

Title: 12/13 PSI - Beyond the Standard Model Lecture 12

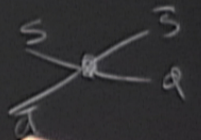
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URL: <http://www.pirsa.org/13030035>

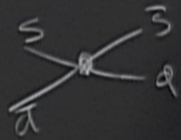
Abstract:

• When $\gamma_u, \gamma_d, W^\pm$ are all included, SM can generate $(\bar{s}_L \sigma^\mu d_L)^2$

• $m_K \Delta m_K = \langle K^0 | H_{\text{eff}} | \bar{K}^0 \rangle$



included, SM can generate $(\bar{S}_L \sigma^\mu d_L)^2$ at loop level.



• When $\gamma_u, \gamma_d, W^\pm$ are all included, SM can generate $(\bar{S}_L \sigma$

• $m_K \Delta m_K = \langle K^0 | H_{\text{eff}} | \bar{K}^0 \rangle$

$$\begin{pmatrix} M_{\text{diag}} & * \\ * & M_{\text{diag}} \end{pmatrix} \frac{\langle K^0 | H_{\text{eff}} | \bar{K}^0 \rangle}{2} = K_{L/S}$$



• When $\gamma_u, \gamma_d, W^\pm$ are all included, SM can generate $(\bar{S}_L \sigma$

• $m_K \Delta m_K = \langle K^0 | H_{\text{eff}} | \bar{K}^0 \rangle$

$\begin{pmatrix} M_{\text{mix}} & * \\ * & M_{\text{mix}} \end{pmatrix} \quad |K^0 H \bar{K}^0\rangle = K_{\frac{1}{\sqrt{2}}}$



• When $\gamma_u, \gamma_d, W^\pm$ are all included, SM can generate $(\bar{S}_L \sigma$

• $m_K \Delta m_K = \langle K^0 | H_{\text{eff}} | \bar{K}^0 \rangle$

• When $\gamma_u, \gamma_d, W^\pm$ are all included, SM can generate $(\bar{s}_L \sigma^\mu d_L)$

• $m_K \Delta m_K = \langle K^0 | H_{\text{eff}} | \bar{K}^0 \rangle, \quad \langle K^0 | \frac{1}{\Lambda^2}$

- When $\gamma_u, \gamma_d, W^\pm$ are all included, SM can generate $(\bar{s}_L \sigma^\mu d_L)$
- $m_K \Delta m_K = \langle K^0 | H_{\text{eff}} | \bar{K}^0 \rangle$, $\langle K^0 | \frac{2}{\Lambda^2} (\bar{s}_L \sigma^\mu d_L)^2 | \bar{K}^0 \rangle = \frac{2}{\Lambda^2}$

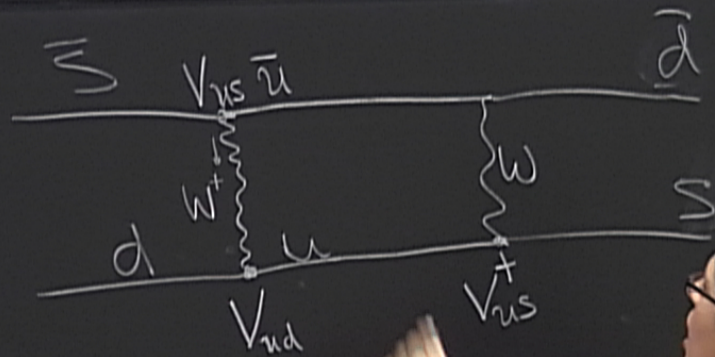
if all included, SM can generate $(\bar{s}_L \sigma^\mu d_L)^2$ at loop level.

