

Constraints on unparticle interaction from $b \rightarrow s\gamma$

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ABSTRACT: We study unparticle effects on $b \rightarrow s\gamma$. The unparticle contributions can contribute significantly to both left- and right-handed chirality amplitudes. Using available experimental data and SM calculation for $B \rightarrow X_s\gamma$, we obtain constraints on various vector and scalar unparticle couplings. We find that the constraints sensitively depend on the unparticle dimension d_U . For d_U close to one, the constraints can be very stringent. The constraints become weak when d_U is increased. In general the constraints on scalar unparticle couplings are weaker than those for vector unparticle couplings. Sizeable coupling strength for unparticles with quarks is still allowed. We also show that polarization measurement in $\Lambda_b \rightarrow \Lambda\gamma$ can further constrain the couplings.

KEYWORDS: Beyond Standard Model, B-Physics, Rare Decays, Weak Decays.

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1. Introduction

Recently Georgi proposed an interesting idea to describe possible scale invariant effect at low energies by unparticles[1]. It was argued that operators O_{SI} made of fields in the scale invariant sector may interact with operators O_{SM} of dimension d_{SM} made of Standard Model (SM) fields at some high energy scale by exchanging particles with large masses, $M_{\mathcal{U}}$, with the generic form $O_{SM}O_{SI}/M_{\mathcal{U}}^k$. At another scale $\Lambda_{\mathcal{U}}$ the scale invariant sector induce dimensional transmutation, below that scale the operator O_{SI} matches onto an unparticle operator $O_{\mathcal{U}}$ with dimension $d_{\mathcal{U}}$ and the unparticle interaction with SM particles at low energy has the form

$$\lambda\Lambda_{\mathcal{U}}^{4-d_{SM}-d_{\mathcal{U}}}O_{SM}O_{\mathcal{U}}. \tag{1.1}$$

Study of unparticle effects has drawn a lot of attentions from more theoretically related work to more phenomenologically studies. There are many possible ways unparticles may interact with the SM particles[2]. Most of the phenomenological work concentrate on possible effects of unparticle interactions with SM particles and constraints on the interaction strength $\lambda/\Lambda_{\mathcal{U}}^{4-d_{SM}-d_{\mathcal{U}}}$. One of the subjects where a lot of activities have been devoted to is the study of low energy rare flavor changing processes involving quarks[3] and charged leptons[4, 5]. In this work we study unparticle effects on $b \rightarrow s\gamma$ and constrain unparticle interactions using known SM values and current experimental data for $B \rightarrow X_s\gamma$.

The rare $b \rightarrow s\gamma$ decay process has been shown to provide interesting constraints on possible new physics beyond the SM[6]. Experimentally the leading contribution to $B \rightarrow X_s\gamma$ with large γ energy E_γ is dominated by $b \rightarrow s\gamma$. Experimental measurement on this decay has achieved very high precision with $B(B \rightarrow X_s\gamma)$ given by[7] $(3.52 \pm 0.23 \pm 0.09) \times 10^{-4}$, with $E_\gamma > 1.6\text{GeV}$. On the theoretical side, the SM calculation for $B(B \rightarrow X_s\gamma)$ has been evaluated at the NNLO order [8] with $(3.15 \pm 0.23) \times 10^{-4}$ for $E_\gamma > 1.6\text{GeV}$. It is clear that experimental data and SM prediction agree with each other very well leaving small room for new physics beyond the SM. Taking this on the positive side, the process $B \rightarrow X_s\gamma$ can provide stringent constraints on possible new physics beyond the SM. Several flavor changing processes have been studied[3–5], but unparticle contribution to $b \rightarrow s\gamma$ has not been studied. We therefore concentrate on this subject.

Although at present the detailed dynamics for interaction between unparticles and SM particles are not known, unparticle effects on various physical processes can be studied from effective theory point of view using eq.(1.1). The main task is then, as many phenomenological studies of unparticle physics, to use available data to constrain the allowed parameter space and to see how large the unparticle effects can be and to test possible effects experimentally.

In principle, when the unparticle sector is coupled to the SM sector the scale invariance is broken due to finite mass of the SM fields[9] and also due to spontaneous symmetry breaking of Higgs vacuum expectation value if coupled[10]. The unparticle behavior may only exist in a window below the scale Λ_U and above a scale μ where the scale invariance is broken again by SM particle effects. If this is the case, the contributions of the unparticles should only be within this window and below μ the effects should be replaced by that resulted from the residual degrees of freedom. However, at this stage there is no specific way, as far as we know, to describe such effects. In our study of unparticle effects on $b \rightarrow s\gamma$, we will follow most of the phenomenological studies in the literature assuming that the unparticle effects from the scale Λ_U down to zero.

We will study $b \rightarrow s\gamma$ using the lowest possible dimension operators due to scalar and vector unparticle and SM fields interactions. The unparticle contributions can contribute significantly to both left- and right-handed chirality amplitudes. Using available experimental data and SM calculation mentioned above, we obtain constraints on various vector and scalar unparticle couplings. We find that the constraints sensitively depend on the unparticle dimension d_U . For d_U close to one, the constraints can be very stringent. The constraints become weak when d_U is increased. In general the constraints on scalar unparticle couplings are weaker than those for vector unparticle couplings. Sizeable coupling strength for unparticles with quarks is still allowed. We also find that polarization measurement in $\Lambda_b \rightarrow \Lambda\gamma$ can further constraint the couplings.

2. Unparticle contribution to $b \rightarrow s\gamma$

The lowest dimension operators, which can generate contributions to $b \rightarrow s\gamma$ at one loop level, come from interaction of vector unparticle with quarks and are given by[2]

$$\lambda'_{QQ}\Lambda_U^{1-d_U}\bar{Q}_L\gamma_\mu Q_L O_U^\mu, \quad \lambda'_{DD}\Lambda_U^{1-d_U}\bar{D}_R\gamma_\mu D_R O_U^\mu.$$

Here $Q_L = (U_L, D_L)^T$, D_R are the SM left-handed quark doublet, and right-handed down-quark, respectively.

