2 \) which has not been fixed yet. The new CLEO data [17] \( BR(B^- \to D^0\pi^-) = (4.7 \pm 0.6) \times 10^{-3}, BR(B^- \to D^{\ast0}\pi^-) = (5.0 \pm 1.0) \times 10^{-3}, BR(B^- \to D^0\rho^-) = (10.7 \pm 1.9) \times 10^{-3} \) and \( BR(B^- \to D^{\ast0}\rho^-) = (14.1 \pm 3.7) \times 10^{-3} \), allow to conclude that the ratio \( a_2/a_1 \) is positive. Clearly this result depends on the relative phase of the hadronic matrix elements. Our choice is the “natural” one, i.e. we assume (analogously to [14]) that for a decay \( B \to M_1M_2 \) (\( M_1 \) and \( M_2 \) scalar or vector mesons) the phase is the one determined under the assumption of spin and flavour symmetry in the meson spectrum. Of course these symmetries are (even badly) broken in many decays; one should therefore be aware of the possibility to have a different phase between the two terms in such cases.

Our results for \( B^- \) decays are reported in Table V, while in Table VI we compute analogous results for the \( B_s \) non leptonic decay channels. In doing the calculations we have neglected the mixing \( \eta-\eta' \), and we have assumed ideal mixing between \( \omega \) and \( \phi \). Moreover we have not taken into account final state interactions, whose effect we cannot evaluate at the moment (in \( D \) decays, as shown in [12], their effect was in some cases rather significant), and all effects of mixing and CP violation.

We also note that our reported theoretical errors in Tables IV, V and VI only reflect the uncertainties in the weak couplings reported in Table I. Since the form factor \( A_0 \) at \( q^2 = 0 \) has an uncertainty of about 100% (see Table I), the \( BR \)'s containing this coupling have a large error, as one can see in some entries of the Tables IV-VI and should therefore be taken with care.
Let us finally comment on the decays with two charmed mesons in the final state (see Tables IVb, Va and VIb). Our results are in agreement with data from both CLEO and ARGUS collaboration\cite{30,17}. According to the discussion of ref. \cite{31}, however, the correct value of the $a_1$ coefficient to be used in connection with the factorization hypothesis and the Heavy Quark Effective Theory is $|a_1| \simeq 1.45$. Indeed, as discussed in \cite{31}, since the light quarks do not carry large momenta in these decays, the running strong coupling constant should be computed at a scale lower than $m_c$, which results in a value for the $|a_1|$ coefficient significantly larger than the one used in Tables IV-VI. Using experimental data on decays into $D^{(*)}D^{(*)}$\cite{30,17}, for example ($BR(\bar{B}^0 \rightarrow D^+D^-) = (0.6 \pm 0.45) \times 10^{-2}$) one can see that the above mentioned large value of $|a_1|$ is incompatible with the data. It would be interesting to analyze if such disagreement reflects a breakdown of the factorization approximation or the presence of non leading effects in $1/m_Q$ approximation.

In conclusion, we have performed, in the factorization approximation, an analysis of two body non leptonic decays of the $B$ and $B_s$ mesons; our study has been based on semileptonic amplitudes obtained by an effective lagrangian having chiral and heavy quark symmetries and has employed semileptonic exclusive $D$ decays as an input. Our results are in agreement with the experimental data, whenever they are available, and indicate, similarly to other analyses, a positive value for the ratio of the non leptonic coefficients $a_2/a_1$. Our results represent, in our opinion, a preliminary indication that $B$ semileptonic decays to light mesons can be related to the analogous $D$ decays without major violations of the heavy quark flavour symmetry.

Acknowledgement: We would like to thank Professor S. Stone for discussions on the CLEO results. We would like to thank R. Casalbuoni, P. Colangelo and F. Feruglio for frequent discussions and exchanges during the course of this work.
References

[1] N. Isgur and M.B. Wise, Phys. Lett. B232 (1989) 113; ibidem B237 (1990) 527; M.B. Voloshin and M.A. Shifman, Sov. J. Nucl. Phys. 45 (1987) 292; ibidem 47 (1988) 511; H.D. Politzer and M.B. Wise, Phys. Lett. B206 (1988) 681; ibidem B208 (1988) 504; E. Eichten and B. Hill, Phys. Lett. 234B (1990) 511; H. Georgi, Phys. Lett. B240 (1990) 447; B. Grinstein, Nucl. Phys. B339 (1990) 253; A.F. Falk, H. Georgi, B. Grinstein and M.B. Wise, Nucl. Phys. B343 (1990) 1.

