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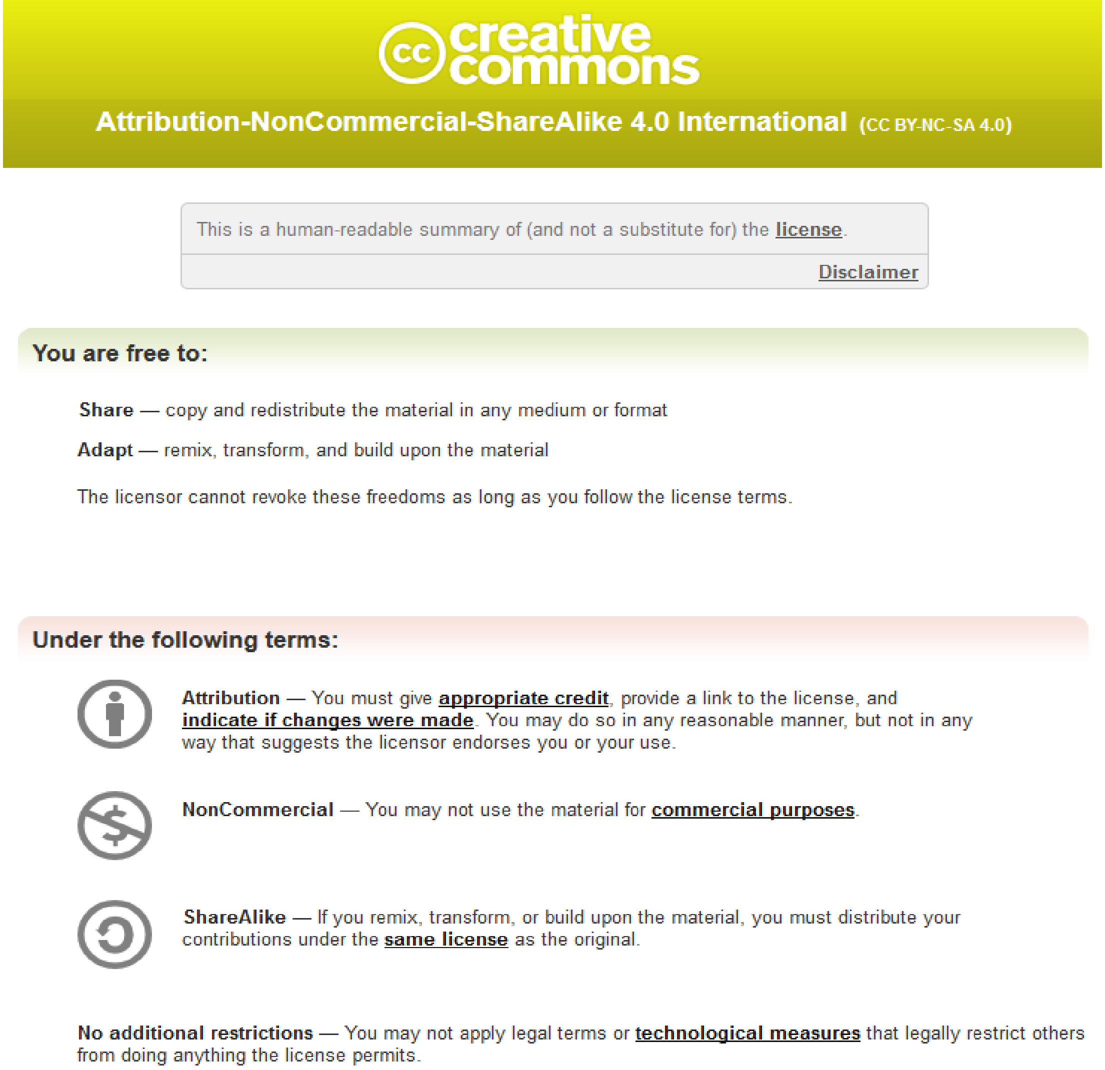

PROCEEDINGS OF SCIENCE

Direct CP violation in $B \to \rho^0(\omega)\pi$ and $B \to \rho^0(\omega)K$

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We calculate the direct CP violating asymmetry parameter, a_{CP}, for $B \to \pi^+\pi^-\pi$ and $B \to \pi^+\pi^-K$ decays, in the case where $\rho^0-\omega$ mixing effects are taken into account. We find that the direct CP asymmetry for $B^- \to \pi^+\pi^-\pi^-$, $\bar{B}^0 \to \pi^+\pi^-\pi^0$, $B^- \to \pi^+\pi^-K^-$ and $\bar{B}^0 \to \pi^+\pi^-\bar{K}^0$, reaches its maximum when the invariant mass $\pi^+\pi^-$ is in the vicinity of the ω meson mass. The inclusion of $\rho^0-\omega$ mixing provides an opportunity to erase, without ambiguity, the phase uncertainty mod(π) in the determination of the CKM angles α in case of $b \to u$ and γ in case of $b \to s$.

