PENGUIN CONTRACTIONS AND FACTORIZATION IN $B \rightarrow K\pi$ DECAYS

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We study $\Lambda_{QCD}/m_B$ corrections to factorization in $B \rightarrow K\pi$ decays. First, we analyze these decay channels within factorization, showing that, irrespectively of the value of $\gamma$, it is not possible to reproduce the experimental data. Then, we discuss $\Lambda_{QCD}/m_B$ corrections to these processes, and argue that there is a class of doubly Cabibbo enhanced non-factorizable contributions, usually called charming penguins, that cannot be neglected. Including these corrections, we obtain an excellent agreement with experimental data. Furthermore, contrary to what is obtained with factorization, we predict sizable rate asymmetries in $B^\pm \rightarrow K^{\pm}\pi^0$ and $B \rightarrow K^\pm\pi^\mp$.

1 Introduction

The theoretical understanding of non-leptonic two body $B$ decays is a fundamental step for testing flavour physics and CP violation in the Standard Model and for detecting signals of new physics. The increasing accuracy of the experimental measurements at the $B$ factories calls for a significant improvement of the theoretical predictions. In this respect, important progress has been recently achieved by systematic studies of factorization made by two independent groups. These studies, while confirming the physical idea that factorization holds for hadrons containing heavy quarks, $m_Q \gg \Lambda_{QCD}$, give the explicit formulæ necessary to compute quantitatively the relevant amplitudes at the leading order in $\Lambda_{QCD}/m_Q$. At this Workshop, many talks and posters have discussed in detail the predictions for various nonleptonic $B$ decay channels using the formalism of ref. However, only perturbative corrections to factorization can be computed using these two approaches. The question which naturally arises is whether in practice the power-suppressed corrections, for which quantitative estimates are missing to date, may be phenomenologically important for $B$ decays. This problem was previously addressed in refs. In particular, the main conclusion of refs. was that penguin contractions of the leading operators of the effective weak Hamiltonian, $Q_1$ and $Q_2$, although formally of $O(\Lambda_{QCD}/m_Q)$, may be important in cases where the factorized amplitudes are either colour or Cabibbo suppressed. The most dramatic effect of these non-factorizable penguin contractions manifested itself in the very large enhancement of the $B \rightarrow K\pi$ branching ratios, as was also emerging from the first measurements by the CLEO Collaboration. In this case, the effect was caused by Cabibbo-enhanced penguin contractions of the operators $Q_1^c$ and $Q_2^c$, usually referred to as charming penguins. Since the original publications, about three years ago, several other decay channels have been measured and the precision of the measurements is constantly improving in time. With respect to the previous analyses, it is now possible to attempt a more quantitative study of charming penguin effects and of the corrections expected to the factorized predictions.

In this talk, we will focus on $B \rightarrow K\pi$ decays, where the effect of $O(\Lambda_{QCD}/m_Q)$ corrections to factorization is most striking. The interested reader can find a more general analysis, including also $B \rightarrow \pi\pi$ decays, in ref.

2 Formalism

The physical amplitudes for $B \rightarrow K\pi$ decays are more conveniently written in terms of RG invariant parameters built using the Wick contractions of the effective Hamiltonian. In the heavy quark limit, following the approach of ref. it is possible to compute these RG invariant parameters using factorization. The formalism has been developed so that it is possible to include also the perturbative corrections to order $\alpha_s$. An alternative approach is provided by the formalism of ref. The two methods differ in the treatment of the $O(\alpha_s)$ terms. We present results obtained with the formalism of ref. only, with the addition of the non-perturbative $\Lambda_{QCD}/m_b$ corrections to factorization. A comparison with the formalism of ref. will be presented elsewhere.

In the leading amplitudes, we have taken into account the SU(3) breaking terms by using the appropriate decay constants, $f_K$ and $f_\pi$ and form factors, $f_K(0)$ and $f_\pi(0)$. As for $\Lambda_{QCD}/m_b$ corrections, we have assumed in-
stead SU(3) symmetry and neglected Zweig-suppressed contributions. In this approximation, all the Cabibbo-enhanced $\Lambda_{QCD}/m_b$ corrections to $B \to K\pi$ decays can be reabsorbed in a single parameter $P_1$. This parameter includes not only the charming penguin contribution, but also annihilation and penguin contributions of penguin operators. It does not include leading emission amplitudes of penguin operators ($Q_3-Q_6$) which have been explicitly evaluated using factorization. Had we included these terms, this contribution would correspond to the parameter $P_4$ of ref.\textsuperscript{2}. For simplicity, in the following we will continue to refer to $P_1$ as the charming penguin contribution.

