Recap:

* Effective Hamiltonians at work: K physics

- $\Delta I = \frac{1}{2}$ rule
  - Watson theorem
  - QCD corrections
  - penguins
  - negative interference

- ε_K
  - Meson-antimeson mixing $\quad \frac{q}{p} = \sqrt{\frac{H_{21}}{H_{12}}} = \frac{2M_{12}^* - i\Gamma_{12}^*}{\Delta m - \frac{i}{2}\Delta\Gamma}$

    $|B_{H,L}\rangle = p|B^0\rangle \pm q|\bar{B}^0\rangle$

    $\langle B_H|B_L\rangle = \delta = |p|^2 - |q|^2 = \frac{1-|\frac{q}{p}|^2}{1+|\frac{q}{p}|^2} = 0$ if CP conserved

  - Kaon case: $\Delta\Gamma_K \simeq -2\Delta m_K$ & $\Gamma_{12} \simeq A_0^* \bar{A}_0$

    $\varepsilon_K = \frac{1-\lambda_0}{1+\lambda_0} \simeq \frac{e^{i\frac{\pi}{4}}}{\sqrt{2}\Delta m_K} \operatorname{Im} M_{12}$

- tree-level CKM: $|V_{us}|, |V_{cb}|, |V_{ub}|, \gamma$ $\Rightarrow$ prediction for ε_K

* $D-\bar{D}$ mixing

with respect to $K\bar{K}$ mixing, $t \to b$ and $c \to s$

In K mixing, CP conserving mixing from u and c, CPV from t and c

In D mixing, bottom contribution down by $\frac{m_b^2}{m_t^2} \sim 10^{-3}$

$\Rightarrow$ approx. Two-family $\Rightarrow$ no CPV

GIM $\Leftrightarrow$ SU(3) (U-spin) everything LD

$\Rightarrow$ search for NP in δ

* $B-\bar{B}$ mixing $\quad |\Gamma_{12}| \ll |M_{12}|$

$\Delta m_B = 2|M_{12}| \qquad \frac{\Delta\Gamma}{\Delta m} = \operatorname{Re}\frac{\Gamma_{12}}{M_{12}} \qquad \frac{q}{p} = -\frac{M_{12}^*}{M_{12}}\left(1 - \frac{1}{2}\operatorname{Im}\frac{\Gamma_{12}}{M_{12}}\right)$

$\left|\frac{q}{p}\right| - 1 = -\frac{1}{2}\operatorname{Im}\frac{\Gamma_{12}}{M_{12}}$

New: can estimate Γ_{12}!

* CPV in mixing $\qquad$ * Time-dependent CP asymmetries $\qquad$ * UTA

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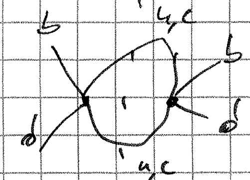
We need $|M_{12}|$ and $\frac{\Gamma_{12}}{M_{12}}$ for B_d and B_s mesons.

B_d:

M_{12} is easy: $-\frac{G_F^2 M_W^2}{4\pi^2} S_0(x_t)\, \eta_b\, m_B f_B^2 B_B (V_{tb}^* V_{td})^2$

so that $\left(\frac{q}{p}\right)_d = -\frac{(V_{tb} V_{td}^*)^2}{|V_{tb} V_{td}^*|^2}\left(1 - \frac{1}{2} \operatorname{Im} \frac{\Gamma_{12}}{M_{12}}\right) = -\frac{V_{tb} V_{td}^*}{V_{tb}^* V_{td}}\left(1 - \frac{1}{2} \operatorname{Im} \frac{\Gamma_{12}}{M_{12}}\right)$

What about Γ_{12}?

