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ABOUT A POSSIBILITY FOR OBSERVATION OF CP-VIOLATION IN B-MESON DECAYS IN FIXED TARGET EXPERIMENTS

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The study of CP-violation effects is of great interest for a deeper understanding of a lot of aspects of particle physics. Although a quarter of a century has passed since their discovery, the neutral kaon system is still the only one in which these effects were observed. This is the reason why a search for other sources of CP-violation still remains a problem of principle. In the frame of modern theoretical representations, B mesons are the most promising objects for such a search. It is also of great importance that CP-violation quantities measured in B decays can be critical tests of some main statute of the standard model (SM). These quantities are expressed through the SM parameters without essential hadronic corrections in contrary to those measured in the decays of hadrons consisting of lighter quarks, i.e. kaons. This allows one not only to verify the validity of the SM but also to estimate the possibility of lying outside its frame, i.e. to feel "New Physics".

Because of importance, it is planned to carry out experiments on a search for CP-violation in B decays at most of the accelerators with sufficiently high energy. Unfortunately, the observation of CP-violation effects is connected with great difficulties caused mainly by smallness of these effects and the B production cross section. According to some estimates [2,3], for the observation of CP-violation, the integrated luminosity of an experiment should be sufficient for the production of $10^8 \div 10^{12}$ B's. Such high luminosity is not achievable at the existing colliders, but it can be achieved at fixed target accelerators if experiments are carried out in hadron beams with intensities of $\gg 10^7$ particles per s. In such experiments a problem arises to distinguish the asymmetry, reflecting CP-violation in the B decays, from the one connected with the difference between the characteristics of B and $\bar{B}$ production. To solve this problem, the complete identification of both associatively produced B and $\bar{B}$ is usually suggested. This requires the reconstruction of $B/\bar{B}$ decay vertices and the identification of all secondary particles. Obviously, such an approach is not feasible in experiments carried out in high flux beams. In this paper an approach is put forward which does not require the complete identification of both associatively produced beauty particles and allows one to perform experiments in high intensity beams of hadrons. Certainly, only time-integrated CP-violation effects are considered.

One of the essential effects of CP-violation must manifest itself as an asymmetry of widths of B^0 and $\bar{B}^0$ decays into the same hadron final state f with definite CP-parity:

$$\delta = [\Gamma(B^0 \to f)-\Gamma(\bar{B}^0 \to f)]/[\Gamma(B^0 \to f)+\Gamma(\bar{B}^0 \to f)]. \qquad (1)$$

To measure this asymmetry experimentally is of interest because its calculation is practically independent of hadronic corrections and directly connected with parameters of the Cabibbo-Kobajashi-Maskawa (CKM) matrix. This asymmetry is due to the effects of CP-violation analogous to those which are characterized by the parameter ε' in the decays of neutral kaons [4]. The asymmetry arises from interference between the amplitudes of transitions:

$$B^0 \to f$$

and $B^0 \to \bar{B}^0 \to f$.

The latter is possible only if $B^0 \to \bar{B}^0$ mixing exists. Mixing is usually described by the Pais-Treiman parameter r which

equals the time-integrated probability of $\bar{B}^0$ observation when B^0 has been produced. The asymmetry (1) is zero if there is no mixing (r=0) or mixing is maximum (r=1). In the first case one of the amplitudes is suppressed and in the second both amplitudes become physically undistinguishable. As the mixing parameter for B_d mesons*) measured in the ARGUS experiment is 0.21±0.08 [6] and indicates a large (≈ 1) parameter for B_s mixing [7], CP-violation in B_d decays must lead to a much larger asymmetry (1) than that for B_s decays. Because of this CP-violation is considered here only in B_d decays.

