Model-Independent Constraints on Lepton-Flavor-Violating Decays of the Top Quark

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Introduction

- LHC: huge top physics potential ($10^8 t$'s!).
- t unique, good place to look for New Physics (NP).
- Neutrino osc: Nature has lepton flavor violation.
- $t \to u(c)e^{\pm}\mu^{\mp}$: distinctive experimental signature.
- Are there experimental constraints on NP contributions to $t \to u(c)e^{\pm}\mu^{\mp}$?
- Take set of effective operators

$$\mathcal{L}_{eff} = \sum_i \frac{C_i}{\Lambda^{d-4}} \mathcal{O}_i + h.c.$$

to get constraints from B, K decays and $\mu \to e\gamma$.

Operators Contributing to $t \to u(c)e^{\pm}\mu^{\mp}$

- Take dimension-6, $SU(3) \times SU(2) \times U(1)$-invariant op's.
- Separate into 2 classes, depending on T_L or t_R in operator.

Class One:

$$
\begin{aligned}
\mathcal{O}_{1,ijk} &= \bar{u}^i_R \gamma^\mu t_R \bar{L}^j_L \gamma_\mu L^k_L \\
\mathcal{O}_{2,ijk} &= \bar{u}^i_R \gamma^\mu t_R \bar{l}^j_R \gamma_\mu l^k_R \\
\mathcal{O}_{3,ijk} &= \epsilon^{ab} \bar{Q}^i_{La} t_R \bar{L}^j_{Lb} l^k_R \\
\mathcal{O}_{4,ijk} &= \epsilon^{ab} \bar{Q}^i_{La} \sigma^{\mu\nu} t_R \bar{L}^j_{Lb} \sigma_{\mu\nu} l^k_R
\end{aligned}
$$

Class Two:

$$
\begin{aligned}
\mathcal{O}_{5,ijk} &= \bar{Q}^i_L \gamma^\mu T_L \bar{L}^j_L \gamma_\mu L^k_L \\
\mathcal{O}_{6,ijk} &= \bar{Q}^i_L \gamma^\mu T_L \bar{l}^j_R \gamma_\mu l^k_R \\
\mathcal{O}_{7,ijk} &= \epsilon^{ab} \bar{u}^i_R T_{La} \bar{l_R}^j L^k_{Lb} \\
\mathcal{O}_{8,ijk} &= \epsilon^{ab} \bar{u}^i_R \sigma^{\mu\nu} T_{La} \bar{l_R}^j \sigma_{\mu\nu} L^k_{Lb}
\end{aligned}
$$

$i = u, c$; $\quad j, k = e\mu, \mu e$

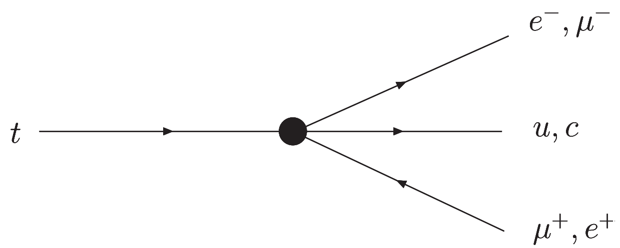
$a, b = SU(2)$ indices

Q_L, L_L, T_L: l.h. doublets

u_R, l_R, t_r: r.h. singlets

Contributions of Op's to $t \rightarrow u(c)e^{\pm}\mu^{\mp}$

- Top decay for all op's proceeds via



- Assume can measure branching ratio of 10^{-7}.
- Taking $m_t = 170$ GeV and $|C_{n,ijk}| = 1$,

$$\Lambda \geq \begin{array}{lll} 2.1 & \text{TeV} & (n = 1, 2, 5, \text{ and } 6) \\ 1.5 & \text{TeV} & (n = 3 \text{ and } 7) \\ 4.0 & \text{TeV} & (n = 4 \text{ and } 8) \end{array}$$

- Results independent of flavor indices i, j, k.

