$B \to \pi\pi$ decays: branching ratios and CP asymmetries

M. I. Vysotsky[a*]

[a] *Institute of Theoretical and Experimental Physics*
Moscow, Russia

Abstract

Theoretically motivated and experimentally confirmed smallness of the penguin amplitude in $B \to \pi\pi$ decays allows to calculate the value of the unitarity triangle angle $\alpha(\phi_2)$ with good accuracy. The relatively large branching ratio of the decay into $\pi^0\pi^0$ is explained by the large value of FSI phase difference between decay amplitudes with $I = 0$ and $I = 2$.

I am very grateful to the QUARKS 2006 organizers for stimulating and creative atmosphere. This talk is based on paper [1].

1 Introduction

It was found long ago that the experimental data on branching ratios and CP asymmetries of $B \to \pi\pi$ decays allow to determine the value of the unitarity triangle angle α with essentially no hadronic input using isospin invariance of strong interactions only [2]. However, large experimental uncertainties in particular in the values of the direct CP asymmetries lead to poor accuracy in the value of α determined in this way.

If the penguin amplitudes were negligible in charmless strangeless B decays we would determine the value of unitarity triangle angle α from CP asymmetry S_{+-} extracted from $B \to \pi^+\pi^-$ decay data with essentially no theoretical uncertainties. As it was found in paper [3] neglecting penguin amplitudes one gets the values of angle α from CP asymmetries in B_d decays to $\pi^+\pi^-$, $\rho^+\rho^-$ and $\pi^\pm\rho^\mp$ consistent with the global fit of unitarity triangle. Since the penguin contributions to these decays are different [4] the fact that the numerical values of α are close to each other testifies in favor of smallness of penguin amplitudes. Small penguin corrections to these decay amplitudes were accounted for in [5] where the hadronic amplitudes were found from the quark amplitudes with the help of factorization. However, it is well known that the branching ratio of $B_d(\bar{B}_d) \to \pi^0\pi^0$ decay predicted by factorization appears to be more than 10 times smaller than the experimental data. The way out of this contradiction could be large FSI phases in $B \to \pi\pi$ decays. The validity of this theoretical ingredient will be checked by the more accurate experimental data.

Though the penguin contribution is relatively small compared to tree amplitudes and can be neglected in the first approximation in the decay probabilities and in the CPV parameters S it determines the CPV parameters C and should be accounted for in the analysis of the complete set of observables.

The charmless strangeless B decays are described by $b \to u\bar{u}d$ quark transition. The effective Hamiltonian responsible for this transition consists of two parts: the tree level weak amplitude (operators O_1 and O_2 in standard notations) dressed by gluons and the gluon penguin amplitudes (operators O_3–O_6); the parametrically small electroweak penguins are omitted.

* **e-mail**: vysotsky@itep.ru

The gluon penguins being very important in $\Delta S = 1$ strange particles nonleptonic weak decays are almost negligible in the probabilities of $\Delta B = 1$, $\Delta S = 0$ transitions. The reason is twofold: firstly, Wilson coefficients are much smaller in case of B decays because infrared cutoff is at $\mu \sim m_b$ instead of $\mu \sim \Lambda_{QCD}$; secondly, the enhancement factor originated from the right-handed currents $m_\pi^2/m_s(m_u + m_d) \sim 10$ for strange particles decays is replaced by $m_\pi^2/m_b(m_u + m_d) \sim 1/3$ for beauty hadrons. That is why after presenting the general phenomenological expressions for the amplitudes we will start our analysis of $B \to \pi\pi$ decays in Section 2 by the sequestered Hamiltonian which does not contain penguin contributions [1]. From the experimental data on $B_d(\bar{B}_d) \to \pi^+\pi^-, \pi^0\pi^0$ and $B_u \to \pi^+\pi^0$ branching ratios we will extract the moduli of the amplitudes of the decays into $\pi\pi$ states with isospin zero A_0 and two A_2 and find the final state interaction (FSI) phase shift $\delta \equiv \delta_2 - \delta_0$ between these two amplitudes. The value of the unitarity triangle angle α in this approximation is directly determined by CP asymmetry S_{+-}.

