在leptoquark模型下计算$t\to c\gamma$衰变的分支比

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研究动机

- top夸克作为标准模型（SM）中最重的基本粒子，可以衰变为与规范或标量玻色子相关的其他轻夸克。在所有可能的衰变模式中，顶夸克的味道改变中性流（FCNC）衰变在SM中不存在树图阶的贡献，在圈图阶的贡献也被GIM机制抑制[1]，因此这类过程对新物理的贡献非常敏感。

- Leptoquarks（LQs）是在统一物质的标准模型（SM）的扩展中以一种特别自然的方式出现的假设粒子[2]。LQs可以把夸克变成轻子，反之亦然。这一特殊性质使其有别于所有其他的基本粒子。

- 所以，我们尝试在leptoquark模型下对top夸克的稀有衰变$t\to c\gamma$过程进行研究，以便用现有实验测量对leptoquark模型中的一些参数进行限制。

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leptoquark模型

leptoquark模型[3]

$(SU(3), SU(2), U(1))$	Spin	Symbol	Type	F
$(\bar{\mathbf{3}}, \mathbf{3}, 1/3)$	0	S_3	$LL\,(S_1^L)$	-2
$(\mathbf{3}, \mathbf{2}, 7/6)$	0	R_2	$RL\,(S^L_{1/2}),\ LR\,(S^R_{1/2})$	0
$(\mathbf{3}, \mathbf{2}, 1/6)$	0	$\tilde{R}_2$	$RL\,(\tilde{S}^L_{1/2}),\ \overline{LR}\,(\tilde{S}^{\overline{L}}_{1/2})$	0
$(\bar{\mathbf{3}}, \mathbf{1}, 4/3)$	0	$\tilde{S}_1$	$RR\,(\tilde{S}_0^R)$	-2
$(\bar{\mathbf{3}}, \mathbf{1}, 1/3)$	0	S_1	$LL\,(S_0^L),\ RR\,(S_0^R),\ \overline{RR}\,(S_0^{\overline{R}})$	-2
$(\bar{\mathbf{3}}, \mathbf{1}, -2/3)$	0	$\bar{S}_1$	$\overline{RR}\,(\bar{S}_0^{\overline{R}})$	-2
$(\mathbf{3}, \mathbf{3}, 2/3)$	1	U_3	$LL\,(V_1^L)$	0
$(\bar{\mathbf{3}}, \mathbf{2}, 5/6)$	1	V_2	$RL\,(V^L_{1/2}),\ LR\,(V^R_{1/2})$	-2
$(\bar{\mathbf{3}}, \mathbf{2}, -1/6)$	1	$\tilde{V}_2$	$RL\,(\tilde{V}^L_{1/2}),\ \overline{LR}\,(\tilde{V}^{\overline{R}}_{1/2})$	-2
$(\mathbf{3}, \mathbf{1}, 5/3)$	1	$\tilde{U}_1$	$RR\,(\tilde{V}_0^R)$	0
$(\mathbf{3}, \mathbf{1}, 2/3)$	1	U_1	$LL\,(V_0^L),\ RR\,(V_0^R),\ \overline{RR}\,(V_0^{\overline{R}})$	0
$(\mathbf{3}, \mathbf{1}, -1/3)$	1	$\bar{U}_1$	$\overline{RR}\,(\bar{V}_0^{\overline{R}})$	0

Table 1: List of scalar and vector LQs.