[2] for a clearly written introduction to heavy quark symmetry see H. Georgi, lectures at 1991 TASI, Boulder (World Scientific) to be published.

[3] M.B. Wise, Phys. Rev. D45 (1992) R2188; T. M. Yan, H.-Y. Cheng, C.-Y. Cheung, G.-L. Lin, Y.C. Lin and H.-L. Yu, Phys. Rev. D46 (1992) 1148; G. Burdman and J. F. Donoghue, Phys. Lett. B280 (1992) 287; P. Cho, Phys. Lett. B285 (1992) 145.

[4] R. Casalbuoni, A. Deandrea, N. Di Bartolomeo, F. Feruglio, R. Gatto and G. Nardulli, Phys. Lett. B292 (1992) 371.

[5] R. Casalbuoni, A. Deandrea, N. Di Bartolomeo, F. Feruglio, R. Gatto, and G. Nardulli, Phys. Lett. B299 (1993) 139.

[6] I. I. Bigi, in B decays, S. Stone ed. (Singapore 1992) p.102.

[7] M.K. Gaillard and B.W. Lee, Phys. Rev. Lett. 33 (1974) 108; G. Altarelli and L. Maiani, Phys. Lett. B52 (1974) 351; F.J. Gilman and M.B. Wise, Phys. Rev. D20 (1979) 2392.

[8] A. J. Buras, M. Jamin, M. E. Lautenbacher and P. H. Weisz, Nucl. Phys. B370 (1992) 69.

[9] A. J. Buras, J. M. Gerard and R. Rueckl, Nucl. Phys. B268 (1986) 16.

[10] J. D. Bjorken, Nucl. Phys. B (Proc. Suppl.) 11 (1989) 325.

[11] D. Bortoletto and S. Stone, Phys. Rev. Lett. 65 (1990) 2951.

[12] M. Bauer, B. Stech and M. Wirbel, Z. Phys. C34 (1987) 103.

[13] N. Desphande, M. Gronau and D. Sutherland, Phys. Lett. B90 (1980) 431.

[14] M. Neubert, V. Rieckert, B. Stech and Q. P. Xu, in Heavy Flavours, A. J. Buras and M. Lindner eds. (Singapore 1992) p. 286.

[15] B. Blok and M. Shifman, Nucl. Phys. B389 (1993) 534.

[16] Q. P. Xu and A. N. Kamal, preprint Alberta THY-18-93.

[17] S. Stone, talk presented at the 5th Int. Symposium on Heavy Flavour Physics (Montreal, Canada, July 6-10, 1993).

[18] R. Casalbuoni, A. Deandrea, N. Di Bartolomeo, R. Gatto and G. Nardulli, to appear in Phys. Lett. B.

[19] C. A. Dominguez and N. Paver, Phys. Lett. B197 (1987) 423; (E) B199 (1987) 596.
[20] P. Blasi, P. Colangelo, G. Nardulli and N. Paver, University of Bari preprint (1993).

[21] G. Nardulli, Riv. Nuovo Cimento, 15, 10 (1992) 1.

[22] R. Poling, talk presented at the 5th Int. Symposium on Heavy Flavour Physics (Montreal, Canada, July 6-10, 1993).

[23] A. V. Radyushkin, Phys. Lett. B271 (1991) 218; P. Colangelo, G. Nardulli and N. Paver, Phys. Lett. B293 (1992) 207.

[24] M. Neubert, Phys. Rev. D45 (1992) 2451.

[25] M. Neubert, Phys. Lett. B264 (1991) 455.

[26] ARGUS Collab., H. Albrecht et al., Phys. Lett. B229 (1989) 175; CLEO Collab., D. Bortoletto et al., Phys. Rev. Lett. 63 (1989) 1667.

[27] M. Luke, Phys. Lett. B252 (1990) 447.