Scalar unparticle interaction with quarks can also induce $b \rightarrow s\gamma$. The lowest dimension operators which can contribute to $b \rightarrow s\gamma$ is at order $\Lambda_U^{-d_U}$. The following operator will generate finite contributions to $b \rightarrow s\gamma$ at one loop level[2]

$$\lambda^{YD}\Lambda_U^{-d_U}\bar{Q}_L\tilde{H}D_R O_U, \tag{2.1}$$

where H is the SM Higgs doublet transforming under the SM gauge group $SU(2)_L \times U(1)_Y$ as $(2, 1)$.

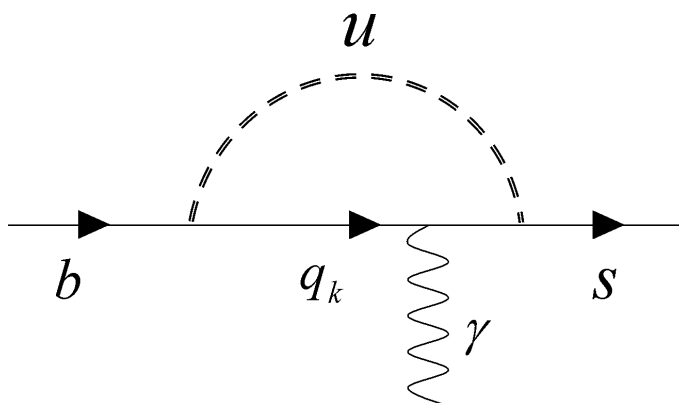


Figure 1: One loop Feynmann diagram for $b \rightarrow s\gamma$ by exchanging an unparticle. The q_k can be d , s , and b quark.

After the Higgs develops a non-zero vacuum expectation value $\langle H \rangle = v$, the above interaction between quarks and an unparticle becomes

$$\lambda_{sb}^{\text{YD}} v \Lambda_{\mathcal{U}}^{-d_{\mathcal{U}}} \bar{s}_L b_R \mathcal{O}_{\mathcal{U}}. \quad (2.2)$$

At the same order in $\Lambda_{\mathcal{U}}$, there are several other operators involving quarks and a scalar unparticle, such as [2] $\bar{Q}_L \gamma_{\mu} \partial^{\mu} Q_L \mathcal{O}_{\mathcal{U}}$, $\bar{D}_R \gamma_{\mu} \partial^{\mu} D_R \mathcal{O}_{\mathcal{U}}$, $\bar{Q}_L \gamma_{\mu} Q_L \partial^{\mu} \mathcal{O}_{\mathcal{U}}$, and $\bar{D}_R \gamma_{\mu} D_R \partial^{\mu} \mathcal{O}_{\mathcal{U}}$. However, their one loop contributions to $b \rightarrow s\gamma$ diverge due to derivative couplings. Additional parameters or operators are needed to render these divergences making the effects not calculable. We will not consider their effects here.

The one loop Feynmann diagram giving contribution to $b \rightarrow s\gamma$ is shown in Fig. 1. We will indicate the incoming b quark by q_i and the out going s quark by q_j . The formula obtained can be easily adapted for other incoming and out going fermions. We obtain the vector unparticle contribution to $q_i \rightarrow q_j \gamma$ amplitude as

$$\mathcal{M}_v(q_i \rightarrow q_j \gamma) = \frac{Qe}{2m_i} N_v(d_{\mathcal{U}}) \bar{q}_j i \sigma_{\mu\nu} \epsilon^{*\mu} q^{\nu} (A_v^L L + A_v^R R) q_i, \quad (2.3)$$

where q and ϵ^{μ} are the photon momentum and polarization, respectively. $N_v(d_{\mathcal{U}}) = (A_{d_{\mathcal{U}}}/16\pi^2 \sin(\pi d_{\mathcal{U}}))(m_i/\Lambda_{\mathcal{U}})^{2d_{\mathcal{U}}-2}$ with $A_{d_{\mathcal{U}}} = (16\pi^{5/2}/(2\pi)^{2d_{\mathcal{U}}})\Gamma(d_{\mathcal{U}} + 1/2)/\Gamma(d_{\mathcal{U}} - 1)\Gamma(2d_{\mathcal{U}})$, and

$$\begin{aligned} A_v^R = & \left[-2f_1 + 2f_2 - f_{2x} + \frac{1}{2-d_{\mathcal{U}}}(f_1 - 3f_{2x}) + z_{ki}^2(f_3 - 2f_{3x}) \right] \lambda_{jk}^L \lambda_{ki}^L \\ & + z_{ji} \left[-2f_1 + f_2 + f_{2x} + \frac{1}{2-d_{\mathcal{U}}}(f_1 - 3f_2 + 3f_{2x}) - z_{ki}^2(f_3 - 2f_{3x}) \right] \lambda_{jk}^R \lambda_{ki}^R \\ & + z_{ki} \left[4f_1 - f_2 + \frac{1}{2-d_{\mathcal{U}}}(3f_2 - 2f_1) + z_{ki}^2 f_3 \right] \lambda_{jk}^L \lambda_{ki}^R - f_3 z_{ji} z_{ki} \lambda_{jk}^R \lambda_{ki}^L \end{aligned}$$

$$\begin{aligned}
 A_v^L = & \left[-2f_1 + 2f_2 - f_{2x} + \frac{1}{2-d_U}(f_1 - 3f_{2x}) + z_{ki}^2(f_3 - 2f_{3x}) \right] \lambda_{jk}^R \lambda_{ki}^R \\
 & + z_{ji} \left[-2f_1 + f_2 + f_{2x} + \frac{1}{2-d_U}(f_1 - 3f_2 + 3f_{2x}) - z_{ki}^2(f_3 - 2f_{3x}) \right] \lambda_{jk}^L \lambda_{ki}^L \\
 & + z_{ki} \left[4f_1 - f_2 + \frac{1}{2-d_U}(3f_2 - 2f_1) + z_{ki}^2 f_3 \right] \lambda_{jk}^R \lambda_{ki}^L - f_3 z_{ji} z_{ki} \lambda_{jk}^L \lambda_{ki}^R, \quad (2.4)
 \end{aligned}$$

where $z_{ji} = m_j/m_i$. $\lambda^L = \lambda'_{QQ}$, and $\lambda^R = \lambda'_{DD}$. The functions $f_i(d_U)$ are defined as