$F = 3B + L$

leptoquark模型

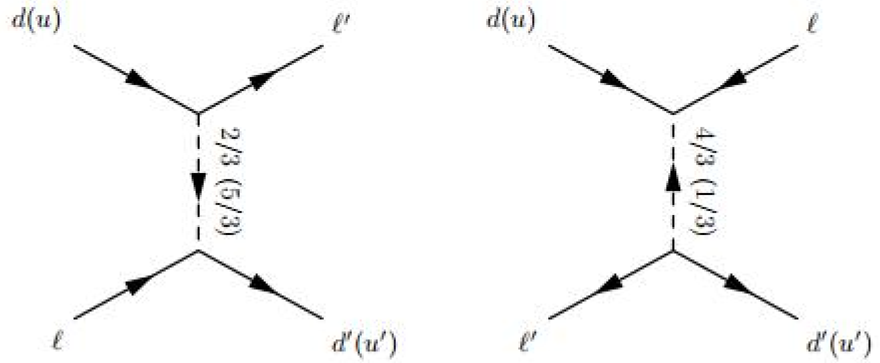

Figure 1: Diagrams of rare meson decays of flavor $(\bar{d}' d)(\bar{\ell}' \ell)$ and $(\bar{u}' u)(\bar{\ell}' \ell)$ induced by LQs. The $F = 0$ LQs contribute as shown in the left-hand side diagram, $|F| = 2$ as shown in the right-hand diagram. Propagators are labeled by charge of the relevant components of the LQ.

leptoquark模型

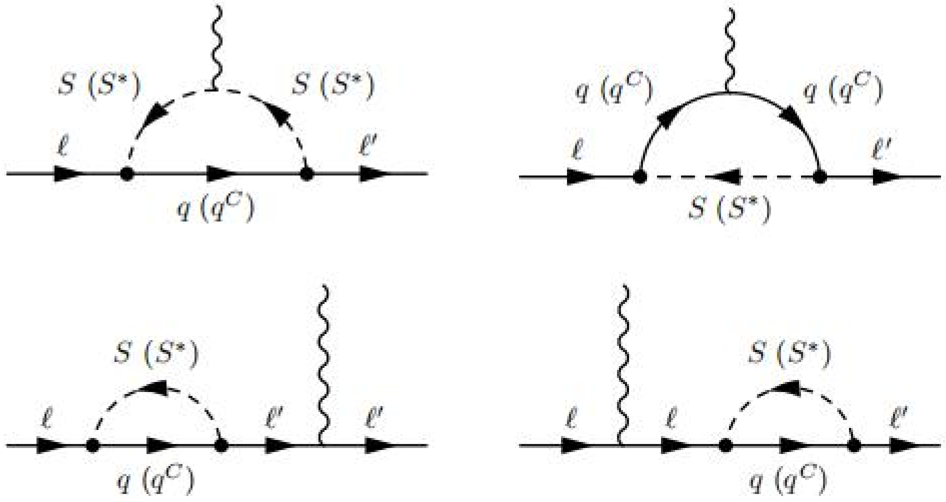

Figure 2: One loop scalar LQ contributions to $\ell \to \ell'\gamma$ and to dipole moments of leptons.