While the absolute values of the amplitudes A_0 and A_2 are reproduced with good accuracy by the factorization formulas, the FSI phase shift appears to be unexpectedly large, $\delta = -(53^o \pm 7^o)$. This is the reason why $B \to \pi^0\pi^0$ decay probability is significantly enhanced in comparison with the naive factorization approach, where one neglects δ. In Section 3 we consider the theoretical estimates of δ and show how FSI can enhance B width to neutral pions not enhancing that to neutral ρ mesons in accordance with experimentally observed suppression of $B \to \rho^0\rho^0$ decay width.

In Section 4 the penguin contributions are considered; the corrections to the numerical values of A_0 and δ due to gluon penguin amplitudes are determined, as well as the correction to the unitarity triangle angle α and the values of CP asymmetries C_{+-} and C_{00}. In Conclusions the pattern of the $B \to \pi\pi$ decay amplitudes emerging from the experimental data is presented.

2 Decay amplitudes from branching ratios

The quark Hamiltonian responsible for $B \to \pi\pi$ decays has the parts with $\Delta I = 1/2$ and $\Delta I = 3/2$ which produce π-mesons in the states with $I = 0$ and $I = 2$ correspondingly. QCD penguins having $\Delta I = 1/2$ contribute only to the $I = 0$ amplitude. Taking into account the corresponding Clebsch–Gordan coefficients and separating the penguin contribution (P) with the CKM phase different from that of A_0 we obtain:

$$\begin{aligned} M_{\bar{B}_d \to \pi^+\pi^-} &= \frac{G_F}{\sqrt{2}} |V_{ub}V_{ud}^*| m_B^2 f_\pi f_+(0) \left\{ e^{-i\gamma} \frac{1}{2\sqrt{3}} A_2 e^{i\delta_2} + \right. \\ &+ \left. e^{-i\gamma} \frac{1}{\sqrt{6}} A_0 e^{i\delta_0} + \left| \frac{V_{td}^* V_{tb}}{V_{ub}V_{ud}^*} \right| e^{i\beta} P e^{i(\delta_p + \tilde{\delta}_0)} \right\} \;, \end{aligned} \tag{1}$$

$$\begin{aligned} M_{\bar{B}_d \to \pi^0\pi^0} &= \frac{G_F}{\sqrt{2}} |V_{ub}V_{ud}^*| m_B^2 f_\pi f_+(0) \left\{ e^{-i\gamma} \frac{1}{\sqrt{3}} A_2 e^{i\delta_2} - \right. \\ &- \left. e^{-i\gamma} \frac{1}{\sqrt{6}} A_0 e^{i\delta_0} - \left| \frac{V_{td}^* V_{tb}}{V_{ub}V_{ud}^*} \right| e^{i\beta} P e^{i(\delta_p + \tilde{\delta}_0)} \right\} \;, \end{aligned} \tag{2}$$

$$M_{\bar{B}_u \to \pi^-\pi^0} = \frac{G_F}{\sqrt{2}} |V_{ub}V_{ud}^*| m_B^2 f_\pi f_+(0) \left\{ \frac{\sqrt{3}}{2\sqrt{2}} e^{-i\gamma} A_2 e^{i\delta_2} \right\} \;, \tag{3}$$

where V_{ik} are CKM matrix elements and the penguin amplitude with an intermediate c-quark multiplied by $V_{ub}V_{ud}^* + V_{cb}V_{cd}^* + V_{tb}V_{td}^* = 0$ is subtracted from the penguin amplitudes with

[1] Let us stress that while from the smallness of $B \to \pi^0\pi^0$ decay width it would follow that penguins are small, the opposite statement is not correct: the relatively large width to neutral pions does not necessary mean that penguins are large.

intermediate u-, c- and t-quarks (the so-called t-convention). To check if the factorization works in $B \to \pi\pi$ decays it is convenient to introduce $f_+(0)$ - the value of the formfactor which enters the amplitude of semileptonic $B_d \to \pi l \nu$ decay at zero momentum transfer in Eqs. (1)-(3). γ and β are the angles of the unitarity triangle; δ_2 and δ_0 are FSI phases of the tree amplitudes with $I = 2$ and $I = 0$ (below we will use $\delta \equiv \delta_2 - \delta_0$), δ_p originates from the imaginary part of the penguin loop with c-quark propagating in it [6] while $\tilde{\delta}_0$ is long distance FSI phase of the penguin amplitude. $\tilde{\delta}_0$ in general is different from δ_0; in Section 4 we will argue that $\rho\rho$ intermediate state generate large value of δ_0 while its contribution into $\tilde{\delta}_0$ is smaller: (pseudo)scalar part of penguin operator do not produce ρ mesons.

