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WEAK CP VIOLATION AND QUANTUM CHROMODYNAMIC EFFECTS BEYOND THE LEADING LOGARITHM*

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ABSTRACT

Once the renormalization point is choosen near the value of quark masses, a power-correction contribution to the standard effective Hamiltonian has to be added. It is found that such corrections might considerably influence the ε'/ε ratio.

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The Kobayashi-Maskawa [1] model, that introduces CP violation in a natural way, has been studied systematically [2,3], with a conclusion that the violation of CP in K^0 decay would be approximately the same as given by the superweak model of Wolfenstein [4]. The discovery [5] that, in addition to the standard left-left terms, the operators with left-right (L-R) chiral structure ("Penguin" terms) enter the effective $\Delta S = 1$ Hamiltonian too, challenged this conclusion. In a pioneering work [6] Gilman and Wise raised the possibility that L-R part of the Hamiltonian,

$$H_{\text{eff}}^{\text{L-R}} = \frac{G}{\sqrt{2}} s_1 c_1 c_3 \mathscr{C} \bar{s} \lambda^a \gamma_\mu (1 - \gamma_5) d \sum_{\text{quarks}} \bar{\psi} \gamma^\mu \lambda^a \psi \quad , \tag{1}$$

yields predictions for the CP violation parameters of the kaon system (in particular ε'/ε) which are distinguishable from those of the superweak model. Even more, they argued that ε'/ε might have a value that could be measured in experiments now planned [7]. The calculation in [6] was done using the coefficient $\mathscr{C}$ (eq. (1)) estimated in the lowest, leading logarithmic, order in strong coupling, but the subsequent analysis [8], in which leading quantum chromodynamic (QCD) effects have been summed to all orders, supported the order-g^2 result.

However, more recently, the ratio ε'/ε was examined by Guberina and Peccei [9]. In contrast to refs. [6] and [8], they got the value considerably smaller and probably below the experimental bounds of the proposed experiments. The discrepancy arose not [10] because of slightly different treatment of QCD corrections [11], but mostly due to differences in the estimation of the K^0 decay amplitude. It is the goal of this work to show how the improved lowest order QCD analysis tends to wipe out these differences, leading to the same final result in both approaches.

The ratio ε'/ε can be calculated from the expression [3]

$$\left|\frac{\varepsilon'}{\varepsilon}\right| \approx \frac{1}{20}\left|\frac{2\xi}{\varepsilon_m + 2\xi}\right| \quad , \qquad (2)$$

where ε_m is the usual contribution to CP violation from the mass matrix, and parameter ξ measures the strength of the imaginary part of H_{eff}, and mostly depends on (1).* In ref. [6], ξ was found to be proportional to the ratio of the imaginary and real part of the coefficient $\mathscr{C}$

$$\xi_{GW} \approx f\,\frac{\mathrm{Im}\,\mathscr{C}}{\mathrm{Re}\,\mathscr{C}} \quad , \qquad (3)$$

where f is the fraction of the real $K^o \to \pi\pi$ $(I=0)$ amplitude that arises from matrix elements of the "Penguin" part of the effective Hamiltonian $(f = 0.75$ was used). In the second approach [9] an expression independent on the real part of $\mathscr{C}$ was used

$$\xi_{GP} \approx b\,\mathrm{Im}\,\mathscr{C} \quad , \qquad (4)$$

where b was estimated in the valence quark model $(b = 3.4$ has been found). The ratio $f/\mathrm{Re}\,\mathscr{C}$ makes ξ_{GW} (3) much bigger than ξ_{GP} (4), and increases the ε'/ε value (2).

It was already pointed out in ref. [9] that the principal contribution to the real part of $\mathscr{C}$ comes from the renormalization-group analysis in the region where non-leading contributions might be important. In this paper the coefficient $\mathscr{C}_2$ (to the order-g^2) beyond the leading-logarithm (LL) is investigated, in order to see how such added corrections influence the expressions (3) and (4). The related technique of calcula-

* In the superweak theory [4] $\varepsilon' = 0$.

tion is explained elsewhere [12], and here I will repeat just the main points.