$$\begin{aligned}
 f_0(d_U) &= \int_0^1 dx \int_0^1 dy \frac{y^{d_U}(1-y)^{1-d_U}}{u^{2-d_U}}, & f_1(d_U) &= \int_0^1 dx \int_0^1 dy \frac{y^{d_U-1}(1-y)^{2-d_U}}{u^{2-d_U}} \\
 f_2(d_U) &= \int_0^1 dx \int_0^1 dy \frac{y^{d_U}(1-y)^{2-d_U}}{u^{2-d_U}}, & f_{2x}(d_U) &= \int_0^1 dx \int_0^1 dy \frac{xy^{d_U}(1-y)^{2-d_U}}{u^{2-d_U}} \\
 f_3(d_U) &= \int_0^1 dx \int_0^1 dy \frac{y^{d_U}(1-y)^{2-d_U}}{u^{3-d_U}}, & f_{3x}(d_U) &= \int_0^1 dx \int_0^1 dy \frac{xy^{d_U}(1-y)^{2-d_U}}{u^{3-d_U}}, \quad (2.5)
 \end{aligned}$$

with $u = z_{ki}^2 - (1-x)(1-y) - x(1-y)z_{ji}^2$.

For scalar contribution, we obtain

$$\mathcal{M}_s(q_i \rightarrow q_j \gamma) = \frac{Qe}{2m_i} N_s(d_U) \bar{q}_j i \sigma_{\mu\nu} \epsilon^{*\mu} q^\nu (A_s^L L + A_s^R R) q_i, \quad (2.6)$$

where $N_s(d_U) = (A_{d_U}/16\pi^2 \sin(\pi d_U))(v^2/m_i^2)(m_i/\Lambda_u)^{2d_U}$, and

$$A_s^R = [f_2(d_U) - f_{2x}(d_U)] \lambda_{jk}^{\text{YD}} \lambda_{ik}^{\text{YD}*} + f_{2x}(d_U) z_{ji} \lambda_{kj}^{\text{YD}*} \lambda_{ki}^{\text{YD}} + f_0(d_U) z_{ki} \lambda_{jk}^{\text{YD}} \lambda_{ki}^{\text{YD}} \quad (2.7)$$

$$A_s^L = [f_2(d_U) - f_{2x}(d_U)] \lambda_{kj}^{\text{YD}*} \lambda_{ki}^{\text{YD}} + f_{2x}(d_U) z_{ji} \lambda_{jk}^{\text{YD}} \lambda_{ik}^{\text{YD}*} + f_0(d_U) z_{ki} \lambda_{kj}^{\text{YD}*} \lambda_{ik}^{\text{YD}*}. \quad (2.8)$$

In our calculations, we will use the central quark masses given in PDG[11]: $m_b = 4.70$ GeV, $m_s = 95$ MeV and $m_s/m_d = 19$.

The above amplitudes are evaluated at the unparticle scale $\mu = \Lambda_U$. When running down to the relevant scale $\mu = m_b$ for $b \rightarrow s\gamma$, there are corrections. The gluonic penguin with the photon γ replaced by a gluon g , $b \rightarrow sg$, generated at Λ_U will also contribute to $b \rightarrow s\gamma$ at a lower scale m_b . The amplitude for $M_{U=v,s}(q_i \rightarrow q_j g)$ is given by

$$\mathcal{M}_U(q_i \rightarrow q_j g) = \frac{g_s}{2m_i} N_v(d_U) \bar{q}_j i \sigma_{\mu\nu} \epsilon_a^{*\mu} q^\nu (A_U^L L + A_U^R R) T^a q_i, \quad (2.9)$$

where g_s is the strong interaction coupling, ϵ_a^μ is the gluon polarization vector and T^a is the generator of the color gauge group $SU(3)_C$ normalized to $\text{Tr}(T^a T^b) = \delta^{ab}/2$.

One can easily translate the above amplitudes into the usual amplitudes defined by

$$\begin{aligned}
 M(b \rightarrow s\gamma) &= -V_{tb} V_{ts}^* \frac{G_F}{\sqrt{2}} \frac{e}{8\pi^2} C_7(\mu) \bar{s} \sigma_{\mu\nu} F^{\mu\nu} (m_s L + m_b R) b, \\
 M(b \rightarrow sg) &= -V_{tb} V_{ts}^* \frac{G_F}{\sqrt{2}} \frac{g_s}{8\pi^2} C_8(\mu) \bar{s} \sigma_{\mu\nu} G_a^{\mu\nu} (m_s L + m_b R) T^a b, \quad (2.10)
 \end{aligned}$$

where $F^{\mu\nu}$ and $G_a^{\mu\nu}$ are the field strength of photon and gluon fields.

Using the leading QCD corrected effective Wilson coefficient at the scale m_b for $b \rightarrow s\gamma$ is given by[12], $C_7^{eff}(m_b) = 0.689C_7(m_W) + 0.087C_8(m_W)$, we obtain an approximate expression for the QCD corrected unparticle contribution, at the scale $\mu = m_b$,

$$\begin{aligned} \tilde{\mathcal{M}}_{\mathcal{U}}(q_i \rightarrow q_j \gamma) &= \bar{q}_j i\sigma_{\mu\nu} \epsilon^{*\mu} q^\nu (\tilde{A}_{\mathcal{U}}^L L + \tilde{A}_{\mathcal{U}}^R R) q_i, \\ \tilde{A}_{\mathcal{U}=v,s}^{L,R} &= \frac{Qe}{2m_i} N_{\mathcal{U}=v,s}(d_{\mathcal{U}}) (0.689 + 0.087/Q) A_{\mathcal{U}=v,s}^{L,R}. \end{aligned} \quad (2.11)$$

Using the above expression one can put constraints on unparticle couplings.

3. Numerical analysis and conclusions

To see how unparticle interactions affect $B \rightarrow X_s \gamma$, we use the following to measure possible unparticle contribution,

$$R_{exp-SM} = \frac{\Gamma_{exp} - \Gamma_{SM}}{\Gamma_{SM}} = \frac{B_{exp}}{B_{SM}} - 1. \quad (3.1)$$

Using the available experimental and SM values, we find $R_{exp-SM} = 0.117 \pm 0.113$ with $E_\gamma > 1.6$ GeV. It is clear that at this stage there is no evidence of new physics beyond SM. However, we can turn the argument around and use allowed value of R to constrain new interactions.

