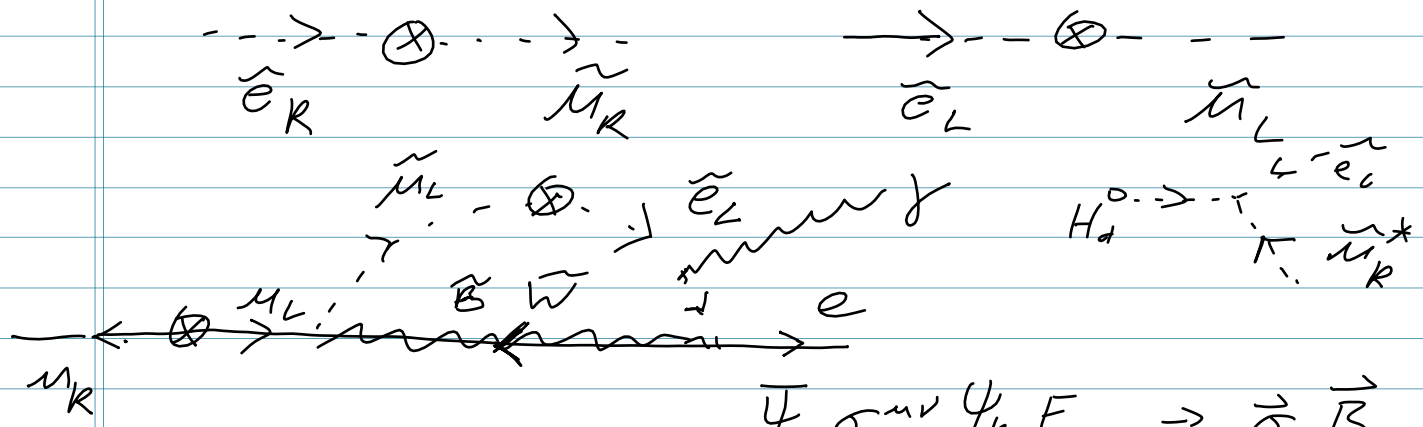
Lecture 16

Problems with Flavor and CP

generically $m^2_{\tilde{e}}, m^2_{\tilde{L}}$ are not diagonal in the same basis as the leptons



$$\bar{\psi}_L \sigma^{\mu\nu} \psi_R F_{\mu\nu} \to \vec{\sigma} \cdot \vec{B}$$

$$\bar{\psi}_L \sigma^{\mu\nu} \gamma_5 \psi_R F_{\mu\nu} \to \vec{\sigma} \cdot \vec{E}$$

$$\sigma^{\mu\nu} = \frac{i}{2}[\gamma^\mu, \gamma^\nu]$$

$$\Gamma_{\mu \to e\gamma} \simeq \left| \frac{2 g^2 e}{16\pi^2} m_\mu \frac{\Delta m^2}{M^2_{susy}} \right|^2 \frac{m_\mu^3}{8\pi}$$

$$\simeq 4 \sin^2\theta_W \left(\frac{\alpha_2}{4\pi}\right)^3 \frac{m_\mu^5}{M^4_{susy}} \left(\frac{\Delta m^2}{M^2_{susy}}\right)^2 2\pi$$

$$\Gamma_\mu = \frac{C_2^2 m_\mu^5}{192\pi^3} = \left(\frac{\sqrt{2} g^2}{8 m_W^2}\right)^2 \frac{m_\mu^5}{192\pi^3}$$

$$= \alpha_2^2 \frac{2}{64} \frac{m_\mu^5}{32\pi M_W^4} = \left(\frac{\alpha_2}{4\pi}\right)^2 \frac{\pi m_\mu^5}{64 M_W^4}$$

(97)

$$\frac{\Gamma_{\mu\to e\gamma}}{\Gamma_{\mu\to e\nu\nu}} = \left(\frac{\alpha_2}{4\pi}\right)^4 \sin^2\theta_W \left(\frac{M_W}{M_{susy}}\right)^4 \left(\frac{\Delta m^2}{M_{susy}^2}\right)^2 \cdot 64$$

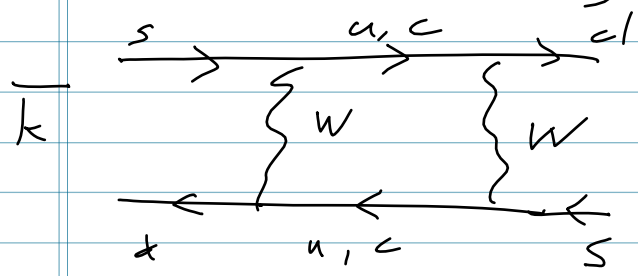
$$\approx \left(\frac{1}{30}\,\frac{1}{10}\right)\left(\frac{80\,GeV}{500\,GeV}\right)^4 \left(\frac{500\,GeV}{M_{susy}}\right)^4 128 \left(\frac{\Delta m^2}{M_{susy}}\right)$$

$$\approx 3\times10^{-4}\left(\frac{500\,GeV}{M_{susy}}\right)^4 \left(\frac{\Delta m^2}{M_{susy}^2}\right)^2$$

$$\left.\frac{\Gamma_{\mu\to e\gamma}}{\Gamma_{\mu\to e\nu\nu}}\right|_{exp} < 5\times10^{-11}$$

$$\left(\frac{\Delta m^2}{M_{susy}^2}\right)\left(\frac{500\,GeV}{M_{susy}}\right)^2 < 4\times10^{-4}$$

