ISSN 1512-1461

PACS: 13.20.He, 13.25.Hw, 11.10.Kk

ON THE NEUTRAL B-MESON DOUBLE PHOTON DECAY IN THE ACD MODEL

G. G. Devidze[1], V.G. Kartvelishvili[2], A. G. Liparteliani[1]

[1]High Energy Physics Institute, Tbilisi State University, University St.9, Tbilisi 0186, Georgia; gela.devidze@tsu.ge
[2]Lancaster University, UK

Abstract:
In the presented paper we have estimated additional to the Standard Model (SM) contributions to $B_{s(d)}\to\gamma\gamma$ decays in the framework of the model with one extra dimension. Estimate of performed calculations shows that it is possible to reach the difference from SM by ~30%.

Success of the Standard Model (SM) do not weaken theoretical arguments in favour of New Physics (NP), which is aticipated at TeV scale. The task to find and identify NP seems to us to be as a most important challenge for High Energy Physics. In spite of successes of SM of particle physics and SM of cosmology (based on traditional theory of General Relativity), there are profound experimental and theoretical reasons to suppose that both are incomplete. For example, the small but nonvanishing neutrino masses and small but nonvanishing value for cosmological constant as well as the presence of dark matter, dark energy and baryon asymmetry of the Universe hint from the experimental point of view to this opinion. Theoretical problems include hierarchy problem, supersymmetry breaking, replication of fermion generations and highly hierarchical structure of fermion mass matrixes, $CP-$conservation in QCD etc.

Very important are questions on : how to identify the manifestation of NP and how to give the preference to some special kind of SM expansion. As a most promissing extentions of the SM are considered SUSY extentions, based on the idea of supersymmetry [1-4] and approaches with large extra dimensions [5-9], though there are also more radical ways beyond SM [10, 11].

In the framework of extra dimensional models with fundamental gravity scale around ~TeV the NP is expected to manifest itself around this scale. As soon as indicated scale will be tested, for example at LHC energies, NP must manifest itself. The question is only in which form it manifests itself. The most direct way to manifest and analyze experimental patterns of NP could consist in the direct production of the new particles like supersymmetric or Kaluza-Klein (KK) resonances. Another possibility consists in indirect manifestation of the effects beyond SM. Beyond SM effects could manifest themselves in the rare decays through the various loop effects before showing themselves in the direct production processes. Importance of such a possibility is hard to be overestimated. To differ various NP scenarios, we are in need to investigate their influence on the flavordynamics.

In this paper we have estimated additional to the SM contribution in the Appelquist-Chang-Dobresku (ACD) model with one extra spatial dimension in the $B_{s(d)}\to\gamma\gamma$ - decays, taking in the account QCD correction as well (recently we have investigated [12-14] the same decays in the ACD model of Universal Extra Dimensions [9], without having in mind QCD corrections).

This process is a part of the flavor physics, where also breakthroughs in the NP directions are anticipated with starting the LHC operation recently. Maybe this processes will more important after constructing and operating in the post LHC-era, when SuperB factory(ies) [15] will thoroughly prolong investigations of LHC samples of flavor physics for NP, presumably founded at LHC. This samples of NP will be subjected more profound understanding just in the post LHC –era at SuperB.

ISSN 1512-1461

Remarkable feature of universal type of extra dimensional models is the preservation of so called KK- parity, which results in the absence tree level Kaluza-Klein contributions into processes, which take place at scales $\mu << 1/r$. Here r is the compactification radii for the extra dimension. In a certain sense the KK-parity conservation is like to preservation of R-parity in supersymmetric theories.

In particular, conservation of KK-parity prohibits single production of zero KK-modes in the processes of interaction for "usual" particles. From this point of view the flavor change neutral current (FCNC) inspired processes like ($K^0 - \overline{K}^0$, $B^0 - \overline{B}^0$), rare B– and K–decays or radiative decays in the quark or lepton sectors are most interesting because they are kind of processes which (not having their tree level analogues) first arise in the SM at one loop level. Hence they are strongly suppressed.

Some authors [12-14, 16-26] have calculated $B_{s(d)} \to \gamma\gamma$ decay without taking into account QCD corrections. The first theoretical analysis of this type was the famous paper [16] of M.K. Gaillard and B.W. Lee, who considered $K_{S,L} \to \gamma\gamma$. In the one loop approximation (where this decays first arise in the perturbation theory) up-quark and W-boson exchanges in the loop are responsible for the process. Concerning the $B_{s(d)} \to \gamma\gamma$, branching ratios in the SM are $Br(B_{s,d} \to \gamma\gamma) \sim 10^{-7(9)}$.

