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RECENT THEORETICAL DEVELOPMENT ON DIRECT CP VIOLATION ε'/ε

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Talk presented in "26th International Conference on High Energy Physics", 6-12 August, 1992, at Dallas, Texas, USA

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RECENT THEORETICAL DEVELOPMENT ON DIRECT CP VIOLATION ε'/ε

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Abstract

In this paper I review recent theoretical development on the direct CP violation parameter ε'/ε in the standard model and the accuracy of the predictions for it.

Direct CP violation is measured by the ratio ε'/ε, which has been studied extensively. The motivation to study the direct CP violation is known to understand the fundmental question: is the CP violation observed in 1964[1] in K^0 decay due to a fifth force —the 'superweak' interaction of Wolfenstein model[2], or a complex phase in the quark mixing matrix of Cabbibo—Kobayashi—Maskawa scheme[3] in the standard model? Since the theoretical predictions for ε'/ε in these two models are diffrent: $\varepsilon'/\varepsilon = 0$ in the superweak model and $\varepsilon'/\varepsilon = O(10^{-3})$[4-6] in the CKM model.

The recent experimental situation is not yet conclusive for these two models, the NA31[7] reported

$$\frac{\varepsilon'}{\varepsilon} = (2.3 \pm 0.7) \times 10^{-3} \qquad (1)$$

and the E731[8] reported the value

$$\frac{\varepsilon'}{\varepsilon} = (0.60 \pm 0.69) \times 10^{-3} \qquad (2)$$

As the calculation of ε'/ε in CKM model is not naive as in the superweak model, it has been studied more than ten years. I will briefly review in this talk the recent theretical development for ε'/ε. In the standard notation

$$\frac{\varepsilon'}{\varepsilon} = 1.25 \times 10^{-3}(\frac{Im\xi_t}{10^{-4}})(\frac{C_6(\mu) < Q_6 >_0}{0.05})(\frac{1-\Omega}{0.07}) \qquad (3)$$

Here (i) $Im\xi_t = |V_{cb}||V_{ub}|sin\delta$ is a parameter of CKM matrix. (ii) $C_6 < Q_6 >_0$ arises from the strong penguin. and (iii) $\Omega = \Omega_{EWP} + \Omega_{\eta-\eta'} + \Omega'$, with $\Omega_{EWP} = (C_8 < Q_8 >_2 + C_7 < Q_7 >_2)/(\omega C_6 < Q_6 >_0)$ being the relative contributions of electroweak penguins and $\Omega_{\eta-\eta'}$ the π^0-η -η' mixing. The Wilson coefficient functions C_i are obtained by integrating the renormalization group equations with both QCD and QED corrections present. It has been studied by many groups. The calculations[9-11] up to 1989 were only limited to the case when top quark mass m_t is much smaller than W-boson mass m_W ($m_t \ll m_W$). While the experimental data in 1989 indicated that the top quark mass may be heavy. In fact, in 1984 it was also pointed out by Chou et al.[12] that top quark mass might be larger than W-boson mass ($m_t > m_W$). It is therefore neccesary to evaluate the coefficient functions C_i in the case that $m_t > m_W$, which were performed in 1989 by several groups[13-17]. The most interesting observations for $m_t > m_W$ are that the coefficient function C_6 has only a very weak dependence on top quark mass, the coefficient functions C_7 and C_8 have, however, a very strong dependence on top quark

mass m_t and are increased very rapidly as top quark mass becomes larger than the W-boson mass, where the renormalization group effects play a crucial rule. Consequently when using the hadronic matrix elements computed with chiral Lagrangians[18] at the tree level, the contributions of electroweak penguin and strong penguin are comparable and important cancellations occur between these two terms when top quark mass is large. Because of this case that one year ago it was thought that for a heavy top quark the ratio ε'/ε could become very small[14-17] and thus imitate the superweak theory[2] for $m_t \sim 210$ GeV.

The estimates for the matrix elements of the operators Q_6, Q_7 and Q_8 are, however, incomplete because they do not reproduce the physical values for the isospin amplitudes A_0 and A_2. For this reason the authors[4-6] improved the estimates for the hadronic matrix elements by including the one-loop corrections in chiral perturbation theory. The numerical calculations found that[4-6] for $\mu = 1$ GeV and $\Lambda_4 = 300$MeV

$$\begin{aligned} < Q_6 >_0 &= 2.8 < Q_6 >_0^{LO} \\ &= 1.44(\frac{125MeV}{m_s})^2 GeV^3 \quad (4) \\ < Q_8 >_2 &= 1.47 < Q_8 >_2^{LO} \\ &= 0.94(\frac{125MeV}{m_s})^2 GeV^3 \quad (5) \\ \Omega_{EWP} &= 0.52\Omega_{EWP}^{LO} \quad (6) \end{aligned}$$

which revealed that the importance of the electroweak penguin relative to the gluon penguin is diminished and reduced by a fact 1.9. Therefore the large cancellation between electroweak penguin and strong penguin does not occur any more even when the mass of the top quark is very large. In addition the next-to-leading order corrections to the Wilson coefficient functions were also found[19] to diminish the Ω_{EWP} by $(20 \sim 30)\%$.

