$\tau - \mu$ Flavor Violation as a Probe of the Scale of New Physics

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BES-III/CLEO-c Workshop, Beijing
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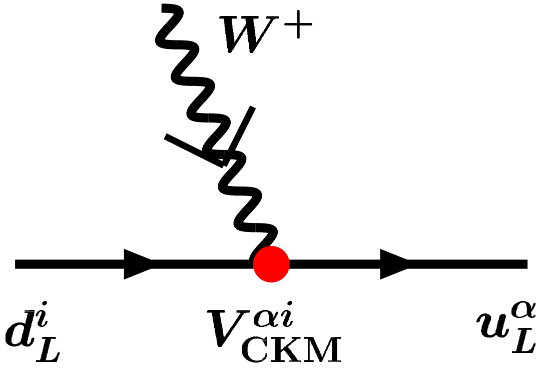
- Introduction/Motivation
- Probe New Interactions at Low Energies
- Concluding Remarks [*]

[*] D. Black, T. Han, H.-J. He, and M. Sher: `hep-ph/0206056 (in PRD)`

Introduction/Motivation

- One of the most challenging puzzles in the Standard Model:

Quark-flavor mixing



where

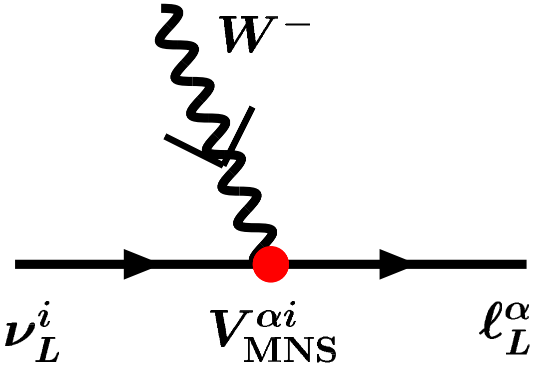
$$V_{CKM}^{\alpha i} = \sum_{\beta=1}^{3} U_{L\,\beta\alpha}^{u\,*} U_{L\,\beta i}^{d}$$

generally from the left-handed quark mass diagonalizations, which has led to very rich physics:

flavor transition; FCNC; CP-violation etc.

- Recent observations indicate the $\nu_\mu - \nu_\tau$ oscillation (atmospheric). In turn, there must be $\mu - \tau$ flavor-mixing.

  The analogue to quark sector is



where

$$V_{MNS}^{\alpha i} = \sum_{\beta=1}^{3} U^{\ell\,*}_{L\,\beta\alpha} U^{\nu}_{L\,\beta i}$$

To explore the underlining dynamics, it is of fundamental importance to observe the charged-lepton transition, such as $\mu \leftrightarrow \tau$.

- Consider generic dim-6 operators:

$$\sum_{j,\alpha,\beta} \frac{C^{j}_{\alpha\beta}}{\Lambda^2} \left(\bar{\mu}\ \Gamma_j\, \tau\right) \left(\bar{f}^{\alpha}\, \Gamma_j\, f^{\beta}\right)$$

where $\Gamma_j \in (1,\ \gamma_5,\ \gamma_\sigma,\ \gamma_\sigma\gamma_5),\ f = \ell,\ q.$