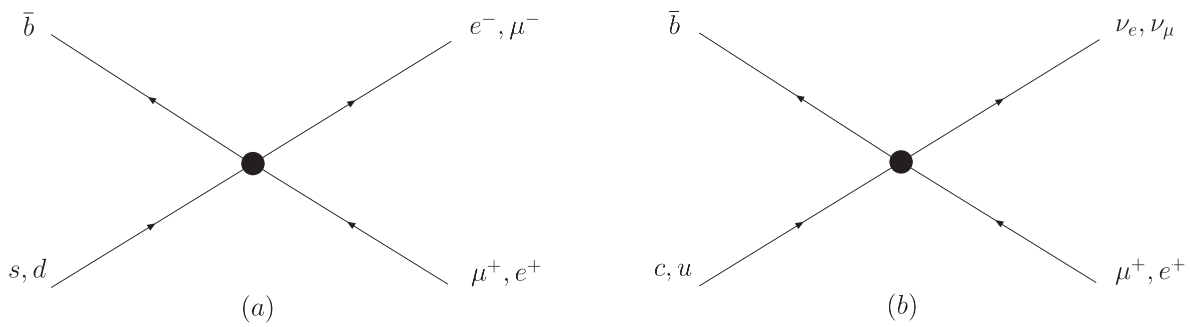
Constraints from B decays

Class Two op's contain T_L, include terms with b quarks.

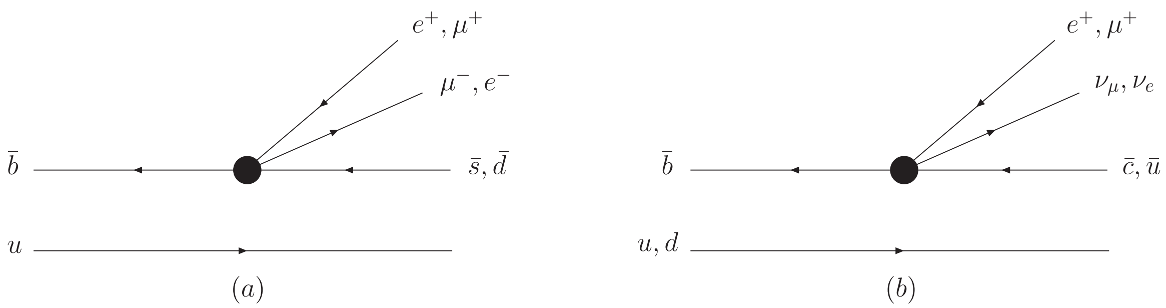
ex: $\mathcal{O}_{6,ijk} = \bar{Q}^i_L \gamma^\mu T_L \bar{l}^j_R \gamma_\mu l^k_R = (\bar{u}^i_L \gamma^\mu t_L + \bar{d}^i_L \gamma^\mu b_L) \bar{l}^j_R \gamma_\mu l^k_R$

$\rightarrow$ contribute at tree-level to B decay.

2-body



3-body



Constraints from 2-body B decays

The Class Two op's contribute to ($\langle 0|\bar{d}\gamma^{\mu}\gamma_5 b|B^0(p)\rangle = i\sqrt{2}F_B p^{\mu}$):

Op's $5, 6$: $B^0, B_s \to e^{\pm}\mu^{\mp}$, $\Gamma = \frac{1}{32\pi}\frac{|C_{n,ijk}|^2}{\Lambda^4}F_B^2 m_B m_\mu^2$
(helicity-suppressed)

Op 7: $B^+, B_c \to \ell^+\nu$, $\Gamma = \frac{1}{32\pi}\frac{|C_{n,ijk}|^2}{\Lambda^4}F_B^2\frac{m_B^5}{(m_b+m_{u(c)})^2}$

