Physics Letters B 709 (2012) 362–365

Contents lists available at SciVerse ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

Can up FCNC solve the ΔA_{CP} puzzle?

Kai Wang, Guohuai Zhu *

Zhejiang Institute of Modern Physics and Department of Physics, Zhejiang University, Hangzhou, Zhejiang 310027, China

ARTICLE INFO

Article history:
Received 28 November 2011
Received in revised form 6 February 2012
Accepted 8 February 2012
Available online 10 February 2012
Editor: T. Yanagida

ABSTRACT

We investigate the attempt using flavor violation gauge interaction in the up sector to explain the LHCb recently observed large ΔA_{CP} ($A_{CP}(D^0 \to K^+K^-) - A_{CP}(D^0 \to \pi^+\pi^-)$). We study an Abelian model that only right-handed up quarks is charged under it and the 1–3 coupling is maximized. The simultaneous 1–3 2–3 mixing is realized by a quark mixing of 1–2 generation. Given the easy identification of top quark, the model can be directly tested by $\Delta F = 1$ and $\Delta F = 2$ processes at the hadron colliders as associated top production $gc \to tZ'$ or same-sign top scattering $uu \to tt$. The direct search bounds are still consistent with the assumption that ut and ct couplings are equal but the same-sign top scattering bound is expected to be reached very soon. However, since there is no CKM-like suppression, the corresponding parameter space for generating ΔA_{CP} is completely excluded by the D^0–$\bar{D}^0$ mixing. We conclude that the up FCNC type models cannot explain the ΔA_{CP} while to be consistent with the D^0–$\bar{D}^0$ mixing constraint at the same time. On the other hand, a model as SM with fourth family extension has better chance to explain the large ΔA_{CP} consistently.

1. Introduction

CP violation in the D meson decay processes $c \to uq\bar{q}$ is highly suppressed in the standard model (SM). Given its small SM expectation, CP violation in D meson decay play important role to probe models beyond SM (see, for example [1] and references therein). Recently, the LHCb Collaboration has reported a measurement of difference in CP asymmetry, $A_{CP}(D^0 \to K^+K^-) - A_{CP}(D^0 \to \pi^+\pi^-)$ based on the data of 580 pb^{-1} [2]. The measured difference in CP asymmetry,

$$\Delta A_{CP} = \left[-0.82 \pm 0.21(\text{stat.}) \pm 0.11(\text{sys.})\right]\% \tag{1}$$

which corresponds to the SM prediction of $\mathcal{O}(10^{-4})$ as an order of magnitude estimation, as explained in the following. Then naively the deviation from the SM prediction is 3.5σ evidence. The CPV in $c \to uq\bar{q}$ arises from the interference between tree level amplitude of SM charged current and the QCD penguin amplitude. As a result of GIM-mechanism [3], the QCD penguin amplitude completely vanish at the limit when internal quarks in penguins are massless. Within the SM framework, non-zero contribution to direct CP violation comes only from the bottom quark which is proportional to $V_{cb}^* V_{ub} m_b^2/m_W^2$. The CKM factor here is very small, suppressed by λ^5. With additional loop factor suppression, the CP violation in $c \to uq\bar{q}$ is typically of $\mathcal{O}(10^{-4})$ in short distance calculation. It is unlikely that nonpertubative effects may enhance the direct CP violation to be significantly above 10^{-3}, though this possibility cannot be excluded [4,5].

The recent measure of difference in $D^0 \to K^+K^-$ and $D^0 \to \pi^+\pi^-$ basically minimize the effect from indirect CP violation, namely CP violation in the D^0–$\bar{D}^0$ mixing. The significant ΔA_{CP} clearly indicates that the observed CP violation should occur in the $c \to uq\bar{q}$ decay directly. To solve the anomaly, new physics is required to enhance the CP violation in $c \to uq\bar{q}$ decay, which has been analyzed recently in [6] in an effective theory approach. One simple extension of SM is to introduce a fourth family of quarks and leptons, the fourth generation down quark b' of 400 GeV can enhance the penguin amplitude by $\mathcal{O}(10^4)$ in mass squared but with suppression from quark mixing. The Cabibbo–Koboyashi–Maskawa quark mixing matrix (CKM) of fourth family is constrained by precision electroweak tests, for instance ρ-parameter and the 34-mixing of λ is allowed [7]. We estimate the suppression from quark mixing of CKM4 is about λ^7 and the penguin amplitude is then enhanced by $\mathcal{O}(10^2)$ from the fourth generation b' contribution. It does provide possible parameter space to accommodate the about 1% CP violation. At the same time, the contribution to the D^0–$\bar{D}^0$ mixing is under control with additional CKM suppression [8]. However, in this Letter, we would like to focus on the other possibility involving top quark.