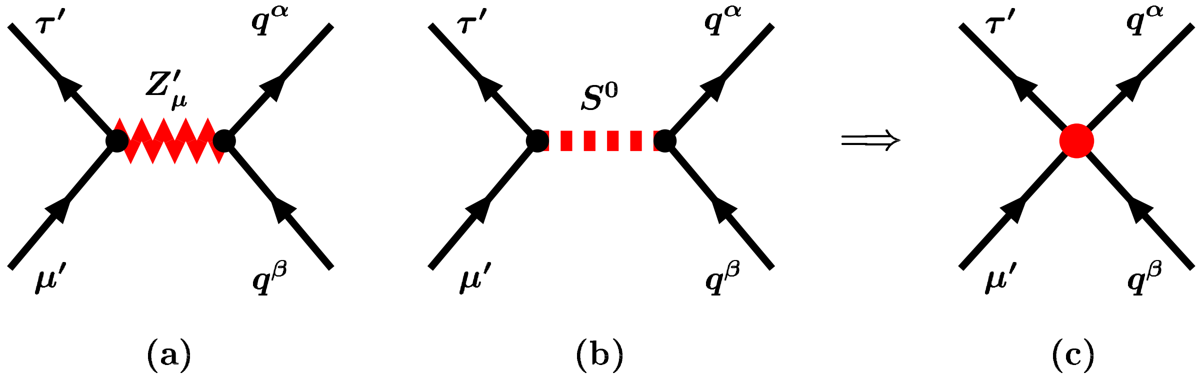
Typically,

$$C^{j}_{\alpha\beta} \sim \mathcal{O}[1-(4\pi)^2], \quad \Lambda \gtrsim 4\pi v.$$

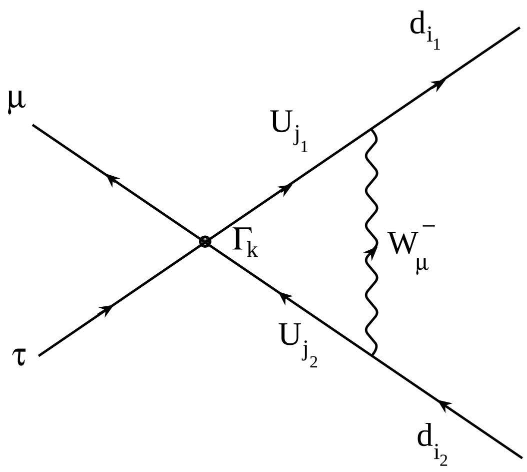
For illustration, we take

$$C^{j}_{\alpha\beta} = 4\pi.$$

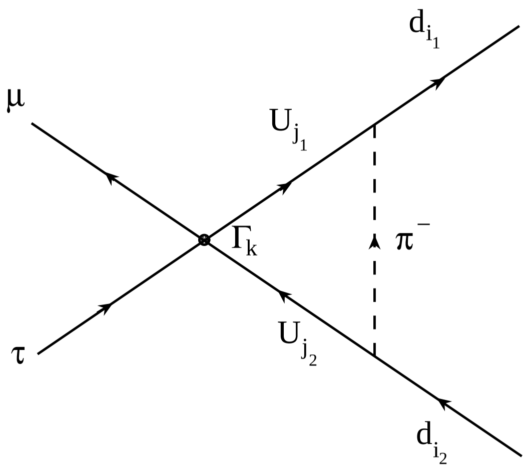
For instance, $\Lambda \sim M$,



- Logarithmic corrections at 1-loop:



(a)



(b)

Contributions to the vector and axial-vector operators

$$\delta C_V^{i_1,i_2} = -\delta C_A^{i_1,i_2} \sim \frac{g^2}{16\pi^2} |V_{i_1,j_1} V^*_{i_2,j_2}| \ln \frac{\Lambda}{M_W} \,,$$

No contribution to the scalar and pseudoscalar operators.

Constraining the operators

- τ to light mesons: $\tau \to \mu M,\ \ \mu M_1 M_2$ (3-body for scalar ops.)