$\Gamma_{12} = \sum_n \langle \bar{B}^0 | H_{\Delta B=1} | n \rangle \langle n | H_{\Delta B=1} | B^0 \rangle =$ 

In the $m_b \to \infty$ limit this object becomes local so that we obtain $\Gamma_{12} = -\frac{G_F^2 m_b^2}{24\pi M_B}\left(C_1(\mu) \langle \bar{B} | Q_1(\mu) | B \rangle + C_2(\mu) \langle \bar{B} | Q_2(\mu) | B \rangle + \delta_{1/m_b}\right)$

$C_i = (V_{tb}^* V_{td})^2 D_i^{uu} + 2 V_{cb}^* V_{cd} V_{tb}^* V_{td} (D_i^{uu} - D_i^{cu}) + (V_{cb}^* V_{cd})^2 (D_i^{cc} + D_i^{uu} - 2D_i^{cu})$

Then, $\frac{\Gamma_{12}}{M_{12}} = \frac{4\pi m_b^2}{3 M_W^2 \eta_B S_0(x_t) \langle \bar{B} | Q_1 | B \rangle} \sum_{i=1,2} \left(D_i^{uu} + 2 \frac{V_{cb}^* V_{cd}}{V_{tb}^* V_{td}} (D_i^{uu} - D_i^{cu}) + \left(\frac{V_{cb}^* V_{cd}}{V_{tb}^* V_{td}}\right)^2 (D_i^{cc} + D_i^{uu} - 2D_i^{cu})\right) \langle \bar{B} | Q_i | B \rangle = \frac{4\pi m_b^2}{3 M_W^2 \eta_B S_0(x_t) \langle \bar{B} | Q_1 | B \rangle} \sum_{i=1,2} \langle \bar{B} | Q_i | B \rangle$

$\left(D_i^{uu} - 2 \frac{e^{i\beta}}{R_t} \underbrace{\vphantom{|}}_{(D_i^{uu} - D_i^{cu})} + \frac{e^{2i\beta}}{R_t^2} \underbrace{\vphantom{|}}_{(D_i^{cc} + D_i^{uu} - 2D_i^{cu})}\right) \Rightarrow$

$\frac{\Delta\Gamma_d}{\Gamma_d} = (5.3 \pm 0.7)\, 10^{-3}$ $\quad A_d^{SL} = (3.1 \pm 0.9)\, 10^{-4}$

$A_d^{SL,exp} = (-5 \pm 56)\, 10^{-4}$

$\beta_s = \arg\left(-\frac{V_{ts} V_{tb}^*}{V_{cs} V_{cb}^*}\right)$

remember: $\frac{\Delta M}{\Gamma}$ ~1 for d, ~25 for s

$\frac{\Delta\Gamma_s}{\Gamma_s} = (0.16 \pm 0.02)$ $\quad A_s^{SL} = (1.3 \pm 0.4)\, 10^{-5}$

$A_s^{SL} = (-2.3 \pm 9.3)\, 10^{-3}$

$$a_{SL} = \frac{N(\bar{B}^0 \to \ell^+ \nu X) - N(B^0 \to \ell^- \nu X)}{N(\bar{B}^0 \to \ell^+ \nu X) - N(B^0 \to \ell^- \nu X)}$$

In the absence of mixing, $B^0 \not\to \ell^- \nu X$ and $\bar{B}^0 \not\to \ell^+ \nu X$.

Thus,

$$N(B^0 \to \ell^- \nu X) = N_0 |A|^2 P(B^0 \to \bar{B}^0)$$

$$N(\bar{B}^0 \to \ell^+ \nu X) = N_0 |A|^2 P(\bar{B}^0 \to B^0)$$

where we assumed that $A(B^0 \to \ell^+ \nu X) = A(\bar{B}^0 \to \ell^- \nu X)$.

Now, $P(B^0 \to \bar{B}^0) = \left|\frac{q}{p}\right|^2 F$ and $P(\bar{B}^0 \to B^0) = \left|\frac{p}{q}\right|^2 F$

$$\left(\cancel{P(B^0 \to \bar{B}^0) = \int dt \langle q B_H(t) + p B_L(t) | q B_H(t) - p B_L(t) | 1 \rangle} \right.$$

$$\left(|B^0(t)\rangle = g_+(t) |B^0\rangle + \frac{q}{p} g_-(t) |\bar{B}^0\rangle \right.$$

$$|\bar{B}^0(t)\rangle = \frac{p}{q} g_-(t) |B^0\rangle + g_+(t) |\bar{B}^0\rangle$$

$$g_\pm(t) = \frac{1}{2}\left(e^{-i\lambda_H t} \pm e^{-i\lambda_L t}\right) = e^{-imt} e^{-\frac{\Gamma t}{2}} \left(\begin{matrix} \cosh \\ -\sinh \end{matrix} \frac{\Delta\Gamma t}{4} \cos\frac{\Delta m t}{2} \begin{matrix} -i\sinh\frac{\Delta\Gamma t}{4} \times \\ +i\cosh\frac{\Delta\Gamma t}{4} \end{matrix} \right.$$