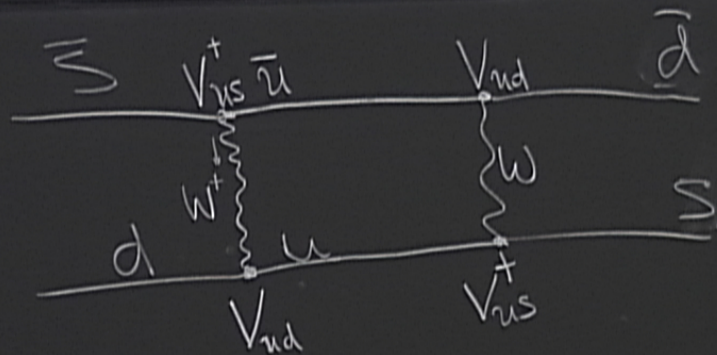
$$\langle K^0 | \frac{1}{\Lambda^2} (\bar{s}_L \sigma^\mu d_L)^2 | K^0 \rangle = \frac{2}{\Lambda^2} f_K^2 m_K^2$$

are all included, SM can generate $(\bar{s}_L \sigma^\mu d_L)^2$ at loop level.

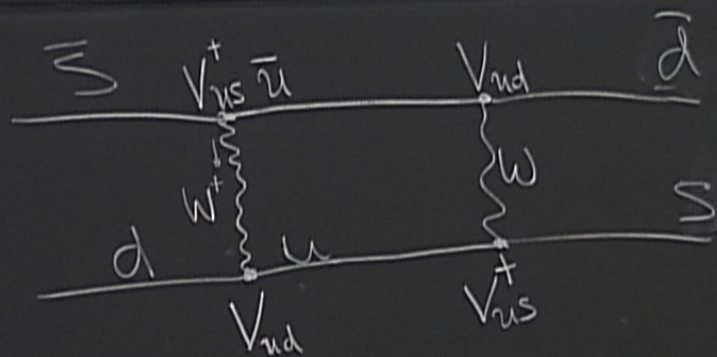
$$H_{\text{eff}} |K^0\rangle, \quad \langle K^0 | \left[\frac{2}{\Lambda^2} \right] (\bar{s}_L \sigma^\mu d_L)^2 |K^0\rangle = \frac{2}{\Lambda^2} f_K^2 m_K^2 B$$

- When $\gamma_u, \gamma_d, W^\pm$ are all included, SM can generate $(\bar{s}_L \sigma^\mu d_L)$
- $m_K \Delta m_K = \langle K^0 | H_{\text{eff}} | \bar{K}^0 \rangle$, $\langle K^0 | \frac{\tau}{\Lambda^2} (\bar{s}_L \sigma^\mu d_L)^2 | \bar{K}^0 \rangle = \frac{\tau}{\Lambda^2} f_K^2 m_K^2 B$
- What is $\frac{\tau}{\Lambda^2}$ from SM

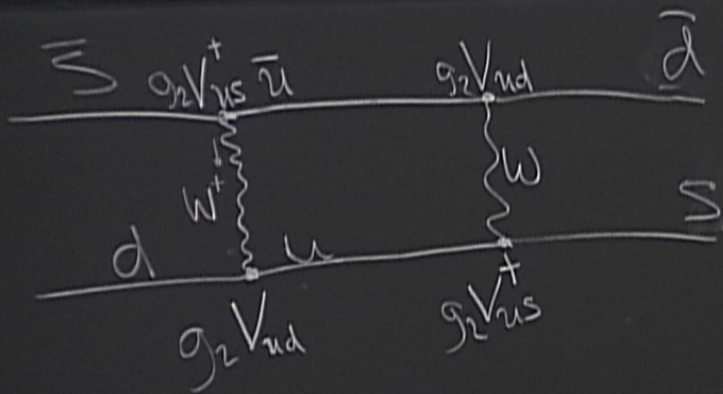




$$\int d^4k \left(\frac{1}{k^2 - m_W^2} \right)^2$$

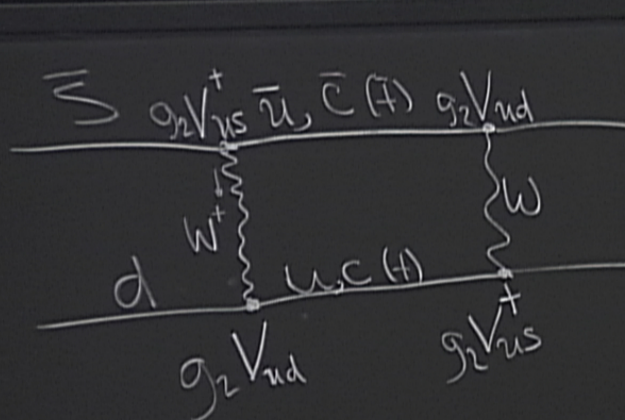


$$\int d^4k \left(\frac{1}{k^2 - m_W^2} \right)^2 \left(\frac{\cancel{k}}{k^2 - m_u^2} \right)^2$$