Top quark contribution is GIM violation. As the heaviest known particle that gets its mass via electroweak symmetry breaking

* Corresponding author.
E-mail addresses: wangkai1@zju.edu.cn (K. Wang), zhugh@zju.edu.cn (G. Zhu).

0370-2693
doi:10.1016/j.physletb.2012.02.021

(EWSB), top quarks couples to the longitudinal polarized W_L state strongly and leads to the enhancement as m_t^2/m_W^2 in the SM penguin of $b \to d_i$ transition. On the other hand, in many new physics models, top quark very often appears in $c \to u$ transition and the $\Delta C = 1$ decay like $c \to uq\bar{q}$ is very sensitive to such models. More interestingly, since top quarks decay before hadronization and can be directly measured at detectors, if the new physics involves top quarks, both $\Delta C = 1$ and $\Delta C = 2$ can also be tested at the collider directly: $gc \to tZ'$ and $cc \to tt$ (or $gu \to tZ'$ and $uu \to tt$).

A recent anomaly observed at the Tevatron basically motivated most of such models of $c \to u$ transition involving the top quarks. CDF Collaboration at Tevatron in this January reported the reconstructed top quark forward–backward asymmetry in the semi-leptonic $t\bar{t}$ system. The most significant deviation appears in the $t\bar{t}$ sample with large $t\bar{t}$ invariant mass $M_{t\bar{t}}$ while the others are mostly within 2 σ. For $M_{t\bar{t}} > 450$ GeV, the forward–backward asymmetry for reconstructed top quark measured in the $t\bar{t}$ rest frame is [9]

$$A_{FB}^{t\bar{t}}(M_{t\bar{t}} > 450\ \text{GeV}) = 0.475 \pm 0.112. \tag{2}$$

The measurement corresponds to the SM prediction $A_{FB}^{t\bar{t}}(\text{CDF}) = 0.128$ [10] which includes both QCD $\mathcal{O}(\alpha_s^3)$ and electroweak $\mathcal{O}(\alpha_s^2\alpha)$ corrections. Again, this deviation appears as over 3σ.[1] Since the other measurements in $t\bar{t}$ like total production rate $\sigma_{t\bar{t}}$ are in good agreement with the SM predictions, the proposals to solve the large A_{FB} all require destructive interference between the new physics and the SM $u\bar{u} \xrightarrow{g} t\bar{t}$, $d\bar{d} \xrightarrow{g} t\bar{t}$. In addition, since the anomaly corresponds to a large $M_{t\bar{t}}$ region, the t-channel proposal [11–15] which maximize the asymmetry at Rutherford singularity $\theta = 0$ match the basic feature of the measurement. Among the proposals, t-channel neutral current process interferes with the largest SM mode $u\bar{t} \xrightarrow{g} t\bar{t}$ and spin-correlation also maximize the positive forward–backward asymmetry [11,14,15]. However, in order to explain the top quark forward–backward asymmetry puzzle, only significant ut coupling is required and this is not sufficient to generate the $c \to u$ transition. In this Letter, we investigate the possibility of generating $c \to u$ transition mediated by the top quark penguin.

Not surprisingly, the most stringent constraint would come from D^0–$\bar{D}^0$ mixing. Unlike the QCD penguin, D^0–$\bar{D}^0$ mixing in the SM is dominated by the strange quark contribution. At amplitude level, the bottom quark contribution in the box diagram is suppressed by a factor of λ^{10} while the corresponding strange quark contribution is only λ^2 suppression but the mass dependence is still quadratic as m_q^2/m_W^2.

