Charming Penguins Saga[1]

M. Ciuchini[⋆], *E. Franco*[‡], *G. Martinelli*[‡], *M. Pierini*[‡] *and L. Silvestrini*[‡]
[⋆] *Dip. di Fisica, Università di Roma Tre and I.N.F.N. Sezione di Roma III*
Via della Vasca Navale 84
I-00146 Roma, ITALY
[‡] *Dip. di Fisica, Università di Roma "La Sapienza" and I.N.F.N. Sezione di Roma*
P.le A. Moro 2
I-00185 Roma, ITALY

1 Introduction

"Charming penguins" started back in 1997, coming out of a study aimed to evaluate hadronic effects in non-leptonic two-body B decays. During the years, several episodes added to the saga:

1. *The penguin menace* [1, 2]. A lattice-inspired Wick-contraction parametrization of hadronic amplitudes was introduced and the observation was put forward that non-factorizable penguin contractions of current-current operators containing two c quarks (the charming penguins) could give large contributions in some B decay channels, notably $B \to K\pi$ (a similar idea was already present in ref. [3]).
2. *The neat hack of the clones* [4]. The original Wick-contraction parametrization was modified by Buras and Silvestrini. The hadronic matrix elements were expressed in terms of new renormalization-group invariant parameters given by suitable combinations of the old ones. Many B decay channels were classified according to the new parametrization. Charming penguins became a more complex object, containing further contractions (annihilations, penguin contractions of penguin operators) in addition to the original one.
3. *A new hope* [5, 6]. The one-loop proof that factorization of hadronic matrix elements holds in the limit $m_b \to \infty$ puts phenomenological approaches based on factorization on a firmer theoretical ground (other theoretical approaches to factorization in the infinite mass limit were already developed, although not at the same level of accuracy [7]). *In this limit*, non-factorizable corrections were shown to be computable using perturbation theory. Perturbative penguins turned out to give in general small contributions. Charming penguins seemed at loss.

[1] Talk given by M. Ciuchini.

4. *Charming penguins strike back* [8]. Using $B \to K\pi$ data, it was shown that the parameter accounting for charming penguins has the expected size of a Λ_{QCD}/m_b correction. Therefore, a sizable non-perturbative effect of charming penguins is not in disagreement with the results on factorization obtained in the infinite mass limit. In addition, it is preferred by the data.

5. *The return of factorization* [9, 10]. While everybody agrees that power-suppressed terms are in general non-perturbative and non-factorizable, it was argued that still the bulk of the Λ_{QCD}/m_b corrections can be either factorized or, failing that, accounted for by few parameters (this framework is called *improved* QCD factorization). In addition, these parameters, once properly defined, are claimed to have negligible effects on $B \to K\pi$ branching ratios. Under these assumptions, which were shown to be compatible with the present data, these branching ratios can be used to extract the CKM angle γ.

Is the saga arrived to its end? Theoretically, it is not clear whether a non-perturbative contribution such as charming penguins is large or small. A recent calculation using renormalons found no sign of it [11], while, on the contrary, it is present and effective in other approaches [12]. The $B \to K\pi$ data certainly call for power-suppressed terms and charming penguins are able to provide what is needed. Other approaches, such as the popular *improved* QCD factorization, are also compatible with the data, but none is able to make predictions based only on the theory, due to the presence of phenomenological parameters. Indeed, the presence of these parameters makes us very skeptical about the possibility of extracting the CKM angle γ from the measurement of the $B \to K\pi$ branching ratios.

2 Charming penguins at work

In this section we collect the main formulae for the amplitudes of $B \to K\pi, \pi\pi$, introducing the parametrization used in the analysis. We refer the reader to the literature for any detail on the origin and the properties of these parameters [1, 2, 4, 8]. From ref. [4], one reads

$$\begin{aligned}
A(B_d \to K^+\pi^-) &= \frac{G_F}{\sqrt{2}}\Big(\lambda_t^s P_1 - \lambda_u^s (E_1 - P_1^{GIM})\Big) \\
A(B^+ \to K^+\pi^0) &= \frac{G_F}{2}\Big(\lambda_t^s P_1 - \lambda_u^s (E_1 + E_2 - P_1^{GIM} + A_1)\Big) + \Delta A \\
A(B^+ \to K^0\pi^+) &= \frac{G_F}{\sqrt{2}}\Big(- \lambda_t^s P_1 + \lambda_u^s (A_1 - P_1^{GIM})\Big) + \Delta A \\
A(B_d \to K^0\pi^0) &= \frac{G_F}{2}\Big(- \lambda_t^s P_1 - \lambda_u^s (E_2 + P_1^{GIM})\Big) + \Delta A
\end{aligned} \tag{1}$$