The charge conjugate amplitudes are obtained by the same formulas with substitution $\beta, \gamma \to -\beta, -\gamma$.

Now we have all the necessary formulas and neglecting the penguin contribution we are able to determine A_0, A_2, δ and the value of the unitarity triangle angle α from the experimental data on B_{+-}, B_{00}, B_{+0} and S_{+-}, which are presented in Table 1. By definition:

$$B_{+-} \equiv 1/2[\mathrm{Br}(B_d \to \pi^+\pi^-) + \mathrm{Br}(\bar{B}_d \to \pi^+\pi^-)] \ ,$$

$$B_{00} \equiv 1/2[\mathrm{Br}(B_d \to \pi^0\pi^0) + \mathrm{Br}(\bar{B}_d \to \pi^0\pi^0)] \ ,$$

$$B_{+0} = \mathrm{Br}(B_u \to \pi^+\pi^0) = \mathrm{Br}(\bar{B}_u \to \pi^-\pi^0) \ ,$$

the last equality holds as far as the electroweak penguins are neglected.

Table 1. Experimental data on $B \to \pi\pi$ decays. Branching ratios are in units of 10^{-6}.

	BABAR	Belle	Heavy Flavor Averaging Group [7]
B_{+-}	5.5 ± 0.5	4.4 ± 0.7	5.0 ± 0.4
B_{00}	1.17 ± 0.33	2.3 ± 0.5	1.45 ± 0.29
B_{+0}	5.8 ± 0.7	5.0 ± 1.3	5.5 ± 0.6
S_{+-}	-0.30 ± 0.17	-0.67 ± 0.16	-0.50 ± 0.12
C_{+-}	-0.09 ± 0.15	-0.56 ± 0.13	-0.37 ± 0.10
C_{00}	-0.12 ± 0.56	-0.44 ± 0.56	-0.28 ± 0.39

To extract the product $A_2 f_+(0)$ from B_{+0} we will use the value of $|V_{ub}|$ obtained from the general fit of the Wolfenstein parameters of CKM matrix (CKM fitter, summer 2005): $A = 0.825 \pm 0.019$, $\lambda = 0.226 \pm 0.001$, $\bar{\rho} = 0.207 \pm 0.040$, $\bar{\eta} = 0.340 \pm 0.023$:

$$|V_{ub}| = (3.90 \pm 0.10) \cdot 10^{-3} \ . \tag{4}$$

From (3) and the experimental data on B_{+0} from the last column of Table 1 we readily get:

$$A_2 f_+(0) = 0.35 \pm 0.02 \ . \tag{5}$$

In order to understand if the factorization works in $B_u \to \pi^+\pi^0$ decay we should determine the value of $f_+(0)$. We find it using the data on $B \to \pi l \nu$ decay from [8]:

$$f_+(0) = 0.22 \pm 0.02 \ , \tag{6}$$

thus getting:

$$A_2 = 1.60 \pm 0.20 \ , \tag{7}$$

which is not far from the result of factorization:

$$A_2^f = \frac{8}{3\sqrt{3}}(c_1 + c_2) \equiv \frac{2}{\sqrt{3}}(a_1 + a_2) = 1.35 \ . \tag{8}$$

We come to the same conclusion as the authors of paper [9]: A_2 is estimated correctly by factorization. Neglecting the penguin contribution we are able to extract the values of A_0 and FSI phases difference δ from (1)-(3) and the experimental data for B_{+-}, B_{00} and B_{+0} from the last column of Table 1. In this way we obtain:

$$A_0 = 1.53 \pm 0.23 \ , \tag{9}$$

which should be compared with the result of factorization:

$$A_0^f = \frac{\sqrt{2}}{3\sqrt{3}}(5c_1 - c_2) = 1.54 \ . \tag{10}$$

In this way we come to the conclusion that factorization works well for the moduli of both decay amplitudes.

