FCNC transition $c \to u\gamma$ in $B_c \to B_u^* \gamma$ decay

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ABSTRACT: We propose the $B_c \to B_u^* \gamma$ decay as the most suitable probe for the flavour changing neutral transition $c \to u\gamma$. We estimate the short and long distance contributions to this decay within the standard model and we find them to be comparable; this is in contrast to radiative decays of D mesons, that are completely dominated by the long distance contributions. Since the $c \to u\gamma$ transition is very sensitive to the physics beyond the standard model, the standard model prediction $Br(B_c \to B_u^* \gamma) \sim 10^{-8}$ obtained here opens a new window for future experiments. The detection of $B_c \to B_u^* \gamma$ decay at branching ratio well above 10^{-8} would signal new physics.

1. Introduction

Flavour changing neutral current (FCNC) transitions occur in the standard model only at the loop level. Hence, they are very rare in the standard model and they present a suitable probe for new physics. The FCNC transitions in the down-quark sector are relatively frequent due to the large mass of the top quark running in the loop and the transition $b \to s$ has indeed been observed [1]. The FCNC transitions in the up-quark sector are especially rare in the standard model due to the small masses of the intermediate down-like quarks that run in the loop. For these transitions, the standard model represents a small background for the possible contributions arising from some new physics. At present, only upper experimental limits on the FCNC transitions in the up-quark sector are available [2].

We study the transition $c \to u\gamma$, which is the most probable FCNC transition in the up-quark sector within the standard model. To probe the $c \to u\gamma$ transition we propose the radiative beauty-conserving decay $B_c \to B_u^* \gamma$ [3]; the B_c meson has been detected recently at Fermilab [4]. We estimate the short distance (SD) and long distance (LD) contributions to $B_c \to B_u^* \gamma$ decay [3] within the standard model. The most serious among long distance contributions is illustrated at the quark level in Fig. 1. It is proportional to the small CKM factor $V_{cb}^* V_{ub}$ and it is therefore relatively small. The short and long distance contributions to $B_c \to B_u^* \gamma$ are found to be comparable [3], which allows us in principle to probe $c \to u\gamma$ transition in this decay. This is in contrast to the case of D meson decays, where the b quark is replaced by d or s quark in Fig. 1 and the corresponding long distance contribution is proportional to the relatively big CKM factors $V_{cd}^* V_{ud}$ or $V_{cs}^* V_{us}$. As a consequence, the radiative D meson decays are completely dominated by the LD contributions [5-9] and it is impossible to extract the short distance $c \to u\gamma$ contribution from the experiment.

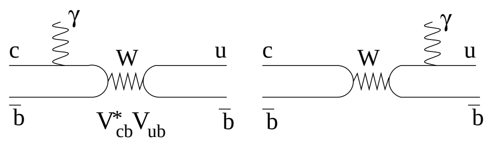

Figure 1: The most serious among the long distance contributions (called the pole contribution) to $B_c \to B_u^* \gamma$ decay at the quark level. The photon can be emitted from any of the quark lines.

*At Heavy Flavours 8 presented by S. Fajfer.

2. The short distance contribution

The SD contribution in $B_c \to B_u^* \gamma$ decay is driven by FCNC $c \to u\gamma$ transition and $\bar{b}$ is a spectator. The $c \to u\gamma$ transition is strongly GIM suppressed at one-loop, QCD logarithms enhance the amplitude by two orders of magnitude [9], while the complete 2-loop QCD corrections further increase the amplitude by two orders of magnitude [9]. The Lagrangian that induces the $c \to u\gamma$ transition is given by

$$\mathcal{L}_{SD}^{c\to u\gamma} = -\frac{G_F}{\sqrt{2}}\frac{e}{4\pi^2}V_{cs}V_{us}^* \; c_7^{c\to u\gamma}(\mu) \times \; \bar{u}\sigma^{\mu\nu}[m_c\frac{1+\gamma_5}{2}+m_u\frac{1-\gamma_5}{2}]c \; F_{\mu\nu} \; .$$

The appropriate renormalization scale μ for $c_7^{c\to u\gamma}$ in $B_c \to B_u^* \gamma$ decay is $\mu = m_c$ (and not $\mu = m_b$), since $\bar{b}$ is merely a spectator in the SD process. The 2-loop QCD calculation was performed in [9], giving $c_7^{c\to u\gamma}(m_c) = -0.0068 - 0.020i$.