In the next section, we discuss the model setup. Then we study the model parameter space required by the ΔA_{CP} measurement in Section 3. In Section 4, various constraints of the model are discussed, in both low energy physics like D^0–$\bar{D}^0$ and collider experiments like same-sign top quark, inclusive $t\bar{t}$ search. We then conclude in the final section.

2. Model

In order to achieve large $c \to u$ transition induced by top quark penguin, the new gauge interaction must couple to both $\bar{t}c$ and $\bar{t}u$. Flavor changing interactions in the SM can only be measured via electroweak charged current interactions. For the SM fermion rotation matrices, the left-handed ones get constrained from the CKM matrix $V_L^u(V_L^d)^\dagger = V_{CKM}$ but only the product instead of the V_L^u and V_L^d respectively. The rotations for the right-handed states are then completely unknown and this gives large degree of freedom.

We first study an Abelian model, a $U(1)_X$ gauge symmetry under which only right-handed up-type quarks transform. With only the SM particle contents, the $U(1)_X$ is anomalous so we expect a UV completion theory. Presumably a much larger gauge group is broken at very high energy and only a $U(1)_X$ survive to low energy and is broken around TeV scale. In this Letter, we don't discuss the detail of the UV theory. Instead, we concentrate on the low energy theory of the electroweak scale $U(1)_X$ gauge boson interacting with the SM fermions.

In the flavor basis of (uct), $U(1)_X$ is

$$T = \lambda_4 = \begin{pmatrix} 0 & 0 & 1 \\ 0 & 0 & 0 \\ 1 & 0 & 0 \end{pmatrix} \tag{3}$$

which shows only ut couples to the Z'. As discussed earlier, there also exists degree of freedom of right-handed up quark rotation. We take a special choice of the rotation V_R^u to illustrate the feature.

$$V_R^u = \begin{pmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{pmatrix}. \tag{4}$$

The CP violating phase $e^{i\delta}$ can be easily included into the above rotation.

Assuming the phase difference δ between the right-handed up quark and charm quark, the effective Lagrangian is then

$$\frac{g_X}{\sqrt{2}} Z'_\mu \left(\bar{t}_R\gamma^\mu u_R c_\theta + e^{-i\delta}\bar{t}_R\gamma^\mu c_R s_\theta\right) \tag{5}$$

where $c_\theta = \cos\theta$, $s_\theta = \sin\theta$, g_X is the coupling constant of the $U(1)_X$.

If the particle Z' is completely neutral which enable Z' to couple $\bar{t}u$, $\bar{u}t$ at the same time. Both $u\bar{u} \to t\bar{t}$ and $uu \to tt$ exist and the first one dominates at the p–$\bar{p}$ collisions at Tevatron while the second one dominates at the Large Hadron Collider (LHC). Given its huge u-valence quark flux at the p–p collider LHC, even with 7 TeV total energy, the Z' receives severe constrain from direct search of $uu \to tt$ [15]. To resolve the same-sign top puzzle, non-Abelian horizontal gauge symmetry models are proposed in [11,14]. In principle, a non-Abelian model where $(u_R t_R)^T$ form a doublet under a $SU(2)_X$ and can avoid large same-sign top quark production and box contribution to D^0–$\bar{D}^0$ mixing. However, the rotation to give ct couplings will generate large uc-mixing mediated by the W^3. $W'^{\pm}$ and W'^3 are nearly degenerate at the $SU(2)_X$ limit. Then the tree level D^0–$\bar{D}^0$ mixing is inevitable. The parameter space that generates the ΔA_{CP} will correspond to unacceptable D^0–$\bar{D}^0$ mixing.