$$\times \sin\frac{\Delta m t}{2}$$

$$\left. \Rightarrow \int |\langle \bar{B}^0 | \bar{B}^0(t) \rangle|^2 dt \quad \cancel{\left|\frac{p}{q}\right|^2} \int |g_-(t)|^2 dt \right)$$

so that

$$a_{SL} = \frac{\left|\frac{p}{q}\right|^2 - \left|\frac{q}{p}\right|^2}{\left|\frac{p}{q}\right|^2 + \left|\frac{q}{p}\right|^2} = \frac{1 - \left|\frac{q}{p}\right|^4}{1 + \left|\frac{q}{p}\right|^4} = \frac{1 - \left(1 - \frac{1}{2}\operatorname{Im}\frac{\Gamma_{12}}{M_{12}}\right)^4}{1 + \left(1 + \frac{1}{2}\operatorname{Im}\frac{\Gamma_{12}}{M_{12}}\right)^4} \simeq \frac{2}{2}\operatorname{Im}\frac{\Gamma_{12}}{M_{12}} = \operatorname{Im}\frac{\Gamma_{12}}{M_{12}}$$

Nel sistema del B, come vedremo, $|\Gamma_{12}| \ll |M_{12}|$ e possiamo allora semplificare le espressioni precedenti:

$$\Delta m_B = 2\,|M_{12}|, \qquad \Delta\Gamma_B = \frac{2\,\mathrm{Re}\left(M_{12}\Gamma_{12}^*\right)}{|M_{12}|}, \qquad \frac{q}{p} = -\frac{M_{12}^*}{|M_{12}|}\left(1 - \frac{1}{2}\,\mathrm{Im}\,\frac{\Gamma_{12}}{M_{12}}\right).$$

$$\frac{\Delta\Gamma}{\Delta m} = \mathrm{Re}\left(\frac{\Gamma_{12}}{M_{12}}\right)$$

$$\Downarrow$$

$$\left|\frac{q}{p}\right| - 1 = -\frac{1}{2}\,\mathrm{Im}\,\frac{\Gamma_{12}}{M_{12}}$$

Consideriamo poi le ampiezze di decadimento:

$$A_f = \langle f | H_{eff} | B^0 \rangle, \qquad \bar{A}_f = \langle f | H_{eff} | \bar{B}^0 \rangle.$$

È comodo scrivere le ampiezze dividendo ogni contributo distinguendo il modulo, eventuali fasi CP-violanti presenti nell'Hamiltoniana efficace e le fasi forti che conservano CP. Poiché CP collega A_f ad $\bar{A}_f$, abbiamo

$$\left|\frac{\bar{A}_f}{A_f}\right| = \left|\frac{\sum_i A_i\, e^{i(\delta_i - \phi_i)}}{\sum_i A_i\, e^{i(\delta_i + \phi_i)}}\right|,$$

con A_i moduli, δ_i fasi forti e ϕ_i fasi "deboli" in H_{eff}.

Introduciamo un parametro complesso

$$\lambda_f = \frac{q}{p}\,\frac{\bar{A}_f}{A_f}.$$

Possiamo allora distinguere tre diversi tipi di violazione di CP:

(1) Violazione di CP nel mixing:

$$\left|\frac{q}{p}\right| \neq 1 \qquad \left(\Rightarrow \mathrm{Im}\,\frac{\Gamma_{12}}{M_{12}} \neq 0\right)$$

Nel B, potrebbe essere osservata nei decadimenti semileptonici:

$$a_{SL} = \frac{\Gamma(\bar{B}^0(t) \to e^+ \nu X) - \Gamma(B^0(t) \to e^- \bar{\nu} X)}{\Gamma(\bar{B}^0(t) \to e^+ \nu X) + \Gamma(B^0(t) \to e^- \bar{\nu} X)} = \frac{1 - |q/p|^4}{1 + |q/p|^4} = \mathrm{Im}\,\frac{\Gamma_{12}}{M_{12}}.$$

L'effetto però nel B è molto piccolo, $\lesssim O(10^{-2})$. Questo perchè

$\frac{\Delta\Gamma_B}{\Gamma_B}$, essendo generato dai canali di decadimento comuni a B e $\bar{B}$,

è $\lesssim 10^{-2}$. D'altro canto, $\frac{\Delta M_B}{\Gamma_B} \approx 0.7$, e dunque $\frac{\Delta\Gamma_B}{\Delta M_B} \lesssim O(10^{-2})$.

