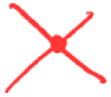
$b \to c \tau \nu$

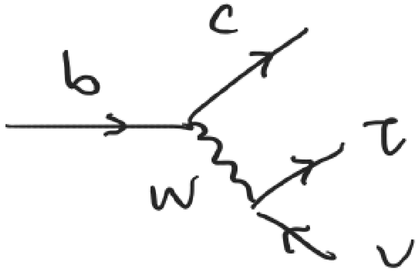
- Model Independent
  - Effective Field Theory (EFT)

- Model Dependent
  - 2HDM
  - W'
  - Leptoquark

$b \to c \tau \nu$ EFT

$\propto \frac{1}{q^2 - m_W^2} \xrightarrow{q^2 \ll m_W^2}$  $\propto \frac{\left(\frac{1}{m_W^2}\right)}{\frac{q^2}{m_W^2} - 1} = -\frac{1}{m_W^2}$

SM :



$$\sim (\bar{c} \gamma^\mu P_L b)(\bar{\tau} \gamma_\mu P_L \nu)$$

Wilson coefficient $(\sim \mathcal{O}(1))$

operator (dim 6)

In general :

$$\mathcal{H} = \frac{4 G_F}{\sqrt{2}} V_{cb} \Big(C_{V_L} O_{V_L} + C_{V_R} O_{V_R} \quad \leftarrow \text{LH, RH vector}$$

$$+ C_{S_L} O_{S_L} + C_{S_R} C_{S_R} \quad \leftarrow \text{LH, RH scalar}$$

$$+ C_T O_T \Big) \quad \leftarrow \text{tensor}$$

Wilson coefficient ($\sim \mathcal{O}(1)$)

operator (dim 6)

$$\mathcal{H} = \frac{4G_F}{\sqrt{2}} V_{cb} \Big(C_{V_L} \mathcal{O}_{V_L} + C_{V_R} \mathcal{O}_{V_R}$$

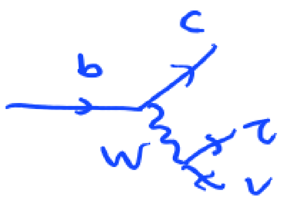
$\leftarrow$ LH, RH vector

$$+ C_{S_L} \mathcal{O}_{S_L} + C_{S_R} C_{S_R}$$

$\leftarrow$ LH, RH scalar

$$+ C_T \mathcal{O}_T \Big)$$

$\leftarrow$ tensor

[

only contributes to $\mathcal{O}_{V_L}$]

$$\mathcal{O}_{V_{L(R)}} = (\bar{c} \gamma^\mu P_{L(R)} b)(\bar{\tau} \gamma_\mu P_L \nu)$$

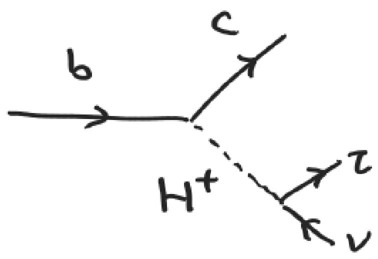
$$\mathcal{O}_{S_{L(R)}} = (\bar{c} \; P_{L(R)} b)(\bar{\tau} \; P_L \nu)$$

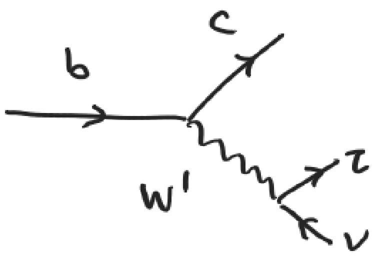
$$\mathcal{O}_T = (\bar{c} \, \sigma^{\mu\nu} P_L b)(\bar{\tau} \, \sigma_{\mu\nu} P_L \nu)$$