The corresponding amplitude for $B_c \to B_u^* \gamma(q,\epsilon)$ decay is proportional to $\epsilon_\mu^* q_\nu \langle B_u^* | \bar{u}\sigma^{\mu\nu}(1\pm\gamma_5)c|B_c\rangle$ taken at $q^2=0$, which can be expressed in terms of the form factors $F_1(0)$ and $F_2(0)$ [10]:

$$\begin{aligned}
&\epsilon_\mu^*\langle B_u^*(p',\epsilon')|\bar{u}i\sigma^{\mu\nu}q_\nu c|B_c(p)\rangle_{q^2=0} = \\
&= \; i\epsilon^{\mu\alpha\beta\gamma}\epsilon_\mu^*\epsilon_\alpha^{*\prime}p'_\beta p_\gamma F_1(0) \; , \\
&\epsilon_\mu^*\langle B_u^*(p',\epsilon')|\bar{u}i\sigma^{\mu\nu}q_\nu\gamma_5 c|B_c(p)\rangle_{q^2=0} = \\
&= \; [(m_{B_c}^2 - m_{B_u^*}^2)\epsilon^*\cdot\epsilon^{*\prime} - 2(\epsilon^{*\prime}\cdot q)(p\cdot\epsilon^*)]F_2(0).
\end{aligned} \qquad (2.1)$$

The form factors defined will be calculated using the ISGW model [11].

3. The long distance contributions

The long distance contributions are calculated using the nonleptonic weak Lagrangian [6]

$$\mathcal{L}^{eff} = -\frac{G_F}{\sqrt{2}}V_{uq_i}V_{cq_j}^*[a_1\bar{u}\gamma^\mu(1-\gamma_5)q_i\bar{q}_j\gamma_\mu(1-\gamma_5)c + \; a_2\bar{u}\gamma^\mu(1-\gamma_5)c)\bar{q}_j\gamma_\mu(1-\gamma_5)q_i] \; , \qquad (3.1)$$

where q_i, q_j are the down quarks d, s, b and a_1, a_2 include the QCD corrections [12].

Quite generally, the LD contributions to $B_c \to B_u^* \gamma$ decay can be separated into two classes [3] related to the two terms of (3.1), as performed previously [5] for $D \to V\gamma$ decays. The class (I), called also the vector meson dominance (VMD) contribution, is related to the a_2 term (3.1) and corresponds to the processes $c \to u\bar{q}_i q_i$ followed by $\bar{q}_i q_i \to \gamma$, while $\bar{b}$ is the spectator in $B_c \to B_u^*\gamma$ decay. At the hadron level the $\bar{q}_i q_i \to \gamma$ transition is expressed using the vector meson dominance (VMD) and the corresponding diagram is depicted in Fig. (2a). The class (II), called also the *pole* contribution, is the most serious long distance contribution and it is presented at the quark level in Fig. 1. It is related to the a_1 term (3.1) and corresponds to the process $c\bar{b} \to u\bar{b}$ with the photon attached to incoming or outgoing quark lines. Selecting the lowest contributing states, the pole contributions are depicted in Fig. (2b) at the hadron level.

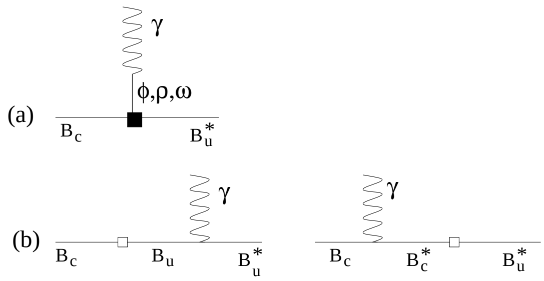

Figure 2: Long distance contributions in $B_c \to B_u^*\gamma$ decay. a) VMD contribution; the black box denotes the action of the Lagrangian (3.3). b) *pole* contribution presented in Fig. 1 at the quark level; the white box denotes the action of the Lagrangian (3.6).