Una stima precisa è difficile a causa delle incertezze adroniche nel calcolo di M_{12} e Γ_{12}.

(2) Violazione di CP nel decadimento:

$$\left|\frac{\bar{A}_{\bar{f}}}{A_f}\right| \neq 1.$$

Questo può avvenire solo se vi sono almeno due contributi all'ampiezza con fasi deboli e forti diverse.

Le asimmetrie di CP nei decadimenti dei B carichi,

$$a_{f^\pm} = \frac{\Gamma(B^+ \to f^+) - \Gamma(B^- \to f^-)}{\Gamma(B^+ \to f^+) + \Gamma(B^- \to f^-)},$$

sono di questo tipo. Si ha $a_{f^\pm} = \dfrac{1 - |\bar{A}_{f^-}/A_{f^+}|^2}{1 + |\bar{A}_{f^-}/A_{f^+}|^2}$.

Nel caso semplice di due ampiezze A_1, A_2 con $A_2 \ll A_1$, si ha

$$a_{f^\pm} = -2\,\frac{A_2}{A_1}\sin(\delta_2 - \delta_1)\sin(\phi_2 - \phi_1).$$

Anche qui il calcolo di $a_{f^\pm}$ richiede la conoscenza sia dei moduli che delle fasi forti delle ampiezze di decadimento, problema in generale molto difficile da risolvere.

(3) Violazione di CP nell'interferenza fra decadimenti con e senza mixing:

$$|\lambda_{f_{CP}}| = 1, \quad \operatorname{Im} \lambda_{f_{CP}} \neq 0.$$

I due casi discussi in precedenza implicano $|\lambda| \neq 1$. C'è però una terza possibilità, che λ abbia una parte immaginaria anche se $|\lambda| = 1$.

Nel B neutro, questo effetto può essere osservato nei decadimenti di B^0 e $\bar{B}^0$ in un autostato di CP f_{CP}:

$$a_{f_{CP}} = \frac{\Gamma(\bar{B}^0(t) \to f_{CP}) - \Gamma(B^0(t) \to f_{CP})}{\Gamma(\bar{B}^0(t) \to f_{CP}) + \Gamma(B^0(t) \to f_{CP})} \underset{(|\lambda|=1)}{=} - \operatorname{Im} \lambda_{f_{CP}} \sin \Delta M_B t.$$

$|\lambda = 1|$ richiede che vi sia un'unica fase debole o un'unica fase forte nel decadimento.

Consideriamo un esempio importante: il caso semplice in cui vi è un'unica fase debole nell'ampiezza di decadimento.

Sia l'Hamiltoniana efficace per il mixing B-$\bar{B}$ data da

$$H_{eff}^{\Delta B=2} = C e^{2i\phi_B} O_{\bar{b}d\bar{b}d},$$

con $O_{\bar{b}d\bar{b}d}$ un operatore locale, C un coefficiente reale e $2\phi_B$ la fase debole del mixing. Allora abbiamo, essendo per il B $|\Gamma_{12}| \ll M_{12}$,

$$\frac{q}{p} = - \frac{2M_{12}^* - i\Gamma_{12}^*}{\Delta m - \frac{i}{2}\Delta\Gamma} \simeq - \frac{2M_{12}^*}{2|M_{12}|} = - e^{-2i\phi_B}.$$

L'ampiezza di decadimento potrà invece essere scritta come

$$A_f = C e^{i\phi_f} e^{i\delta},$$

per cui

$$\lambda_f = \frac{q}{p}\frac{\bar{A}_f}{A_f} = -e^{-2i\phi_B}\frac{C e^{-i\phi_f} e^{i\delta}}{C e^{i\phi_f} e^{i\delta}} = -e^{-2i(\phi_B+\phi_f)}$$

e $\operatorname{Im}\lambda_f = -\sin 2(\phi_B+\phi_f)$.