What about experimental estimates, we have [27]

$$Br(B_s \to \gamma\gamma) < 8.7 \times 10^{-6} \tag{1}$$

$$Br(B_d \to \gamma\gamma) < 6.2 \times 10^{-7} \tag{2}$$

Typical feature for these decays is a clean experimental signature. In addition they are of special interest because these decays could provide us with important test for QCD dynamics in $B-$decays. $B \to \gamma\gamma$ decay modes realize exceptional situation of the nontrivial QCD dynamics, connected with the decaying B , having in mind completely hadronless final states and simple two body kinematics. As far as theoretical expectations for branching ratios for the discussed processes are (roughly) 1-2 orders lower then it is indicated by experimental estimates (1) and (2) and for the reason that NP contributions are strongly restricted by the measurements of $b \to s\gamma$ transitions, maybe it is more expectable the enhancement of NP contributions beyond SM in $B_d \to \gamma\gamma$, then in $B_s \to \gamma\gamma$. As it was mentioned earlier, $B_{s(d)} \to \gamma\gamma$-decays in the ACD model of universal extra dimension were considered in the paper [12-14] without accounting of QCD contributions.

Double photon decays of the neutral $B-$mesons are induced in the SM by quark transitions $b \to s\gamma\gamma$. In these transitions up quarks and $W-$bosons are running in the loop. As concerning ACD model, KK-towers of up quarks and $W-$bosons run in the loop. In addition the contributions into $b \to s\gamma\gamma$ transitions give towers of scalar particles ($a^{\pm}_{(n)}, G_{(n)}{}^{\pm}$) (see fig.1 and fig.2).

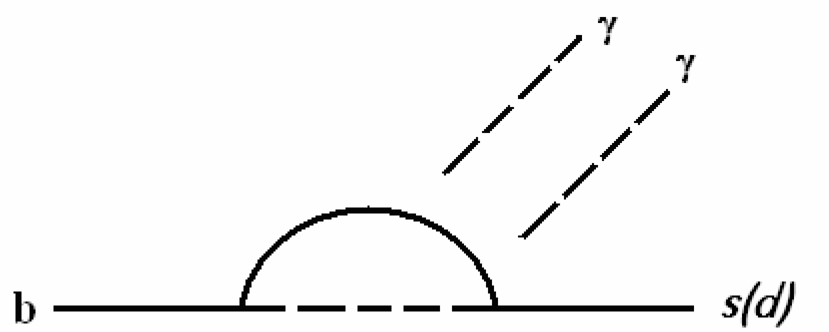

Fig.1 The diagrams, corresponding to "full" ACD model with only additional dimension for the process $B_{s(d)} \to \gamma\gamma$. KK-modes of up quarks (solid lines inside the loop) and $G_{(n)}{}^{\pm}$, $a^{\pm}_{(n)}$, $W_{(n)}$-particles (dashed lines in the loop) are running in the loop; photons are emitted from any charged particle.

ISSN 1512-1461

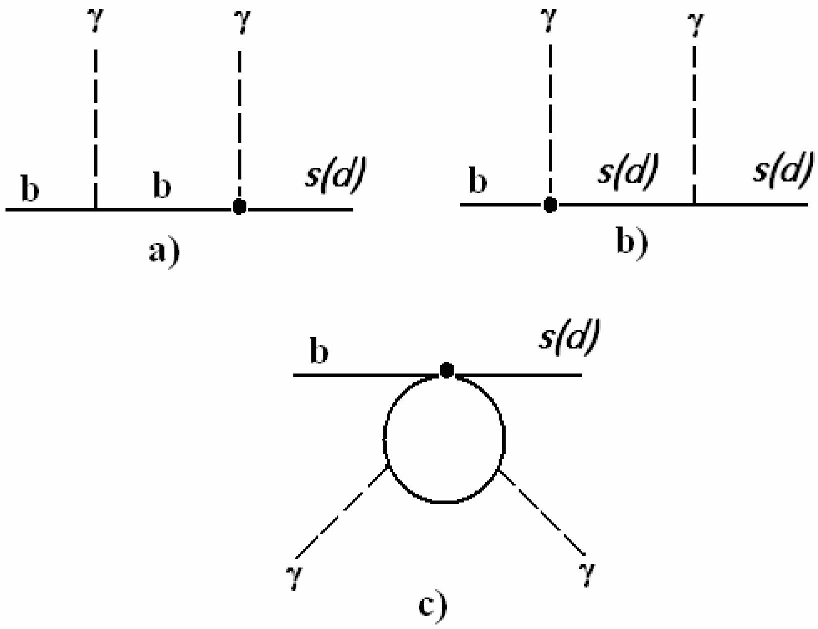

Fig.2 Diagrams, corresponding to the “effective theory” for $B_{s(d)} \to \gamma\gamma$ process.