We proceed with the usual likelihood method, by extracting the input quantities weighted by their distribution, which is assumed to be flat for theoretical errors and Gaussian for experimental ones. Averages and standard deviations are then obtained by weighting the output quantities by the likelihood factor

$$\mathcal{L} = e^{-\frac{1}{2} \sum_i (BR_i - BR_i^{exp})^2/\sigma^2},$$

where $\sigma_i$ are the standard deviations of the experimental BRs $BR_i^{exp}$ given in table\textsuperscript{\ref{table1}}. For more details on the likelihood procedure, the reader is referred to ref.\textsuperscript{2}, where all aspects are discussed at length.

Table 1: Input values used in the numerical analysis. The form factors are taken from refs.\textsuperscript{17,21,22} and the CKM parameters from ref.\textsuperscript{1} and their errors correspond to our average of CLEO, BaBar and Belle results.\textsuperscript{20} All the BRs are given in units of $10^{-6}$.

| $(f_\pi(0))$ | $0.27 \pm 0.08$ |
| $f_K(0)/f_\pi(0)$ | $1.2 \pm 0.1$ |
| $\rho$ | $0.224 \pm 0.038$ |
| $\eta$ | $0.317 \pm 0.040$ |
| $BR(B_d \to K^0\pi^0)$ | $(10.4 \pm 2.6)$ |
| $BR(B^+ \to K^+\pi^0)$ | $(12.1 \pm 1.7)$ |
| $BR(B^+ \to K^0\pi^+)$ | $(17.2 \pm 2.6)$ |
| $BR(B_d \to K^+\pi^-)$ | $(17.2 \pm 1.6)$ |

To analyze $B \to K\pi$ decays, we only need $f_K(0)$. Alternatively we may take only $|V_{ub}|$ from the experiments and fit the value of $\gamma$. In the first case, the results are given in table\textsuperscript{\ref{table2}} labelled as “$\gamma$ UTA” and show a generalized disagreement between predictions and experimental data. In the second case, the value of $\gamma$ is fitted and the results are labelled as “$\gamma$ free”. In this case the disagreement is reduced for $BR(B^+ \to K^0\pi^+)$ and $BR(B_d \to K^+\pi^-)$, but it remains important for $BR(B_d \to K^0\pi^0)$ and $BR(B^+ \to K^+\pi^0)$. The pattern $BR(B^+ \to K^0\pi^+)$:$BR(B_d \to K^+\pi^-)$:$BR(B_d \to K^0\pi^0)$:$BR(B^+ \to K^+\pi^0)$=2:2:1:1, which is suggested by the data, and is well reproduced when the contribution of the charming penguins is large, as discussed in the following, is lost in this case. Moreover the fitted value of $\gamma = (162 \pm 13)^0$ is in striking disagreement with the results of the UTA. Although one may question on the quoted uncertainty of the UTA result, it is clearly impossible to reconcile the two numbers. Thus either there is new physics or $\Lambda_{QCD}/m_b$ corrections are important. We now consider the latter possibility.

### Factorization with Charming penguins

We now discuss the effect of the inclusion of charming penguins, parametrized by $\tilde{P}_1$. In general, this parameter is a complex number and we fit it on the $B \to K\pi$ BRs. In order to have a reference scale for the size of charming penguins, we introduce a suitable “Bag” parameter by writing

$$\tilde{P}_1 = \frac{G_F}{\sqrt{2}} f_\pi f_\pi(0) g_1 \tilde{B}_1,$$

where $\tilde{B}_1$ is the $B$-parameter for $\tilde{P}_1$ and $G_F$ the Fermi constant. We always use $f_\pi(0)$ since, as mentioned before, for these terms we work in the SU(3) limit. $g_1$ is a Clebsh-Gordan parameter which depends on the final $K\pi$ channel. In the case where $|V_{ub}|$ and $\gamma$ are taken from the UTA, we find

$$|\tilde{B}_1| = 0.12 \pm 0.04, \quad \phi \equiv |\text{Arg}(\tilde{B}_1)| = (81 \pm 37)^\circ.$$

Table 2: Values for $B \to K\pi$ BRs obtained in the approach of ref.\textsuperscript{2}.