We turn now to the estimation of these two classes of contributions and we start with the VMD contribution (class (I)) represented by Fig. (2a). The underlying quark processes are $c \to u\bar{s}s(\bar{d}d)$ with $\bar{s}s$, $\bar{d}d$ hadronizing into vector mesons ϕ, ρ, ω which then turn to a photon, while $\bar{b}$ remains a spectator. We neglect the contribution of $\bar{b}b \to \gamma$ in view of the large mass of Υ. The relevant part of the Lagrangian, after using the relations among CKM matrix elements, is

$$\mathcal{L}_{(I)}^{eff} = -\frac{G_F}{\sqrt{2}}a_2(\mu)V_{cs}V_{us}^* \; \bar{u}\gamma^\mu(1-\gamma_5)c \times[\bar{s}\gamma_\mu(1-\gamma_5)s - \bar{d}\gamma_\mu(1-\gamma_5)d]. \quad (3.2)$$

The appropriate scale for $a_2(\mu)$ in $B_c \to B_u^*\gamma$ decay is $\mu = m_c$, since $\bar{b}$ is again merely a spectator in VMD contribution. Thus, we may use $a_2(m_c) = -0.5$, as obtained in the successful phenomenological fit to D meson decays [12]. Defining $\langle V(q,\epsilon)|V_\mu|0\rangle = g_V(q^2)\epsilon^*_\mu$ and using the factorization approximation, the effective Lagrangian that induces the VMD contribution is given by

$$\mathcal{L}^{c\to u\gamma(\epsilon)}_{VMD} = -\frac{G_F e}{\sqrt{2}} a_2(m_c) V_{cs} V^*_{us} C'_{VMD} \times \bar{u}\gamma^\mu(1-\gamma_5)c\ \epsilon^*_\mu\ , \quad (3.3)$$

where

$$C'_{VMD} = \frac{g^2_\rho(0)}{2m^2_\rho} - \frac{g^2_\omega(0)}{6m^2_\omega} - \frac{g^2_\phi(0)}{3m^2_\phi} = (-1.2 \pm 1.2)\cdot 10^{-3}\ GeV^2 \quad (3.4)$$

is obtained by assuming $g_V(m_V) = g_V(0)$, with the mean value and the error in (3.4) calculated from the experimental data on $\Gamma(V \to e^+e^-)$ [2]. Note here the remarkable GIM cancellation carried over to the hadronic level.

Lagrangian (3.3) implies that the VMD amplitude for $B_c \to B^*_u\gamma(q,\epsilon)$ is proportional to $\epsilon^*_\mu\langle B^*_u|\bar{u}\gamma^\mu(1-\gamma_5)c|B_c\rangle$ taken at $q^2 = 0$. For the hadronic matrix elements, one defines appropriate form factors for the vector and axial transitions as follows [10]:

$$\langle B^*_u(p',\epsilon')|\bar{u}\gamma^\mu(1-\gamma_5)c|B_c(p)\rangle = \quad (3.5)$$
$$- \frac{2i}{m_{B_c}+m_{B^*_u}}\epsilon^{\mu\alpha\beta\gamma}\epsilon^{*\prime}_\alpha p'_{beta} p_\gamma V(q^2) + (m_{B_c}+m_{B^*_u})\epsilon^{\mu*\prime}A_1(q^2) - \frac{\epsilon^{*\prime}\cdot q}{m_{B_c}+m_{B^*_u}}(p+p')^\mu A_2(q^2) - 2m_{B^*_u}\frac{\epsilon^{*\prime}\cdot q}{q^2}q^\mu[A_3(q^2)-A_0(q^2)]\ .$$

The requirements of the finite matrix elements at $q^2 = 0$ [12] and of gauge invariance lead to the relations among the various form factors [7], which imply $A_0(0) = A_3(0) = 0$ and $A_2(0) = [(m_{B_c}+m_{B^*_u})/(m_{B_c}-m_{B^*_u})]A_1(0)$. The same relations are obtained by using the prescription that the photon couples only to the transverse polarization of the current [7, 13]. Accordingly, the VMD amplitude will be expressed in terms of two form factors only, $V(0)$ and $A_1(0)$.