$$(V_{ud} V_{us}^*)^2 g_2^4 \int d^4 k \left(\frac{1}{k^2 - m_W^2} \right)^2 \left(\frac{\cancel{k}}{k^2 - m_u^2} \right)^2 \sim \frac{\alpha_2^2}{k^2 - m_W^2} (V_{ud} V_{us}^*)^2$$

$\frac{1}{k^4}$
 $\frac{k}{k^2}$



$$\bar{c} \rightarrow s + W^+ \rightarrow s + u + \bar{d}$$

$$\sim \frac{g^4}{2} \frac{\sum (V_{cd} V_{cs}^*)}{\int d^4 k \left(\frac{1}{k^2 - m_W^2} \right) \left(\frac{1}{k^2 - m_u^2} \right)} \sim \frac{g^4}{2} \frac{(V_{cd} V_{cs}^*)^2}{m_W^2}$$

$$(V^+ V)_{sd}$$

$$\mathbb{I}_{sd} = 0$$

GIM mechanism

$$\frac{\bar{s} \overset{+}{V}_{is} \bar{u} \bar{c} \overset{+}{V}_{id} \bar{d}}{\sim \sum_i \overset{+}{V}_{is} \frac{k+m_i}{k^2} \overset{+}{V}_{id}}$$

$$\overline{s} \overset{+}{V}_{is} \overline{u} \overset{+}{V}_{id} \overline{d} \sim \sum_i \overset{+}{V}_{is} \left(\frac{\cancel{k} + m_i}{k^2 + m_i^2} \right) \overset{+}{V}_{id}$$

$$\overline{s} \overset{+}{V}_{is} \overline{u} \overset{+}{V}_{id} \overline{d} \sim \sum_{i=1,2} \overset{+}{V}_{is} \left(\frac{k+m_i}{k^2+m_i^2} \right) V_{id} = \overset{+}{V}_{us} \frac{k}{k^2} V_{ud} + k$$

$$\overline{s} \xrightarrow{V_{is}^+} \overline{u} \overline{c} \xrightarrow{V_{id}} \overline{d} \sim \sum_{i=1,2} V_{is}^+ \left(\frac{k+m_c}{k^2+m_c^2} \right) V_{id} = V_{us}^+ \frac{k}{k^2} V_{ud} + \frac{k+m_c}{k^2+m_c^2}$$

$$\begin{aligned}
 \sum_{i=1,2} V_{is}^+ \left(\frac{k+m_c}{k^2+m_c^2} \right) V_{id} &= V_{us}^+ \frac{k}{k^2} V_{ud} + \frac{k+m_c}{k^2+m_c^2} \left(-V_{us}^+ V_{ud} - \underbrace{V_{ts}^+ V_{td}}_{\text{ignore}} \right) \\
 &\simeq V_{us}^+ V_{ud} \cdot \frac{m_c}{k^2}
 \end{aligned}$$

$$V_{is}^+ V_{id}$$

$$\begin{aligned}
 \bar{d} & \sim \sum_{i=1,2} V_{is}^+ \left(\frac{k+m_c}{k^2+m_c^2} \right) V_{id} = V_{us}^+ \frac{k}{k^2} V_{ud} + \frac{k+m_c}{k^2+m_c^2} \left(-V_{us}^+ V_{ud} - \underbrace{V_{ts}^+ V_{td}}_{\text{ignore}} \right) \\
 & \approx V_{us}^+ V_{ud} \cdot \frac{m_c}{k^2} \\
 \left(\frac{C}{\Lambda^2} \right)_{\text{"full box"}} & = \left(\frac{C}{\Lambda^2} \right)_{\text{up box}} \cdot \left(\frac{m_c^2}{m_w^2} \right)
 \end{aligned}$$