Op 8: 0 (tensor operator)

$$\text{Br}(B^0 \to e^{\pm}\mu^{\mp}) \leq 1.7\times 10^{-7}(90\%\text{CL}) \to \frac{|C_{5(6),ujk}|}{\Lambda^2} \leq \frac{1}{(3.7\ \text{TeV})^2}$$

$$\text{Br}(B_s \to e^{\pm}\mu^{\mp}) \leq 6.1\times 10^{-6}(90\%\text{CL}) \to \frac{|C_{5(6),cjk}|}{\Lambda^2} \leq \frac{1}{(1.6\ \text{TeV})^2}$$

$$\text{Br}(B^+ \to e^{+}\nu) \leq 9.8\times 10^{-6}(90\%\text{CL}) \to \frac{|C_{7,u\mu e}|}{\Lambda^2} \leq \frac{1}{(17\ \text{TeV})^2}$$

$$\text{Br}(B^+ \to \mu^{+}\nu) \leq 1.7\times 10^{-6}(90\%\text{CL}) \to \frac{|C_{7,ue\mu}|}{\Lambda^2} \leq \frac{1}{(11\ \text{TeV})^2}$$

Constraints from 3-body B decays

$\longrightarrow$ No helicity suppression, op 8 can contribute.

Op's 5,6: Compare to exclusive via $B \to \pi \ell^+ \nu$.

$$\text{Br}(B^+ \to \pi^+ e^+ \mu^-) \quad \le \quad 6.4 \times 10^{-3} \to \frac{|C_{5(6),ujk}|}{\Lambda^2} \le \frac{1}{(1 \quad \text{TeV})^2}$$

$$\text{Br}(B^+ \to K^+ e^\pm \mu^\mp) \quad \le \quad 9.1 \times 10^{-8} \to \frac{|C_{5(6),cjk}|}{\Lambda^2} \le \frac{1}{(16 \quad \text{TeV})^2}$$

Op's 7,8: Take $2\times$ exp. error as estimate of NP contribution.

$$\text{Br}(B \to X_u \ell^+ \nu) = 2.33 \pm .22 \times 10^{-3} \quad \to \quad \frac{|C_{7,ujk}|}{\Lambda^2} \le \frac{1}{(3 \quad \text{TeV})^2}$$

$$\frac{|C_{8,ujk}|}{\Lambda^2} \le \frac{1}{(7 \quad \text{TeV})^2}$$

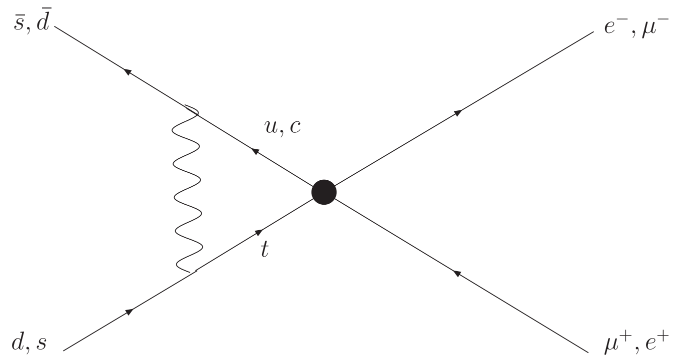
$$\text{Br}(B^- \to X_c e^+ \nu) = 10.8 \pm 0.4 \quad \to \quad \frac{|C_{7,ce\mu}|}{\Lambda^2} \le \frac{1}{(1 \quad \text{TeV})^2}$$

$$\frac{|C_{8,ce\mu}|}{\Lambda^2} \le \frac{1}{(3 \quad \text{TeV})^2}$$

Constraints from K decays

Op's of both classes can contribute at one loop to $K_L \to e^\pm \mu^\mp$:

i.e.,



Br$(K_L \to e^\pm \mu^\mp) \leq 4.7 \times 10^{-12} \quad \to$

$$\frac{|C_{5(6),ujk}(\Lambda)|}{\Lambda^2} \ln \frac{v^2}{\Lambda^2} < \frac{1}{(2.3\text{TeV})^2}$$