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1. Direct *CP* violation

Direct *CP* violating asymmetries in B decays occur through the interference of, at least, two amplitudes with different weak phase, ϕ, and strong phase, δ. The extraction of the weak phase ϕ (which is determined by a combination of CKM matrix elements) is made through the measurement of a *CP* violating asymmetry. However, one must know the strong phase δ which is not still well determined in any theoretical framework. In this regard, the isospin symmetry violating mixing between ρ^0 and ω can be extremely important, since it can lead to a large *CP* violation in B decays such as $B \to \rho^0(\omega)Y \to \pi^+\pi^-Y$ (Y represents a meson) because the strong phase passes through 90^o at the ω resonance. In any phenomenological treatment of the weak decays of hadrons, the starting point is the weak effective Hamiltonian at low energy. It is obtained by integrating out the heavy fields from the Standard Model Lagrangian. The Operator Product Expansion is used to separate the calculation of the amplitude, $A(B \to F) \propto C_i(\mu)\langle F|O_i|B\rangle(\mu)$, into two distinct physical regimes. One is called *hard*, represented by $C_i(\mu)$ and calculated by a perturbative approach. The other is called *soft*, described by $O_i(\mu)$ and derived by using a non-perturbative approach. The operators, $O_i(\mu)$, can be understood as local operators which govern effectively a given decay, reproducing the weak interaction of quarks in a point-like approximation. The Wilson coefficients, $C_i(\mu)$, represent the physical contributions from scales higher than $\mu(= m_b)$ and they can be calculated in perturbation theory because of the property of asymptotic freedom of QCD.

Factorization in B decays involves three fundamental scales: the weak interaction scale, M_W, the b quark mass scale, m_b, and the strong interaction scale, Λ_{QCD}. The QCD factorization (QCDF) approach, based on the concept of color transparency as well as on a soft collinear factorization where the particle energies are bigger than the scale Λ_{QCD}, allows us to write down the matrix elements $\langle F|O_i|B\rangle(\mu)$ at the leading order in Λ_{QCD}/m_b and α_s. The hadronic decay amplitude involves both soft and hard contributions. At leading order, all the non-perturbative effects are assumed to be contained in the semi-leptonic form factors and the light cone distribution amplitudes. Then, non-factorizable interactions are dominated by hard gluon exchanges and can be calculated perturbatively, in order to correct the naive factorization (NF) approximation. It has been also shown that the weak annihilation contributions cannot be neglected in B meson decays even though they are power suppressed in the heavy-quark limit (Λ_{QCD}/m_b). Their contributions are approximated in terms of convolutions of hard scattering kernels with light cone expansions for the final state mesons. Finally, the perturbative calculation of the hard scattering spectator and annihilation contributions is regulated by a physical scale of order Λ_{QCD}.

The direct *CP* violating asymmetry parameter, a_{CP}, is found to be small for most of the non-leptonic B decays when either the naive or QCD factorization framework is applied. However, in the case of B decay channels involving the ρ^0 meson, it appears that the asymmetry may be large in the vicinity of ω meson mass. We stress that $\rho^0 - \omega$ mixing has the dual advantages that the strong phase difference is large (passing rapidly through 90^o at the ω resonance) and well known. In the vector meson dominance model, the photon propagator is dressed by coupling to the vector mesons ρ^0 and ω. In this regard, the $\rho^0 - \omega$ mixing mechanism has been developed. Knowing the ratio, r, between the tree and penguin amplitudes, and the strong phase, δ, as well as the weak phase, ϕ, from the CKM matrix, it is possible to calculate the *CP* violating asymmetry, a_{CP}, including the $\rho^0 - \omega$ mixing mechanism. More detail for all the results presented here can be found in Ref. [1].