The general form for the amplitude $B_{s(d)} \to \gamma\gamma$ is as follows:

$$T(\ B \to \gamma\gamma\ ) = \varepsilon_1^{\mu}(k_1)\ \varepsilon_2^{\nu}(k_2)[Ag_{\mu\nu} + iB\varepsilon_{\mu\nu\alpha\beta}k_1^{\alpha}k_2^{\beta}\,], \tag{3}$$

where, the scalar functions $A(B)$ are $CP-$even (odd) amplitudes for this process.
Using (3), it is straightforward to get expression for decay width

$$\Gamma(B \to \gamma\gamma) = \frac{1}{32\pi M_B}\left[4|A|^2 + \frac{1}{2}M_B^4|B|^2\right] \tag{4}$$

Having in mind the unitarity of the CKM matrix, we can rewrite expressions for A and B as:

$$A = \sum_{i=u,c,t}\lambda_i A_i = \lambda_t\{A_t - A_c\} + \lambda_u\{A_u - A_c\}\,,$$

$$B = \sum_{i=u,c,t}\lambda_i B_i = \lambda_t\{B_t - B_c\} + \lambda_u\{B_u - B_c\} \tag{5}$$

Where $\lambda_i = V_{is(d)}V_{ib}^{*}(V_{ij}$ are elements of the CKM-matrix).

Let us note that we are restricted ourselves, calculating in the leading $\sim 1/M_W^2$ order of the up quark tower contributions. In this approximation the contributions of $u_{(n)}$- and $c_{(n)}$- towers are equal. Hence, we have simply:

$$A = \lambda_t(A_{t(n)} - A_{c(n)}),\ B = \lambda_t(B_{t(n)} - B_{c(n)}) \tag{6}$$

To take into account QCD corrections it is comfortable to use effective Hamiltonian /28/. In the leading ($1/m_w^2$) order it is sufficient to use effective Hamiltonian of the single photon decay of the $b-$quark to evoke all the terms corresponding to double radiative b-quark decay /29-31/. In its turn, the effective Hamiltonian for the inclusive b→sγ process has the following form:

$$H_{eff}(b \to s\gamma) = -\frac{G_F}{\sqrt{2}}V_{ts}^{*}V_{tb}\sum_{i=1}^{8}C_i(\mu)O_i(\mu) \tag{7}$$

where C_i are Wilson coefficients and O_i - corresponding local operators /28/.

In the framework of so called full ACD theory, where we have done our previous calculations /12-14/, this time we made matching procedure and extracted as a result analytical expression for Wilson coefficient $C_7(M_W)$. The diagrams, corresponding to the full version of the

ISSN 1512-1461

ACD model are presented in the fig.1 while the diagrams corresponding to effective Hamiltonian for the double radiative process are shown on the fig.2 (the fat points in the diagrams a) and b) denote insertion of the O_7-operator. In the diagram c) the same fat point denotes that instead it should be inserted operators $O_{1,2,...,6}$). Let us note that in the ACD model irreducible diagrams do not contribute into double radiative B-decays in the $\frac{1}{{M_W}^2}$ order (this happens by the reason that typical masses for the Kaluza-Klein towers are much greater than the mass of the W-boson and the diagrams of the type Gaillard and Lee /16/ are absent in the ACD model. That is why only C_7 is modified in the ACD model. So, analytical expression for
$C_{7,ACD}(M_W)$ has the form:

$$C_{7,ACD} = -\frac{1}{12}(F(x_{t(n)}) - F(x_{c(n)})) \tag{8}$$

$$F(x_{i(n)}) = F_2(x_{i(n)}) - 12\frac{m_i m_{i(n)}}{M_W^2} s_{i(n)} c_{i(n)} f_1(x_{i(n)}) - \frac{3}{2} f_2(x_{i(n)}) \left(1 + \frac{m_i^2}{M_W^2} - 2\frac{m_b m_{s(d)}}{M_{W(n)}^2} \frac{n^2}{R^2 M_W^2} \right)$$