At this point, we remark that the form factors F_1, F_2, V and A_1, needed for the SD and VMD amplitudes cannot be safely related using the Isgur-Wise relations [14], since the masses of b and c quarks composing B_c meson do not permit the $\bar{b}$ quark to be at rest. Therefore we shall determine the corresponding form factors at $q^2 = 0$ independently, using the ISGW model [11].

We now turn to the discussion of the LD contributions of class (II), the *pole* contribution, where the quark process $c\bar{b} \to u\bar{b}$ is driven by

$$\mathcal{L}^{eff}_{(II)} = -\frac{G_F}{\sqrt{2}} a_1(\mu) V_{cb}V^*_{ub}\ \bar{u}\gamma^\mu(1-\gamma_5)b\ \bar{b}\gamma_\mu(1-\gamma_5)c \quad (3.6)$$

and the photon line is attached to any of four quark lines. In terms of hadronic degrees of freedom this diagram is given in Fig. (2b), where the white box represents the action of the Lagrangian (3.6) (we have neglected the contribution of the scalar and axial poles). Considering the scale for $a_1(\mu)$ in $c\bar{b} \to u\bar{b}$, it is difficult to decide between $\mu = m_c$ or $\mu = m_b$, since $\bar{b}$ is not spectator in the pole contribution. As the difference between $a_1(m_c) = 1.2$ and $a_1(m_b) = 1.1$ [12] and is not essential, we take $a_1(m_b) = 1.1$. Note that the pole contribution is relatively small due to the factor $V_{cb}V^*_{ub}$ in (3.6). In D meson decays, the corresponding factor $V_{cs}V^*_{us}$ is much bigger, which makes the pole contribution dominant over the SD and VMD ones [5, 6, 7]. **Different CKM factors in the pole contribution of B_c and D decays are essential in establishing the $B_c \to B^*_u\gamma$ decay as more suitable for the investigation of $c \to u\gamma$ than the D decays.**

To evaluate the amplitude for the pole diagrams given in Fig. (2b) we define

$$\langle 0|A_\mu|P\rangle = f_P p_\mu \quad (3.7)$$
$$\langle V|V_\mu|0\rangle = g_V\epsilon^*_\mu$$
$$\mathcal{A}(P(p)\to V(p',\epsilon')\gamma(\epsilon)) = \mu_P e\epsilon^{\mu\nu\alpha\beta}\epsilon^*_\mu\epsilon^{*\prime}_\nu p_\alpha p'_\beta\ ,$$

where μ_{B_c}, μ_{B_u}, f_{B_c}, f_{B_u}, $g_{B^*_c}$ and $g_{B^*_u}$ will be determined using ISGW model.

4. The amplitude

Using the above Lagrangians and form factor decomposition of Eqs. (2.1), (3.5), (3.7), the final amplitude for $B_c \to B_u^* \gamma$ containing SD and LD contributions can be expressed as

$$A(B_c(p) \to B_u^*(p', \epsilon')\gamma(q, \epsilon)) = + i\epsilon_\mu^{*\prime}\epsilon_\nu^*[A_{PV}(p^\mu p^\nu - g^{\mu\nu} p\dot{q}) + iA_{PC}\epsilon^{\mu\nu\alpha\beta} p'_\alpha p_\beta] , \quad (4.1)$$

where

$$A_{PV} = -\frac{G_F}{\sqrt{2}} e \Bigg(V_{cs}V_{ud}^* \Bigg[\frac{c_7^{c\to u\gamma}(m_c)}{2\pi^2}(m_c - m_u)F_2(0) + 2a_2(m_c)C'_{VMD}\frac{A_1(0)}{m_{B_c} - m_{B_u^*}} \Bigg] \Bigg) ,$$

