$$D_\mu = \partial_\mu + i g_s G_\mu^A T_A^{(3)} + i g W_\mu^a T_a^{(2)} + i g' B_\mu Y$$

$$T_A^{(3)} = t_A^{(3)} = \frac{\lambda_A}{2} \quad \text{on } 3 \qquad T_a^{(2)} = t_a^{(2)} = \frac{\sigma_a}{2} \quad \text{on } 2$$

$$-t_A^{(3)T} = -\frac{\lambda_A^T}{2} \quad \text{on } 3^* \qquad = 0 \quad \text{on } 1$$

$$0 \quad \text{on } 1 \qquad Y = \text{the value}$$

on L

$$D_\mu = \partial_\mu + i g W_\mu^a \frac{\sigma_a}{2} + i g' B_\mu \frac{\mathbb{1}}{2}$$

$$\mathcal{L} \approx \mathcal{L}_{QED+QCD} + \mathcal{L}^{eff}_{weak}$$

$E \ll 300\ GeV$ 1 family

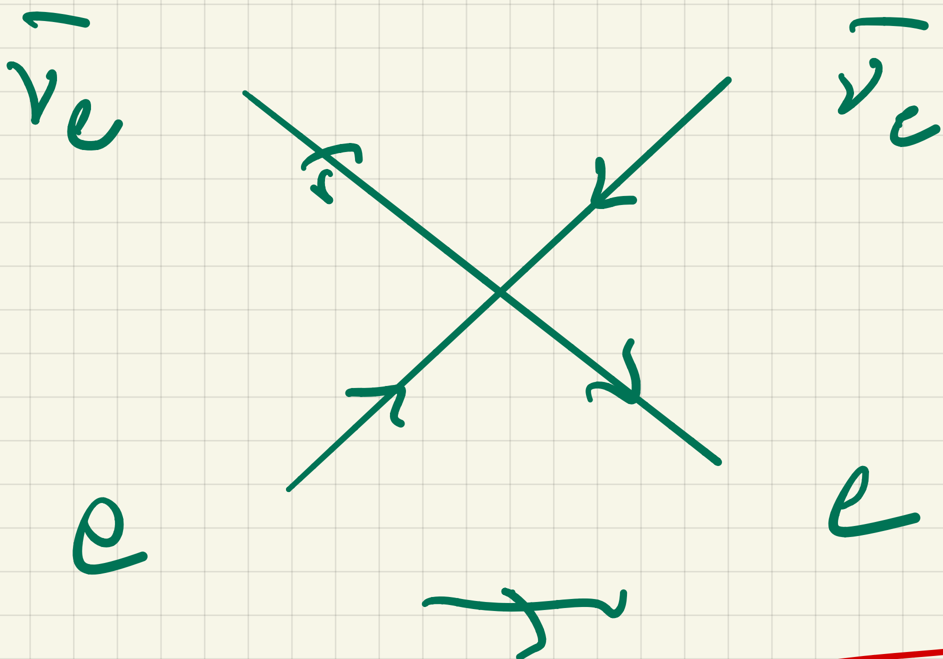
$$\mathcal{L}_{QCD+QED} = \bar{u}(iD^\mu\gamma_\mu - m)u + \bar{d}(iD^\mu\gamma^\mu - m)d$$
$$+ \bar{e} \quad \ldots \quad d$$
$$+ \bar{\nu}_L i\gamma^\mu\partial_\mu \nu_L - \frac{1}{4}V_{\mu\nu}V^{\mu\nu}$$