For the phase difference $\delta \equiv \delta_2 - \delta_0$ we get:

$$\cos\delta = \frac{\sqrt{3}}{4} \frac{B_{+-} - 2B_{00} + \frac{2}{3}\frac{\tau_0}{\tau_+}B_{+0}}{\sqrt{\frac{\tau_0}{\tau_+}B_{+0}}\sqrt{B_{+-} + B_{00} - \frac{2}{3}\frac{\tau_0}{\tau_+}B_{+0}}} \ , \tag{11}$$

$$\delta = \pm(53^o \pm 7^o) \ , \tag{12}$$

where $\tau_0/\tau_+ \equiv \tau(B_d)/\tau(B_u) = 0.92$ is substituted. This is the place where the factorization which predicts the negligible FSI phases fails.

In Section 3 we will present a model in which the pattern of $B \to \pi\pi$ amplitudes obtained above is realized.

Let us turn to the bottom part of Table 1. Since we neglect penguins the experimental value of S_{+-} is directly related to the unitarity triangle angle α:

$$\sin 2\alpha^{\mathrm{T}} = S_{+-} \ , \tag{13}$$

$$\alpha^{\mathrm{T}}_{\mathrm{BABAR}} = 99^o \pm 5^o \ , \ \ \alpha^{\mathrm{T}}_{\mathrm{Belle}} = 111^o \pm 6^o \ , \ \ \alpha^{\mathrm{T}}_{\mathrm{average}} = 105^o \pm 4^o \ ,$$

where index "T" stands for "tree" stressing that penguins are neglected (three other values of α are not compatible with the Standard Model).

3 FSI phases

There are many theoretical papers on the final state interaction (FSI) in the heavy-meson decays. Not going into details let us stress that complete and reliable calculations for B-decays are not performed yet.

We will use the Feynman diagrams approach taking only the low mass intermediate states X, Y into account. This approach coincides with the use of the unitarity condition only if the transitions $\pi\pi \to XY$ are described by the real amplitudes. This is certainly not true for elastic $\pi\pi$-scattering, where the amplitude at large energies is predominantly imaginary. In this formalism the resulting decay matrix elements are:

$$M^I_{\pi\pi} = M^{(0)I}_{XY}\left(\delta_{\pi X}\delta_{\pi Y} + iT^{J=0}_{XY\to\pi\pi}\right) \ , \tag{14}$$

where $M^{(0)I}_{XY}$ are the decay matrix elements without FSI and $T^{J=0}_{XY\to\pi\pi}$ is the $J = 0$ partial wave amplitude of the process $XY \to \pi\pi$[2]. At very high energies the amplitudes of $\pi\pi$ elastic scattering are imaginary and $T^{J=0}_{XY\to\pi\pi}$ do not decrease with energy (mass of a heavy meson). Thus this contribution, according to (14) does not change the phase of the matrix element,

[2] We use the standard normalization with $T^J = \frac{S^J - 1}{2i}$.

but only changes its modulus. The extra phases come from the real parts of the amplitudes, which in Regge model are due to the secondary exchanges ($R \equiv \rho, f, ...$), which decrease with energy as $1/s^{1-\alpha_R(0)} \approx 1/\sqrt{s}$. The contribution of the pion exchange in the t-channel, which is dominant in the process $\rho\rho \to \pi\pi$[3] decreases even faster (as $1/s$). However $\mathrm{Br}(B \to \rho^+\rho^-)$ is substantially larger than $\mathrm{Br}(B \to \pi^+\pi^-)$ and $\rho\rho$ intermediate state is important in (14). This is especially true for color suppressed $B \to \pi^o\pi^o$ decay, where the chain $B \to \rho^+\rho^- \to \pi^o\pi^o$ is enhanced. On the contrary $\pi\pi$ contribution in $B \to \rho\rho$ decay is relatively suppressed. Using Regge analysis of $\pi\pi$ scattering [10] and π-exchange model for $\rho\rho \to \pi\pi$ transitions, we obtain phases due to final state interactions for $\pi\pi$ final state $\delta_2 \approx -12^0$ and $\delta_0 \approx 18^o$. Thus the phase difference $\delta \approx -30^o$ is generated by intermediate $\rho\rho$ and $\pi\pi$ states [4].