$$A_{PC} = -\frac{G_F}{\sqrt{2}} e \Bigg(V_{cs}V_{ud}^* \Bigg[\frac{c_7^{c\to u\gamma}(m_c)}{4\pi^2}(m_c + m_u)F_1(0) + 2a_2(m_c)C'_{VMD}\frac{V(0)}{m_{B_c} + m_{B_u^*}} \Bigg] + V_{cb}V_{ub}^* a_1 \Bigg[\frac{\mu_{B_c} g_{B_c^*} g_{B_u^*}}{m_{B_c^*}^2 - m_{B_u^*}^2} + \frac{\mu_{B_u} m_{B_c}^2 f_{B_c} f_{B_u}}{m_{B_c}^2 - m_{B_u}^2} \Bigg] \Bigg).$$

The first term in Eqs. (4.2) comes from SD contribution, the second term from VMD contribution and the third term from the *pole* contribution. The decay width is then given by

$$\Gamma = \frac{1}{4\pi}\left(\frac{m_{B_c}^2 - m_{B_u^*}^2}{2m_{B_c}}\right)^3 (|A_{PV}|^2 + |A_{PC}|^2) . \quad (4.2)$$

5. The model

To account for the nonperturbative dynamics within the mesons we use the nonrelativistic constituent ISGW quark model [11]. This model is considered to be reliable for a state composed of two heavy quarks, which makes it suitable for treating B_c; in addition the velocity of B_u^* in the rest frame of B_c is to a fair approximation nonrelativistic. In the ISGW model the constituent quarks of mass M move under the influence of the effective potential $V(r) = -4\alpha_s/(3r) + c + br$, $c = -0.81\ GeV$, $b = 0.18\ GeV^2$ [15]. Instead of the accurate solutions of the Schrodinger equation, the variational solutions

$$\psi(\vec{r}) = \pi^{-\frac{3}{4}}\beta^{\frac{3}{2}} e^{-\frac{\beta^2 r^2}{2}} \quad \text{or} \quad \psi(\vec{k}) = \pi^{-\frac{3}{4}}\beta^{-\frac{3}{2}} e^{-\frac{k^2}{2\beta^2}}$$

for S state are used, where β is employed as the variational parameter. The meson state composed of constituent quarks q_1 and $\bar{q}_2$ is given by

$$|M(p)\rangle = \sum_{C,s1,s2} \frac{1}{\sqrt{3}}\sqrt{\frac{2E}{(2\pi)^3}} \int d\vec{k}\psi(\vec{k})\sqrt{\frac{M_1}{E_1}}\sqrt{\frac{M_2}{E_2}} \times f_{s2,s1}\delta(p - p_1 - p_2) b_1^\dagger(\vec{p}_1, s_1, C) d_2^\dagger(\vec{p}_2, s_2, \bar{C})|0\rangle ,$$

where $\vec{k}$ is the momentum of the constituents in the meson rest frame, C denotes the colour, while $f_{s2,s1} = (\bar{\uparrow}\downarrow + \bar{\downarrow}\uparrow)/\sqrt{2}$ for pseudoscalar and $f_{s2,s1} = (\bar{\uparrow}\downarrow - \bar{\downarrow}\uparrow)/\sqrt{2}, \bar{\uparrow}\uparrow, \bar{\downarrow}\downarrow$ for vector mesons. Using the normalization of the spinors as in [16], we obtain in the nonrelativistic limit