$\rightarrow$ only ν_L

Model Dependent

- color singlet





$H^+ : (1,2)_{1/2}$

under
$SU(3)\times SU(2)\times U(1)$
$Q = T_3 + Y$

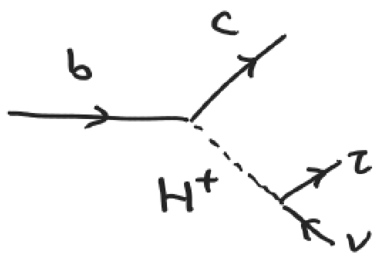
contributes to
C_{S_L} , C_{S_R}

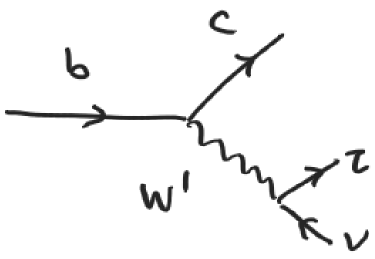
$W' : (1,3)_0$

contributes to
C_{V_L} only

Model Dependent

- color singlet





$H^+ : (1,2)_{1/2}$

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$W' : (1,3)_0$

contributes to

C_{V_L} only

why no C_{V_R} ?

W' is a vector $\left[\sim \tau^a = \begin{pmatrix} \cdot & \cdot \\ \cdot & \cdot \end{pmatrix}\right]$

in fact : $(\bar{c}\gamma^\mu P_L b) \longleftarrow (\bar{Q}\gamma^\mu P_L \tau^a Q)$

$$= ((\bar{c}\ \bar{s})\gamma^\mu P_L \begin{pmatrix} \cdot & \cdot \\ \cdot & \cdot \end{pmatrix}\begin{pmatrix} t \\ b \end{pmatrix})$$

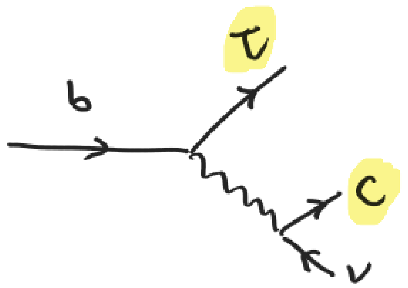
used off diagnal to connect $\bar{c}b$.

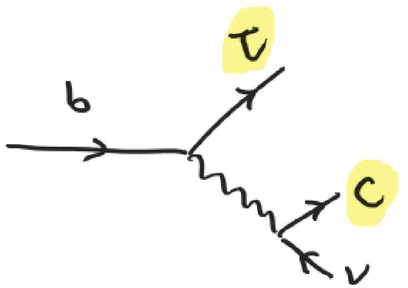
But RH fields are SU(2) singlet :

e.g. b_R , c_R v.s. $b_L \in \begin{pmatrix} t_L \\ b_L \end{pmatrix}$

$c_L \in \begin{pmatrix} c_L \\ s_L \end{pmatrix}$

- <u>color triplet</u> (Leptoquark)



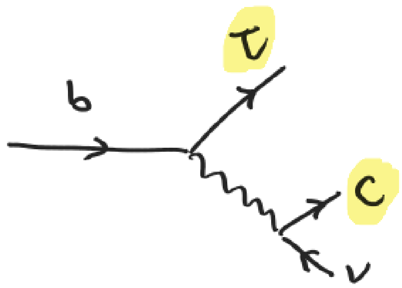


$(3,1)_{2/3} \rightarrow C_{S_L}, C_{S_R}$

or $(3,3)_{2/3} \rightarrow C_{V_L}$

$(3,2)_{7/6} \rightarrow C_{S_L}, C_T$

- **color triplet** (Leptoquark)



$(3,1)_{2/3} \to C_{S_L}, C_{S_R}$

or $(3,3)_{2/3} \to C_{V_L}$

↓

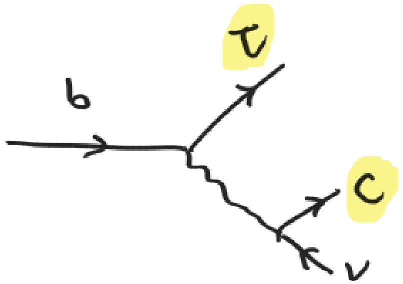
like W'

why singlet?