Concludiamo questa parte con due definizioni utili:

– Violazione INDIRETTA di CP:
corrisponde al caso in cui le fasi CP violanti possono essere
• confinate nelle ampiezze $\Delta F = 2$

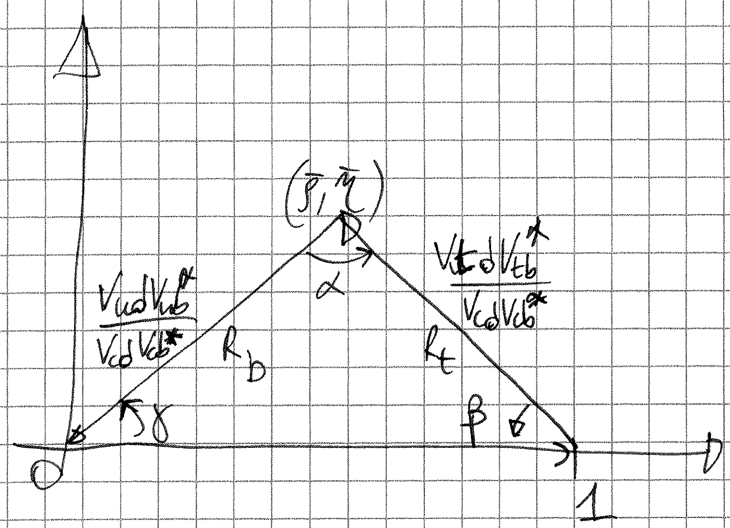
– Violazione DIRETTA di CP:
corrisponde al caso in cui è necessario avere delle fasi nelle ampiezze $\Delta F = 1$.

Allora, la violazione di CP nel mixing è un caso di violazione indiretta di CP, mentre la violazione di CP nel decadimento è un caso di violazione diretta di CP.

La violazione di CP nell'interferenza tra decadimenti con e senza mixing contiene tutti e due i casi: l'osservazione su un singolo canale è indiretta, ma se si ha per due stati finali f_1 ed f_2 $\operatorname{Im}\lambda_{f_1} \neq \operatorname{Im}\lambda_{f_2}$, questo implica la presenza di violazione diretta di CP.

Unitarity gives us triangular relations. For example,

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0 = 1 + \frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*} + \frac{V_{td}V_{tb}^*}{V_{cd}V_{cb}^*}$$



$$R_b = \left|\frac{V_{ud}V_{ub}}{V_{cd}V_{cb}}\right|$$

$$R_t = \left|\frac{V_{td}V_{tb}^*}{V_{cd}V_{cb}^*}\right|$$

$$\gamma = \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right) \qquad \alpha = \arg\left(-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right)$$

$$\beta = \arg\left(-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right)$$

$$\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*} = \frac{c_{12}c_{13}s_{13}e^{i\delta}}{(s_{12}c_{23}-c_{12}s_{23}s_{13}e^{i\delta})\,s_{23}c_{13}} = \frac{c_{12}s_{13}e^{i\delta}}{s_{23}s_{12}c_{23}-s_{23}^2c_{12}s_{13}e^{i\delta}} =$$

$$= \frac{c_{12}A\lambda^3(\rho+i\eta)}{A\lambda^2\left(\lambda c_{23}-c_{12}A\lambda^2A\lambda^3(\rho+i\eta)\right)} = \frac{\sqrt{1-\lambda^2}\,\lambda(\rho+i\eta)}{\lambda\sqrt{1-A^2\lambda^4}-\sqrt{1-\lambda^2}A^2\lambda^5(\rho+i\eta)} =$$

$$= \frac{\sqrt{1-\lambda^2}(\rho+i\eta)}{\sqrt{1-A^2\lambda^4}-A^2\lambda^4\sqrt{1-\lambda^2}(\rho+i\eta)}$$

$$V_{ud}V_{ub}^* = c_{12}c_{13}s_{13}e^{i\delta} = A\lambda^3(\rho+i\eta)\sqrt{1-\lambda^2}+O(\lambda^9) = A\lambda^3(\rho+i\eta)\left(1-\frac{\lambda^2}{2}\right)+O(\lambda^7)$$

$$= A\lambda^3(\bar\rho+i\bar\eta)+O(\lambda^7) \qquad \bar\rho = \rho\left(1-\frac{\lambda^2}{2}\right) \qquad \bar\eta = \eta\left(1-\frac{\lambda^2}{2}\right)$$

$$V_{cd}V_{cb}^* = -(s_{12}c_{23}-c_{12}s_{23}s_{13}e^{i\delta})s_{23}c_{13} = -A\lambda^2\left(\lambda+O(\lambda^5)\right) = -A\lambda^3+O(\lambda^7)$$

$$V_{td}V_{tb}^* = (s_{12}s_{23}-c_{12}c_{23}s_{13}e^{i\delta})c_{23}c_{13} = A\lambda^3\left(1-(\rho+i\eta)\left(1-\frac{\lambda^2}{2}\right)\right)+O(\lambda^7) = A\lambda^3(1-\bar\rho-i\bar\eta)$$