$$\begin{aligned}
 \sum_{i=1,2} V_{is}^+ \left(\frac{k+m_i}{k^2+m_i^2} \right) V_{id} &= V_{us}^+ \frac{k}{k^2} V_{ud} + \frac{k+m_c}{k^2+m_c^2} \left(-V_{us}^+ V_{ud} - \underbrace{V_{ts}^+ V_{td}}_{\text{ignore}} \right) & V_{is}^+ V_{id} &= 0 \\
 \left(\frac{C}{\Lambda^2} \right)_{\text{"full box"}} &= \left(\frac{C}{\Lambda^2} \right)_{\text{up box}} \cdot \left(\frac{m_c^2}{m_W^2} \right) & \frac{\Delta m_K}{m_K} &\sim \frac{f_K^2}{m_W^2} \frac{m_c^2}{m_W^2} \cdot \alpha_2^2 \left(V_{us}^+ V_{ud} \right)^2 \sim 10^{-14} \\
 & & & \frac{10^{-6}}{10^{-4}} \cdot \frac{\left(\frac{1}{20} \right)^2 (2)^2}{10^{-4}} \cdot 1
 \end{aligned}$$

$$\frac{\Delta m_K}{m_K} \sim \left(\frac{f_K}{m_W} \right)^2 \cdot (V_{ud} V_{us}^*)^2 \cdot \alpha_s^2 \cdot \frac{m_c^2}{m_W^2} \sim$$

$$\left(\frac{100 \text{ MeV}}{100 \text{ GeV}} \right)^2 \quad \left(1 \cdot \frac{1}{5} \right)^2 \quad \left(\frac{1}{20} \right)^2 \quad \left(\frac{1 \text{ GeV}}{100 \text{ GeV}} \right)^2$$

$$10^{-6} \quad 4 \cdot 10^{-2} \quad \frac{1}{4} 10^{-2} \quad 10^{-4}$$

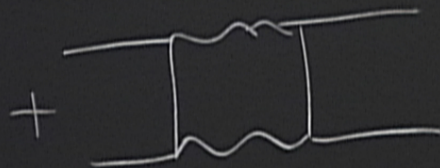
$$\bar{s} \xrightarrow{V_{us}^+} u, \bar{c} \xrightarrow{V_{cd}} d$$

$$\sim \sum_{i=1,2} V_{is}^+ \left(\frac{k+m_c}{k^2+m_c^2} \right) V_{id} = V_{us}^+ \frac{k}{k^2} V_{ud}$$

$$\simeq V_{us}^+ V_{ud} \frac{m_c}{k^2}$$

$$\left(\frac{C}{\Lambda^2} \right)_{\text{full box}}$$

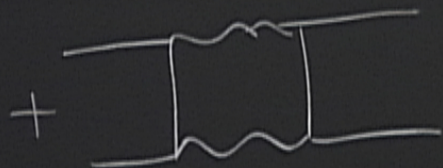
$$\cdot \left(\frac{m_c^2}{m_w^2} \right)$$



+

$$\bar{s} \xrightarrow{V_{is}^+} \bar{u} \xrightarrow{V_{ud}} \bar{d}$$

$$\sim \sum_{i=1,2} V_{is}^+ \left(\frac{k+m_c}{k^2+m_c^2} \right) V_{id} = V_{us}^+ \frac{k}{k^2} V_{ud}$$



+ long-distance

$$\left(\frac{C}{\Lambda^2} \right)_{\text{full box}} = \left(\frac{C}{\Lambda^2} \right)_{\text{up box}} \approx V_{us}^+ V_{ud} \frac{m_c}{k^2} \cdot \left(\frac{m_c^2}{m_W^2} \right)$$