3. Direct CP violation in *D* decays

For singly Cabibbo suppressed (SCS) D decays, the SM penguin contributions can be safely neglected, as they are highly suppressed by the CKM factor $V*_{cb}V_{ub}$, the GIM suppression m_b^2/m_W^2 and the loop factors (see, for example [1] and references therein). However the Z'-induced FCNC is only loop suppressed, which may provide large enough CP violation effects to account for the LHCb measurement. The relevant $\Delta C = 1$ effective Hamiltonian is given by

[1] The CDF observation is not confirmed by the D0 Collaboration. The unfolded D0 measurement of $A_{FB}^{t\bar{t}}(M_{t\bar{t}} > 450\ \text{GeV}) = 0.115 \pm 0.06$ which is within 1σ of SM prediction [10].

$$H_{eff}^{\Delta C=1} = \frac{G_F}{\sqrt{2}}\left[\sum_{p=d,s}\lambda_p\left(C_1 Q_1^p + C_2 Q_2^p\right) + \sum_{i=3}^{6}\tilde{C}_i(\mu)\tilde{Q}_i(\mu)\right] + \text{H.c.}, \tag{6}$$

with $\lambda_p = V_{cp}^\star V_{up}$ are the CKM factors. $Q_1^p = (\bar{p}c)_{V-A}(\bar{u}p)_{V-A}$ and $Q_2^p = (\bar{p}_\alpha c_\beta)_{V-A}(\bar{u}_\beta p_\alpha)_{V-A}$ are the SM current–current operators where α, β are color indices. By integrating out the right-handed Z' field, one obtains $\tilde{Q}_{3,5} = (\bar{u}c)_{V+A}\sum_q(\bar{q}q)_{V\pm A}$ and $\tilde{Q}_{4,6} = (\bar{u}_\alpha c_\beta)_{V+A}\sum_q(\bar{q}_\beta q_\alpha)_{V\pm A}$ with $q = u, d, s$. For order-of-magnitude estimation for $D \to KK, \pi\pi$ decays, we use naive factorization with the Wilson coefficients at leading order. The magnitude of direct CP violation is determined by the ratio of new physics amplitude over the SM amplitude

$$\frac{A_{NF}(D \to PP)}{A_{SM}(D \to PP)} = \frac{\tilde{C}_4 + \tilde{C}_3/N_c + r_\chi(\tilde{C}_6 + \tilde{C}_5/N_c)}{\lambda_p(C_1 + C_2/N_c)} \tag{7}$$

where $r_\chi = 2m_K^2/m_c(m_s + m_q) = 2m_\pi^2/m_c(m_u + m_d)$ in the $SU(3)$ flavor limit with $m_q = (m_u + m_d)/2$. $P = K, \pi$ and $N_c = 3$ in the naive factorization. The Z'-induced Wilson coefficients at leading order can be obtained at the scale $\mu \simeq m_t$ as

$$\tilde{C}_{4,6} = -3\tilde{C}_{3,5} = \frac{\alpha_s(m_t) g_X^2 \sin 2\theta e^{-i\delta}}{64\sqrt{2}\pi G_F m_{Z'}^2} E_0\left(m_t^2/m_{Z'}^2\right) \tag{8}$$

with the loop function [16]

$$E_0(x) = -\frac{2}{3}\ln x + \frac{x(18 - 11x - x^2)}{12(1-x)^3} + \frac{x^2(15 - 16x + 4x^2)}{6(1-x)^4}\ln x. \tag{9}$$

Notice that the renormalization group evolution of $\tilde{C}_i$ is the same as that of the SM QCD penguin operators by $L \leftrightarrow R$ interchange. The Wilson coefficients at the scale μ_c can then be evaluated as

$$\tilde{C}(\mu_c) = U_5(\mu_c, m_t)\tilde{C}(m_t) \tag{10}$$

with the expression of U_5 given in [17]. Here we have ignored the b quark mass threshold for simplicity. As the U-spin symmetry predicts $A_{CP}(K^+K^-) = -A_{CP}(\pi^+\pi^-)$, the LHCb evidence implies $A_{CP}(K^+K^-) \simeq -0.0041 \pm 0.0012$ in the flavor symmetry limit. Numerically we take $m_c(m_c) = 1.64$ GeV and $m_s = 100$ MeV, $m_q = 4.5$ MeV at $\mu = 2$ GeV. Assuming the maximal CP phase $\delta = \pi/2$, we show in Fig. 1 the contour plot of $A_{CP}(K^+K^-)$ as a function of the parameters $M_{Z'}$ and $g_X\sqrt{\sin 2\theta}$.