Sign of δ is negative, just as in the case of $K \to \pi\pi$ decays. In this way in the numerical estimates we will use negative value of δ from (12):

$$\delta \approx -(50 \pm 7)^o \ , \ \delta_0 = 30^o \ , \ \delta_2 = -20^o \ . \tag{15}$$

As far as $\mathrm{Br}(B \to \rho^+\rho^-)$ is much larger than $\mathrm{Br}(B \to \pi^+\pi^-)$ because of enhancement in tree amplitudes but not in penguin amplitudes (contribution of penguins in $B \to \rho\rho$ amplitude is small) we should expect $\tilde{\delta}_0$ to be substantially smaller than δ_0.

Note that in this model there is little change in moduli of amplitudes in comparison with factorization predictions.

For $B \to \rho\rho$ decays the same model gives $\approx -5^o$ for $I = 2$ and $+5^o$ for $I = 0$ amplitudes, resulting in a small phase difference $\approx 10^o$, consistent with experimentally observed smallness of $\mathrm{Br}(B \to \rho^0\rho^0)$ in comparison with $\mathrm{Br}(B \to \rho^+\rho^-, \rho^+\rho^0)$.

Thus the lowest mass hadronic intermediate states may produce the phases which are consistent with the data on $B \to \pi\pi$ and $B \to \rho\rho$ decays. There are many high-mass states as well, and they can lead to additional phases (the inclusion of πa_1 intermediate state makes $\delta \approx -40^o$).

4 Taking penguins into account

Let us analyse to what changes of the parameters introduced and calculated in Section 2 penguins lead. Since QCD penguins contribute only to $I = 0$ amplitude the value of A_2 extracted from B_{+0} remains the same, see (7). The requirement that the numerical values of B_{+-} and B_{00} are not shifted when penguins are taken into account leads to the following shifts of the amplitude A_0 and phase difference δ:

$$A_0 \to A_0 + \tilde{A}_0 \ , \ \ \delta \to \delta + \tilde{\delta} \ , \tag{16}$$

$$\tilde{A}_0 = \sqrt{6}\left|\frac{V_{td}}{V_{ub}}\right| \cos\alpha \cos(\delta_p + \tilde{\delta}_0 - \delta_0) P \ , \tag{17}$$

$$\tilde{\delta} = -\sqrt{6}\left|\frac{V_{td}}{V_{ub}}\right| \cos\alpha \sin(\delta_p + \tilde{\delta}_0 - \delta_0) P/A_0 \ , \tag{18}$$

where only the terms linear in P are taken into account. For numerical estimates we take:

$$\left|\frac{V_{td}}{V_{ub}}\right| = \frac{\sin\gamma}{\sin\beta} \approx 2.3 \pm 0.2 \ , \tag{19}$$

where $\beta = 22^o$, $\gamma = 60^o \pm 10^o$. In the factorization approach we have[5] :

$$P^f = -a_4 - \frac{2m_\pi^2}{(m_u + m_d)m_b} a_6 = 0.06 \ , \tag{20}$$

[3] In B-decays transverse polarizations of ρ-mesons are small that is why a_2 and ω exchanges in $\rho\rho \to \pi\pi$ amplitudes are suppressed.

[4] An accuracy of this number is about 15^o.

[5] Note that the definition of P used in the present paper differs in sign from that in [5].

and shifts of A_0 and δ are small:

$$-0.12 < \tilde{A}_0 < 0.12 \ , \quad -4^o < \tilde{\delta} < 4^o \tag{21}$$

for

$$A_0 = 1.5 \ , \quad -1 < \cos(\delta_p + \tilde{\delta}_0 - \delta_0) \ , \quad \sin(\delta_p + \tilde{\delta}_0 - \delta_0) < 1 \ \text{ and } \ 70^o < \alpha < 110^o \ . \tag{22}$$

In particular even if the penguin contribution is underestimated by factor 2, the statement that $\delta + \tilde{\delta}$ is large still holds[6] (note that α can be closer to 90^o).