$\Delta F = 2$ interactions beyond the SM.

If we go beyond the SM, we can consider the most general set of $\Delta F=2$ operators. Using Fierz Transformations, it can be shown that the most general basis is the following:

$$Q_1 = \bar{d}_L \gamma_\mu s_L \, \bar{d}_L \gamma^\mu s_L \qquad \tilde{Q}_1 = \bar{d}_R \gamma_\mu s_R \, \bar{d}_R \gamma_\mu s_R$$

$$Q_2 = \bar{d}_R s_L \, \bar{d}_R s_L \qquad \tilde{Q}_2 = \bar{d}_L s_R \, \bar{d}_L s_R$$

$$Q_3 = \bar{d}_R^\alpha s_L^\beta \, \bar{d}_R^\beta s_L^\alpha \qquad \tilde{Q}_3 = \bar{d}_L^\alpha s_R^\beta \, \bar{d}_L^\beta s_R^\alpha$$

$$Q_4 = \bar{d}_R s_L \, \bar{d}_L s_R$$

$$Q_5 = \bar{d}_R^\alpha s_L^\beta \, \bar{d}_L^\beta s_R^\alpha$$

Anomalous dimensions:

$$\frac{\alpha_s}{4\pi}\begin{pmatrix} 4 & 0 & 0 & 0 & 0 \\ 0 & -\frac{28}{3} & \frac{4}{3} & 0 & 0 \\ 0 & \frac{16}{3} & \frac{32}{3} & 0 & 0 \\ 0 & 0 & 0 & -16 & 0 \\ 0 & 0 & 0 & -6 & 2 \end{pmatrix}$$

accidentally large Terms.

large negative $\gamma_0 \Rightarrow$ enhancement in the running

Matrix elements:

$$\langle K^0 | \bar{d}\gamma_\mu \gamma_5 s | 0\rangle\langle 0 | \bar{d}\gamma^\mu \gamma_5 s | \bar{K}^0\rangle = \frac{m_K F_K^2}{2} \quad \text{from } \langle 0 | \bar{d}\gamma^\mu\gamma_5 s | \bar{K}^0\rangle = -i p_K^\mu \frac{F_K}{\sqrt{2 m_K}}$$

now using

$$\partial_\mu \langle 0 | \bar{d}\gamma^\mu \gamma_5 s | \bar{K}^0\rangle = \begin{cases} -i(m_s + m_d)\langle 0 | \bar{d}\gamma_5 s | \bar{K}^0\rangle \\ m_K^2 \frac{F_K}{\sqrt{2 m_K}} \end{cases}$$

We get $\langle K^0 | \bar{d}\gamma_5 s | 0\rangle\langle 0 | \bar{d}\gamma_5 s | \bar{K}^0\rangle = -\left(\frac{m_K}{m_s + m_d}\right)^2 \frac{m_K F_K^2}{2}$

enhanced by one order of magnitude

Take $C_4 = \frac{1}{\Lambda^2}$ at $\mu \sim \Lambda$.

Run down to 2 GeV, compute the matrix element and take ratio with the Standard Model (top contribution for simplicity)

$$\frac{\frac{1}{\Lambda^2}\,\eta_4 \left(\frac{m_K}{m_s+m_d}\right)^2 \frac{m_K F_K^2}{20}}{\frac{G_F^2 M_W^2}{4\pi^2}\,\frac{F_K^2 m_K}{2}\,\eta\,\mathrm{Im}\,\lambda_t\,\mathrm{Re}\,\lambda_t\, S_0(x_t)} \sim \frac{4\pi^2\cdot 10\cdot 10}{\Lambda^2\, 10^{-10}\, 10^4\, 0.5\, \lambda^{10}} \sim$$

$$\frac{400\cdot 10\cdot 10}{\Lambda^2 10^{-10} 10^4 0.5\, 10^{-7}} = \frac{1}{\Lambda^2 10^{-18}}$$