4. Collider implications

As we discussed earlier, the up FCNC model is motivated to explain the top quark forward–backward asymmetry. Fig. 1 shows the best fit parameter region for such Z' to explain the direct CP violation of $D \to K^+K^-$. The dominant contribution for top quark A_{FB} is through ut coupling which is $g_X \cos\theta$ in the above model. For a particular choice of $\theta \in \{0, \pi/4\}$, the parameter space is consistent with the 1σ fitting of $A_{FB}^{t\bar{t}}(M_{t\bar{t}} > 450\text{ GeV})$ [15] observed by the CDF Collaboration.

The flavor violating processes not only appear in the low energy physics but also appear in the collider experiments. However, due to the challenge in the identification of the light quarks states, only when the flavor violation involves top quarks directly, the measurements become possible. In these models with up FCNC, both $\Delta F = 1$ and $\Delta F = 2$ effects are observable at hadron collider.

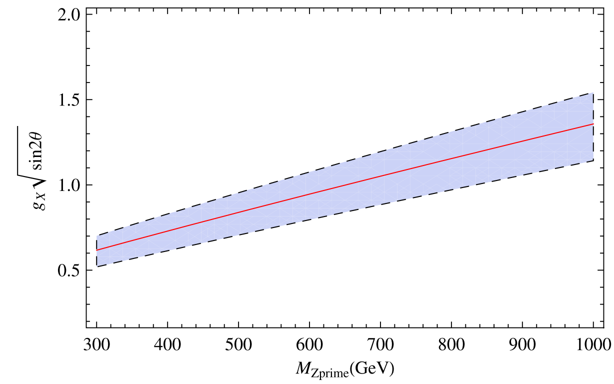

Fig. 1. Contour plot of the direct CP violation of $D \to K^+K^-$ as a function of the parameters $M_{Z'}$ and $g_X\sqrt{\sin 2\theta}$. The solid red line represents the experimental central value and the light blue (grey) region corresponds to one sigma contour. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this Letter.)

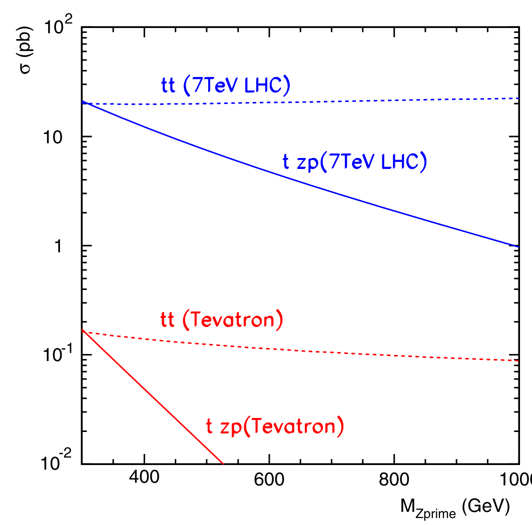

Fig. 2. Production cross sections for $\sigma(pp \to tt/\bar{t}\bar{t})$ at Tevatron and the 7 TeV LHC and the $\sigma(pp \to tZ'/\bar{t}Z')$ at Tevatron and the 7 TeV LHC. The coupling is taken to be $\theta = \pi/4$.

The $\Delta F = 1$ processes correspond to single top production associated with the Z' $gc \to tZ'$ or $gu \to tZ'$. For Abelian model, Z' can also mediate $uu \to tt$ or $cc \to tt$. The Large Hadron Collider (LHC) is a proton–proton collider with center-of-mass energy 7 TeV in the first two years running. The same-sign positive top quark pair ($uu \to tt$) becomes particular interesting at the LHC given its large u-valence quark parton flux. However, the $\sigma_{uu\to tt}$ is proportional to $\cos^4\theta$ while the $\sigma_{cc\to tt}$ has a factor as $\sin^4\theta$. The bounds from flavor physics is only on $\sin 2\theta$. In addition, without phase-space suppression at the 7 TeV LHC, the tZ' associate production is significant. Since Z' equally decays into $u\bar{t}$ and $t\bar{u}$, the associated production tZ' or $\bar{t}Z'$ will contribute to $tt + j$, $\bar{t}\bar{t} + j$ and $t\bar{t} + j$ final states. And the $t\bar{t} + j$ will appear in the inclusive $t\bar{t}$ search. However, it has been studied in [15], the best-fit parameter space to explain the top quark A_{FB} via Z' is largely excluded by the Tevatron/LHC same-sign top search and the inclusive $t\bar{t}$ at the LHC for $t\bar{t} + j$. We will not use the fitting parameter from top quark A_{FB}. Instead, we focus on the Z' that can explain the ΔA_{CP} alone where the ut coupling does not dominate the Z' penguin. With larger ct coupling, the direct search bound is weaker. To illustrate the feature, we take the $\theta = \pi/4$ so that $\sin 2\theta$ reaches its maximal.