$$\begin{aligned}
 & \left(\frac{V_{ud} V_{us}}{V_{ud} V_{us}} \right)^2 \propto \alpha_s^2 \quad \frac{m_c^2}{m_w^2} \sim \boxed{10^{-14}} \\
 & \left(\frac{1 \text{ GeV}}{100 \text{ GeV}} \right)^2 \quad \left(1 - \frac{1}{5} \right)^2 \quad \left(\frac{1}{20} \right)^2 \quad \text{VS.} \quad \frac{\alpha_s^2}{m_w^2} \\
 & 10^{-6} \quad 4 \cdot 10^{-2} \quad \frac{1}{4} 10^{-2} \quad 10^{-4}
 \end{aligned}$$

$$\begin{aligned}
 &= V_{us}^+ \frac{k}{k^2} V_{ud} + \frac{k+m_c}{k^2+m_c^2} \left(-V_{us}^+ V_{ud} - \underbrace{V_{ts}^+ V_{td}}_{\text{ignore}} \right) + \frac{k+m_t}{k^2+m_t^2} V_{is}^+ V_{id} = 0 \\
 &\approx V_{us}^+ V_{ud} \cdot \frac{m_c}{k^2} \\
 &\cdot \left(\frac{m_c^2}{m_w^2} \right) \quad \Delta m_K \sim \frac{f_K^2}{m_w^2} \frac{m_c^2}{m_w^2} \cdot \alpha_2^2 \left(V_{us}^+ V_{ud} \right)^2 \sim 10^{-14} \\
 &\text{box} \quad 10^{-6} \quad 10^{-4} \cdot \frac{\left(\frac{1}{20} \right)^2 (2)^2}{10^{-4}} \quad 1
 \end{aligned}$$

$$\begin{pmatrix} S_L \\ \tilde{S}_L \end{pmatrix}, \begin{pmatrix} d_L \\ \tilde{d}_L \end{pmatrix}$$

$$A^\mu$$

$$\lambda^\alpha \leftarrow \text{gaugino}$$

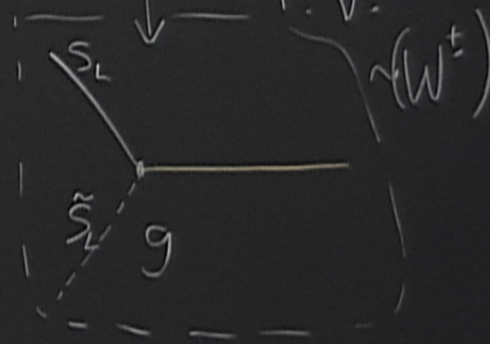
$$\bar{S}_L \sigma^\mu A_\mu S_L \rightarrow \left| (\partial + iA) \tilde{S}_L \right|^2$$

$$g \text{ (wavy line) } \Rightarrow$$

$$\tilde{d} \text{ (dashed line) } \Rightarrow$$

$$g^2 \text{ (wavy line) } \Rightarrow$$

CAN PRODUCE F.V.



S

$$\begin{pmatrix} S_L \\ \tilde{S}_L \end{pmatrix}, \begin{pmatrix} d_L \\ \tilde{d}_L \end{pmatrix}$$

$$A^\mu$$

$$\lambda^d \leftarrow \text{gaugino}$$

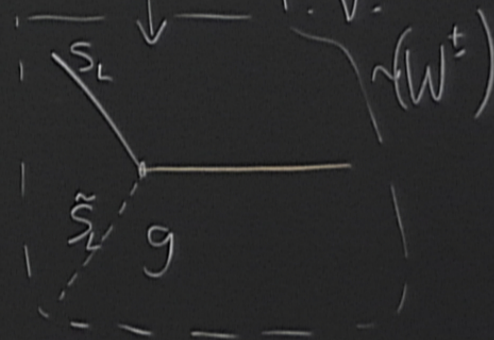
$$\bar{S}_L \sigma^\mu A_\mu S_L \rightarrow \left| (\partial + iA) \tilde{S}_L \right|^2$$

$$g \text{ (wavy line) } \Rightarrow$$

$$\tilde{d} \text{ (dashed line) } g$$

$$g^2 \text{ (wavy line) }$$

CAN PRODUCE F.V.



SUSY

Soft breaking $\Rightarrow$ Add mass terms
that violate SUSY

PRODUCE
F.V.

