EXTRA DIMENSIONS

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LECTURE 2: ADDENDUM

FROM WEAK BASIS TO MASS BASIS

- Yukawa or mass: 3×3 complex matrix $\rightarrow$

  diagonalize by *bi*-unitary transformation:

$$\left(\bar{d}_L\text{weak}\ \bar{s}_L\text{weak}\right)(M_d)_{2\times 2}\begin{pmatrix} d_R\,\text{weak} \\ s_R\,\text{weak}\end{pmatrix} =$$

$$\left(\bar{d}_L\text{mass}\ \bar{s}_L\text{mass}\right) D_L^\dagger M_d D_R \begin{pmatrix} d_R\,\text{mass} \\ s_R\,\text{mass}\end{pmatrix} \qquad (1)$$

  where

$$\begin{pmatrix} d_{L,R}\,\text{weak} \\ s_{L,R}\,\text{weak}\end{pmatrix} = D_{L,R}\begin{pmatrix} d_{L,R}\,\text{mass} \\ s_{L,R}\,\text{mass}\end{pmatrix} \qquad (2)$$

$$M_d^{\text{diag.}} = D_L^\dagger M_d D_R \qquad (3)$$

FCNC IN SM

Not at tree-level (Z vertex preserves flavor):

$$\bar{d}^i_{L\,\text{weak}} Z_\mu \gamma^\mu d^i_{L\,\text{weak}} = \bar{d}^i_{L\,\text{mass}} Z_\mu \gamma^\mu d^i_{L\,\text{mass}} \tag{4}$$

- Charged current/W couplings convert up to down:

$$\bar{u}^i_{L\,\text{weak}} W^\mu \gamma_\mu d^i_{L\,\text{weak}} = \bar{u}_{L\,\text{mass}} W^\mu \gamma_\mu V_{CKM} d_{L\,\text{mass}} \tag{5}$$

where

$$\begin{aligned} V_{CKM}\,(\text{CKM matrix}) &= U_L^\dagger D_L \\ &\neq 1 \end{aligned} \tag{6}$$

Use in loops to change one down-type to another:

$\Delta S = 2$ process

GIM MECHANISM

Naively,

$$\begin{aligned}\mathcal{M} &\sim g_2^4 \int \frac{d^4k}{(2\pi)^4} V_{CKM}^4 \frac{1}{\not{k}-m_i} \frac{1}{\not{k}-m_j} \frac{1}{k^2 - M_W^2} \\ &\sim g_2^4 \left(V_{us}V_{cd}\right)^2 \frac{1}{16\pi^2 M_W^2} \end{aligned} \tag{7}$$

too large compared to experimental value!

- Use unitarity:

$$\sum_i V_{is}^\dagger V_{id} = 0 \tag{8}$$

vanishes if $m_i = m_j$

$\rightarrow$

$$\mathcal{M} \sim \frac{g_2^4}{16\pi^2} \left(V_{us}V_{cd}\right)^2 \frac{m_c^2 - m_u^2}{M_W^4} \tag{9}$$

Extra suppression $\sim m_c^2/M_W^2 \sim 10^{-4}$