Fig. 2 gives the $pp \to tt$ production rate at Tevatron and the 7 TeV LHC with $\theta = \pi/4$ in Fig. 1. The $p\bar{p} \to tt/\bar{t}\bar{t}$ at Tevatron is below 0.2 pb for these best fit points and this corresponds to about 10 pure-leptonic same-sign top events with one b-tagging (50% tagging efficiency) before any cut for integrated luminosity of 2 fb^{-1}. CDF measured 3 events for 2 fb^{-1} [18] with the acceptance range from 1.5% to 3%. It is still consistent with the measurements. At LHC with 35 pb^{-1}, the prediction is about 20 events of pure-leptonic same-sign top with one b-tagging. Since tt production is mostly t-channel, one expects the cut efficiency for the forward–backward region top quarks are less. The latest LHC observation is 2 events for 35 pb^{-1} [19]. It seems to be still consistent with the observation at this moment. However, given its large rate, the parameter region should soon be probed by the CMS or ATLAS experiments. The tZ' production which comes into the inclusive $t\bar{t}$ search is still within the error bar of the measurements.

5. D^0–$\bar{D}^0$ mixing

Any theory that contributes to $c \to uq\bar{q}$ is inevitable to generate the $\Delta C = 2$ process of D^0–$\bar{D}^0$ mixing. In the SM, D^0–$\bar{D}^0$ mixing is very slow due to the GIM mechanism, which is particularly effective in D meson since the b quark contribution is accidentally suppressed by a very small CKM factor. But new physics without flavor suppression could easily saturate or even badly violate the experimental bound. The strongest bound comes from the Belle results [20] $x = (0.80 \pm 0.29 \pm 0.17)\%$, $y = (0.33 \pm 0.24 \pm 0.15)\%$, which leads to [21]

$$\left|M_{12}^D\right| \lesssim 1.2 \times 10^{-14}\ \text{GeV} \tag{11}$$

assuming CP conservation in mixing. Otherwise, the bound would be relaxed by a factor ~ 2.

It is straightforward to evaluate the Z' contribution to the D^0–$\bar{D}^0$ mixing,

$$M_{12}^D = \frac{g_X^4 \sin^2 2\theta}{1536\pi^2 m_{Z'}^2}\left(\frac{\alpha_s(m_t)}{\alpha_s(\mu_c)}\right)^{6/23} F(x_t, x_t) f_D^2 m_D \tag{12}$$

with $x_t = m_t^2/m_{Z'}^2$. The vacuum insertion approximation has been adopted in the above for simplicity

$$\left\langle D^0\right|(\bar{u}c)_{V+A}(\bar{u}c)_{V+A}\left|\bar{D}^0\right\rangle = \frac{8}{3} m_D^2 f_D^2 \tag{13}$$

and the Inami–Lim loop function $F(x, y)$ [16] reads

$$F(x, x) = \frac{4 + 4x - 15x^2 + x^3}{4(1-x)^2} + \frac{x(4 - 4x - 3x^2)}{2(1-x)^3}\ln x \tag{14}$$

in the limit $y \to x$. Taking $f_D = 220$ MeV, one finds unfortunately that the Z'-induced D^0–$\bar{D}^0$ mixing is two to three orders of magnitude larger than the experimental bound Eq. (11), for the favored parameter region shown in Fig. 1.