The coefficient $\mathscr{C}_2$ is calculated basically by considering diagrams in fig. 1. The indicated subtraction insures that $\mathscr{C}_2$ is free of any dynamical effect [12]. The result of calculation is

$$\frac{8\pi^2}{g^2}\mathscr{C}_2 \approx \left[L\left(\frac{c}{u}\right) + s_2^2 L\left(\frac{t}{c}\right)\right] - i\,\frac{s_2c_2s_3}{c_1c_3}\sin\delta\left[L\left(\frac{t}{c}\right)\right]$$

$$= A - i\,\frac{s_2c_2s_3}{c_1c_3}\sin\delta\, B \quad , \qquad (5)$$

where

$$L\left(\frac{a}{b}\right) = \int_0^1 dx\; x(1-x)\;\ell n\,\frac{a^2+\mu^2x(1-x)}{b^2+\mu^2x(1-x)} \quad . \qquad (6)$$

In the LL approximation one supposes that $m_t \gg m_c \gg \mu \gg m_u$, and retains only leading terms in expansions of the integrals (6):

$$A_{LL} = \frac{1}{6}\left(\ell n\,\frac{m_c^2}{\mu^2} + s_2^2\;\ell n\,\frac{m_t^2}{m_c^2}\right) \quad , \qquad (7a)$$

$$B_{LL} = \frac{1}{6}\left(\ell n\,\frac{m_t^2}{m_c^2}\right) \quad . \qquad (7b)$$

However, for a more realistic choice, $m_c \gtrsim \mu$, in the evolution of the integrals (6) one must not forget power-corrections of the order μ^2/m_c^2, and the expression (5) gets much richer structure. In fig. 2, the real and (normalized) imaginary part of the function $\mathscr{C}_2$ (5) together with appropriate LL parts (7) are displayed. One can see that the real part of $\mathscr{C}_2$ depends crucially on non-leading corrections. For the choice $0.5 < \mu/m_c < 0.8$, Re$\mathscr{C}_2$ is <u>increased</u> by a factor 2 to 6, compared to the LL result. On the other hand, the $\mathrm{Im}\mathscr{C}_2$ remains almost unchanged. If the true $\mathscr{C}$ (with all-order strong corrections taken into account) exhibits the same behavior,* the parameter ξ_{GP} (4) will stay unaltered, and ξ_{GW} (3) will decrease to the order ξ_{GP}.

The consequences are obvious: when QCD corrections are calculated beyond the LL, both approaches (refs. [6], [8] and [9]) tend to give the same result for ε'/ε ratio, i.e., the result quoted in ref. [9]:

$$\frac{1}{250} \lesssim |\varepsilon'/\varepsilon| \lesssim \frac{1}{500} \qquad . \tag{8}$$

There is no doubt that if the measured value for ε'/ε happens to be different from zero, one will [10] finally have strong and explicit evidence on the importance of the L-R structure (1) in an effective $\Delta S = 1$ Hamiltonian. On the other hand, the value indicated in (8) seems to be so small, that even if the upcoming experiments [7] find no evidence that the ε'/ε differs from zero, neither the CP violating model [1] nor the "Penguin" concept can be ruled out.

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* By now it is not possible to treat non-leading QCD corrections analytically to all orders, and my conclusions rely on the lowest order calculation. However, there are some indications [12] from other $\Delta S = 1$ decays that the $\mathrm{Re}\mathscr{C}$ is bigger than given by ordinary LL QCD analysis.

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FIGURE CAPTIONS

Fig. 1. Basic diagrams for calculating the coefficient $\mathscr{C}_2$. The heavy dot represents the local operator from the effective Hamiltonian.

Fig. 2. The real (A) and imaginary (B) part of the coefficient $\mathscr{C}_2$. The calculation is done under the assumption that quark-mass parameters are constant in a considered range of μ. The values $m_t = 15$ GeV, $m_c = 1.5$ GeV and $\theta_2 = 15^{\circ}$ were used.