To compare with data and aim at the leading correction from unparticle to the SM prediction, we first define an effective SM for $b \rightarrow s\gamma$ amplitude $\tilde{A}_{SM}^{L,R}$ with $\tilde{A}_{SM}^L/\tilde{A}_{SM}^R \approx m_s/m_b$, as should be in the SM, such that the corresponding Wilson coefficient at the leading order amplitude[12] reproduces the SM prediction for the branching ratio with relevant in put parameters from Ref.[11]. We then add to it the leading QCD corrected unparticle contribution $\tilde{A}_{\mathcal{U}}^{L,R}$ to obtain the total amplitude. Replacing Γ_{exp} by Γ_{un-SM} determined by the total SM and unparticle leading contributions, we obtain a quantity similar to R_{exp-SM}

$$R_{un-SM} = \frac{|\tilde{A}_{SM}^L + \tilde{A}_{\mathcal{U}}^L|^2 + |\tilde{A}_{SM}^R + \tilde{A}_{\mathcal{U}}^R|^2}{|\tilde{A}_{SM}^L|^2 + |\tilde{A}_{SM}^R|^2} - 1. \quad (3.2)$$

We finally approximate R_{un-SM} to R_{exp-SM} and obtain constraints on unparticle couplings. There are higher order SM corrections to the above formula, but for our purpose of obtaining leading constraints on unparticle effects, this should be sufficient.

In the SM $\tilde{A}_{SM}^L/\tilde{A}_{SM}^R = m_s/m_b$. It is obvious that the main contribution of SM is the right hand couplings. For unparticle contributions, $\tilde{A}_{\mathcal{U}}^L$ can be comparable or even larger than $\tilde{A}_{\mathcal{U}}^R$. We will obtain bounds on the unparticle couplings from data and known SM numbers allow the theoretical value R_{un-SM} to be in the 1σ range. Depending on the intermediate quarks exchanged in the loop, different quark-unparticle couplings can appear. We will constrain the coupling for each of the combinations with non-zero contribution and set other equal to zero first assuming the couplings are all real.

There are three possibilities involving a quark in the loop. We discuss them in the following.

- a) For d quark and vector unparticle in the loop, it is possible to constrain $\lambda_{sd}^R \lambda_{db}^R$, $\lambda_{sd}^L \lambda_{db}^L$, $\lambda_{sd}^R \lambda_{db}^L$, $\lambda_{sd}^L \lambda_{db}^R$. For scalar unparticle in the loop, it is possible to constrain $\lambda_{sd}^{YD} \lambda_{bd}^{YD*}$, $\lambda_{ds}^{YD*} \lambda_{db}^{YD}$, $\lambda_{sd}^{YD} \lambda_{db}^{YD}$, and $\lambda_{ds}^{YD*} \lambda_{bd}^{YD*}$.
- b) For s quark and vector unparticle in the loop, it is possible to constrain $\lambda_{ss}^R \lambda_{sb}^R$, $\lambda_{ss}^L \lambda_{sb}^L$, $\lambda_{ss}^R \lambda_{sb}^L$ and $\lambda_{ss}^L \lambda_{sb}^R$. For scalar unparticle in the loop, it is possible to constrain $\lambda_{ss}^{YD} \lambda_{bs}^{YD*}$, $\lambda_{ss}^{YD} \lambda_{sb}^{YD}$, $\lambda_{ss}^{YD*} \lambda_{sb}^{YD}$, and $\lambda_{ss}^{YD*} \lambda_{bs}^{YD*}$. For real couplings, there are only two needed to be considered, with sub-indices (ss, sb) and (ss, bs) .
- c) For b quark and vector unparticle in the loop, it is possible to constrain $\lambda_{sb}^R \lambda_{bb}^R$, $\lambda_{sb}^L \lambda_{bb}^L$, $\lambda_{sb}^R \lambda_{bb}^L$ and $\lambda_{sb}^L \lambda_{bb}^R$. For scalar unparticle in the loop, it is possible to constrain $\lambda_{sb}^{YD} \lambda_{bb}^{YD*}$, $\lambda_{sb}^{YD} \lambda_{bb}^{YD}$, $\lambda_{bs}^{YD*} \lambda_{bb}^{YD}$, and $\lambda_{bs}^{YD*} \lambda_{bb}^{YD*}$. For real couplings, there are only two needed to be considered, with sub-indices (sb, bb) and (bs, bb) .

The various constraints are shown in Tables I, II and III for different values of unparticle dimension d_U with Λ_U set to be 1 TeV. The central values for the unparticle couplings are obtained by taking the SM leading values and require the unparticle contributions to produce the central value of R_{exp-SM} . In general there are two solutions. One comes from constructive interference contribution relative to the SM dominant contribution, and another from destructive interference. In the case that the unparticle contribution is dominated by the same chirality, $R = (1 + \gamma_5)/2$, amplitude as that of the dominate one in SM, the allowed unparticle amplitude from destructive case will be larger than the SM one. These are the cases with one of the central values (absolute values) much larger than the other in the tables. We hold the view that SM should dominate the contribution to $b \rightarrow s\gamma$, therefore we consider these cases not good ones for constraints.

For bounds on the couplings, we list the bounds corresponding to positive and negative solutions separately in the same way as their central values. Positive numbers indicate that the couplings should be smaller than the numbers listed, and negative numbers indicate that the couplings should be larger than the numbers listed.

It can be seen that the constraints sensitively depend on the unparticle dimension parameter d_U . For d_U not too far away from 1, the constraints are stringent, but become weaker as d_U increases. It is also clear that the constraints on the vector unparticle couplings are stronger than those for scalar unparticle couplings. This can be easily understood by noticing that the scalar unparticle couplings is suppressed by a factor of v/Λ_U compared with vector unparticle couplings. Sizeable coupling strength for unparticles with quarks is still allowed.