The asymmetry (1) is expressed through the mixing parameter, r, the parameter of CP-violation at this mixing, ε, and the ratio of decay amplitudes $\rho = A(B_d \to f)/A(\bar{B}_d \to f)$ [8]:

$$\delta = k(r)\cdot \mathrm{Im}\,\Lambda, \qquad (2a)$$

where

$$k(r) = \sqrt{2\cdot r\cdot (1-r)/(1+r)} \approx 0.48, \qquad (2b)$$

$$\Lambda = [(1-\varepsilon)/(1+\varepsilon)]\cdot\rho \approx -\eta\cdot \exp(2\cdot i\cdot\Phi) \qquad (2c)$$

and η is the CP-parity of the final hadronic state f. The value of k(r) is obtained using the ARGUS data for r. The approximation in (2c) is caused by $|(1-\varepsilon)/(1+\varepsilon)| \approx 1$ through smallness of $\mathrm{Re}\,\varepsilon$**) and $|\rho|=1$ through CPT conservation and

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*) Here the notations define the quark contents of mesons in agreement with the suggestion of the Particle Data Group[5]: $B_d=\bar{b}d$, $\bar{B}_d=b\bar{d}$, $B_s=\bar{b}s$, $\bar{B}_s=b\bar{s}$, $B^+_u=\bar{b}u$, $B^-_u=b\bar{u}$ and so on.

**) A small real part of the parameter ε is due to smallness of $\Delta\Gamma/\Gamma$, where Γ is the full width of Bd decays and $\Delta\Gamma$ the difference between the CP-even and CP-odd states composed of neutral B's.

hermiticity of the weak interaction hamiltonian. The phase Φ can be calculated in the frame of theoretical models, e.g., the SM. So, the experimental measurement of the asymmetry (1) and, consequently, the phase Φ can be a critical test of these models.

To measure the asymmetry (1) in an experiment, it is necessary to identify (to tag) the flavour of the initial B_d or $\bar{B}_d$ at the moment of their production. This can be done through the sign of the lepton (muon) from the semi-leptonic decay of associatively produced beauty particle. The asymmetry

$$A = [N(f,l^-)-N(f,l^+)]/[N(f,l^-)+N(f,l^+)] \qquad (3)$$

can be measured experimentally in this case. Here $N(f,l^\pm)$ are the numbers of events containing the final state f and lepton $(l^\pm)$ from the decay of associatively produced beauty particle. If only $B_d\bar{B}_d$ pair production is taken into account, the observed asymmetry (3) is simply related to the sought one (1):

$$A = g(r)\cdot\delta,$$

where the factor

$$g(r) = (1-r)/(1+r) \approx 0.65 \qquad (4)$$

defines the asymmetry of tagging which arises from the mixing of $B_d(\bar{B}_d)$ used for this tagging. In the general case, if the type of associatively produced beauty particle cannot be identified, the relation between the asymmetries (1) and (3) is not so simple. Additive corrections for δ, in addition to multiplicative ones, arise. If these corrections cannot be obtained, the additive ones lead to the impossibility of δ detection and the multiplicative ones to a systematic error of its measurement. So, for the detection of CP-asymmetry, it

is necessary as a minimum to obtain the sources of additive corrections and to search for the ways of their removal.

If $B_d(\bar{B}_d)$ are tagged by the above mentioned means (by the sign of the lepton), an uncontrolled difference between A and δ arises. Its origin is due to the difference between the B_d and $\bar{B}_d$ production cross sections and the differences of the semi-leptonic branching ratios of a variety of associatively produced beauty particles (B_d, B_s, Λ_b etc.) used for the tagging. The quantities defining the measured asymmetry (3) are proportional to the decay widths $\Gamma(B_d \rightarrow f)$ and $\Gamma(\bar{B}_d \rightarrow f)$:

$$N(f,l^-) \propto \Gamma(B_d \rightarrow f)\cdot W(B_d,l^-)$$

and $N(f,l^+) \propto \Gamma(\bar{B}_d \rightarrow f)\cdot W(\bar{B}_d,l^+)$.