$$D_\mu = \partial_\mu + ig_s T_A^{(3)} G^A_\mu + ieA_\mu Q$$

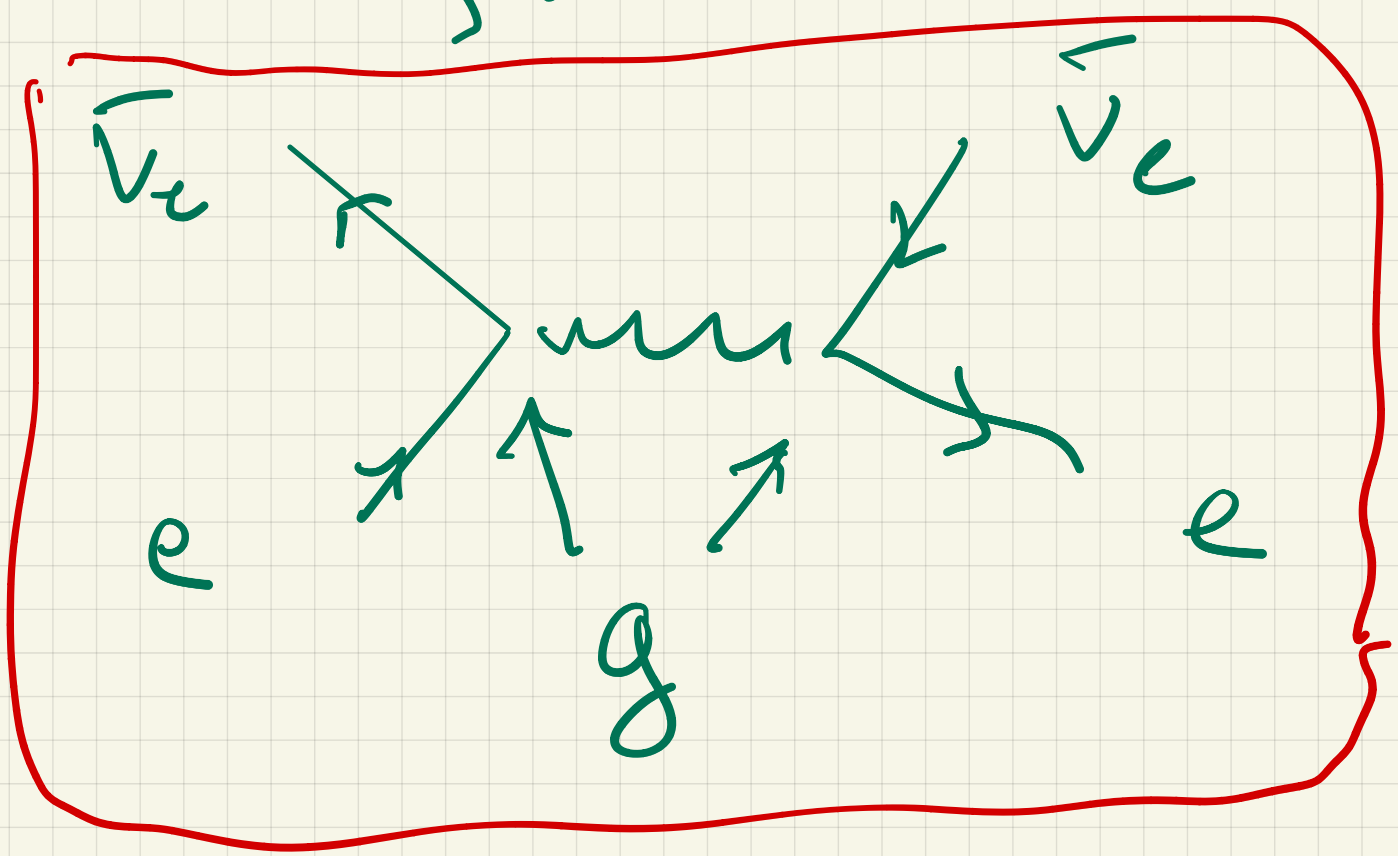
$$\mathcal{L}^{eff}_{weak} = \frac{G_F}{\sqrt{2}} j^\mu_c j^{c\dagger}_\mu \quad \left(G_F^{-1/2} \sim 300\ GeV \right)$$

$$\left(j^\mu_c = \overline{\nu_{eL}}\gamma^\mu e_L + \overline{u_L}\gamma^\mu d_L \qquad \psi_{L,R} = P_{L,R}\psi \right.$$
$$\left. P_{L,R} = 1 \mp \gamma_5/2 \right)$$

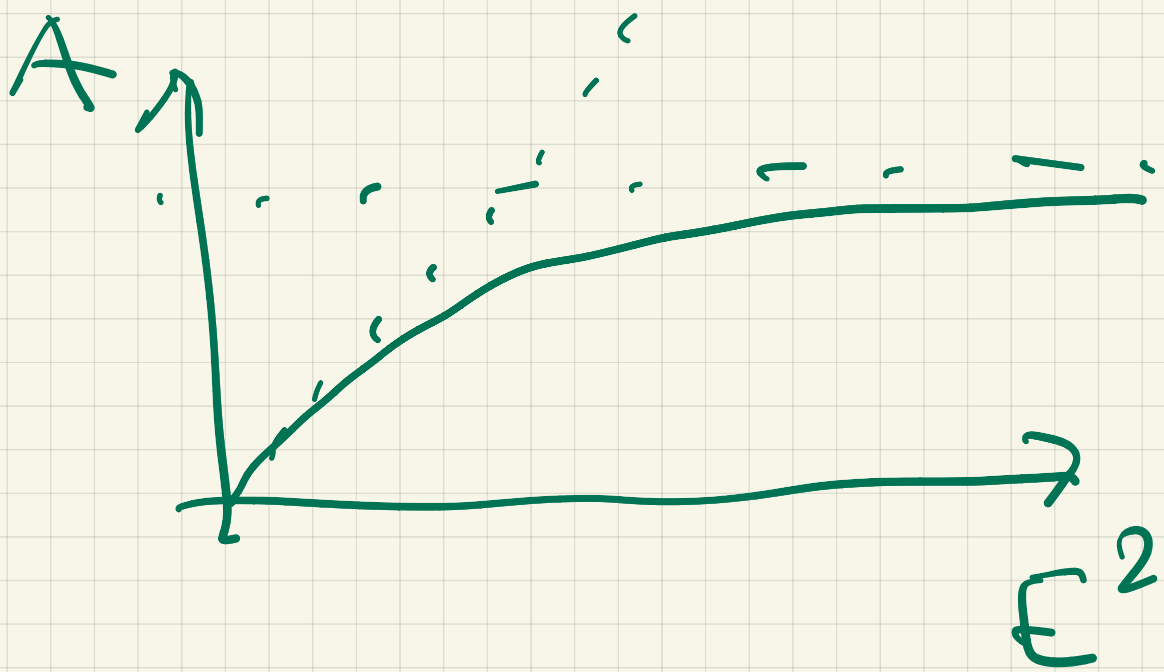
$$= 4\frac{G_F}{\sqrt{2}}\, \bar{\nu}_{eL}\gamma^\mu e_L\, \bar{e}_L \gamma_\mu \nu_{eL} + \dots$$