Note that using $B \rightarrow X_s \gamma$ branching ratio alone, it is not possible to distinguish the above solutions since it is proportional to $|\tilde{A}_R^{\text{total}}|^2 + |\tilde{A}_L^{\text{total}}|^2$ which is how the constraints are obtained. We comment that measurement of polarization α_Λ in $\Lambda_b \rightarrow \Lambda \gamma$ can provide more information to distinguish some of the solutions. The polarization parameter α_Λ is defined by[13]

$$\frac{d\Gamma}{\Gamma d \cos \theta} = \frac{1}{2}(1 + \alpha_\Lambda \cos \theta), \quad \alpha_\Lambda = \frac{|\tilde{A}_R^{\text{total}}|^2 - |\tilde{A}_L^{\text{total}}|^2}{|\tilde{A}_R^{\text{total}}|^2 + |\tilde{A}_L^{\text{total}}|^2}, \quad (3.3)$$

d_{Λ}	1.1	1.3	1.5	1.7	1.9
$\lambda_{sd}^R \lambda_{db}^R$ c-value	$-2.4 \times 10^{-5} (2.1 \times 10^{-5})$	-0.00079(0.00073)	-0.019(0.019)	-0.28(0.3)	-1.2(1.3)
α_{Λ}	0.79(0.79)	0.79(0.79)	0.79(0.79)	0.79(0.79)	0.79(0.79)
$\lambda_{sd}^R \lambda_{db}^R$ bound	$-3.2 \times 10^{-5} (3.0 \times 10^{-5})$	-0.0011(0.0010)	-0.026(0.026)	-0.39(0.41)	-1.6(1.8)
α_{Λ}	0.62(0.63)	0.62(0.63)	0.63(0.63)	0.63(0.62)	0.63(0.62)
$\lambda_{sd}^L \lambda_{db}^L$ c-value	$-0.00013 (3.9 \times 10^{-6})$	-0.0028(0.00021)	-0.019(0.019)	-0.077(1.1)	-0.21(7.0)
α_{Λ}	$\sim 1.(1.)$	$\sim 1.(1.)$	$\sim 1.(1.)$	$\sim 1.(1.)$	$\sim 1.(1.)$
$\lambda_{sd}^L \lambda_{db}^L$ bound	$-0.00013 (7.4 \times 10^{-6})$	-0.0030(0.00038)	-0.026(0.026)	-0.14(1.1)	-0.41(7.2)
α_{Λ}	$\sim 1.(1.)$	$\sim 1.(1.)$	$\sim 1.(1.)$	$\sim 1.(1.)$	$\sim 1.(1.)$
$\lambda_{sd}^R \lambda_{db}^L$ c-value	-0.00035(0.0056)	-0.068(0.12)	-14(1.6)	-	-
α_{Λ}	$\sim 1.(0.98)$	0.99(0.99)	0.84($\sim 1.$)	-	-
$\lambda_{sd}^R \lambda_{db}^L$ bound	-0.00065(0.0059)	-0.1(0.15)	-16.(2.9)	-	-
α_{Λ}	$\sim 1.(0.98)$	0.99(0.99)	0.83(0.99)	-	-
$\lambda_{sd}^L \lambda_{db}^R$ c-value	-0.0010(0.0019)	-0.068(0.12)	-4.9(4.6)	-	-
α_{Λ}	0.88(0.64)	0.88(0.64)	0.81(0.81)	-	-
$\lambda_{sd}^L \lambda_{db}^R$ bound	-0.0016(0.0024)	-0.1(0.15)	-6.8(6.6)	-	-
α_{Λ}	0.75(0.45)	0.75(0.46)	0.66(0.66)	-	-
$\lambda_{sd}^{YD} \lambda_{bd}^{YD}$ c-value	-0.0015(0.048)	-0.054(0.74)	-4.2(4.2)	-	-
α_{Λ}	$\sim 1.(0.94)$	$\sim 1.(0.99)$	$\sim 1.(1.)$	-	-
$\lambda_{sd}^{YD} \lambda_{bd}^{YD}$ bound	-0.0028(0.049)	-0.099(0.78)	-5.9(5.9)	-	-
α_{Λ}	$\sim 1.(0.95)$	$\sim 1.(0.99)$	$\sim 1.(1.)$	-	-
$\lambda_{ds}^{YD} \lambda_{db}^{YD}$ c-value	-0.0061(0.012)	-0.17(0.23)	-4.2(4.2)	-	-
α_{Λ}	0.87(0.63)	0.83(0.74)	0.79(0.79)	-	-
$\lambda_{ds}^{YD} \lambda_{db}^{YD}$ bound	-0.0093(0.015)	-0.25(0.31)	-5.9(5.9)	-	-
α_{Λ}	0.75(0.44)	0.68(0.57)	0.63(0.63)	-	-
$\lambda_{sd}^{YD} \lambda_{db}^{YD}$ c-value	-0.013(0.31)	-0.79(4.4)	-	-	-
α_{Λ}	$\sim 1.(1.)$	$\sim 1.(1.)$	-	-	-
$\lambda_{sd}^{YD} \lambda_{db}^{YD}$ bound	-0.025(0.32)	-1.4(5.0)	-	-	-
α_{Λ}	$\sim 1.(1.)$	$\sim 1.(1.)$	-	-	-
$\lambda_{ds}^{YD} \lambda_{bd}^{YD}$ c-value	-0.061(0.067)	-1.8(1.9)	-	-	-
α_{Λ}	0.79(0.79)	0.79(0.79)	-	-	-
$\lambda_{ds}^{YD} \lambda_{bd}^{YD}$ bound	-0.087(0.093)	-2.6(2.7)	-	-	-
α_{Λ}	0.63(0.63)	0.63(0.63)	-	-	-

Table 1: Central values (c-value) and bounds for unparticle couplings with d quark in the loop for $\Lambda_U = 1$ TeV. In the table “-” indicates that the central values are larger than 10 implying weak constraints which we do not list. The corresponding values for α_{Λ} are listed below the constraints on couplings. In the table “ $\sim 1.$ ” indicates a value very close to one.

where Γ is the decay rate for $\Lambda_b \rightarrow \Lambda \gamma$, and θ is the angle between the Λ polarization and the photon momentum directions.

In the SM, since $\tilde{A}_{SM}^L / \tilde{A}_{SM}^R = m_s / m_b$, one would have $\alpha_{\Lambda} \approx 1$. In the Tables, we list α_{Λ} for the corresponding constraints on the couplings. We see that unparticle contributions can change the value for α_{Λ} significantly. Future measurement for α_{Λ} can provide more information about unparticle interactions.