Where $F_2(x)$ is the Inami-Lim function /31/

$$F_2(x) = \frac{3x^3 - 2x^2}{4(x-1)^4}\ln x + \frac{7x - 5x^2 - 8x^3}{24(x-1)^3}, \quad f_1(x) = \frac{-5x^2 + 8x - 3 + 2(3x - 2)\ln x}{6(1-x)^3},$$

$$f_2(x) = \frac{-2x^3 - 3x^2 + 6x - 1 + 6x^2 \ln x}{12(1-x)^4}, \quad x_{i(n)} = m_{i(n)}^2 / M_{W(n)}^2 . \tag{9}$$

Using expression for Wilson coefficient $C_7(\mu_W)$ on the scale μ_W for ACD model (see (8)) it is possible to get for $C_7(\mu_b)$, which is more relevant for the discussed decay $B_{s(d)} \to \gamma\gamma$ via renormalization group equation the following expression/33/:

$$C_7(\mu_b) \approx \left(\frac{\alpha_s(\mu_W)}{\alpha_s(\mu_b)} \right)^{\frac{16}{23}} C_7(\mu_W) - 0.158 \tag{10}$$

With help of (10) we can numerically estimate Wilson coefficient C_7 on the scale μ_b. All necessary experimental data we need for this purposes are taken in /27/. As a result, we have $C_7(\mu_b) = -0.245$ (in frame of the SM one has $C_{7,SM}(\mu_b) = -0.3$).
Through direct calculation we obtain for A and B:

$$A = -i\frac{\sqrt{2}\alpha}{6\pi} f_B G_F \frac{m_b^3}{m_{s(d)}} \frac{M_W^2}{M_{W(n)}^2} \lambda_t C_7 , \tag{11}$$

$$B = -i\frac{\sqrt{2}\alpha}{3\pi} f_B G_F \frac{m_b}{m_{s(d)}} \frac{M_W^2}{M_{W(n)}^2} \lambda_t C_7 \; .$$

We already are ready to compare ACD contribution with those of SM one, using (8)-(11).
The amplitudes A and B in frame of SM have following form [29-31]:

$$A_{SM} = (0.3)i\frac{\sqrt{2}}{6\pi}\alpha f_B G_F \lambda_t \frac{m_b^3}{m_{s(d)}}, \quad B_{SM} = (0.44)i\frac{\sqrt{2}}{3\pi}\alpha f_B G_F \lambda_t \frac{m_b}{m_{s(d)}} \tag{12}$$

Numerical analysis shows that in case of B_s-meson decay we can reach the difference from SM $\sim 30\%$ (1/R~250 GeV). With decreasing of the compactification radii the ACD contribution for the partial width for B- double radiative decay decreases sharply and becomes less than 5% at

ISSN 1512-1461

1/R~1000 GeV. Various calculations show /33,34/ that the impact of universal extra dimensions on the wide class of flavour changing neutral current inspired phenomena is caused by different mechanisms such as changes in the Inami-Lim /32/ functions via pure Kaluza-Klein contributions, modifications of unitary triangles in the ACD model, and so on. In addition QCD corrections influence these mechanisms and hence the physical observables. The analysis of refs./33,34/ has demonstrated that some processes are enhanced and others are suppressed comparing to the SM as a result of combined analysis.

Conclusion

In this paper we have discussed one of the ways on the theoretical road for manifestation of NP in the $B-$sector, particularly, in the double radiative B-decays. Experimental success of SM is very expressive in the last decades after its acknowledgement. At least we know only experimental derivation from “standard thinking” due to discovery of small finite (but nonzero) neutrino masses in the various neutrino oscillation experiments. Therefore it is important to know how numerous and at which confidence level will be realized intervention of any kind of new physics (NP) beyond SM in all sectors of the knowledge of high energy physics.

Flavor changing neutral current inspired rare processes belong to the class of processes which are especially sensitive to abovementioned intervention. As for $B-$meson double radiative decays, due to their clean experimental signature and having in mind that the difference among experimental and theoretical SM estimates for $B_{s(d)} \to \gamma\gamma$ is around 1-2 orders consequently, then in case of experimental observation of a few events with these decays, for example at LHC_b (what is not excluded) and all the more in case of intensive investigation at SuperB (probably already founded that time on LHC_b samples) opens the possibility for abovementioned NP intervention. Let us note that following to our estimations in the ACD model the derivation from SM predictions for the BR ($B_s \to \gamma\gamma$) could be ~30%. The papers [33, 34] also indicate on the enhancement of some processes like $K_L \to \pi^0 e^+ e^-, K^+ \to \pi^+ \bar{\nu}\nu, K_L \to \pi^0 \bar{\nu}\nu, B \to X_{d(s)} \bar{\nu}\nu$,

$K_L \to \mu^+\mu^-, B_{d(s)} \to \mu^+\mu^-, B \to X_s \mu^+\mu^-$ relatively to SM in the ACD model, while other transitions ($B \to X_s\gamma, B \to X_s g$) could be decreased.