Here $W(\overset{(-)}{B}_d,l^\mp)$ defines the probability of the simultaneous production of $B_d/\bar{B}_d$ with a lepton $(l^\mp)$ from the decay of associatively produced beauty antiparticle/particle. Each of these quantities represents a sum over all possible types of beauty antiparticles/particles which can be produced associatively with $B_d/\bar{B}_d$:

$$W(B_d,l^-) = \sum_i \sigma(B_d,\bar{B}_i)\cdot Br(\bar{B}_i \longrightarrow l^- + \ldots)$$

and $$W(\bar{B}_d,l^+) = \sum_i \sigma(\bar{B}_d,B_i)\cdot Br(B_i \longrightarrow l^+ + \ldots).$$

Here $\sigma(B_d,\bar{B}_i)/\sigma(\bar{B}_d,B_i)$ denotes the cross section of the simultaneous production of $B_d/\bar{B}_d$ with a beauty antiparticle/particle of the i-th type (B_i = B_d, B_s, B_u, Λ_b, etc.) and $Br(\overset{(-)}{B}_i \longrightarrow l^\mp + \ldots)$ is the semi-leptonic branching ratio of corresponding antiparticle/particle. It is obvious that A coincides with the CP-asymmetry δ if $W(B_d,l^-)$ = $W(\bar{B}_d,l^+)$ only. This equality is fulfilled for symmetrical beauty particle production at e^+e^- or $p\bar{p}$ colliders. In fixed target experiments the inequality of these quantities is due to both the difference of the B_d and $\bar{B}_d$ production cross sections, $\sigma(B_d,\bar{B}_i) \neq \sigma(\bar{B}_d,B_i)$, and the distinctions of the semi-leptonic branching ratios of different types of beauty particles, $Br(\overset{(-)}{B}_i \longrightarrow l^{\mp} + ..) \neq Br(\overset{(-)}{B}_j \longrightarrow l^{\mp} + ..)$ if $i \neq j$. Defining the asymmetry related to this inequality by

$$\gamma = [W(B_d,l^-)-W(\bar{B}_d,l^+)]/[W(B_d,l^-)+W(\bar{B}_d,l^+)],$$

one obtains that

$$A = (\gamma+\delta)/(1+\gamma\cdot\delta). \qquad (5)$$

In the general case, γ is unknown and changes substantially with varying the reaction energy or the kinematic region of $B_d(\bar{B}_d)$ detection. Thus, it is impossible to establish the existence of the CP-asymmetry δ in the B_d decays by measuring experimentally only the value of A.

For the observation of the CP-asymmetry δ, it is suggested here to detect two B_d decays into the final states f and f' which are opposite in CP-parities but identical in other respects and to measure the corresponding asymmetries (3) denoted as A and A', respectively. The states f and f' must be detected in the same kinematic region. So, the same value of γ enters into expressions for A and A'. In accordance with (2), the CP-asymmetries for such decays are opposite in sign and equal in absolute value, $\delta=-\delta'$. By analogy with (6), one obtains:

$$A' = (\gamma-\delta)/(1-\gamma\cdot\delta). \qquad (6)$$

So, δ can be simply obtained using expressions (5) and (6) for A and A'. Moreover, for small asymmetries, $|\gamma\cdot\delta| \ll 1$:

$$\delta \approx 0.5\cdot(A-A').$$

Thus, it is possible, in principle, to establish the existence of CP-violation in the B_d decays by observation of the difference between the two asymmetries A and A'. To

measure the value of the CP-asymmetry (1), it is necessary to estimate multiplicative corrections for δ arising in the discussed approach.

As among the detected events there are events containing $B_d\bar{B}_d$ or $B_d\bar{B}_s/\bar{B}_dB_s$ pairs, it is necessary to take into account the correction coefficients (4) caused by tagging asymmetry due to the mixing of $B_d/\bar{B}_d$ or $B_s/\bar{B}_s$ used for the tagging. These coefficients are approximately equal to 0.65 and 0 for $B_d/\bar{B}_d$ and $B_s/\bar{B}_s$, respectively. If the relative production rates between different types of beauty particles are $B_d{:}B_u{:}B_s{:}\Lambda_b \approx 0.38{:}0.38{:}0.15{:}0.09$ [3], the average value of the observable CP-asymmetry $\bar{\delta}$ is somewhat less than (1):

$$\bar{\delta} \approx 0.7\cdot\delta.$$

Some corrections for the measured asymmetry (1) are connected with that among the detected leptons there are leptons which are not produced from the decays of beauty particles. However, one can assume that among leptons with high transverse momenta (P_T) such a rate must be small because the average transverse momenta of the produced beauty particles are large. Besides, corresponding background events are not correlated with the detected decays $B_d(\bar{B}_d) \rightarrow f/f'$ and, consequently, they can be estimated.