2. Isospin symmetry violation and direct *CP* violation in *B* decays

In Fig. 1, we show the *CP* violating asymmetry for $B^- \to \rho^0(\omega)\pi^- \to \pi^+\pi^-\pi^-$ and $\bar{B}^0 \to \rho^0(\omega)\pi^0 \to \pi^+\pi^-\pi^0$ respectively, as a function of the energy, $\sqrt{S}$, of the two pions coming from ρ^0 decay, the form factor, $F_1^{B\to\pi}$, and the CKM matrix element parameters ρ and η. For comparison, on the same plot we show the *CP* violating asymmetries, a_{CP}, when NF is applied as well as QCDF where default values for the phases, $\varphi_{H,A}^{M_i}$, and parameters, $\rho_{H,A}^{M_i}$ are used. In the latter case, we take $\varphi_{H,A}^{M_i} = 0$ and $\rho_{H,A}^{M_i} = 1$ for all the particles. Focusing first on Fig. 1, where the asymmetry for $B^- \to \rho^0(\omega)\pi^- \to \pi^+\pi^-\pi^-$ is plotted, we observe that the *CP* violating asymmetry parameter, a_{CP}, can be large outside the region where the invariant mass of the $\pi^+\pi^-$ pair is in the vicinity of the ω resonance. This is the first consequence of QCD factorization, since within this framework, the strong phase can be generated not only by the $\rho^0 - \omega$ mechanism but also by the Wilson coefficients. Because of the strong phase that is either at the order of α_s or power suppressed by Λ_{QCD}/m_b, the *CP* violating asymmetry, a_{CP}, may be small but a large asymmetry cannot be excluded. At the ω resonance, the asymmetry parameter, a_{CP}, for $B^- \to \pi^+\pi^-\pi^-$, is around 0% in our case. In comparison, the asymmetry parameter, a_{CP}, (still at the ω resonance) obtained by applying the naive factorization gives -10% whereas it gives -2% in case of QCDF with default values for $\varphi_{H,A}^{M_i}$ and $\rho_{H,A}^{M_i}$. The results are quite different between these approaches because of the strong phase mentioned previously.

On the same figure, the asymmetry violating parameter, a_{CP}, is shown for the decay $\bar{B}^0 \to \pi^+\pi^-\pi^0$. In the vicinity of the ω resonance, the QCDF approach gives an asymmetry of the order -8%. We obtain -20% and $+5\%$ in the case of NF and QCDF with the default values for $\varphi_{H,A}^{M_i}$ and $\rho_{H,A}^{M_i}$. It appears as well that the asymmetry depends strongly on the CKM matrix parameters ρ and η, as expected. When QCDF is applied, the asymmetry for the decay $B^- \to \pi^+\pi^-\pi^-$, varies from 12% to 5% outside the region of the ω resonance whereas for the decay $\bar{B}^0 \to \pi^+\pi^-\pi^0$, the asymmetry varies from 10% down to -20%, depending on the CKM matrix element parameters, ρ and η. In the vicinity of the ω resonance, the asymmetry, a_{CP}, takes values from -2% to 5% for $B^- \to \pi^+\pi^-\pi^-$ and from 5% to -30% for $\bar{B}^0 \to \pi^+\pi^-\pi^0$ when ρ and η vary. For the decay $B^- \to \pi^+\pi^-K^-$, the asymmetry, a_{CP}, in the vicinity of the ω resonance, is about $+60\%$ with QCDF, -40% with NF and -45% with QCDF and default values for $\varphi_{H,A}^{M_i}$ and $\rho_{H,A}^{M_i}$. For the decay $\bar{B}^0 \to \pi^+\pi^-\bar{K}^0$, when $\sqrt{S}$ is near the ω resonance, the asymmetry, a_{CP} is about $+70\%$ with QCDF, -60% with NF and -15% with QCDF and usual default values for $\varphi_{H,A}^{M_i}$ and $\rho_{H,A}^{M_i}$. There is no agreement, for the value of the asymmetry between the naive and QCD factorization at the ω resonance except that, in both cases, the *CP* violating asymmetry, a_{CP} reaches its maximum in the vicinity of ω. Similar conclusions can be drawn to that of previous case regarding the sensitivity of the asymmetry parameter, a_{CP}, as well as the CKM matrix element parameters, ρ and η.

We included $\rho^0 - \omega$ mixing in order to investigate its effect on this *CP* violating asymmetry. The mixing through isospin violation between ω and ρ^0, allows us to obtain a difference of the strong phase reaching its maximum at the ω resonance. $\rho^0 - \omega$ mixing provides an opportunity to remove the phase uncertainty mod(π) in the determination of two CKM angles, α in the case of $B \to \rho^0\pi$ and γ in the case of $B \to \rho^0 K$. This phase uncertainty usually arises from the conventional determination of $\sin 2\alpha$ or $\sin 2\gamma$ in indirect *CP* violation. In QCDF, the strong phase can be generated dynamically, however, the mechanism suffers from end-point singularities which are not well