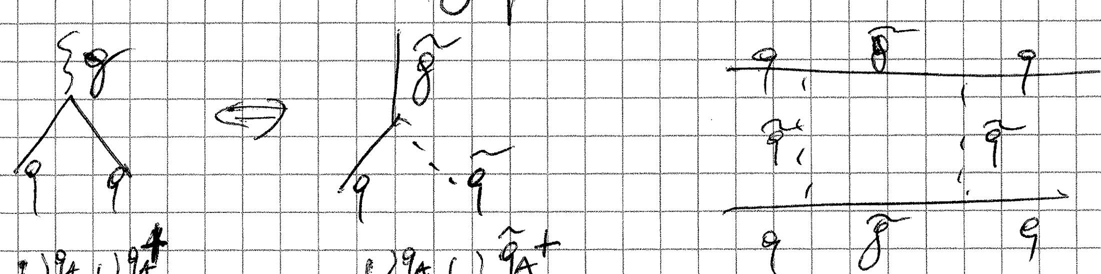
$O(1)$ for $\Lambda = 10^9$ GeV $= 10^6$ TeV

Doing it carefully one finds $\sim 5\cdot 10^5$ TeV

3,5 orders of magnitude come from the CKM structure.

Explicit examples:

* MSSM with arbitrary flavour structure

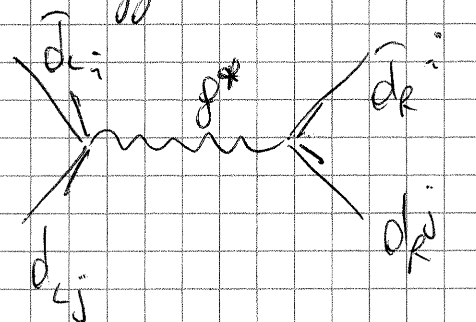


$U^{q_A} U^{q_A^+}$ $\Rightarrow$ flavour diagonal

$U^{q_A} U^{\tilde q_A^+}$ $\Rightarrow$ flavour changing

$C \sim \frac{\alpha_s^2}{m_{SUSY}^2}$

* Composite Higgs models



$$C \sim \frac{(4\pi)^2}{N} \frac{1}{m_{\rho^*}^2} \xi_i^Q \xi_j^Q \xi_i^d \xi_j^d$$

$$\sim \frac{1}{m_{\rho^*}^2} \frac{m_{d_i} m_{d_j}}{v^2}$$

effective scale lowered by $\sqrt{\frac{m_d m_s}{v^2}} \sim 5 \cdot 10^{-5}$

$\Rightarrow$ Tens of TeV's

Minimal flavour violation

Assume NP does not introduce any additional source of flavour violation. This implies Yukawas are the only source of flavour violation. Make the SM Lagrangian formally invariant under global flavour symmetry promoting Y's to spurions transforming under $SU(3)_{Q_L} \otimes SU(3)_{u_R} \otimes SU(3)_{d_R}$:

$$Y_u \sim (3, \bar{3}, 1) \qquad Y_d \sim (3, 1, \bar{3}).$$

Using the global symmetry can go to the basis

$$Y_D = \lambda_d \qquad Y_u = V^\dagger \lambda_u$$

with λ_q diagonal and V the CKM matrix.

Then the basic building block of FCNC operators is $(\lambda_{FC})_{ij} \sim \lambda_t^2 V_{3i}^* V_{3j}$ for $i \neq j$

Get automatically only the SM operator with CKM-suppressed contributions in $\Delta F = 2$:

$$Q = \left(\bar{Q}_L \lambda_{FC} \gamma_\mu Q_L\right)^2$$

Enforces SM-like CKM suppression in all sectors + chiral suppression.

However:

1) In GUTs, the global flavour symmetry of the gauge sector reduces to $SU(3)_{10} \otimes SU(3)_{\bar{5}}$ in $SU(5)$ and to $SU(3)_{16}$ in $SO(10)$ $\Rightarrow$ constraining power decreases

2) Assumes Yukawas are fundamental objects

The second point is at variance with flavour models, where the hierarchical structure of the Yukawas is explained in terms of symmetries.