One of the main sources of systematic errors of the studied asymmetry δ is due to the admixture of leptons from the semi-leptonic decays of charmed particles which are also secondaries from the decays of beauty particles. These leptons are opposite in sign to those directly produced from the decays of beauty particles/antiparticles. Such a confusion leads to tagging asymmetry:

$$\xi = [N(lb^{\mp})-N(lc^{\mp})]/[N(lb^{\mp})+N(lc^{\pm})],$$

where $N(lb^+)$ and $N(lc^+)$ are the numbers of detected leptons which are from the decays of beauty and secondary charmed particles, respectively. A multiplicative correction, $A=\xi\cdot\delta$, arises from this tagging asymmetry. But, multipionic emission in the semi-leptonic decays is suppressed because of the isoscalar nature of the dominant transitions in such decays [9]. Then, due to a higher decay energy, the leptons from the decays of beauty particles have greater average value of P_T than those from the decays of secondary charmed particles. Consequently, the value of ξ tends to 1 at sufficiently high P_T and the corresponding systematic error becomes negligible.

The final states f and f' satisfying the required conditions are produced in the decays:

$$B_d(\bar{B}_d) \rightarrow J/\Psi + K_s. \tag{7a}$$

and

$$B_d(\bar{B}_d) \rightarrow J/\Psi + K_L. \tag{7b}$$

These states are opposite in CP parities but identical in other respects. Due to a maximum mixing of K^0 and $\bar{K}^0$, they are produced with equal probability in the considered decays (7a) and (7b). Consequently, the states f and f' are identical in quark contents. This leads to the same CKM matrix terms entering into expressions for the phase Φ definition and, consequently, to the same absolute value of the expected asymmetries (1) for these decays. The phase Φ can be calculated taking into account the corresponding quark diagrams for the studied decays. From such calculations it follows that the asymmetry δ usually becomes larger at smaller values of the decay widths. This is connected with that the CP-violation terms of the CKM matrix, which enter into the decay amplitude, are small and almost do not influence on the value of the decay width. So, the contribution of these terms to the decay amplitude is larger, and, consequently, the observed asymmetry becomes more significant with decreasing the decay width. Therefore, for choosing B^0 decays to search for the CP-asymmetry (1), it is necessary to compromise between smallness of the quantity δ and the decay width. From this point of view, the considered decays (7) are optimum in spite of small decay widths. According to theoretical estimates [2,10,11], the branching ratio of these decays is $(0.7\div5.0)\cdot10^{-3}$. This is apparently confirmed by the data [12] of the ARGUS experiment. The estimate of the corresponding asymmetry δ is limited by the precision of existing data on the CKM matrix terms entering into the phase definition [13]:

$$\Phi = \arg(U^*_{tb}\cdot U_{td}\cdot U_{cb}\cdot U^*_{cs}\cdot U_{cs}\cdot U^*_{cd}).$$

The expected asymmetry δ calculated in [3,13] equals from 0.07 to 0.30 in absolute value.

The decays (7) can be reliably identified experimentally by the explicit topology of two neutral Vee's and by the final state invariant mass. J/Ψ can be identified by the decay into $\mu^+\mu^-$, K_s into $\pi^+\pi^-$ and K_L into $\pi^+\pi^-\pi^0$ or $\pi^\pm\mu^\mp\overset{(-)}{\nu}$ *).