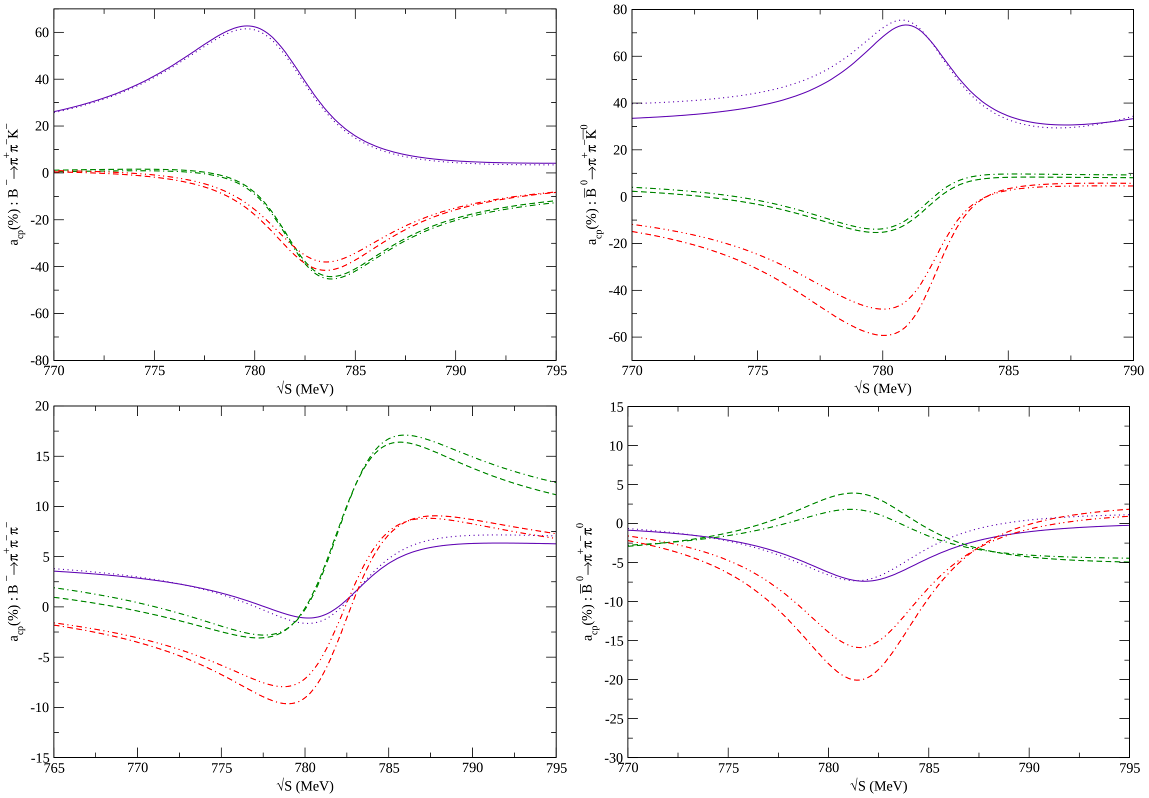

Figure 1: First row, *CP* violating asymmetry, a_{CP}, for $B^- \to \pi^+\pi^-K^-, \bar{B}^0 \to \pi^+\pi^-\bar{K}^0$ for max CKM matrix elements. Solid line (dotted line) for QCDF, dot-dot-dashed line (dot-dash-dashed line) for NF, dot-dashed line (dashed line) for QCDF with default values and for $F^{B\to K} = 0.35(0.42)$. Second row, *CP* violating asymmetry, a_{CP}, for $B^- \to \pi^+\pi^-\pi^-, \bar{B}^0 \to \pi^+\pi^-\pi^0$, for max CKM matrix elements. Same notation for lines as in first row with $F^{B\to\pi} = 0.27(0.35)$. All the figures are given as a function of $\sqrt{S}$.

controlled. It is now apparent that the Cabibbo-Kobayashi-Maskawa matrix is the dominant source of *CP* violation in flavour changing processes in *B* decays. The corrections to this dominant source coming from beyond the Standard Model are not expected to be large. In fact, the main remaining uncertainty is to deal with the procedure of factorization. The QCDF gives us an explicit picture of factorization in the heavy quark limit. It takes into account all the leading contributions as well as subleading corrections to the naive factorization. The soft collinear effective theory (SCET) has been proposed as a new procedure for factorization. In the last case, it allows one to formulate a collinear factorization theorem in terms of effective operators where new effective degrees of freedom are involved, in order to take into account the collinear, soft and ultrasoft quarks and gluons. All of these investigations allow us to increase our knowledge of *B* physics and to look for new physics beyond the Standard Model.

References

[1] O. Leitner, X. H. Guo and A. W. Thomas, J. Phys. G **31**, 199 (2005) [arXiv:hep-ph/0411392] and references therein.