[28] M. Neubert, Phys. Rev. D46 (1992) 3914.

[29] P. Kim, talk presented at the 5th Int. Symposium on Heavy Flavour Physics (Montreal, Canada, July 6-10, 1993).

[30] Particle Data Group, Review of Particle Properties, Phys. Rev. D45 (1992) S1.

[31] B. Grinstein, W. Kilian, T. Mannel and M. B. Wise, Nucl. Phys. B363 (1991) 19.
Tables Captions

Table I  Form factors at zero momentum transfer for $B \rightarrow P$ and $B \rightarrow V$ semileptonic transitions (see ref.[5]). Indicated errors are from the experimental inputs. The form factors $A_1$ and $A_2$ are relatively well known, while $A_0$ has a relative error $\sim 100%$.

Table II  Pole masses for different states. Units are GeV.

Table III  Values of leptonic decay constants. For particles that can couple to different weak currents, the corresponding weak current is indicated within brackets. For $\phi$ and $\omega$ we assume ideal mixing, while $\eta$ is the pure octet component.

Table IV  Predicted widths and branching ratios for $\bar{B}^0$ decays. We use in the Tables $\tau_{\bar{B}^0} = \tau_{B_s} = \tau_{B^-} = 14 \times 10^{-13} s$, $V_{ub} = 0.003$, $V_{cb} = 0.04$. The quoted errors come only from the uncertainties of the form factors of Table I.

Table V  Predicted widths and branching ratios for $B^-$ decays.

Table VI  Predicted widths and branching ratios for $\bar{B}_s^0$ decays.
Table I

| Decay          | $F_1 = F_0$ | $V$ | $A_1$ | $A_2$ | $A_3 = A_0$ |
|----------------|-------------|-----|-------|-------|-------------|
| $B \rightarrow K$ | 0.49 ± 0.12 |     |       |       |             |
| $B \rightarrow \pi^\pm$ | 0.53 ± 0.12 |     |       |       |             |
| $B \rightarrow \eta$ | 0.49 ± 0.12 |     |       |       |             |
| $B_s \rightarrow \eta$ | 0.52 ± 0.12 |     |       |       |             |
| $B_s \rightarrow K$ | 0.52 ± 0.12 |     |       |       |             |
| $B \rightarrow \rho^\pm$ | 0.62 ± 0.12 | 0.21 ± 0.02 | 0.20 ± 0.08 | 0.24 ± 0.24 |
| $B \rightarrow \omega$ | 0.62 ± 0.12 | 0.21 ± 0.02 | 0.20 ± 0.08 | 0.24 ± 0.24 |
| $B \rightarrow K^*$ | 0.61 ± 0.12 | 0.20 ± 0.02 | 0.20 ± 0.08 | 0.20 ± 0.20 |
| $B_s \rightarrow K^*$ | 0.64 ± 0.12 | 0.20 ± 0.02 | 0.21 ± 0.08 | 0.17 ± 0.21 |
| $B_s \rightarrow \phi$ | 0.62 ± 0.12 | 0.19 ± 0.02 | 0.20 ± 0.08 | 0.17 ± 0.18 |

Table II

| State | $J^P$ | $0^-$ | $1^-$ | $0^+$ | $1^+$ |
|-------|-------|-------|-------|-------|-------|
| $dc$  | 1.87  | 2.01  | 2.47  | 2.42  |       |
| $sc$  | 1.97  | 2.11  | 2.60  | 2.53  |       |
| $\bar{u}b$ | 5.27 | 5.32  | 5.78  | 5.71  |       |
| $\bar{s}b$ | 5.38 | 5.43  | 5.89  | 5.82  |       |

Table III

| Particle | $f_P$ | Particle | $f_V$ |
|----------|-------|----------|-------|
| $\pi^\pm$ | 132   | $\rho^\pm$ | 221   |
| $K$       | 162   | $K^*$    | 221   |
| $D$       | 240   | $D^*$    | 240   |
| $D_s$     | 270   | $D_s^*$  | 270   |
| $\eta(u\bar{u}/d\bar{d})$ | 54 | $J/\psi$ | 409   |
| $\eta(s\bar{s})$ | -108 | $\phi$ | 221   |
| $\omega$  |       |          | 156   |