# Model-Independent Constraints on Lepton-Flavor-Violating Top Decays

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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, $\mu \to e\gamma$...

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

- 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:**

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

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

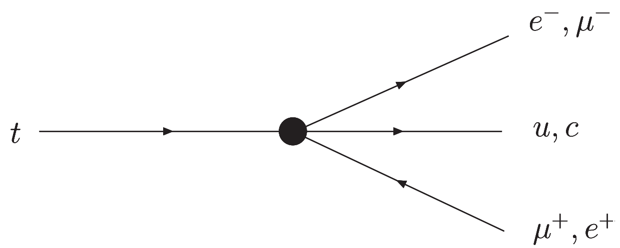
$a, b = SU(2)$ indices

$Q_L, L_L, T_L$: l.h. doublets

$u_R, l_R, t_r$: r.h. singlets

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

- 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 $i, j, k$.

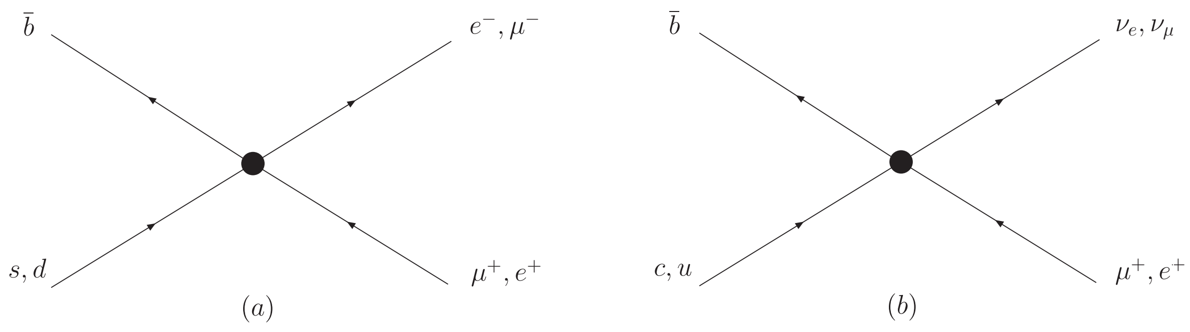
# Constraints from $B$ decays

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

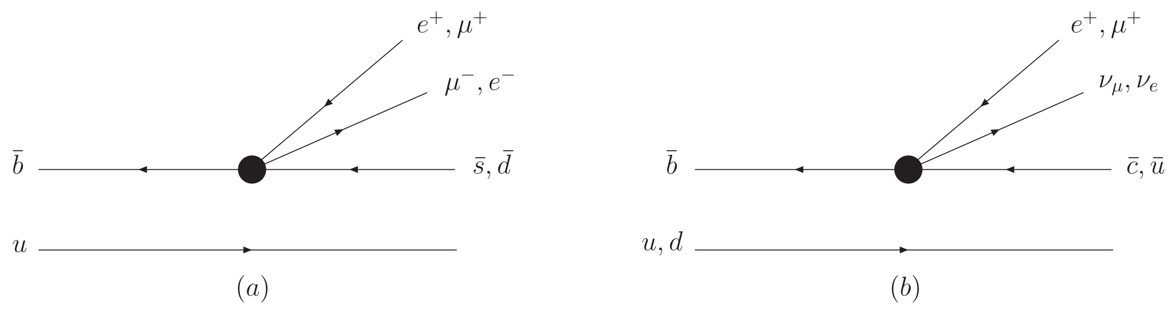
ex: $\mathcal{O}_{6,ijk} = \bar{Q}^i_L \gamma^\mu T_L \bar{l}^j_R \gamma_\mu l^k_R = (\bar{u}^i_L \gamma^\mu t_L + \bar{d}^{i\prime}_L \gamma^\mu b'_L)\bar{l}^j_R \gamma_\mu l^k_R$

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

2-body




3-body



# Constraints from 2-body $B$ decays

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

Op's $5, 6$: $B^0, B_s \to e^\pm\mu^\mp$, $\Gamma = \frac{1}{64\pi}\frac{|C_{n,ijk}|^2}{\Lambda^4}F_B^2 m_B m_\mu^2$

(helicity-suppressed)

Op 7: $B^+, B_c \to \ell^+\nu$, $\Gamma = \frac{1}{64\pi}\frac{|C_{n,ijk}|^2}{\Lambda^4}F_B^2\frac{m_B^5}{(m_b+m_{u(c)})^2}$