The following two equations for direct CP asymmetries determine P and $\delta_p + \tilde{\delta}_0 - \delta_0$ (as far as A_0, A_2 and $\delta = \delta_2 - \delta_0$ are known):

$$\begin{aligned} C_{+-} &= -\frac{\tilde{P}}{\sqrt{3}} \sin\alpha [\sqrt{2} A_0 \sin(\delta_0 - \tilde{\delta}_0 - \delta_p) + A_2 \sin(\delta_2 - \tilde{\delta}_0 - \delta_p)] / \\ &/ \ [\frac{A_0^2}{6} + \frac{A_2^2}{12} + \frac{A_0 A_2}{3\sqrt{2}} \cos\delta - \sqrt{\frac{2}{3}} A_0 \tilde{P} \cos\alpha \cos(\delta_0 - \tilde{\delta}_0 - \delta_P) - \\ &- \ \frac{A_2 \tilde{P}}{\sqrt{3}} \cos\alpha \cos(\delta_2 - \tilde{\delta}_0 - \delta_p) + \tilde{P}^2] \ , \end{aligned} \tag{23}$$

$$\begin{aligned} C_{00} &= -\sqrt{\frac{2}{3}} \tilde{P} \sin\alpha [A_0 \sin(\delta_0 - \tilde{\delta}_0 - \delta_p) - \sqrt{2} A_2 \sin(\delta_2 - \tilde{\delta}_0 - \delta_p)] / \\ &/ \ [\frac{A_0^2}{6} + \frac{A_2^2}{3} - \frac{\sqrt{2}}{3} A_0 A_2 \cos\delta - \sqrt{\frac{2}{3}} A_0 \tilde{P} \cos\alpha \cos(\delta_0 - \tilde{\delta}_0 - \delta_p) + \\ &+ \ \frac{2}{\sqrt{3}} A_2 \tilde{P} \cos\alpha \cos(\delta_2 - \tilde{\delta}_0 - \delta_p) + \tilde{P}^2] \ , \end{aligned} \tag{24}$$

where

$$\tilde{P} \equiv \left| \frac{V_{td}^* V_{tb}}{V_{ub} V_{ud}^*} \right| P \approx 2.3 P \ . \tag{25}$$

Three last terms in denominators of (23) and (24) lead to less than 10% variations of the numerical values of C_{+-} and C_{00} for $\tilde{P} < 0.3$. Neglecting them we get:

$$\frac{\sin(\delta_2 - \tilde{\delta}_0 - \delta_p)}{\sin(\delta_0 - \tilde{\delta}_0 - \delta_p)} = \frac{1 - 0.57 \frac{C_{00}}{C_{+-}}}{1.4 + 0.41 \frac{C_{00}}{C_{+-}}} \ , \tag{26}$$

where the numerical values for A_2, A_0 and δ from (7), (9) and (12) correspondingly were used.

From the central values in the last column in Table 1 of C_{+-} and C_{00} we get:

$$\delta_0 - \tilde{\delta}_0 - \delta_p = 70^o \ , \quad P = 0.11 \ . \tag{27}$$

The numerical value of P is two times larger than the factorization estimate of it presented in (20), while $\delta_0 - \tilde{\delta}_0 - \delta_p$ largely deviates from 30^o which is our estimate of δ_0, while $\tilde{\delta}_0$ should be considerably smaller as well as δ_p the latter being close to 30^o only for very asymmetric configurations of quarks in π mesons and is smaller otherwise [6]. If the experimental accuracy of C_{ik} were good we would be able to use the results obtained for determination of the value of the angle α from S_{+-}, realizing in this way Gronau-London approach [2].

However the experimental uncertainty in C_{00} is very big, while the measurements of C_{+-} by Belle and BABAR contradict each other. So let us look which values of the direct asymmetries follow from our formulas.

[6]Indication of factor 2 underestimate follows from the probability of $b \to s$ penguin dominated $B^+ \to K^0 \pi^+$ decay.