| $BR$ | $\gamma$ UTA | $\gamma$ free |
| --- | --- | --- |
| $K^0\pi^0$ | $5.9 \pm 0.2$ | $5.7 \pm 0.4$ |
| $K^+\pi^0$ | $4.8 \pm 0.2$ | $9.1 \pm 0.5$ |
| $K^0\pi^+$ | $11.7 \pm 0.5$ | $11.6 \pm 0.8$ |
| $K^+\pi^-$ | $9.8 \pm 0.4$ | $17.7 \pm 1.$ |

Results with factorization

We start by considering the case in which we stick to factorization and take the CKM parameters $|V_{ub}|$ and $\gamma$ from other experimental determinations. Here and in all the other cases where $|V_{ub}|$ and $\gamma$ are taken from the standard Unitarity Triangle Analysis (UTA), we use as equivalent input parameters the values of $\tilde{\rho}$ and $\tilde{\eta}$ given in table\textsuperscript{\ref{table1}} from the analysis of ref.\textsuperscript{2}. These values correspond to

$$\gamma = (54.8 \pm 6.2)^0.$$

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$$\gamma = (54.8 \pm 6.2)^0.$$
Table 3: Values for $B \to K\pi$ BRs and rate CP asymmetries (in absolute value) obtained taking into account the contributions of charming penguins, and using the values of $\bar{\rho}$ and $\bar{\eta}$ in Table 1. All the BRs are given in units of $10^{-6}$.

| Channel   | BR   | $|A|$ |
|-----------|------|-----|
| $K^0\pi^0$ | $9.2 \pm 1.1$ | $0.0 \pm 0.0$ |
| $K^+\pi^0$ | $11.1 \pm 1.6$ | $0.3 \pm 0.1$ |
| $K^0\pi^+$ | $18.4 \pm 2.1$ | $0.0 \pm 0.0$ |
| $K^+\pi^-$ | $17.5 \pm 1.3$ | $0.3 \pm 0.1$ |

There is a twofold ambiguity on the sign of the phase which cannot be fixed by considering only CP-averaged BRs, see fig. 1. We will return on this point in the following. In table 3 we give the corresponding predicted values and uncertainties for the relevant branching ratios. We observe a remarkable improvement in the fit. Once charming penguins are included, very little sensitivity to $\gamma$ is left and therefore no information on $\gamma$ can be extracted from the study of $B \to K\pi$ BRs. However, the presence of a large phase in the charming penguin contribution opens up the possibility of observing a large rate CP asymmetry,

$$A = \frac{\Gamma(\bar{B} \to f) - \Gamma(B \to f)}{\Gamma(\bar{B} \to f) + \Gamma(B \to f)}.$$  \hspace{1cm} (5)

in $B \to K\pi$ decays. Indeed, while these asymmetries come out to be always negligible if one uses the approach of ref. 7, when charming penguins are included we predict visible asymmetries in two $B \to K\pi$ channels, as reported in table 3 and in figs. 2 and 3. Once the sign of the asymmetry is determined experimentally, the sign ambiguity in the charming penguin phase can be resolved. With improved experimental data, in the future one might think of extracting informations on $\gamma$ from these asymmetries, exploiting the fact that they are proportional to $\sin \gamma \sin \phi$ (neglecting the very small perturbative strong phases).

4 Conclusions

We have studied $B \to K\pi$ decays, taking as a starting point the factorized amplitude as obtained in the approach of ref. 7, and adding Cabibbo-enhanced nonperturbative $\Lambda_{QCD}/m_B$ corrections (charming penguins), which turn out to be dominant in these channels. We have shown that

- using factorization and the information on $\gamma$ from the UTA, all $B \to K\pi$ BRs come out to be much smaller than the experimental value;
- even treating $\gamma$ as a free parameter, a sizable discrepancy between factorized predictions and experimental data remains present;
- the inclusion of charming penguins, which is mandatory in these channels where they are doubly Cabibbo-enhanced, gives a perfect agreement with data irrespectively of the value of $\gamma$;
- once charming penguins are included, no information on $\gamma$ can be extracted from CP-averaged $B \to K\pi$ BRs;
- sizable rate asymmetries are predicted for $B_d \to K^+\pi^-$ and $B^+ \to K^+\pi^0$, and an experimental determination of the sign of the asymmetry can re-
solve the sign ambiguity on the charming penguin strong phase;

• in the future, with more precise measurements, one might think of extracting informations on γ combining experimental values of CP-averaged BRs and rate asymmetries.

For a more detailed discussion of these issues, together with a careful analysis of B → ππ decays, we refer the reader to ref. [3].

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