$$\begin{aligned}
V(q^2) &= \frac{m_{B_c} + m_{B_u^*}}{2} F_3(q^2) \times \left[\frac{1}{M_u} - \frac{M_b(M_c - M_u)\beta_{B_c}^2}{M_c M_u m_{B_u^*}(\beta_{B_c}^2 + \beta_{B_u^*}^2)}\right] , \\
A_1(q^2) &= F_2(q^2) = \frac{2m_{B_c}}{m_{B_c} + m_{B_u^*}} F_3(q^2) , \\
F_1(q^2) &= 2F_3(q^2)\Bigg[1 + (m_{B_c} - m_{B_u^*}) \times \left(\frac{1}{2M_u} - \frac{M_b(M_c + M_u)\beta_{B_c}^2}{2M_c M_u m_{B_u^*}(\beta_{B_c}^2 + \beta_{B_u^*}^2)}\right)\Bigg] , \\
\mu_{B_c} &= \sqrt{\frac{m_{B_c^*}}{m_{B_c}}}\left(\frac{2\beta_{B_c}\beta_{B_c^*}}{\beta_{B_c}^2 + \beta_{B_c^*}^2}\right)^{\frac{3}{2}}\left[\frac{2}{3M_c} - \frac{1}{3M_b}\right] , \\
f_{B_c} &= \frac{2\sqrt{3}\beta_{B_c}^{\frac{3}{2}}}{\pi^{\frac{3}{4}}\sqrt{m_{B_c}}} , \\
g_{B_c^*} &= m_{B_c^*}\frac{2\sqrt{3}\beta_{B_c^*}^{\frac{3}{2}}}{\pi^{\frac{3}{4}}\sqrt{m_{B_c^*}}}
\end{aligned} \quad (5.1)$$

and analogously for μ_{B_u}, f_{B_u} and $g_{B_u^*}$. Here

$$F_3(q^2) = \sqrt{\frac{m_{B_u^*}}{m_{B_c}}}\left(\frac{2\beta_{B_c}\beta_{B_u^*}}{\beta_{B_c}^2 + \beta_{B_u^*}^2}\right)^{3/2} \times \exp\left(-\frac{M_b^2}{2m_{B_c}m_{B_u^*}}\frac{[(m_{B_c} - m_{B_u^*})^2 - q^2]}{\kappa^2(\beta_{B_c}^2 + \beta_{B_u^*}^2)}\right) ,$$

where $\kappa = 0.7$ [11]. The results for $V(q^2)$ and $A_1(q^2)$ reproduce the results of [11], while $F_1(q^2)$ and $F_2(q^2)$ represent, to our knowledge, the new results within ISGW model. Using parameters β [15] and meson masses given in Table 1 and the constituent quark masses $M_u = 0.33\ GeV$, $M_c = 1.82\ GeV$ and $M_b = 5.2\ GeV$ [15] we get

$$f_{B_u} = 0.18\ GeV,\ g_{B_u^*} = 0.86\ GeV^2,\ \mu_{B_u} = 1.81\ GeV^{-1}$$

$$f_{B_c} = 0.51\ GeV,\ g_{B_c^*} = 2.41\ GeV^2,\ \mu_{B_c} = 0.28\ GeV^{-1}$$

while the form factors evaluated at $q^2 = 0$ are given in Table 2.

	B_c	B_c^*	B_u	B_u^*
m	6.40 [4]	6.42 [15]	5.28 [2]	5.325 [2]
β	0.92	0.75	0.43	0.40

Table 1: Parameters β (taken from [15]) and masses of pseudoscalar and vector mesons in GeV.

$A_1(0)$	$V(0)$	$F_1(0)$	$F_2(0)$
0.24	1.3	0.48	0.24

Table 2: The $B_c \to B_u^*$ form factors at $q^2 = 0$ calculated using ISGW model [11].