Op 8: $0$ (tensor operator)

$$\text{Br}(B^0 \to e^\pm\mu^\mp) \leq 1.7\times 10^{-7}(90\%\text{CL})$$

$$\to \frac{|C_{5(6),ujk}|}{\Lambda^2} \leq \frac{1}{(3.7\ \text{TeV})^2}, \quad \frac{|C_{5(6),cjk}|}{\Lambda^2} \leq \frac{1}{(1.8\ \text{TeV})^2}$$

$$\text{Br}(B^+ \to e^+\nu) \leq 9.8\times 10^{-6}(90\%\text{CL}) \to \frac{|C_{7,u\mu e}|}{\Lambda^2} \leq \frac{1}{(16\ \text{TeV})^2}$$

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

# Constraints from 3-body $B$ decays

Similar to $t$ decays: no helicity suppression, op 8 can contribute.

Op's 5,6: Br$(B^+ \to K^+ e^\pm \mu^\mp) \leq 9.1 \times 10^{-8}$,

Compare to inclusive via $B \to \pi \ell^+ \nu$.

$$\to \frac{|C_{5(6),cjk}|}{\Lambda^2} \leq \frac{1}{(16\ \text{TeV})^2}, \qquad \frac{|C_{5(6),ujk}|}{\Lambda^2} \leq \frac{1}{(8\ \text{TeV})^2}$$

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

Br$(B \to X_u \ell^+ \nu) = 2.33 \pm .22 \times 10^{-3}$, Br$(B^- \to X_c e^+ \nu) = 10.8 \pm 0.4\,\%$ :

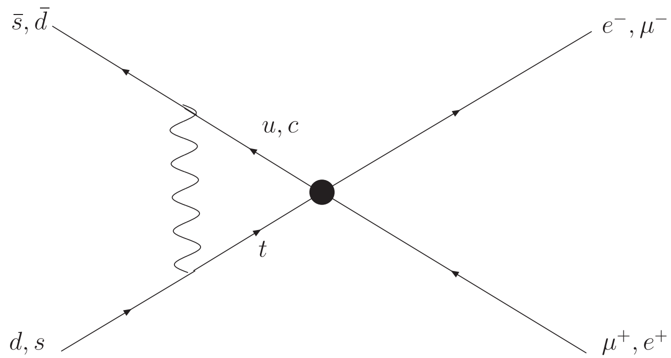
$$\to \frac{|C_{7,ujk}|}{\Lambda^2} \leq \frac{1}{(3\ \text{TeV})^2}, \qquad \frac{|C_{7,cjk}|}{\Lambda^2} \leq \frac{1}{(1\ \text{TeV})^2}$$

$$\frac{|C_{8,ujk}|}{\Lambda^2} \leq \frac{1}{(7\ \text{TeV})^2}, \qquad \frac{|C_{8,cjk}|}{\Lambda^2} \leq \frac{1}{(3\ \text{TeV})^2}$$

# Constraints from $K$ decays

Again, Class Two op's give (CKM-suppressed) contributions at tree level to $K_L \to e^{\pm}\mu^{\mp}$ (just like $B$ case).

Op's of both classes can contribute at one loop. i.e.,




Using $\mathrm{Br}(K_L \to e^{\pm}\mu^{\mp}) \leq 4.7 \times 10^{-12}$: (3-body $K$ decays weaker)