$$
\begin{aligned}
A(B_d \to \pi^+\pi^-) &= \frac{G_F}{\sqrt{2}}\Big(\lambda_t^d(P_1+P_3) - \lambda_u^d(E_1 + A_2 - P_1^{GIM}) - P_3^{GIM}\Big) \\
A(B_d \to \pi^+\pi^0) &= \frac{G_F}{2}\Big(-\lambda_u^d(E_1+E_2)\Big) + \Delta A \\
A(B_d \to \pi^0\pi^0) &= \frac{G_F}{2}\Big(-\lambda_t^s(P_1+P_3) - \lambda_u^s(E_2 + P_1^{GIM} + P_3^{GIM} - A_2)\Big) + \Delta A\,,
\end{aligned}
$$

where $\lambda_{q'}^q = V_{q'q}V_{q'b}^*$. Neglecting the A_i, these parameters can be rewritten as

$$
\begin{aligned}
&E_1 = a_1^c A_{\pi K}\,,\ E_2 = a_2^c A_{K\pi}\,,\ A_1 = A_2 = 0\,, \\
&P_1 = a_4^c A_{\pi K} + \tilde{P}_1\,,\ P_1^{GIM} = (a_4^c - a_4^u)A_{\pi K} + \tilde{P}_1^{GIM}\,.
\end{aligned} \tag{2}
$$

The terms proportional to a_i^q gives the parameters computed in the limit $m_b \to \infty$ using QCD factorization. Their definition, together with those of $A_{\pi K}$, $A_{K\pi}$, etc., can be found for instance in ref. [9], although power-suppressed terms included there, proportional to the chiral factors $r_{K,\pi}^{\chi}$, should be discarded in eqs. (2). In our case, in fact, terms of $O(\Lambda_{QCD}/m_b)$ are accounted for by two phenomenological parameters: the charming-penguin parameter $\tilde{P}_1$ and the GIM-penguin parameter $\tilde{P}_1^{GIM}$. In $B \to K\pi$ there are no other contributions, once flavour $SU(2)$ symmetry is used and few other doubly Cabibbo-suppressed terms, including corrections to emission parametes E_1 and E_2, some annihilations (A_1) and the Zweig-suppressed contactions (ΔA), are neglected [4]. On the contrary, further power-suppressed terms (A_2, P_3, P_3^{GIM}) enter the $B \to \pi\pi$ amplitudes, all with the same power of the Cabibbo angle. Therefore, these modes are subject to a larger uncertainty than the $B \to K\pi$ ones.

Using the inputs collected in Table 1, we fit the value of the complex parameter $\tilde{P}_1 = (0.13 \pm 0.02)\, e^{\pm i(114\pm 35)^o}$ in units of $f_\pi F_\pi(M_\pi)$. Notice that the sign of the phase is practically not constrained by the data. This result is almost independent of the inputs used for the CKM parameters ρ and η, namely whether these parameters are taken from the usual unitarity triangle analysis (UTA) [14, 15] or only the constraint from $|V_{ub}/V_{cb}|$ is used.

$\lvert V_{cb}\rvert\times 10^3$	$\lvert V_{ub}\rvert\times 10^3$	$\hat{B}_K$	$f_{B_d}\sqrt{B_d}$ (MeV)	ξ
40.9 ± 1.0	3.70 ± 0.42	$0.86\pm 0.06\pm 0.14$	$230\pm 30\pm 15$	$1.16\pm 0.03\pm 0.04$
$F_K(M_K^2)$	$\mathcal{B}(K^+\pi^-)\times 10^6$	$\mathcal{B}(K^+\pi^0)\times 10^6$	$\mathcal{B}(K^0\pi^+)\times 10^6$	$\mathcal{B}(K^0\pi^0)\times 10^6$
0.32 ± 0.12	18.6 ± 1.1	11.5 ± 1.3	17.9 ± 1.7	8.9 ± 2.3
$F_\pi(M_\pi^2)$	$\mathcal{B}(\pi^+\pi^-)\times 10^6$	$\mathcal{B}(\pi^+\pi^0)\times 10^6$	$\mathcal{B}(\pi^0\pi^0)\times 10^6$	
0.27 ± 0.08	5.2 ± 0.6	4.9 ± 1.1	<3.4 *BaBar*	

Table 1: Values of the input parameters used in our analysis. The CP-averaged branching ratios $\mathcal{B}$ are taken from ref. [13].