There are several studies of unparticle flavor changing effects in B decays. The couplings are constrained from several processes[3], such as stringent constraints on the couplings $(\lambda'_{(d,s)b})^2$ and $(\lambda_{(d,s)}^{YD} - \lambda_{b(d,s)}^{YD*})^2$ from $B_{d,s} - \bar{B}_{d,s}$ mixing[3]. If all λ'_{ij} (or λ_{ij}^{YD}) are similar in size, the constraints from these considerations are stronger than the ones ob-

$d_{\mathcal{U}}$	1.1	1.3	1.5	1.7	1.9
$\lambda_{ss}^R \lambda_{sb}^R$ c-value	$-2.2 \times 10^{-5} (2.0 \times 10^{-5})$	-0.00076(0.00071)	-0.018(0.018)	-0.27(0.29)	-1.2(1.3)
α_{Λ}	0.79(0.79)	0.79(0.79)	0.79(0.79)	0.79(0.79)	0.79(0.79)
$\lambda_{ss}^R \lambda_{sb}^R$ bound	$-3.1 \times 10^{-5} (2.8 \times 10^{-5})$	-0.0011(0.0010)	-0.026(0.026)	-0.39(0.41)	-1.6(1.8)
α_{Λ}	0.62(0.63)	0.62(0.63)	0.63(0.63)	0.63(0.62)	0.63(0.62)
$\lambda_{ss}^L \lambda_{sb}^L$ c-value	$-0.00011 (4.2 \times 10^{-6})$	-0.0024(0.00023)	-0.016(0.021)	-0.075(1.1)	-0.21(7.0)
α_{Λ}	$\sim 1.(1.)$	$\sim 1.(1.)$	$\sim 1.(1.)$	$\sim 1.(1.)$	$\sim 1.(1.)$
$\lambda_{ss}^L \lambda_{sb}^L$ bound	$-0.00011 (7.9 \times 10^{-6})$	-0.0025(0.00042)	-0.024(0.028)	-0.14(1.1)	-0.41(7.2)
α_{Λ}	$\sim 1.(1.)$	$\sim 1.(1.)$	$\sim 1.(1.)$	$\sim 1.(1.)$	$\sim 1.(1.)$
$\lambda_{ss}^R \lambda_{sb}^L$ c-value	$-0.0019 (7.7 \times 10^{-5})$	-0.085(0.0048)	-2.5(0.21)	-48(6.2)	-
α_{Λ}	-0.65($\sim 1.$)	$\sim -1.(1.)$	-0.74(0.99)	-0.3(0.97)	-
$\lambda_{ss}^R \lambda_{sb}^L$ bound	-0.0020(0.00015)	-0.089(0.0090)	-2.6(0.38)	-	-
α_{Λ}	-0.60($\sim 1.$)	-0.99(0.98)	-0.81(0.96)	-	-
$\lambda_{ss}^L \lambda_{sb}^R$ c-value	-0.00013(0.0011)	-0.0083(0.049)	-0.81(0.63)	-60(4.9)	-
α_{Λ}	0.99(-0.32)	0.99(0.37)	0.94(0.94)	0.56(0.99)	-
$\lambda_{ss}^L \lambda_{sb}^R$ bound	-0.00024(0.0012)	-0.014(0.055)	-1.1(0.92)	-64(9.1)	-
α_{Λ}	0.96(-0.43)	0.96(0.28)	0.89(0.89)	0.54(0.98)	-
$\lambda_{ss}^{YD} \lambda_{bs}^{YD}$ c-value	-0.0014(0.021)	-0.05(0.37)	-3.0(2.8)	-	-
α_{Λ}	$\sim 1.(0.92)$	$\sim 1.(1.)$	$\sim 1.(1.)$	-	-
$\lambda_{ss}^{YD} \lambda_{bs}^{YD}$ bound	-0.0026(0.022)	-0.089(0.41)	-4.2(4.0)	-	-
α_{Λ}	$\sim 1.(0.9)$	$\sim 1.(1.)$	$\sim 1.(1.)$	-	-
$\lambda_{ss}^{YD} \lambda_{sb}^{YD}$ c-value	-0.0019(0.015)	-0.11(0.16)	-6.7(1.3)	-	-
α_{Λ}	0.98(0.42)	0.92(0.86)	0.54(0.98)	-	-
$\lambda_{ss}^{YD} \lambda_{sb}^{YD}$ bound	-0.0033(0.017)	-0.17(0.22)	-7.7(2.2)	-	-
α_{Λ}	0.95(0.33)	0.84(0.76)	0.44(0.94)	-	-

Table 2: Central values (c-value) and bounds for unparticle couplings with s quark in the loop for $\Lambda_{\mathcal{U}} = 1$ TeV. In the table “-” indicates that the central values are larger than 10 implying weak constraints which we do not list. The corresponding values for α_{Λ} are listed below the constraints on couplings. In the table “ $\sim 1.$ ” indicates a value very close to one.

tained on Tables I, II and III. However, one cannot exclude that the couplings are different for different generations, therefore the constraints obtained here are on different combinations and are new. There are also several studies of radiative decays involving leptons[5]. The couplings obtained here are in general less stringent compared with the ones involving leptons. The bounds obtained here involve quarks and are, again, new ones.

In conclusion, we have studied unparticle effects on $b \rightarrow s\gamma$. The unparticle contributions can contribute significantly to both left- and right-handed chirality amplitudes. Using available experimental data on $b \rightarrow s\gamma$ and SM calculation, we have obtained new constraints on various vector and scalar unparticle couplings. The constraints sensitively depend on the unparticle dimension $d_{\mathcal{U}}$. For $d_{\mathcal{U}}$ close to one, the constraints can be very stringent. The constraints become weaker when $d_{\mathcal{U}}$ is increased. In general the constraints on scalar unparticle couplings are weaker than those for vector unparticles. Sizeable coupling strength for scalar unparticles are still allowed leaving rooms for direct search for unparticle effects at colliders, such as LHC. Polarization measurement in $\Lambda_b \rightarrow \Lambda\gamma$ can further constraint the couplings.