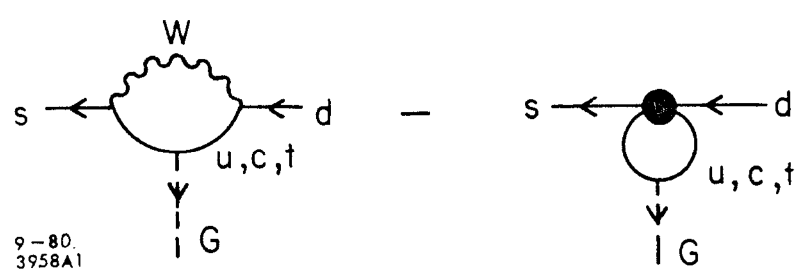

Fig. 1

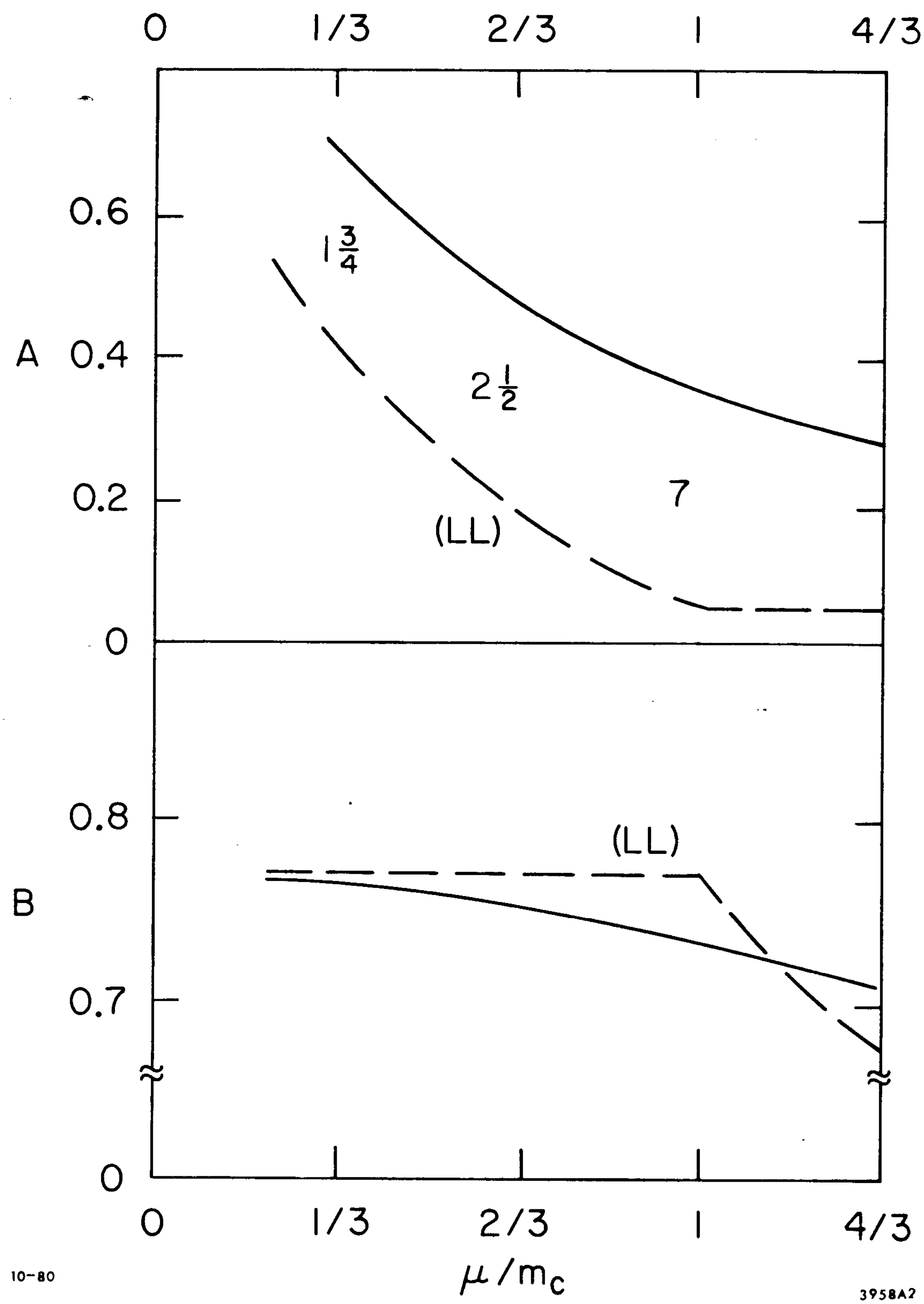
0
1/3
2/3
1
4/3
0.6
0.4
0.2
0
A
$1\frac{3}{4}$
$2\frac{1}{2}$
7
(LL)
0.8
0.7
B
(LL)
0
0
1/3
2/3
1
4/3
10-80
μ/m_c
3958A2

Fig. 2