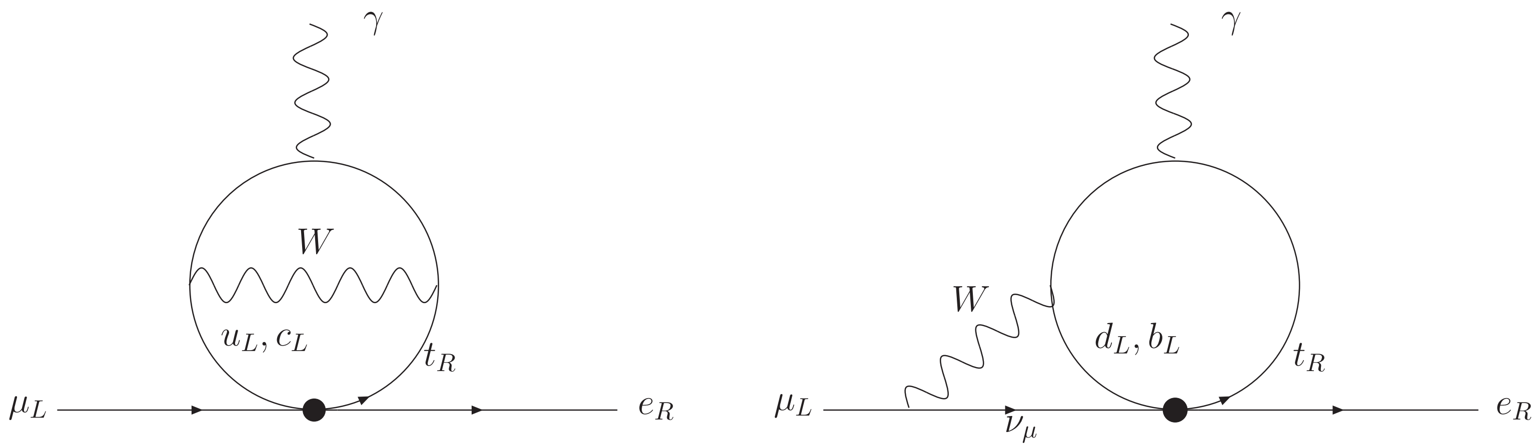
$$\frac{|C_{5(6),cjk}(\Lambda)|}{\Lambda^2} \ln \frac{v^2}{\Lambda^2} < \frac{1}{(1.6\text{TeV})^2}$$

$$\frac{|C_{4,ujk}|}{\Lambda^2} \lesssim \frac{1}{(1\text{TeV})^2}$$

- Constraints from 3-body K decays weaker.

$\mu \to e\gamma$

Ops 3, 4 can contribute to $\mu \to e\gamma$ at 2 loops, i.e.,



$Br(\mu \to e\gamma) < 1.2 \times 10^{-11} \to$ yet to come

Results

Operator	$t \to u(c)e^{\pm}\mu^{\mp}$	B, 2-body	B, 3-body	K	$\mu \to e\gamma$
$\mathcal{O}_{1(2),ijk}$	2.1	-	-	-	-
$\mathcal{O}_{3,ijk}$	1.5	-	-	-	maybe
$\mathcal{O}_{4,ujk}$	4.0	-	-	1	maybe
$\mathcal{O}_{4,cjk}$	4.0	-	-	-	maybe
$\mathcal{O}_{5(6),ujk}$	2.1	3.7	1	6	-
$\mathcal{O}_{5(6),cjk}$	2.1	1.6	16	3.7	-
$\mathcal{O}_{7,ue\mu}$	1.5	11	3	-	-
$\mathcal{O}_{7,u\mu e}$	1.5	17	3	-	-
$\mathcal{O}_{7,ce\mu}$	1.5	-	1	-	-
$\mathcal{O}_{7,c\mu e}$	1.5	-	-	-	-
$\mathcal{O}_{8,ujk}$	4.0	-	7	-	-
$\mathcal{O}_{8,ce\mu}$	4.0	-	3	-	-
$\mathcal{O}_{8,c\mu e}$	4.0	-	-	-	-

Conclusions

- Operators which can give $t \to u(c)e^{\pm}\mu^{\mp}$ probe $\sim$ few TeV range.
- Several operators constrained by B, K decays, possibly $\mu \to e\gamma$.
- Some operators currently not constrained.
- $t \to u(c)e^{\pm}\mu^{\mp}$ could occur at LHC!