$K\bar{K}$ mixing

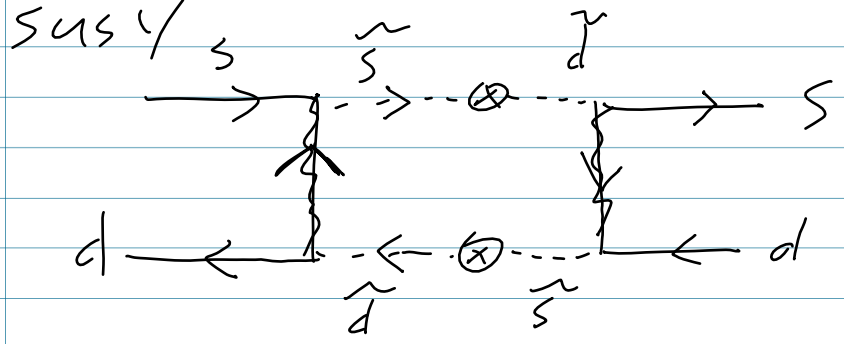


$\bar{K}$ K $\begin{pmatrix} V_{ud} & V_{us} \\ V_{cd} & V_{cs} \end{pmatrix}$

massless limit $\propto (V_{di} V_{is}^*)(V_{sj}^* V_{jd}) = \delta_{ds}\delta_{sd} = 0$

leading term $\mathcal{M}_{K\bar{K}}^{SM} \sim \frac{g_2^4}{16\pi^2} \frac{m_c^2}{M_W^4} \sin^2\theta_c \cos^2\theta_c$

(predicted $m_c \simeq 1$ GeV before discovered)



$$\mathcal{M}_{K\bar{K}}^{MSSM} \sim \frac{(\sqrt{2}\, g_3)^4}{16\pi^2} \left(\frac{\Delta m_Q^2}{M_{susy}^2}\right)^2 \frac{1}{M_{susy}^2}$$

$$\frac{\mathcal{M}_{K\bar{K}}^{MSSM}}{\mathcal{M}_{K\bar{K}}^{SM}} = 4\left(\frac{g_3}{g}\right)^4 \left(\frac{\Delta m_Q^2}{M_{susy}^2}\right) \frac{M_W^4}{m_c^2 M_{susy}^2 \sin^2\theta_c \cos^2\theta_c} < 1$$

$$\left(\frac{\Delta m_Q^2}{M_{susy}^2}\right) < \frac{1}{2}\left(\frac{\alpha_2}{\alpha_3}\right) \frac{m_c^2 M_{susy}}{M_W^2} \sin^2\theta_c \cos^2\theta_c$$

$$\frac{\Delta m^2}{M_{susy}^2} \lesssim \frac{1}{2}\left(\frac{0.03}{0.1}\right)\frac{1.4\,GeV\; M_{susy}}{(80\,GeV)^2}\;\frac{1000\,GeV}{1\,TeV}$$

22.9

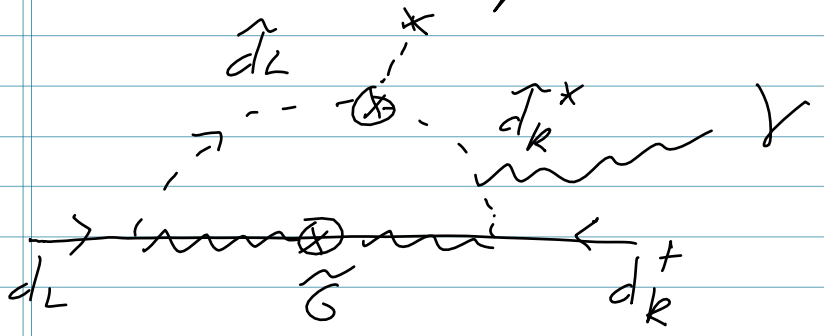
$$\lesssim 4\times 10^{-3}\;\frac{M_{susy}}{500\,GeV}$$

$$|\epsilon| \simeq \frac{1}{2}\left|\frac{Im(iM_{K\bar{K}})}{Re(iM_{K\bar{K}})}\right| \sim 10^{-3}$$

$$10^{-3} > \frac{1}{2}\,\frac{Im\, iM_{K\bar{K}}^{MSSM}}{Re\, iM_{K\bar{K}}^{MSSM}} = \frac{1}{2}\,\frac{Im\left|\frac{\Delta m_Q^2}{M_{susy}^2}\right|^2\left(\frac{1}{M_{susy}^2}\right)^2}{Re\left(\frac{\Delta m_Q^2}{M_{susy}^2}\right)^2\frac{1}{M_{susy}^2}}$$

$$Im\left(\frac{\Delta m_Q^2}{M_{susy}^2}\right) < 0.1\; Re\left(\frac{\Delta m_Q^2}{M_{susy}^2}\right)$$