leptoquark模型

LQ	$t \to c\gamma$ decays	$b \to s\gamma$ decays
S_3	$\sqrt{2}(V^* y_3^{LL} U)_{ij} \bar{u}_L^{C\,i} S_3^{-2/3} \nu_L^j$ $-(V^* y_3^{LL})_{ij} \bar{u}_L^{C\,i} S_3^{1/3} e_L^j$	$-(y_3^{LL} U)_{ij} \bar{d}_L^{C\,i} S_3^{1/3} \nu_L^j$ $-\sqrt{2} y_{3\,ij}^{LL} \bar{d}_L^{C\,i} S_3^{4/3} e_L^j$
R_2	$(y_2^{RL} U)_{ij} \bar{u}_R^i \nu_L^j R_2^{2/3}$ $-y_{2\,ij}^{RL} \bar{u}_R^i e_L^j R_2^{5/3} + (y_2^{LR} V^\dagger)_{ij} \bar{e}_R^i u_L^j R_2^{5/3\,*}$	$+y_{2\,ij}^{LR} \bar{e}_R^i d_L^j R_2^{2/3\,*}$
$\tilde{R}_2$		$(\tilde{y}_2^{RL} U)_{ij} \bar{d}_R^i \nu_L^j \tilde{R}_2^{-1/3}$ $-\tilde{y}_{2\,ij}^{RL} \bar{d}_R^i e_L^j \tilde{R}_2^{2/3}$
$\tilde{S}_1$		$+\tilde{y}_{1\,ij}^{RR} \bar{d}_R^{C\,i} \tilde{S}_1 e_R^j$
S_1	$(V^* y_1^{LL})_{ij} \bar{u}_L^{C\,i} S_1 e_L^j + y_{1\,ij}^{RR} \bar{u}_R^{C\,i} S_1 e_R^j$	$-(y_1^{LL} U)_{ij} \bar{d}_L^{C\,i} S_1 \nu_L^j$
U_3	$(V x_3^{LL} U)_{ij} \bar{u}_L^i \gamma^\mu U_{3,\mu}^{2/3} \nu_L^j$ $+\sqrt{2}(V x_3^{LL})_{ij} \bar{u}_L^i \gamma^\mu U_{3,\mu}^{5/3} e_L^j$	$\sqrt{2}(x_3^{LL} U)_{ij} \bar{d}_L^i \gamma^\mu U_{3,\mu}^{-1/3} \nu_L^j$ $-x_{3\,ij}^{LL} \bar{d}_L^i \gamma^\mu U_{3,\mu}^{2/3} e_L^j$
V_2	$(V^* x_2^{LR})_{ij} \bar{u}_L^{C\,i} \gamma^\mu V_{2,\mu}^{1/3} e_R^j$	$-(x_2^{RL} U)_{ij} \bar{d}_R^{C\,i} \gamma^\mu V_{2,\mu}^{1/3} \nu_L^j$ $+x_{2\,ij}^{RL} \bar{d}_R^{C\,i} \gamma^\mu V_{2,\mu}^{4/3} e_L^j - x_{2\,ij}^{LR} \bar{d}_L^{C\,i} \gamma^\mu V_{2,\mu}^{4/3} e_R^j$
$\tilde{V}_2$	$(\tilde{x}_2^{RL} U)_{ij} \bar{u}_R^{C\,i} \gamma^\mu \tilde{V}_{2,\mu}^{-2/3} \nu_L^j$ $-\tilde{x}_{2\,ij}^{RL} \bar{u}_R^{C\,i} \gamma^\mu \tilde{V}_{2,\mu}^{1/3} e_L^j$	
$\tilde{U}_1$	$\tilde{x}_{1\,ij}^{RR} \bar{u}_R^i \gamma^\mu \tilde{U}_{1,\mu} e_R^j$	
U_1	$(V x_1^{LL} U)_{ij} \bar{u}_L^i \gamma^\mu U_{1,\mu} \nu_L^j$	$x_{1\,ij}^{LL} \bar{d}_L^i \gamma^\mu U_{1,\mu} e_L^j + x_{1\,ij}^{RR} \bar{d}_R^i \gamma^\mu U_{1,\mu} e_R^j$

leptoquark模型

$R_2 = (\mathbf{3}, \mathbf{2}, 7/6)$

$$\mathcal{L} \supset -y^{RL}_{2\,ij}\bar{u}^i_R R^a_2 \epsilon^{ab} L^{j,b}_L + y^{LR}_{2\,ij}\bar{e}^i_R R^{a\,*}_2 Q^{j,a}_L + \text{h.c.}.$$

$$\mathcal{L} \supset -y^{RL}_{2\,ij}\bar{u}^i_R e^j_L R^{5/3}_2 + (y^{RL}_2 U)_{ij}\bar{u}^i_R \nu^j_L R^{2/3}_2 + \\ +(y^{LR}_2 V^\dagger)_{ij}\bar{e}^i_R u^j_L R^{5/3\,*}_2 + y^{LR}_{2\,ij}\bar{e}^i_R d^j_L R^{2/3\,*}_2 + \text{h.c.},$$

$S_1 = (\bar{\mathbf{3}}, \mathbf{1}, 1/3)$

$$\mathcal{L} \supset +y^{LL}_{1\,ij}\bar{Q}^{C\,i,a}_L S_1 \epsilon^{ab} L^{j,b}_L + y^{RR}_{1\,ij}\bar{u}^{C\,i}_R S_1 e^j_R + y^{\overline{RR}}_{1\,ij}\bar{d}^{C\,i}_R S_1 \nu^j_R + \\ + z^{LL}_{1\,ij}\bar{Q}^{C\,i,a}_L S^*_1 \epsilon^{ab} Q^{j,b}_L + z^{RR}_{1\,ij}\bar{u}^{C\,i}_R S^*_1 d^j_R + \text{h.c.},$$