$d_{\mathcal{U}}$	1.1	1.3	1.5	1.7	1.9
$\lambda_{sb}^R \lambda_{bb}^R$ c-value	-0.00020(0.00026)	-0.0043(0.0053)	-0.067(0.079)	-0.63(0.72)	-1.6(1.8)
α_{Λ}	0.81(0.76)	0.81(0.77)	0.80(0.78)	0.80(0.78)	0.79(0.79)
$\lambda_{sb}^R \lambda_{bb}^R$ bound	-0.00030(0.00035)	-0.0063(0.0072)	-0.096(0.11)	-0.90(0.99)	-2.2(2.4)
α_{Λ}	0.65(0.59)	0.65(0.60)	0.64(0.61)	0.63(0.62)	0.63(0.62)
$\lambda_{sb}^L \lambda_{bb}^L$ c-value	-3.8×10^{-5} (0.0014)	-0.00080(0.029)	-0.012(0.44)	-0.11(4.0)	-0.28(10)
α_{Λ}	~ 1 .(1.)	~ 1 .(1.)	~ 1 .(1.)	~ 1 .(1.)	~ 1 .(1.)
$\lambda_{sb}^L \lambda_{bb}^L$ bound	-7.3×10^{-5} (0.0014)	-0.0015(0.030)	-0.023(0.45)	-0.21(4.2)	-0.53(10)
α_{Λ}	~ 1 .(1.)	~ 1 .(1.)	~ 1 .(1.)	~ 1 .(1.)	~ 1 .(1.)
$\lambda_{sb}^R \lambda_{bb}^L$ c-value	-9.8×10^{-5} (8.9×10^{-5})	-0.0025(0.0023)	-0.050(0.046)	-0.76(0.7)	-5.7(5.2)
α_{Λ}	0.79(0.79)	0.79(0.79)	0.8(0.78)	0.8(0.78)	0.8(0.78)
$\lambda_{sb}^R \lambda_{bb}^L$ bound	-0.00014(0.00013)	-0.0034(0.0032)	-0.070(0.065)	-1.1(0.99)	-7.9(7.4)
α_{Λ}	0.63(0.62)	0.63(0.62)	0.63(0.62)	0.63(0.62)	0.63(0.62)
$\lambda_{sb}^L \lambda_{bb}^R$ c-value	-0.00056(1.6×10^{-5})	-0.014(0.00039)	-0.29(0.0080)	-4.4(0.12)	-33.(0.91)
α_{Λ}	~ 1 .(1.)	~ 1 .(1.)	~ 1 .(1.)	~ 1 .(1.)	~ 1 .(1.)
$\lambda_{sb}^L \lambda_{bb}^R$ bound	-0.00058(3.0×10^{-5})	-0.015(0.00075)	-0.30(0.015)	-4.5(0.23)	-34(1.7)
α_{Λ}	~ 1 .(1.)	~ 1 .(1.)	~ 1 .(1.)	~ 1 .(1.)	~ 1 .(1.)
$\lambda_{sb}^{YD} \lambda_{bb}^{YD}$ c-value	-0.027(0.00075)	-0.42(0.011)	-5.0(0.14)	-39(1.1)	-86(2.4)
α_{Λ}	~ 1 .(1.)	~ 1 .(1.)	~ 1 .(1.)	~ 1 .(1.)	~ 1 .(1.)
$\lambda_{sb}^{YD} \lambda_{bb}^{YD}$ bound	-0.028(0.0014)	-0.43(0.022)	-5.1(0.27)	-40(2.1)	-88(4.5)
α_{Λ}	~ 1 .(1.)	~ 1 .(1.)	~ 1 .(1.)	~ 1 .(1.)	~ 1 .(1.)
$\lambda_{bs}^{YD} \lambda_{bb}^{YD}$ c-value	-0.0048(0.0042)	-0.074(0.065)	-0.89(0.78)	-6.9(6.1)	-
α_{Λ}	~ 1 .(0.99)	~ 1 .(0.99)	~ 1 .(1.)	~ 1 .(1.)	-
$\lambda_{bs}^{YD} \lambda_{bb}^{YD}$ bound	-0.0066(0.0060)	-0.10(0.092)	-1.2(1.1)	-9.5(8.7)	-
α_{Λ}	0.99(0.98)	~ 1 .(0.99)	~ 1 .(0.99)	~ 1 .(1.)	-

Table 3: Central values (c-value) and bounds for unparticle couplings with b quark in the loop for $\Lambda_{\mathcal{U}} = 1$ TeV. In the table “-” indicates that the central values are larger than 10 implying weak constraints which we do not list. The corresponding values for α_{Λ} are listed below the constraints on couplings. In the table “ ~ 1 .” indicates a value very close to one.

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References

- [1] H. Georgi, *Unparticle physics*, *Phys. Rev. Lett.* **98** (2007) 221601 [[hep-ph/0703260](#)]; *Another odd thing about unparticle physics*, *Phys. Lett.* **B 650** (2007) 275 [[arXiv:0704.2457](#)].
- [2] S.-L. Chen and X.-G. He, *Interactions of unparticles with standard model particles*, *Phys. Rev.* **D 76** (2007) 091702 [[arXiv:0705.3946](#)].
- [3] M. Luo and G. Zhu, *Some phenomenologies of unparticle physics*, *Phys. Lett.* **B 659** (2008) 341 [[arXiv:0704.3532](#)];
C.-H. Chen and C.-Q. Geng, *Unparticle physics on direct CP-violation*, *Phys. Rev.* **D 76** (2007) 115003 [[arXiv:0705.0689](#)];
X.-Q. Li and Z.-T. Wei, *Unparticle physics effects on D^0 - \bar{D}^0 mixing*, *Phys. Lett.* **B 651** (2007) 380 [[arXiv:0705.1821](#)];