Electric Dipole moments



$\vec{\sigma} \cdot \vec{E}$ ← even under T

odd under T

$$n_{edm} < 0.97 \times 10^{-25} \text{ e cm}$$

$$\mathcal{M} \sim \frac{g_3^2}{16\pi^2} e \delta \frac{v A_d^{adM_{susy}} c_\beta}{M_{susy}^3} \sim \frac{\alpha_3}{4\pi} \frac{e v c_\beta a_d \delta}{M_{susy}^2}$$

$$\sim \frac{.1}{10} \frac{246\,GeV}{(500\,GeV)^2} \left(\frac{500\,GeV}{M_{susy}}\right)^2 e\, a_d c_\beta \delta$$

$$\sim 10^{-5}\,GeV^{-1}\, a_d \delta c_\beta\, e \left(\frac{500GeV}{M_{susy}}\right)^2 \frac{100cm}{1m} \frac{1m}{5\times10^{15}GeV}$$

$$\sim 2\times10^{-19}\,e\,cm\; a_d \delta c_\beta \left(\frac{500\,GeV}{M_{susy}}\right)^2$$

$$\left(\frac{500\,GeV}{M_{susy}}\right)^2 a_d \delta c_\beta < 5\times10^{-7}$$

$$a_d = y_d = \frac{\sqrt{2}\, m_d}{v c_\beta}$$

$$\delta \left(\frac{500}{M_{susy}}\right)^2 < 10^{-2}$$

restrict ourselves to safe neighborhoods of 105 dimensional parameter space

"soft breaking universality"

1) $m^2_{soft} \propto I$ → degeneracy

2) $A_p \propto Y_p$ → only third has significant cubic terms

3) no new CP violation

"more minimal SSM"

quadratic div. cancel to $\mathcal{O}\left(\frac{\alpha}{4\pi}\right)$

$\tilde{t}_L$ $\tilde{t}_R$, $\tilde{b}_L$ $\tilde{H}_u$ $\tilde{t}_d$, $\tilde{B}$ $\tilde{W}$ < 1 TeV

1st 2nd gen. sparticles $M \gtrsim 20$ TeV
rough degeneracy remove FCNC and CP problems

'Alignment'

$$m^2_{\tilde{Q}} = Y_u^* Y_u^T + Y_d^* Y_d^T$$

$$m^2_{\tilde{u}} = Y_u^\dagger Y_u$$

$$m_{\tilde{d}} = Y_d^\dagger Y_d$$

O'Raifeartaigh

no simultaneous solution for

$$\frac{\partial W}{\partial \phi_i} = 0$$

$$W = -k^2\phi_1 + m\phi_2\phi_3 + \frac{y}{2}\phi_1\phi_3^2$$

$$F_1^* = \frac{\partial W}{\partial \phi_1} = -k^2 + \frac{y}{2}\phi_3^2 \quad \rightarrow \quad \phi_3 \neq 0$$

$$F_2^* = \frac{\partial W}{\partial \phi_2} = m\phi_3 \quad \rightarrow \quad \phi_3 = 0$$

$$F_3^* = \frac{\partial W}{\partial \phi_3} = m\phi_2 + y\phi_1\phi_3$$

$$V = |F_1|^2 + |F_2|^2 + |F_3|^2 > 0$$

global minimum at $\phi_2 = \phi_3 = 0$

$V_{min} = |F_1|^2 = k^4$ $\quad$ ϕ_1 is undetermined

F-flat direction

$$V = \left|-k^2 + \frac{y}{2}\phi_3^2\right|^2 + |m\phi_3|^2 + |m\phi_2 + y\phi_1\phi_3|^2$$

$$= k^4 - k^2\frac{y}{2}\phi_3^{*2} - \frac{k^2}{2}y\phi_3^2 + m^2\phi_3^*\phi_3 + m^2\phi_2^*\phi_2$$

+ interactions

$$\phi_3 = \frac{1}{\sqrt{2}}(a + ib) \qquad \phi_3^2 = \frac{1}{2}(a^2 + 2aib - b^2)$$

$$\phi_3^2 + \phi_3^{*2} = (a^2 - b^2)$$