$A \propto G_F E^2$



$$A \sim \frac{g^2}{E^2 - M^2}\cdot E^2 \sim \begin{cases} E \ll M & \to -g^2/M^2 E^2 \\ E \gg M & \to g^2 \end{cases}$$



$$\left(\frac{g}{\sqrt{2}}\,\bar{\nu}_{eL}\gamma^\mu e_L W^+_\mu + h.c.\right) + \left(\frac{g}{\sqrt{2}}\,\bar{u}_L\gamma^\mu d_L W^+_\mu + h.c.\right)$$

W^+_μ vector of Lorentz

$SU(3)_c$ singlet

$Q = 1$

$$\frac{G_F}{\sqrt{2}} = \frac{g^2}{8M_W^2}$$

$$\mathcal{L} = \begin{pmatrix} \nu_{eL} \\ e_L \end{pmatrix} : \frac{g}{\sqrt{2}} \overline{\nu_{eL}} \gamma^\mu e_L W_\mu^+ + h.c \; \widehat{=}$$

$$= \frac{g}{\sqrt{2}} \bar{L} \gamma^\mu \begin{pmatrix} 0 & 1 \\ 0 & 0 \end{pmatrix} L W_\mu^+ + \frac{g}{\sqrt{2}} \bar{L} \gamma^\mu \begin{pmatrix} 0 & 0 \\ 1 & 0 \end{pmatrix} L W_\mu^-$$

$$W_\mu^\pm = \frac{W_\mu^1 \mp i W_\mu^2}{\sqrt{2}} \qquad W_\mu^{1,2} \text{ real}$$

$$= g \bar{L} \gamma^\mu \left(W_\mu^1 T_1 + W_\mu^2 T_2 \right) L \qquad \underline{T_1, T_2 = \frac{\sigma_{1,2}}{2}}$$

$$[T_1, T_2] = i T_3 = i \frac{\sigma_3}{2} \qquad SU(2) \qquad G \supseteq SU(2)$$

$$+ g \bar{L} \gamma^\mu W_\mu^3 T_3 L \qquad L \sim 2 \; SU(2)_L$$

e_R SU(2) singlet

$$Q\,L = \begin{pmatrix} Q_\nu & 0 \\ 0 & Q_e \end{pmatrix} L \qquad Q = \begin{pmatrix} 0 & 0 \\ 0 & -1 \end{pmatrix} \qquad Tr(Q) \neq 0$$

$$Y = Q - T_3 = \begin{pmatrix} 0 & 0 \\ 0 & -1 \end{pmatrix} - \begin{pmatrix} 1/2 & 0 \\ 0 & -1/2 \end{pmatrix} = -\frac{1}{2}\mathbb{1}$$

$$[Y, T_a] \qquad Y \to U(1)_Y \qquad G = SU(3)_c \times SU(2)_L \times U(1)_Y$$

$$Y_{e_R} = -1 - 0 = -1$$

$$Q = \begin{pmatrix} u_L \\ d_L \end{pmatrix}$$

$$\frac{g}{\sqrt{2}} \bar{u}_L \gamma^\mu d_L W_\mu^+ + h.c. = g \bar{Q} \gamma^\mu (W_\mu^1 T_1 + W_\mu^2 T_2) Q$$

$u_R, d_R \sim 1 \quad SU(2)_L \quad + g \, \ldots \, W_\mu^3 T_3 \, \ldots$

$Y = Q - T_3 \qquad Q$

$$Y = \begin{pmatrix} 2/3 & 0 \\ 0 & -1/3 \end{pmatrix} - \begin{pmatrix} 1/2 & 0 \\ 0 & -1/2 \end{pmatrix} = \begin{pmatrix} 1/6 & 0 \\ 0 & 1/6 \end{pmatrix}$$

$Y = \quad 2/3 \quad u_R$

$\qquad -1/3 \quad d_R$