Mode	UTA		$\lvert V_{ub}/V_{cb}\rvert$	
	$\mathcal{B}$ (10^{-6})	$\lvert\mathcal{A}_{CP}\rvert$	$\mathcal{B}$ (10^{-6})	$\lvert\mathcal{A}_{CP}\rvert$
$\pi^+\pi^-$	8.9 ± 3.3	0.37 ± 0.17	8.7 ± 3.6	0.39 ± 0.20
$\pi^+\pi^0$	5.4 ± 2.1	–	5.5 ± 2.2	–
$\pi^0\pi^0$	0.44 ± 0.13	0.61 ± 0.26	0.69 ± 0.27	0.45 ± 0.27
$K^+\pi^-$	18.4 ± 1.0	0.21 ± 0.10	18.8 ± 1.0	0.21 ± 0.12
$K^+\pi^0$	10.3 ± 0.9	0.22 ± 0.11	10.7 ± 1.0	0.22 ± 0.13
$K^0\pi^+$	19.3 ± 1.2	0.00 ± 0.00	18.1 ± 1.5	0.00 ± 0.00
$K^0\pi^0$	8.7 ± 0.8	0.04 ± 0.02	8.2 ± 1.2	0.04 ± 0.03

Table 2: Predictions for CP-averaged branching ratios $\mathcal{B}$ and absolute value of the CP asymmetries $|\mathcal{A}_{CP}|$. The left (right) columns show results obtained using constraints on the CKM parameters ρ and η obtained from the UTA (the measurement of $|V_{ub}/V_{cb}|$). The last four channels are those used for fitting the charming penguin parameter $\tilde{P}_1$.

For the sake of simplicity, we also neglect here the contribution of $\tilde{P}_1^{GIM}$. The $B \to K\pi$ data do not constrain this parameter very effectively, since its contribution is doubly Cabibbo suppressed with respect to $\tilde{P}_1$. The remaining $\pi^+\pi^-$ mode alone is not sufficient to fully determine the complex parameter $\tilde{P}_1^{GIM}$. It is interesting, however, to notice that the GIM-penguin contribution is potentially able to enhance the $\mathcal{B}(B \to \pi^0\pi^0)$ up to few $\times 10^{-6}$ [8].

Table 2 shows the predicted values of the CP-averaged branching ratios $\mathcal{B}$ and the absolute value of the CP-asymmetries $|\mathcal{A}_{CP}|$ for the $B \to K\pi$ and $B \to \pi\pi$ modes, since the data are not able to fix the sign of asymmetries. Charming penguins are able to reproduce the $K\pi$ data and are also consistent with the only $\pi\pi$ mode measured so far. It is interesting to notice that the latest measurements improve the consistency, for a comparison see refs. [2, 8].

3 Remarks on the different approaches

Since the different approaches aiming at evaluating power-suppressed terms contain phenomenological parameters, it is natural to ask whether, after all, they are equivalent or not, even if the physical mechanism invoked to introduce the parameters is not the same. To answer this question, it is useful to compute the parameters $\tilde{P}_1$ and $\tilde{P}_1^{GIM}$ within *improved* QCD factorization. They read

$$\tilde{P}_1 = r_K^\chi a_6^c A_{\pi K} + b_3 B_{\pi K} \ , \ \tilde{P}_1^{GIM} = r_K^\chi (a_6^c - a_6^u) A_{\pi K} \ , \tag{3}$$

where the functions a_i^q (b_i) contain the complex parameter ρ_H (ρ_A), see ref. [9] for the definitions. These two parameters account for chirally-enhanced terms, origi-

nating from hard-spectator interactions and annihilations respectively, which are not computable within the *improved* QCD factorization.

The functional dependence of the amplitudes on the phenomenological parameters in the two approaches is different. For instance, the GIM-penguin parameter is a pure short-distance correction in the *improved* QCD factorization, since the ρ_H dependence cancels out in the difference $a_6^c - a_6^u$. In practice, however, the main contribution of the phenomenological parameters to the $B \to K\pi$ amplitudes comes from the annihilation term b_3, i.e. from ρ_A . This term behaves effectively as the charming-penguin parameter, enhancing the Cabibbo-favored amplitude.