$$\mathcal{L} \supset -(y^{LL}_1 U)_{ij}\bar{d}^{C\,i}_L S_1 \nu^j_L + (V^* y^{LL}_1)_{ij}\bar{u}^{C\,i}_L S_1 e^j_L + y^{RR}_{1\,ij}\bar{u}^{C\,i}_R S_1 e^j_R + \\ + y^{\overline{RR}}_{1\,ij}\bar{d}^{C\,i}_R S_1 \nu^j_R + (V^* z^{LL}_1)_{ij}\bar{u}^{C\,i}_L S^*_1 d^j_L - (z^{LL}_1 V^\dagger)_{ij}\bar{d}^{C\,i}_L S^*_1 u^j_L + \\ + z^{RR}_{1\,ij}\bar{u}^{C\,i}_R S^*_1 d^j_R + \text{h.c.}.$$

leptoquark模型

$S_3 = (\bar{\mathbf{3}}, \mathbf{3}, 1/3)$

$$\mathcal{L} \supset + y_{3\,ij}^{LL} \bar{Q}_L^{C\,i,a} \epsilon^{ab} (\tau^k S_3^k)^{bc} L_L^j + z_{3\,ij}^{LL} \bar{Q}_L^{C\,i,a} \epsilon^{ab} ((\tau^k S_3^k)^\dagger)^{bc} Q_L^j + \text{h.c.},$$

$$\begin{aligned}\mathcal{L} \supset & -(y_3^{LL}U)_{ij} \bar{d}_L^{C\,i} S_3^{1/3} \nu_L^j - \sqrt{2} y_{3\,ij}^{LL} \bar{d}_L^{C\,i} S_3^{4/3} e_L^j \\ & + \sqrt{2}(V^* y_3^{LL} U)_{ij} \bar{u}_L^{C\,i} S_3^{-2/3} \nu_L^j - (V^* y_3^{LL})_{ij} \bar{u}_L^{C\,i} S_3^{1/3} e_L^j \\ & - (z_3^{LL} V^\dagger)_{ij} \bar{d}_L^{C\,i} S_3^{1/3\,*} u_L^j - \sqrt{2} z_{3\,ij}^{LL} \bar{d}_L^{C\,i} S_3^{-2/3\,*} d_L^j + \\ & + \sqrt{2}(V^* z_3^{LL} V^\dagger)_{ij} \bar{u}_L^{C\,i} S_3^{4/3\,*} u_L^j - (V^* z_3^{LL})_{ij} \bar{u}_L^{C\,i} S_3^{1/3\,*} d_L^j + \text{h.c.},\end{aligned}$$