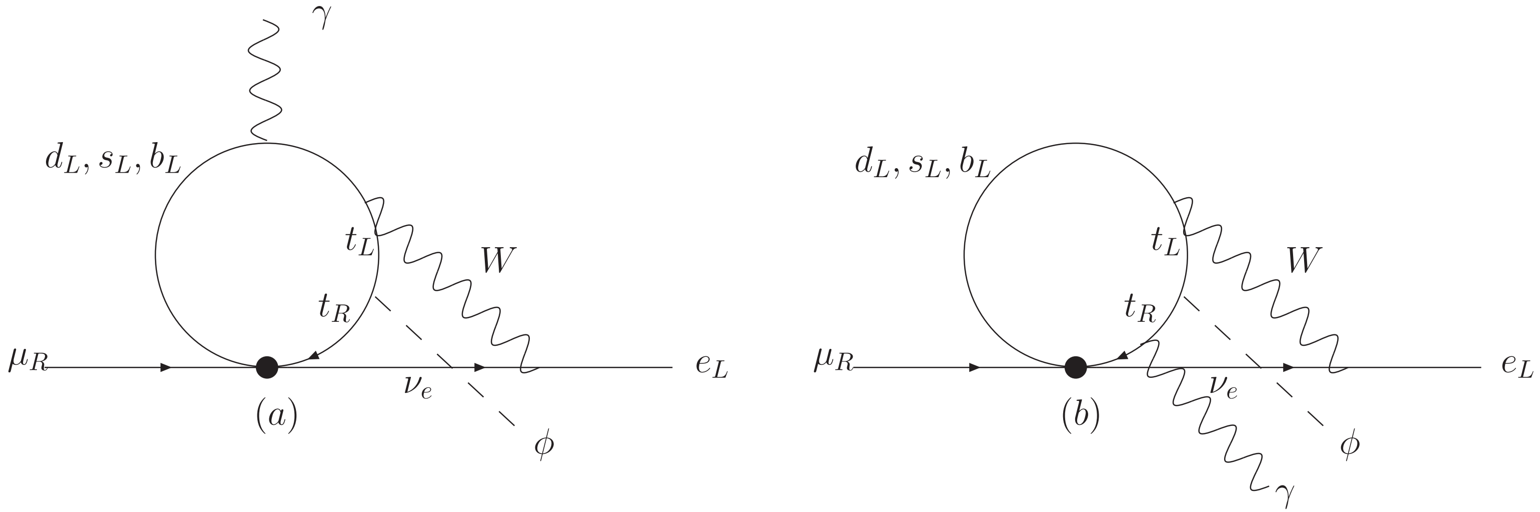
$$\frac{|C_{5(6),ujk}|}{\Lambda^2} < \frac{1}{(60\ \text{TeV})^2}$$

$$\frac{|C_{5(6),cjk}|}{\Lambda^2} < \frac{1}{(40\ \text{TeV})^2}$$

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

# $\mu \to e\gamma$ and $\mu \to e$ Conversion

Ops 3, 4: $\mu \to e\gamma$ via GIM-sup'd ($\sim m_b^2/m_W^2$) 2-loop diags:




$$\text{Br}(\mu \to e\gamma) < 1.2 \times 10^{-11} \to \frac{|C_{3,cjk}|}{\Lambda^2} \lesssim \frac{1}{(1\ \text{TeV})^2}$$

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

$\mu \to e$ conversion: same diagrams as $K_L$ decay,
Limits from SINDRUM II similar to or weaker than $K_L$'s.

# Results

| Operator | $t \to u(c)e^{\pm}\mu^{\mp}$ | $B$, 2-body | $B$, 3-body | $K_L$ |
|---|---|---|---|---|
| $\mathcal{O}_{1(2),ijk}$ | 2.1 | - | - | - |
| $\mathcal{O}_{3,ijk}, i = u$ | 1.5 | - | - | - |
| $\mathcal{O}_{3,ijk}, i = c$ | 1.5 | - | - | - |
| $\mathcal{O}_{4,ijk}, i = u$ | 4.0 | - | - | 1 |
| $\mathcal{O}_{4,ijk}, i = c$ | 4.0 | - | - | - |
| $\mathcal{O}_{5(6),ijk}, i = u$ | 2.1 | 3.7 | 8 | 60 |
| $\mathcal{O}_{5(6),ijk}, i = c$ | 2.1 | 1.8 | 16 | 40 |
| $\mathcal{O}_{7,ijk}, i = u, j = e, k = \mu$ | 1.5 | 10 | 3 | - |
| $\mathcal{O}_{7,ijk}, i = u, j = \mu, k = e$ | 1.5 | 16 | 3 | - |
| $\mathcal{O}_{7,ijk}, i = c$ | 1.5 | - | 1 | - |
| $\mathcal{O}_{8,ijk}, i = u$ | 4.0 | - | 7 | - |
| $\mathcal{O}_{8,ijk}, i = c$ | 4.0 | - | 3 | - |

Class One operators largely unconstrained.

# 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.
- Some operators currently not constrained.
- $t \to u(c)e^{\pm}\mu^{\mp}$ could occur at LHC!
- arXiv: 0807.4199 (hep-ph), accepted to PRD.