Notice that a vanishing ρ_A (and ρ_H), which turns out to be compatible with the data, does not mean that the phenomenological contribution is negligible. In fact, the parameters are defined so that the phenomenological terms are functions of $X_{A(H)} = (1 + \rho_{A(H)}) \log(m_B/\mu_h)$, where the scale μ_h is assumed to be 0.5 GeV [9].

4 Non-leptonic B decays and the extraction of γ

The presence of complex phenomenological parameters in the amplitudes makes the extraction of γ very problematic. We checked using the $|V_{ub}/V_{cb}|$-constrained fit that almost any value of γ is allowed, given the uncertainty on $\tilde{P}_1$. This seems a general problem which make us doubt recent claims proposing non-leptonic B decays as an effective tool for the CKM matrix determination. Even more, we think that the combination of the contraint from $B \to K\pi$ decays on γ with the others can even be misleading. The reason is very simple: γ is looked for through the effect of interefence terms in the branching ratios. The presence of a competing amplitude with a new phase, i.e. the one containing the phenomenological parameter, makes the extraction of γ much more complicated. Although weak and strong phases can be disentangled in principle, in practice we checked that not only the task is very difficult now, but the situation improves slowly as data become more accurate, even when the CP asymmetries will be measured.

Concerning various analyses based on the *improved* QCD factorization claiming to find a "large" value of $\gamma \sim 90^o$, we just notice that, as far as we know, they all assume the bound $|\rho_A| < 1$, suggested in ref. [9] as a theoretical prejudice and supported by the observation that even $|\rho_A| = 0$ produces a good fit to $\mathcal{B}(B \to K\pi)$. A better fit, however, can be obtained letting $|\rho_A|$ take values up to about 3. As shown in ref. [15], by doing so, the contribution of the constraint from non-leptonic B decays to a global fit of γ becomes totally negligible. In other words, for $|\rho_A| \sim 3$, the annihilation amplitude containing ρ_A becomes competitive with the others, improving the fit to the $\mathcal{B}$s on the one hand and weakening the predictivity on γ on the other.

References

[1] M. Ciuchini, E. Franco, G. Martinelli and L. Silvestrini, Nucl. Phys. B **501**, 271 (1997) [arXiv:hep-ph/9703353].

[2] M. Ciuchini, R. Contino, E. Franco, G. Martinelli and L. Silvestrini, Nucl. Phys. B **512**, 3 (1998) [Erratum-ibid. B **531**, 656 (1998)] [arXiv:hep-ph/9708222].

[3] P. Colangelo, G. Nardulli, N. Paver and Riazuddin, Z. Phys. C **45**, 575 (1990).

[4] A. J. Buras and L. Silvestrini, Nucl. Phys. B **569**, 3 (2000) [arXiv:hep-ph/9812392].

[5] M. Beneke, G. Buchalla, M. Neubert and C. T. Sachrajda, Phys. Rev. Lett. **83**, 1914 (1999) [arXiv:hep-ph/9905312].

[6] M. Beneke, G. Buchalla, M. Neubert and C. T. Sachrajda, Nucl. Phys. B **591**, 313 (2000) [arXiv:hep-ph/0006124].

[7] H.-N. Li, these proceedings and references therein.

[8] M. Ciuchini, E. Franco, G. Martinelli, M. Pierini and L. Silvestrini, Phys. Lett. B **515**, 33 (2001) [arXiv:hep-ph/0104126].

[9] M. Beneke, G. Buchalla, M. Neubert and C. T. Sachrajda, Nucl. Phys. B **606**, 245 (2001) [arXiv:hep-ph/0104110].

[10] M. Beneke, these proceedings.

[11] M. Neubert and B. D. Pecjak, JHEP **0202**, 028 (2002) [arXiv:hep-ph/0202128].

[12] C. Isola, M. Ladisa, G. Nardulli, T. N. Pham and P. Santorelli, Phys. Rev. D **65**, 094005 (2002) [arXiv:hep-ph/0110411].

[13] R. Patterson, these proceedings.

[14] M. Ciuchini *et al.*, JHEP **0107**, 013 (2001) [arXiv:hep-ph/0012308].

[15] M. Ciuchini, Nucl. Phys. Proc. Suppl. **109**, 307 (2002) [arXiv:hep-ph/0112133].