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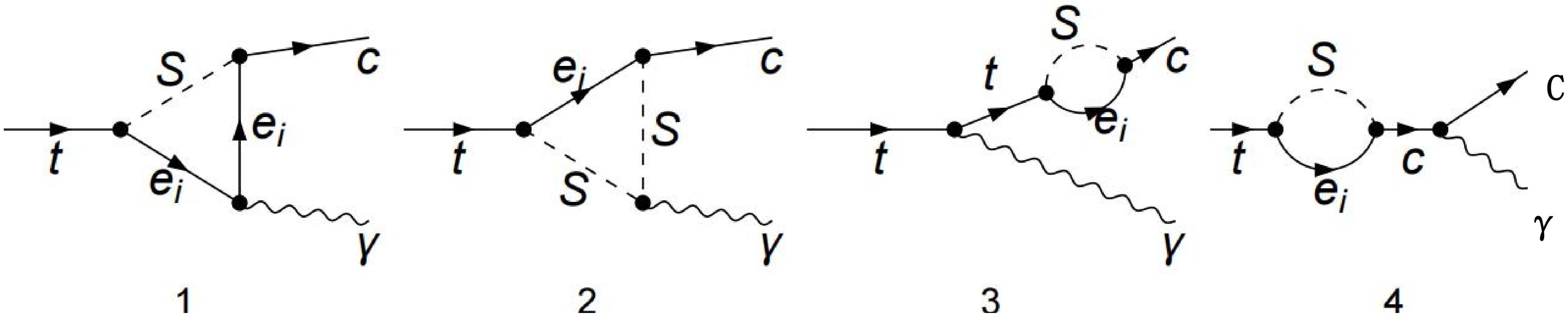
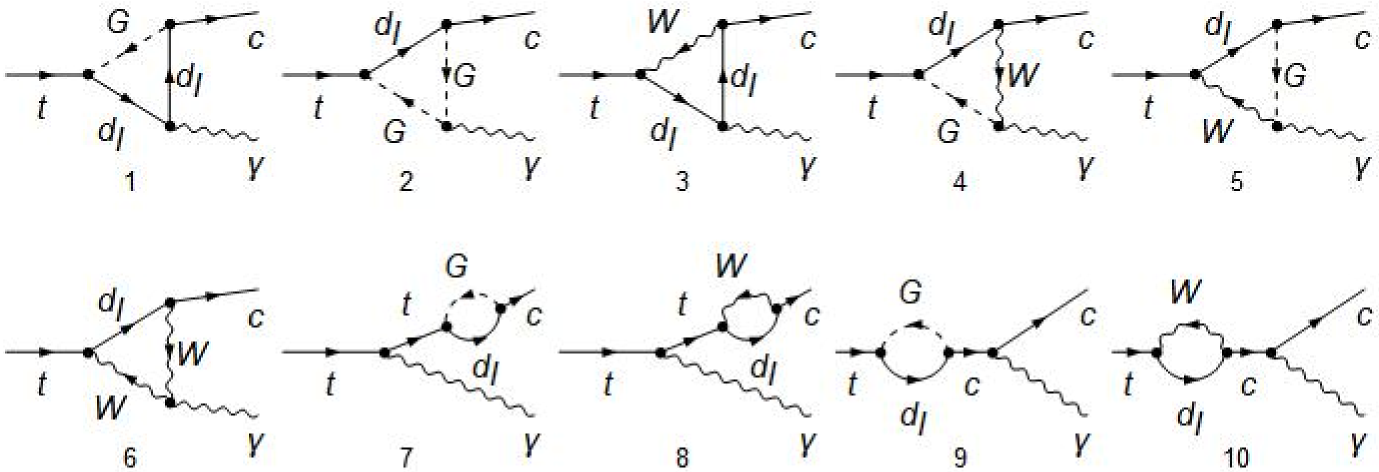
计算过程

计算过程

t→cγ within leptoquark





t→cγ within SM

计算过程

$$\mathcal{M}(t \to c\gamma) = \frac{i}{m_t + m_c}\bar{u}(p_c)[\sigma^{\mu\nu}q_\nu(A_L P_L + B_R P_R)]u(p_t)\epsilon_\mu^\star(q)\,. \tag{1}$$ [4, 5]

$$\mathcal{M}(t \to c\gamma) = \bar{u}(p_c)[i\sigma^{\mu\nu}q_\nu(A_\gamma + B_\gamma\gamma_5)]u(p_t)\epsilon_\mu^\star(q)\,, \tag{2}$$ [6, 7]

$$A_\gamma = \frac{1}{2(m_t + m_c)}(A_L + B_R)\,, \qquad B_\gamma = \frac{1}{2(m_t + m_c)}(-A_L + B_R)\,. \tag{3}$$

$$\Gamma(t \to c\gamma) = \frac{1}{16\pi}\frac{(m_t^2 - m_c^2)^3}{m_t^3(m_t + m_c)^2}(|A_L|^2 + |B_R|^2)\,, \tag{4}$$ [4, 5]

$$\Gamma(t \to c\gamma) = \frac{1}{\pi}\left[\frac{m_t^2 - m_c^2}{2m_t}\right]^3(|A_\gamma|^2 + |B_\gamma|^2)\,, \tag{5}$$ [6, 7]

$$B(t \to c\gamma) = \frac{\Gamma(t \to c\gamma)}{\Gamma(t \to bW^+)} \tag{6}$$

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数值结果

数值结果

	R2	S1	S3
Br(LQ参数→0) SM	2.98897×10^{-14}	2.98897×10^{-14}	2.98897×10^{-14}
Br(LQ参数→1)	2.9677×10^{-8}	9.04445×10^{-9}	2.99118×10^{-9}

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THANK YOU