6. The results

We use the central value of the current quark masses $m_u = 0.0035\ GeV$, $m_c = 1.25\ GeV$ from [2] and $V_{cb} = 0.04$, $V_{ub} = 0.0035$. The SD, VMD and *pole* contributions to amplitudes A_{PC} and A_{PV} needed to compute the amplitude (4.1) and the decay rate (4.2) are given in Table 3, where the error is due only to the uncertainty in parameter C'_{VMD} (3.4). In Table 4 we present the total branching ratio and separately also the SD and LD part of the branching ratios for $B_c \to B_u^*\gamma$ decay, where we have taken $\tau(B_c) = 0.46^{+0.18}_{-0.16} \pm 0.03\ ps$ as measured by CDF Collaboration recently [4]. Note that SD and LD contributions give branching ratios of comparable size $\sim 10^{-8}$, which in principle allows to probe the $c \to u\gamma$ transition in $B_c \to B_u^*\gamma$ decay. Experimental detection of $B_c \to B_u^*\gamma$ decay at the branching ratio well above 10^{-8} would clearly indicate a signal for new physics. The measurement of this decay would probe different scenarios of physics beyond the standard model: the non-minimal supersymmetric model [17] and the standard model with four generations [18], for example, predict $Br(c \to u\gamma)$ up to 10^{-5}, which would enhance $Br(B_c \to B_u^*\gamma)$ up to 10^{-6}. The branching ratios for D meson decays with flavour content $c\bar{q} \to u\bar{q}\gamma$, on the other hand, are of order 10^{-6} even within the standard model [6, 7, 9]: they are driven mainly by the long distance pole contributions analogous to those in Fig. 1, which overshadow the $c \to u\gamma$ transition (predicted at the branching ratio $\sim 10^{-9}$ in the standard model) and possible signals of new physics.

A_{PV}^{SD}	A_{PV}^{VMD}	A_{PV}^{pole}
$5.7 + 17\ i$	-14 ± 14	0
A_{PC}^{SD}	A_{PC}^{VMD}	A_{PC}^{pole}
$5.7 + 17\ i$	-7.3 ± 7.3	-21

Table 3: The parity conserving (PC) and parity violating (PV) amplitudes (4.1) for $B_c \to B_u^*\gamma$ decay. The short distance (SD), vector meson dominance (VMD) and *pole* contributions as predicted by ISGW model are given separately in units of $10^{-11}\ GeV^{-1}$. The error-bars are due to the uncertainty in $C'_{VMD} = (1.2 \pm 1.2)\ 10^{-3}\ GeV^2$ (3.4).

Br^{SD}	Br^{LD}	Br^{tot}
$4.7 \cdot 10^{-9}$	$(7.5^{+7.7}_{-4.3}) \cdot 10^{-9}$	$(8.5^{+5.8}_{-2.5}) \cdot 10^{-9}$

Table 4: The total branching ratio for $B_c \to B_u^*\gamma$ decay and its short distance (SD) and long distance (LD) parts as predicted by ISGW model. The error-bars are due to the uncertainty in $C'_{VMD} = (1.2 \pm 1.2)\ 10^{-3}\ GeV^2$ (3.4).

7. Summary

The long distance contribution in $B_c \to B_u^*\gamma$ decay is relatively small and this decay is proposed as the most suitable decay to probe the flavour changing neutral transition $c \to u\gamma$. The short distance part (driven by $c \to u\gamma$) and the long distance part of the branching ratio for $B_c \to B_u^*\gamma$ decay, presented in Table 4, are of comparable size. They are both of order 10^{-8} and the short distance contribution can in principle be disentangled in this channel. Since $c \to u\gamma$ transition is sensitive to the physics beyond the standard model, it would be very desirable to compare the standard model prediction of $Br(B_c \to B_u^*\gamma) = (8.5^{+5.8}_{-2.5}) \cdot 10^{-9}$ presented here to the experimental data in the future. The detection of $B_c \to B_u^*\gamma$ decay at a branching ratio well above

10^{-8} would signal new physics. In comparison to $B_c \to B_u^* \gamma$ decay, the D meson decays are far less suitable for probing $c \to u\gamma$ transition, since they are almost completely dominated by the long distance effects.

Finally, we wish to stress that $B_c \to B_u^* \gamma$ is characterized by a very clear signature: their detection requires the observation of a B_u/B_d decay in coincidence with two photons. The $B_c \to B_u^* \gamma$ transition involves the emission of a high energy (985 MeV) and of a low energy (45 MeV) photon in the respective centers of mass of B_c, B_u^*.

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