$\sim (W^\pm)$

SUSY

Soft breaking $\Rightarrow$ Add mass terms
that violate SUSY

$$m_{\tilde{q}}^2 (\tilde{q}_{Li}^* \tilde{q}_{Lj}) + m_{\tilde{u}}^2 (\tilde{u}_{Ri}^* \tilde{u}_{Rj}) + m_{\tilde{d}}^2 (\tilde{d}_{Ri}^* \tilde{d}_{Rj}) +$$

PRODUCE
F.V.
 $\sim (W^\pm)$

SUSY

Soft breaking $\Rightarrow$ Add mass terms
that violate SUSY

$$m_{\tilde{q}}^2 (\tilde{q}_{Li}^* \tilde{q}_{Lj}) + m_{\tilde{u}}^2 (\tilde{u}_{Ri}^* \tilde{u}_{Rj}) + m_{\tilde{d}}^2 (\tilde{d}_{Ri}^* \tilde{d}_{Rj}) + m_{\tilde{\chi}}^2 \dots$$

PRODUCE
F.V.
 $\gamma(W^\pm)$

SUSY

Soft breaking $\Rightarrow$ Add mass terms
that violate SUSY

$$m_{\tilde{q}}^2 (\tilde{q}_{L,i}^* \tilde{q}_{L,j}) + m_{\tilde{u}}^2 (\tilde{u}_{R,i}^* \tilde{u}_{R,j}) + m_{\tilde{d}}^2 (\tilde{d}_{R,i}^* \tilde{d}_{R,j}) + m_{\tilde{t}}^2 \dots$$

PRODUCE
F.V.

$\sim (W^\pm)$

SUSY

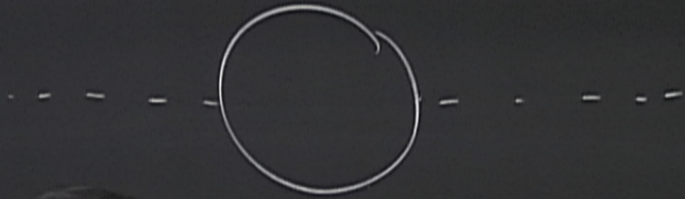
Soft breaking $\Rightarrow$ Add mass terms
that violate SUSY

$$m_{\tilde{q}_{ij}}^2 (\tilde{q}_{Li}^* \tilde{q}_{Lj}) + m_{\tilde{u}}^2 (\tilde{u}_L^* \tilde{u}_R) + m_{\tilde{d}}^2 (\tilde{d}_L^* \tilde{d}_R) + m_{\tilde{\chi}}^2 \dots$$

$$+ M_3 \tilde{\lambda}^a \lambda_a$$

$a = 1 \dots 8$

PRODUCE
F.V.
 $(W^\pm)$



$$g^{\alpha} \quad g^2$$

$$m_H^2 = m_{H,0}^2 + \underbrace{\delta m_H^2}_{\propto M_{\text{High}}^2}$$

$$m_{\tilde{q}}^2 = m_{\tilde{q},0}^2 + \underbrace{\delta m_{\tilde{q}}^2}_{\propto m_{\tilde{q}}^2}$$

SUSY

Soft breaking $\Rightarrow$ Add mass terms
that violate SUSY

$$m_{\tilde{q}}^2 (\tilde{q}_{L,i}^* \tilde{q}_{L,j}) + m_{\tilde{u}}^2 (\tilde{u}_{R,i}^* \tilde{u}_{R,j}) + m_{\tilde{d}}^2 (\tilde{d}_{R,i}^* \tilde{d}_{R,j}) + m_{\tilde{\tau}}^2 (\tilde{\tau}_{R,i}^* \tilde{\tau}_{R,j})$$

$$+ M_3 \lambda^a \lambda_a$$

$a = 1 \dots 8$

PRODUCE
F.V.

$h(W^\pm)$

$$m_{\tilde{q}}^2 = \delta_{ij} M_{11}^2 + \frac{\hat{m}_{12}^2}{(Y_u^\dagger Y_u)_{ij}}$$

$$\delta \rightarrow V^\dagger \delta V = \delta$$