Because now connect b with τ, both are lower component of $\binom{\cdot}{\cdot}$

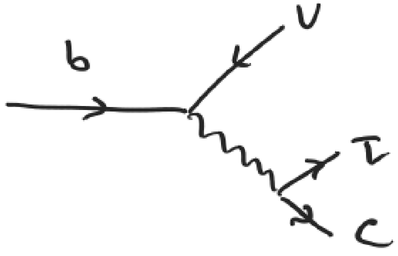
So, no need off diagonal

e.g. $(\bar{\nu}\,\bar{\tau})\binom{t}{b} \to \bar{\tau} b$

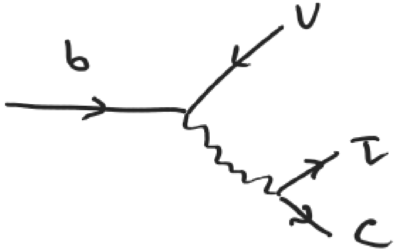


$(3,2)_{7/6} \to C_{S_L}, C_T$

- <u>color triplet</u> (Leptoquark)



$(3,2)_{-5/3} \to C_{S_R}$



?

$(3,1)_{-1/3} \to C_{V_L}, C_{S_L}, C_T$

or $(3,3)_{-1/3} \to C_{V_L}$

More

Because there is $SU(2)_L$

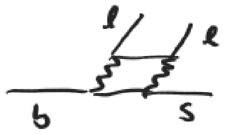
if NP affects $c \in \begin{pmatrix} c \\ s \end{pmatrix} \Rightarrow$ will also affect $s \in \begin{pmatrix} c \\ s \end{pmatrix}$

e.g. $b \to s \bar{\nu} \nu$, $b \to s \tau \tau$

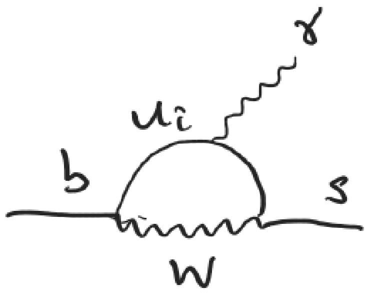
$B_s - \bar{B}_s$ mixing

$b \to s\ell\ell$, $b \to s\nu\nu$, $b \to s\gamma$

SM :



$\sim O_9, O_{10}$



$$\mathcal{H}_{b\to s\ell\ell} = -\frac{4G_F}{\sqrt{2}} V_{tb}V_{ts}^* \Big[C_9 O_9 + C_9' O_9' + C_{10} O_{10} + C_{10}' O_{10}' + C_S O_S + C_S' O_S' + C_P O_P + C_P' O_P' + C_T O_T + C_{TS} O_{TS} \Big]$$

$$\mathcal{H}_{b\to s\gamma} = -\frac{4G_F}{\sqrt{2}} V_{tb}V_{ts}^* C_7 O_7$$

$$O_7 = \frac{e}{16\pi^2} m_b (\bar{s}\gamma^\mu P_L \sigma^{\mu\nu} b) F_{\mu\nu}$$

$$O_9^{(\prime)} = \frac{\alpha}{4\pi}(\bar{s}\gamma^\mu P_{L(R)} b)(\bar{\ell}\gamma_\mu \ell) , \quad O_{10}^{(\prime)} = \frac{\alpha}{4\pi}(\bar{s}\gamma^\mu P_{L(R)} b)(\bar{\ell}\gamma_\mu\gamma^5 \ell)$$

$$O_S^{(\prime)} = \frac{\alpha}{4\pi}(\bar{s} P_{L(R)} b)(\bar{\ell}\ell) , \quad O_P^{(\prime)} = \frac{\alpha}{4\pi}(\bar{s} P_{L(R)} b)(\bar{\ell}\gamma^5\ell)$$

$$O_{T(TS)} = \frac{\alpha}{4\pi}(\bar{s}\sigma_{\mu\nu} b)(\bar{\ell}\sigma^{\mu\nu}\gamma^5\ell)$$

This will also contributes to $b \to s\ell\ell$ (?)