The accuracy of the improved estimates were discussed in detail in the most recent paper[6]. One of the criteria is the scale μ – *dependence*. The quantities which enter physical processes are $C_i(\mu) < Q_i >_I$ and, in principle, should be independent of μ. For that a useful approach was developed by Bardeen, Buras and Gerard[20], who suggested to calculate the chiral loops with a finite cutoff M_{cut} and regard M_{cut} to be a physical quantity which is not removed by counter terms, but instead is identified with the renormalization scale μ of the short distance contribution $C_i(\mu)$. It was noted that for $\Lambda_4 = 200$MeV and when μ changes from 0.6 GeV to 1.0 GeV the variation for $C_6 < Q_6 >$ is about 18%. These should be compared with a variation of 100% for $< Q_6 >$ alone. The improvement for $< Q_8 >_2$ is even more impressive, since the variation of $C_8(\mu) < Q_8 >_2$ is 1% while $< Q_8 >_2$ varies 65%.

Additional support for chiral calculations comes from the fact that they reproduce the transition amplitudes A_0 and A_2. Similar calculations were published earlier[20] and included the one-loop corrections for $< Q_1 >_I$ and $< Q_2 >_I$. When the new values for $< Q_6 >$ were included, a better agreement for A_0 was found[5,6], see table 1.

Moreover, most of the models which favor to the $\Delta I = 1/2$ amplitude A_0 also obtained big values of $< Q_6 >_0$. For example, $< Q_6 >_0 = 1.46(\frac{125MeV}{m_s})^2 GeV^3$ in a linear σ chiral dynamic model[21] and $< Q_6 >_0 = 1.40 GeV^3$ in the bag model[22] , comparing these values with eq.(4), a remarkable agreement occur among these models.

The estimates of $Im\xi_t$ depend on elements of the CKM matrix and CP phase δ. The matrix elements $|V_{cb}|$ and $|V_{ub}|$ are determined directly from semileptonic B-meson decays[23,24]

$$|V_{cb}| = 0.041 \pm 0.003, \quad \frac{|V_{ub}|}{|V_{cb}|} = 0.12 \pm 0.03 \quad (7)$$

The estimate of the CP phase is quite standard from fitting the ϵ_k parameter for K^0 mesons

Table 1. Predictions for the amplitude A_0 in unit of 10^{-7} GeV. In parentheses are the earlier values of BBG[20]

m_s(MeV)	100	125	150	175	200
A_0^{th}/A_0^{exp}	1.18	0.96	0.84	0.76	0.72
	(0.78)	(0.67)	(0.63)	(0.61)	(0.60)

and $B^0 - \bar{B}^0$ mixing . Choosing for the additional parameters[25]

$$B_k = 0.75 \pm 0.20 \qquad (8)$$

and

$$\sqrt{\eta_B^{QCD}}\sqrt{B_B} f_B = 120 \pm 18 MeV \qquad (9)$$

where the stable values of f_B calculated from QCD are sensitive to the choice of the pole mass of the bottom quark[26]. With these input prameters the range of $Im\xi_t$ is given by

$$0.58 \times 10^{-4}\varepsilon_t \leq Im\xi_t \leq 2.85 \times 10^{-4}\chi_t \qquad (10)$$

$$\varepsilon = [\frac{140GeV}{m_t}]^{1.42}(1 + 0.1ln\frac{140GeV}{m_t}) \qquad (11)$$

$$\chi_t = [\frac{140GeV}{m_t}]^{0.8}\sqrt{1 + 0.754(1 - \frac{140GeV}{m_t})^{1.6}}$$

After a brief review for the theoretical development of the calculations for each factors involved in the computation of ε'/ε, it is now in the position to make the conclusions for the ratio ε'/ε. For $100GeV \leq m_t \leq 250GeV$

i) The superweak behavor of ε'/ε in the CKM scheme of the standard model is excluded definitely since

$$0.35 \leq 1 - \Omega \leq 0.70 \qquad (12)$$

ii) ε'/ε is enhanced by a factor 3.5 due to next-to- leading order contributions

$$C_6 < Q_6 >_0 = 3.5 C_6 < Q_6 >_0 |_{LO} \qquad (13)$$

iii) The big uncertanties still mainly come from the range of $Im\xi_t$.

$$0.24 \times 10^{-4} \leq Im\xi_t \leq 2.6 \times 10^{-4} \qquad (14)$$

iv) The allowed values of ε'/ε

$$(\frac{150MeV}{m_s})^2 0.46\times10^{-3} \leq \frac{\varepsilon'}{\varepsilon} \leq 8.7\times10^{-3}(\frac{150MeV}{m_s})^2 \qquad (15)$$

v) Simultaneously the $\Delta I = 1/2$ amplitudes are closer to the data and the dependence of the amplitudes on μ is also improved.

vi) Taking the plausible central values of input parameters, a consisitent prediction comes to

$$m_t \sim 140GeV, \ \delta \sim 150^0 \qquad (16)$$

and

$$\frac{\varepsilon'}{\varepsilon} = 2.6 \times 10^{-3}(\frac{150MeV}{m_s})^2 \qquad (17)$$

It is therefore optimistic that the measurement of the ratio ε'/ε is sufficient to distinguish the superweak model and CKM model. Let us wait for the improved new experiments NA48, KTeV, DAPHNE and CP LEAR.

ACKNOWLEDGMENT

I wish to thank E.A. Paschos for many enjoyable collaborations and useful suggestions. Many thanks go also to K.C. Chou and T.D. Lee for their encouragements and W.A. Bardeen and J.M. Gerard for their useful discussions.

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