For the tagging it is possible to identify reliably the muon from the semi-leptonic decay of associatively

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*) In the case of the K_L semi-leptonic decay, the K_L momentum can be obtained by measuring the momenta of charged particles, $\pi^\pm$ and $\mu^\mp$, and the geometry of the production and decay vertices. The K_L momentum ambiguity arising from such a measurement leads to a combinatorial background in the invariant mass spectra in which a signal of the decays (7) should be searched for. But such a background among the selected B will be negligible if the mass resolution is high enough.

produced beauty particle and to measure the sign of its electric charge. Consequently, the suggested experiment must be optimized for the detection of trimuon events containing neutral Vee from the K_S/K_L decay with its vertex situated downstream the interaction one. Such events have a clear signature allowing one to select them in high intensity hadron beams.

Taking into account the presented estimates of the asymmetry (1) and the corrections arising in the frame of the considered approach, one obtains that for the observation of δ with a statistical significance of three standard deviations, it is necessary to accumulate ≈ 1500 each of the decays (7a) and (7b). Considering the composite branching ratio of all the decays which lead to the observable final states, one gets that more than 10^8 $B\bar{B}$ pairs should be produced for such statistics. The corresponding upper limit can be obtained by calculating the acceptance of a real experimental set-up. This acceptance cannot be high due to a limited size of the set-up and a long lifetime of K_L. The expected cross section of beauty particle hadroproduction within an energy region of 2÷3 TeV is from 0.1 to 0.2 μb per nucleon [14]. From these estimates it follows that the intensity of hadron beams in the discussed experiment must be greater than 10^{10} particles per s.

Summary

The general possibility is shown for the detection (and for the measurement under favourable conditions) of CP-violation in the B_d decays in a fixed target experiment carried out in high intensity beams. This requires to detect approximately equal numbers (≈1500) of the decays $B_d \to J/\psi + K_S$ and $B_d \to J/\psi + K_L$ in the same kinematic region. A muon from the semi-leptonic decay of an associatively produced beauty particle should be detected in each of these events. The B_d decays can be identified by the invariant mass of the final state characterized by a clear signature. The control that the muon is from the semi-leptonic decay of beauty particle can be done by analysing its transverse momentum which must be correlated with kinematic parameters of the detected B_d decays. The difference between the muon charge asymmetries measured respectively for each of two samples of events containing the first and second of the detected B_d decays, gives evidence for the observation of CP-violation in these decays.

The approach suggested to measure CP-violation in the B_d decays differs from most of the discussed ones because it does not require neither precise measurements of the vertices of beauty particle decays nor the identification of secondary charged hadrons. Such an approach substantially simplifies the performance of an experiment and makes it possible to do it in high intensity hadron beams and, thus, to reach the necessary luminosity. Nevertheless, the suggested experiment is extremely complex and needs careful optimization. One can assume that the 3 TeV UNK which is being built at Serpukhov (USSR) is an energy-optimal accelerator. But it may be possible that the experiment can be performed also at the FNAL Tevatron (USA).

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О возможности наблюдения CP-несохранения
в распадах B-мезонов в экспериментах
с фиксированной мишенью

Предложен подход к регистрации CP-несохранения в распадах нейтральных B-мезонов в экспериментах с фиксированной мишенью, проводимых на пучках высоких интенсивностей. Обсуждаются возникающие в таком подходе систематические ошибки асимметрии распадов, обусловленной CP-несохранением.

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Kekelidze V.D. E2-88-460

About a Possibility for Observation
of CP-Violation in B-Meson Decays
in Fixed Target Experiments

An approach to the detection of CP-violation in the decays of neutral B mesons at fixed target accelerators is suggested. This approach is feasible in experiments with high intensity hadron beams and, thus, allows one to employ one of the main advantages of fixed target accelerators. Possible systematic errors of the CP asymmetry measurement are also discussed. The B^0 decays into $J/\Psi+K_S$ and $J/\Psi+K_L$ are considered as an optimum for the detection of CP-violation.

The investigation has been performed at the Laboratory of High Energy Physics.

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