The work is performed partly due to financial support of ISTC grant # G1458 and GNSF grants # GNSF/ST07/4-185 & GNSF/ST08/4-421. Authors express their gratitude to I. Antoniadis, I.Bigi, C. Greub, G.Dvali, G. Hiller, U. Meissner, A. Rusetsky and G.G. Volkov for the discussions and support.

ISSN 1512-1461

REFERENCES

1. Yu. A. Golfand and E. P. Likhtman, JETP Lett. (1971), **13(8),** 452.
2. D. V. Volkov, V. P.Akulov, JETP Lett. (1972), **16(11)**, 621.
3. D. V. Volkov, V. P. Akulov and V. A. Soroka, JETP Lett. (1975), **22(7)**, 396.
4. J. Wess and B. Zumino, Nucl. Phys. B, (1974), **70**, 39.
5. N. Arkani-Hamed, S. Dimopoulos, and G. Dvali, Phys.Lett. B(1998), **429**, 263.
6. I. Antoniadis, N. Arkani-Hamed, S. Dimopoulos, and G. Dvali, Phys. Lett. B (1998), **436**, 257.
7. L. Randall and R. Sundrum, Phys. Lett. (1999), **83**, 3370.
8. L. Randall and R. Sundrum, Phys. Lett. (1999), **83**, 46090.
9. T. Appelquist, H.C. Cheng, and B.A. Dobrescu, Phys. Rev. D, (2001), **64**, 035002.
10. L.N. Lipatov, M.R. de Traubenberg, and G.G. Volkov, J. Math. Phys. (2008), **49**, 013502.
11. G.G. Volkov, Annales Fond. Broglie, (2006), **31**, 227, e-Print: hep-ph/0607334.
12. G.Devidze, A.Liparteliani, and U.-G. Meissner, Phys. Lett. B (2006), **634**, 59.
13. I.I. Bigi, G.Devidze, A. Liparteliani, and U.-G. Meissner, Phys. Rev. D, (2008), **78**, 097501.
14. G.G.Devidze, G.R. Dzibuti, and A.G. Liparteliani, Phys. Atom. Nucl. (2007), **70**, 1131.
15. D.G.Hitlin et al., hep-ph/0810.1312.
16. M.K. Gaillard and B.W. Lee. Phys. Rev. D, (1974), **10**, 897.
17. G.L. Lin, J.Liu and Y.P.Yau, Phys. Rev. D, (1990), **42**, 2314.
18. Simma and D.Wyler Nucl.Phys. B, (1992), **381**, 501.
19. L. Reina, G.Ricciardi, and A. Soni, Phys. Rev. D, (1997), **56**, 5805.
20. S.W. Bosch and G. Buchalla, J. High Energy Phys. (2002), **08**, 54.
21. G.G. Devidze, G.R. Dzibuti, and A.G. Liparteliani, Nucl. Phys. B, (1996), **468**, 241.
22. G. Devidze and G. Dzhibuti. Phys.Lett, B, (1998), **429**, 48.
23. D. Choudhury and J.Ellis, Phys. Lett. B, (1998), **433,** 102.
24. Zhen-jun Xiao, Cai-Dian Lu, Wu-jun Huo, Phys. Rev. D, (2003), **67**, 094021.
25. J.O. Eeg and K. Kumericki, Eur. Phys. J. C, (2000), **17**, 163.
26. E. Vanem and J.O. Eeg, Phys. Rev. D, (1998), **58**, 114010.
27. Particle Data Group, http://pdg.lbl.gov
28. G. Buchalla, A. J. Buras and M.E. Lautenbacher, Rev. Mod. Phys. (1996), **68**, 1125.
29. C-H.V. Chang and G-L. Lin, Y-P. Yao, Phys. Lett. B, (1997), **415,** 395.
30. G.Hiller and E.O.Iltan, Phys. Lett B, (1997), **409**, 425.
31. G.Hiller and E.O.Iltan, Phys., Mod. Phys. Lett. A, (1997), **12,** 2837.
32. T. Inami and C.S. Lim, Prog. Th. Phys. (1981), **65,** 297.
33. A.J. Buras, A. Poschenrieder, M. Spranger and A. Weiler, Nucl. Phys. B, (2004), **678,** 455.
34. A.J. Buras, M. Spranger and A. Weiler, Nucl. Phys. B, (2003), **660**, 225.

Article received: 2010-07-20