Bound	1	γ_5	γ_σ	$\gamma_\sigma\gamma_5$
$\bar{u}u$	2.6 TeV $(\tau \to \mu\pi^+\pi^-)$	12 TeV $(\tau \to \mu\pi^0)$	12 TeV $(\tau \to \mu\rho)$	11 TeV $(\tau \to \mu\pi^0)$
$\bar{d}d$	2.6 TeV $(\tau \to \mu\pi^+\pi^-)$	12 TeV $(\tau \to \mu\pi^0)$	12 TeV $(\tau \to \mu\rho)$	11 TeV $(\tau \to \mu\pi^0)$
$\bar{s}s$	1.5 TeV $(\tau \to \mu K^+K-)$	9.9 TeV $(\tau \to \mu\eta)$	14 TeV $(\tau \to \mu\phi)$	9.5 TeV $(\tau \to \mu\eta)$
$\bar{s}d$	2.3 TeV $(\tau \to \mu K^+\pi^-)$	3.7 TeV $(\tau \to \mu K^0)$	13 TeV $(\tau \to \mu K^\star)$	3.6 TeV $(\tau \to \mu K^0)$
$\bar{c}u$	$\star$	$\star$	550 GeV $(\tau \to \mu\phi)$	550 GeV $(\tau \to \mu\phi)$
$\bar{c}c$	$\star$	$\star$	1.1 TeV $(\tau \to \mu\phi)$	1.1 TeV $(\tau \to \mu\phi)$

$\Gamma_\tau \sim \Lambda^{-4} \implies \Lambda \gtrsim 1.5 - 14$ TeV.

- $B,\ t$ decays: $B \to \mu\tau,\quad B \to \mu\tau M,\quad t \to \mu\tau\ u$-jet

Bound	1	γ_5	γ_σ	$\gamma_\sigma\gamma_5$
$\bar{b}d$	2.2 TeV $(B \to \pi\mu\tau)$	9.3 TeV $(B \to \mu\tau)$	2.2 TeV $(B \to \pi\mu\tau)$	8.2 TeV $(B \to \mu\tau)$
$\bar{b}s$	2.6 TeV $(B \to K\mu\tau)$	2.8 TeV $(B_s \to \mu\tau)$	2.6 TeV $(B \to K\mu\tau)$	2.5 TeV $(B_s \to \mu\tau)$
$\bar{t}c$	190 GeV $(t \to c\mu\tau)$	190 GeV $(t \to c\mu\tau)$	310 GeV $(B \to \mu\tau)$	310 GeV $(B \to \mu\tau)$
$\bar{t}u$	190 GeV $(t \to u\mu\tau)$	190 GeV $(t \to u\mu\tau)$	650 GeV $(B \to \mu\tau)$	650 GeV $(B \to \mu\tau)$
$\bar{b}b$	$\star$	$\star$	180 GeV $(\Upsilon \to \mu\tau)$	$\star$
$\bar{t}t$	$\star$	$\star$	75 GeV $(B \to \mu\tau)$	120 GeV $(B \to \mu\tau)$

$$\Gamma_B \sim \Lambda_{bq}^{-4} \implies \Lambda \gtrsim 3 - 9 \text{ TeV}.$$

but very weak on Λ_t

- Pure leptonic processes at 90% C.L. (from PDG):

$$\begin{array}{ll} \mathrm{Br}[\tau^- \to \mu^-\mu^-\mu^+] \ < \ 1.9 \times 10^{-6}, & \mathrm{Br}[\tau^- \to \mu^-\mu^-e^+] \ < \ 1.5 \times 10^{-6}, \\ \mathrm{Br}[\tau^- \to \mu^-\mu^+e^-] \ < \ 1.8 \times 10^{-6}, & \mathrm{Br}[\tau^- \to \mu^-e^-e^+] \ < \ 1.7 \times 10^{-6}, \end{array}$$

leading to the following bounds

$$\Lambda \ > \begin{cases} (12.8,\ 13.5,\ 11.9,\ 11.0)\ \mathrm{TeV}, & (\Gamma_j = S,\ P), \\ (18.0,\ 19.1,\ 15.4,\ 15.6)\ \mathrm{TeV}, & (\Gamma_j = V,\ A), \end{cases}$$

Also, from

$$\mathrm{Br}[\tau \to \mu\nu\bar{\nu}] = (17.37 \pm 0.07)\%,$$

we derive the bound

$$\Lambda \ > \begin{cases} 2.2\ \mathrm{TeV}, & (\Gamma_j = S,\ P), \\ 3.1\ \mathrm{TeV}, & (\Gamma_j = V,\ A), \end{cases}$$

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- Other mixings among $e,\ \mu,\ \tau$.