6. Conclusion

In this Letter, we investigate the up FCNC models of flavor violation gauge interaction in the up sector to explain the LHCb recent observed large ΔA_{CP} ($A_{CP}(D^0 \to K^+K^-) - A_{CP}(D^0 \to \pi^+\pi^-)$). To illustrate the feature, we study an Abelian model that only right-handed up quarks is charged under it and the 1–3 coupling is maximized. The simultaneous 1–3 and 2–3 mixing is realized by a quark mixing of 1–2 generation. Given the easy identification of top quark, the model can be directly tested by $\Delta F = 1$ and $\Delta F = 2$ processes at the hadron colliders as associated top production $gc \to tZ'$ or same-sign top scattering $uu \to tt$. The direct search bounds are still consistent with the assumption that ut and ct couplings are equal but the same-sign top scattering bound is expected to be reached very soon.

However, since there is no CKM-like suppression, the corresponding parameter space for generating ΔA_{CP} is completely excluded by the D^0–$\bar{D}^0$ mixing. We conclude that the up FCNC type models cannot explain the ΔA_{CP} while to be consistent with the D^0–$\bar{D}^0$ mixing constraint. On the other hand, a model as SM with fourth family extension has better chance to explain the large ΔA_{CP} consistently.

Acknowledgements

We would like to thank Ming-Xing Luo for useful discussion. K.W. is supported by the Fundamental Research Funds for the Central Universities (2011QNA3017). G.Z. is supported by the National Science Foundation of China (No. 11075139 and No. 10705024) and the Fundamental Research Funds for the Central Universities.

References

[1] Y. Grossman, A.L. Kagan, Y. Nir, Phys. Rev. D 75 (2007) 036008, hep-ph/0609178.
[2] Matt Charles, for LHCb Collaboration, LHCb-CONF-2011-061.
[3] S.L. Glashow, J. Iliopoulos, L. Maiani, Phys. Rev. D 2 (1970) 1285.
[4] M. Golden, B. Grinstein, Phys. Lett. B 222 (1989) 501.
[5] J. Brod, A.L. Kagan, J. Zupan, arXiv:1111.5000 [hep-ph].
[6] G. Isidori, J.F. Kamenik, Z. Ligeti, G. Perez, arXiv:1111.4987 [hep-ph].
[7] M.S. Chanowitz, Phys. Rev. D 035018 (2010), arXiv:1007.0043 [hep-ph].
[8] K. Wang, G. Zhu, in preparation.
[9] T. Aaltonen, et al., CDF Collaboration, Phys. Rev. D 83 (2011) 112003, arXiv:1101.0034 [hep-ex].
[10] W. Hollik, D. Pagani, arXiv:1107.2606 [hep-ph].
[11] S. Jung, H. Murayama, A. Pierce, J.D. Wells, Phys. Rev. D 81 (2010) 015004, arXiv:0907.4112 [hep-ph].
[12] K. Cheung, W.-Y. Keung, T.-C. Yuan, Phys. Lett. B 682 (2009) 287, arXiv:0908.2589 [hep-ph].
[13] J. Shu, T.M.P. Tait, K. Wang, Phys. Rev. D 81 (2010) 034012, arXiv:0911.3237 [hep-ph].
[14] S. Jung, A. Pierce, J.D. Wells, Phys. Rev. D 83 (2011) 114039, arXiv:1103.4835 [hep-ph].
[15] J. Shu, K. Wang, G. Zhu, arXiv:1104.0083 [hep-ph].
[16] T. Inami, C.S. Lim, Prog. Theor. Phys. 65 (1981) 297;
T. Inami, C.S. Lim, Prog. Theor. Phys. 65 (1981) 1772 (Erratum).
[17] G. Buchalla, A.J. Buras, M.E. Lautenbacher, Rev. Mod. Phys. 68 (1996) 1125, hep-ph/9512380.
[18] T. Aaltonen, et al., CDF Collaboration, Phys. Rev. Lett. 102 (2009) 041801, arXiv:0809.4903 [hep-ex].
[19] S. Chatrchyan, et al., CMS Collaboration, JHEP 1106 (2011) 077, arXiv:1104.3168 [hep-ex].
[20] K. Abe, et al., BELLE Collaboration, Phys. Rev. Lett. 99 (2007) 131803, arXiv:0704.1000 [hep-ex].
[21] Y. Nir, JHEP 0705 (2007) 102, hep-ph/0703235.