- C.-D. Lu, W. Wang and Y.-M. Wang, *Lepton flavor violating processes in unparticle physics*, *Phys. Rev. D* **76** (2007) 077701 [[arXiv:0705.2909](#)];
- T.M. Aliev, A.S. Cornell and N. Gaur, *$B \rightarrow K(K^*)$ missing energy in Unparticle physics*, *JHEP* **07** (2007) 072 [[arXiv:0705.4542](#)];
- C.-H. Chen and C.-Q. Geng, *Unparticle phase effects*, *Phys. Rev. D* **76** (2007) 036007 [[arXiv:0706.0850](#)];
- R. Zwicky, *Unparticles at heavy flavour scales: CP-violating phenomena*, *Phys. Rev. D* **77** (2008) 036004 [[arXiv:0707.0677](#)];
- R. Mohanta and A.K. Giri, *Unparticle effect on $B_s - \bar{B}_s$ mixing and its implications for $B_s \rightarrow J/\psi\phi, \phi\phi$ decays*, *Phys. Rev. D* **76** (2007) 075015 [[arXiv:0707.1234](#)];
- C.-S. Huang and X.-H. Wu, *Direct CP-violation of $B \rightarrow l\nu$ in unparticle physics*, *Phys. Rev. D* **77** (2008) 075014 [[arXiv:0707.1268](#)];
- A. Lenz, *Unparticle physics effects in B_s mixing*, *Phys. Rev. D* **76** (2007) 065006 [[arXiv:0707.1535](#)];
- R. Mohanta and A.K. Giri, *Possible signatures of unparticles in rare annihilation type B decays*, *Phys. Rev. D* **76** (2007) 057701 [[arXiv:0707.3308](#)];
- C.-H. Chen and C.-Q. Geng, *Flavors and phases in unparticle physics*, *Phys. Lett. B* **661** (2008) 118 [[arXiv:0709.0235](#)];
- T.M. Aliev and M. Savci, *Unparticle physics effects in $(\Lambda_b^- \rightarrow \Lambda + \text{missing energy})$ processes*, *Phys. Lett. B* **662** (2008) 165 [[arXiv:0710.1505](#)];
- S.-L. Chen, X.-G. He, X.-Q. Li, H.-C. Tsai and Z.-T. Wei, *Constraints on unparticle interactions from particle and antiparticle oscillations*, [arXiv:0710.3663](#);
- R. Mohanta and A.K. Giri, *Probing the unparticle signal in $b \rightarrow d$ penguin processes*, *Phys. Lett. B* **660** (2008) 376 [[arXiv:0711.3516](#)];
- Y.-f. Wu and D.-X. Zhang, *On unparticles and $K^+ \rightarrow \pi^+$ missing energy*, [arXiv:0712.3923](#);
- C.-H. Chen, C.S. Kim and Y.W. Yoon, *$B_{d,s} - \bar{B}_{d,s}$ mixings and $B_{u,d} \rightarrow (\pi, K)\pi$ decays in unparticle physics*, [arXiv:0801.0895](#);
- V. Bashiry, *CP-conserving unparticle phase effects on the unpolarized and polarized direct CP asymmetry in $b \rightarrow d\ell^+\ell^-$ transition*, [arXiv:0801.1490](#);
- M.J. Aslam and C.-D. Lu, *$B \rightarrow 0^+(1^+)$ missing energy in unparticle physics*, [arXiv:0802.0739](#);
- Y. Wu and D.-X. Zhang, *On unparticles and $B \rightarrow X_s + \text{missing energy}$* , [arXiv:0804.1843](#).
- [4] T.M. Aliev, A.S. Cornell and N. Gaur, *Lepton flavour violation in unparticle physics*, *Phys. Lett. B* **657** (2007) 77 [[arXiv:0705.1326](#)];
- D. Choudhury, D.K. Ghosh and Mamta, *Unparticles and muon decay*, *Phys. Lett. B* **658** (2008) 148 [[arXiv:0705.3637](#)];
- E.O. Iltan, *Unparticle physics and lepton flavor violating radion decays in the Randall-Sundrum scenario*, [arXiv:0711.2744](#); *Lepton flavor violating $l_i \rightarrow l_j\gamma\gamma$ decays induced by scalar unparticle*, [arXiv:0801.0301](#);
- A. Hektor, Y. Kajiyama and K. Kannike, *Muon anomalous magnetic moment and lepton flavor violating tau decay in unparticle physics*, [arXiv:0802.4015](#).
- [5] G.-J. Ding and M.-L. Yan, *Lepton flavor violating $\mu^- \rightarrow e\gamma$ and $\mu^- e$ conversion in unparticle physics*, *Phys. Rev. D* **77** (2008) 014005; *LFV $\mu \rightarrow e\gamma$ and $\mu - e$ conversion in unparticle physics*, [arXiv:0709.3435](#).
- [6] J.L. Hewett, *Top ten models constrained by $b \rightarrow s\gamma$* , [hep-ph/9406302](#);
- X.G. He, T.D. Nguyen and R.R. Volkas, *B meson rare decays in two Higgs doublets models*, *Phys. Rev. D* **38** (1988) 814;

- C.-K. Chua, X.-G. He and W.-S. Hou, *CP violating $b \rightarrow s\gamma$ decay in supersymmetric models*, *Phys. Rev. D* **60** (1999) 014003 [[hep-ph/9808431](#)];
X.-G. He and B. McKellar, *Constraints on the anomalous $W W$ gamma couplings from $b \rightarrow s\gamma$* , *Phys. Lett. B* **320** (1994) 165 [[hep-ph/9309228](#)].
- [7] HEAVY FLAVOR AVERAGING GROUP (HFAG), online at <http://www.slac.stanford.edu/xorg/hfag/rare/winter08/radll/btosg.pdf> (2008).
- [8] M. Misiak et al., *Estimate of $\mathcal{B}(\bar{B} \rightarrow X_s\gamma)$ at $O(\alpha_s^2)$* , *Phys. Rev. Lett.* **98** (2007) 022002 [[hep-ph/0609232](#)].
- [9] N.G. Deshpande, X.-G. He and J. Jiang, *Supersymmetric unparticle effects on Higgs boson mass and dark matter*, *Phys. Lett. B* **656** (2007) 91 [[arXiv:0707.2959](#)].
- [10] P.J. Fox, A. Rajaraman and Y. Shirman, *Bounds on unparticles from the Higgs Sector*, *Phys. Rev. D* **76** (2007) 075004 [[arXiv:0705.3092](#)].
- [11] PARTICLE DATA GROUP collaboration, W.M. Yao et al., *Review of particle physics*, *J. Phys. G* **33** (2006) 1.
- [12] A.J. Buras, M. Misiak, M. Müinz and S. Pokorski, *Theoretical uncertainties and phenomenological aspects of $B \rightarrow X(s)\gamma$ decay*, *Nucl. Phys. B* **424** (1994) 374 [[hep-ph/9311345](#)].
- [13] T. Mannel and S. Recksiegel, *Flavour changing neutral current decays of heavy baryons: the case $\Lambda/b \rightarrow \Lambda\gamma$* , *J. Phys. G* **24** (1998) 979 [[hep-ph/9701399](#)];
C.-K. Chua, X.-G. He and W.-S. Hou, *CP violating $b \rightarrow s\gamma$ decay in supersymmetric models*, *Phys. Rev. D* **60** (1999) 014003 [[hep-ph/9808431](#)].