Lepton Flavor Universality

$$R_K = \frac{\Gamma(B \to K e^+ e^+)}{\Gamma(B \to K \mu^+ \mu^-)} \overset{SM}{=} 1 + \mathcal{O}(10^{-3})$$

[for γ-inclusive rate]

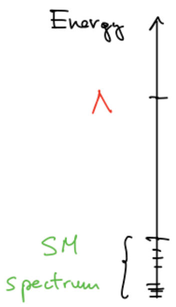
- Why LFU holds within the SM?
- Why is it interesting to test LFU?
- The $b \to s\ell\ell$ system : R_K is not alone ...

I. Why LFU holds within the SM?

LFU is an approximate accidental symmetry of $\mathcal{L}_{SM}$

accidental symm. = symm not imposed, but emerging in the renormalizable (= low-energy) part of QFT

(E.g. baryon number)



$$\mathcal{L}_{SM\text{-}EFT} = \mathcal{L}^{d\leq 4} + \sum_i \frac{c_i^{[d]}}{\Lambda^{d-4}} \mathcal{O}_i^d(\psi_{SM})$$

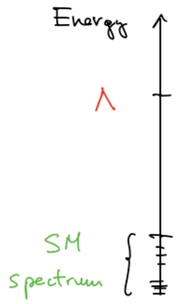
$$\mathcal{L}^{d\leq 4} = \mathcal{L}_{SM}$$

$\Downarrow$

the only $d=4$ ops. we can write distinguishing e, μ, τ are the Yukawa interactions

$$\left\{ \begin{array}{l} y_e \approx 3\times 10^{-6} \qquad y_\mu \approx 3\times 10^{-4} \qquad y_\tau \approx 1\times 10^{-2} \qquad \ll \qquad g_{SM}^{gauge} \\ \text{Limit} \quad y_{e,\mu,\tau} \to 0 \quad \Rightarrow \quad \text{LFU in } \mathcal{L}_{SM} \end{array} \right.$$

II. Why is it interesting to test LFU?



$$\mathcal{L}_{SM-EFT} = \mathcal{L}^{d\leq 4} + \sum_i \frac{c_i^{[d]}}{\Lambda^{d-4}} O_i^d(\psi_{SM})$$

Testing accidental symm. is a very powerful probe of high-energy dynamics

LFU tested very precisely in many systems,
($\pi \to \ell\nu$, $K \to \ell\nu$, $\tau \to \ell\nu\bar{\nu}$, $Z \to \ell\ell$)
but not yet in semileptonic b [3rd gen.] decays

A "semi-historical" example :

1974 : $\mathcal{L}_{SM}$ (2 gen.)

- Renormalizable
- Excellent descr. of all known phenomena but $\cancel{CP}$ in $K-\bar{K}$

[single observable!]

$\Downarrow$

CP is an accidental symm.

$$\hookrightarrow \quad \mathcal{L}_{EFT} = \mathcal{L}_{SM}(2\text{ gen.}) + \frac{e^{i\delta}}{\Lambda^2_{SW}}(\bar{s}\gamma_\mu d)^2$$

$\Lambda_{SW} \approx 10^4\,\text{TeV} \Rightarrow$ "Super-weak" interaction [Wolfenstein]

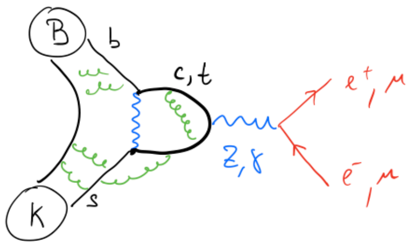
We now know that $\frac{1}{\Lambda^2_{SW}} = \frac{G_F^2 m_t^2}{4\pi^2}|V_{ts}V_{td}|^2$

Lessons :
- Accidental symm. probe high-energy scales
- Scales of higher-dim ops can be misleading
- Light gen. easily insensitive to NP

III. The $b \to s\ell\ell$ system : R_K is not alone ...

$b \to s\ell\ell$ transitions occurs to 2^{nd} order in G_F

$\Downarrow$



build $\mathcal{L}_{eff}$ to separate scales

$$\mathcal{L}_{eff} = \frac{G_F}{\sqrt{2}} V_{tb}^* V_{ts} \sum_i Q_i(\mu)$$

FCNC ops

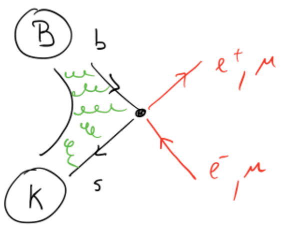
$$Q_9^\ell = \bar{b}_L \gamma^\mu s_L \; \bar{\ell}\gamma_\mu \ell$$

$$Q_{10}^\ell = \bar{b}_L \gamma^\mu s_L \; \bar{\ell}\gamma_\mu \gamma_5 \ell$$

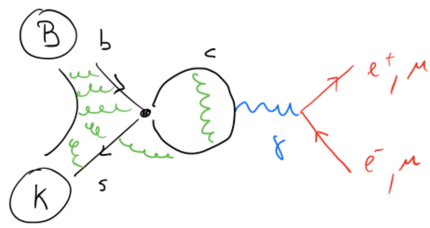
4-quark ops

$$Q_2^c = \bar{b}_L \gamma^\mu s_L \; \bar{c}_L \gamma_\mu c_L$$

$\vdots$



"easy & clean"



more complicated

$$\underset{\substack{\uparrow \\ \text{LFU}}}{C_i^e = C_i^\mu} \qquad C_9^{SM} \approx -C_{10}^{SM}$$

(LH int.)

- obscure short-distance for $q^2 \sim m_{\psi, \psi'}$
- small for $q^2 \ll m^2_\psi$ non-pert effects $\mathcal{O}\left(\frac{\Lambda^2_{QCD}}{m_c^2}\right)$

KEY observation: $\begin{cases} \text{cannot induce } \cancel{\text{LFU}} \\ \text{cannot induce } \Delta C_{10} \; [\Rightarrow B_s \to \mu^+\mu^-] \end{cases}$

If th. error underestimated, we can expect a q^2-dependent shift in C_9 universal in e & μ