Denominator of the expression for C_{+-} is close to one and in the expression in brackets in nominator first term dominates. Neglecting $\tilde{\delta}_0$ and δ_p and taking $\delta_0 = 30^o$, $\delta_2 = -20^o$ we get $C_{+-} = -0.04$ for the value of penguin amplitude obtained in the factorization approach, (20). We reproduce BABAR central value of C_{+-} if we suppose that factorization underestimate penguin amplitude by factor 2; however in order to reproduce Belle number we should accept that factorization is wrong by factor 10, which looks highly improbable.

What to do if C_{+-} appeared to be equal to the average of the present day Belle and BABAR results $C_{+-} \approx -0.3$? One possibility is to suppose that $\delta_2 - \tilde{\delta}_0 - \delta_P \approx 0$, while $\delta_0 - \tilde{\delta}_0 - \delta_P \approx 50^o$ and to look for FSI mechanism which provides such a result.[7]

C_{00} is also negative while its absolute value is much larger than C_{+-}: denominator is about .55 while in nominator both terms are negative.

The requirement that the value of CP asymmetry S_{+-} is not changed when penguins are taken into account leads to the following shift of the value of the unitarity triangle angle α:

$$\alpha = \alpha^T + \tilde{\alpha} \ , \tag{28}$$

$$\tilde{\alpha} = -\frac{\tilde{P}}{2\sqrt{3}} \sin\alpha[\sqrt{2}A_0 \cos(\delta_0 - \tilde{\delta}_0 - \delta_P) + A_2 \cos(\delta_2 - \tilde{\delta}_0 - \delta_P)] \ . \tag{29}$$

Substituting the numerical values of A_2 from (7), A_0 from (9), $\tilde{P}$ from (25) and substituting $\sin\alpha$ by one and both cos by 0.9 we get:

$$\tilde{\alpha} \approx -2.3P \approx -7^o, \tag{30}$$

where the result of the matrix element of the penguin operator calculation in factorization approximation (20) is used. We observe that our approach is at least selfconsistent: the shift of α due to penguin contribution is small. For the BABAR value of S_{+-} we obtain:

$$\alpha_{\rm BABAR} = \alpha^T_{\rm BABAR} + \tilde{\alpha} = 92^o \pm 5^o \ . \tag{31}$$

In the case of the averaged experimental values we get:

$$\alpha_{\rm average} = \alpha^T_{\rm average} + \tilde{\alpha} = 98^o \pm 4^o \ . \tag{32}$$

Theoretical uncertainty of the value of α can be estimated in the following way. Let us suppose that the accuracy of the factorization calculation of the penguin amplitude is 100%. Then:

$$\tilde{\alpha} = -7^o \pm 7^o_{\rm theor} \ , \tag{33}$$

$$\alpha_{\rm average} = 98^o \pm 4^o_{\rm exp} \pm 7^o_{\rm theor} \ , \tag{34}$$

while BABAR value is smaller:

$$\alpha_{\rm BABAR} = 92^o \pm 5^o_{\rm exp} \pm 7^o_{\rm theor} \ . \tag{35}$$

Better theoretical accuracy of α follows from $B \to \rho^+\rho^-$ decays, where penguin contribution is two times smaller. Since FSI phases are small in these decays, results of the paper [5] are directly applicable:

$$\alpha^{\rho\rho} = 92^o \pm 7^o_{\rm exp} \pm 4^o_{\rm theor} \ , \tag{36}$$

where we take the WHOLE penguine contribution as an estimate of the theoretical uncertainty.

The model independent isospin analysis of $B \to \rho\rho$ decays performed by BABAR gives [13]:

$$\alpha^{\rho\rho}_{BABAR} = 100^o \pm 13^o \ , \tag{37}$$

[7] Let us note that in [11] argument in favor of $C_{+-} \approx 0.3$ is presented, which is based on the comparison of the direct CP-violation in $B(\bar{B}) \to \pi^+\pi^-$ and $B(\bar{B}) \to K^+\pi^-(K^-\pi^+)$ decays (see also [12]).

while the analogous analysis performed by Belle gives [14] :

$$\alpha^{\rho\rho}_{Belle} = 87^o \pm 17^o \ . \tag{38}$$

Finally, the global CKM fit results are[15, 16]:

$$\alpha_{CKMfitter} = 97^o \pm 5^o \ , \ \alpha_{UTfit} = 95^o \pm 5^o \ . \tag{39}$$

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