Embedding the Universal See-Saw Mechanism in Pati-Salam Model

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Pati-Salam Gauge Group

- The model is based on the gauge group defined as

$$SU(4)_C \times SU(2)_L \times SU(2)_R$$

(J.C.Pati, A.Salam,1973)

- The electric charge generator is given by

$$Q = T_{3L} + T_{3R} + \frac{B-L}{2}$$

- This gauge group extends the Standard Model (SM) by identifying the $SU(3)$ color group as a subgroup of $SU(4)$ and treating the lepton number as the fourth color.

$$4 \rightarrow 3_{\frac{1}{3}} \oplus 1_{-1}$$

Attractive Features

- Quark-lepton unification through $SU(4)_c$.
- Quantization of electric charge leading to $Q_p + Q_e = 0$.
- The electroweak sector extends to be left-right (LR) symmetric.
- Existence of right-handed neutrinos.
- It treats $B - L$ as local gauge symmetry and gauge interaction itself conserves $B - L$ and fermion number.
- The absence of proton decay mediating processes opens the window to realize the symmetry at a low scale.
- A stepping stone to higher unification such as $SO(10), E_6, SU(16)$ etc.

Particle Spectrum

- SM fermion spectrum (including right-handed neutrino)

$$Q_L^{i=1} = \begin{pmatrix} u_r & u_g & u_b & \nu_e \\ d_r & d_g & d_b & e \end{pmatrix}_L \sim (4,2,1);$$

$$Q_R^{i=1} = \begin{pmatrix} u_r & u_g & u_b & \nu_e \\ d_r & d_g & d_b & e \end{pmatrix}_R \sim (4,1,2)$$

- The simple Higgs sector comprises only left- and right-handed doublets of $SU(2)$.

$$\chi_L = \begin{pmatrix} \chi_u^r & \chi_u^b & \chi_u^g & \chi_\nu \\ \chi_d^r & \chi_d^b & \chi_d^g & \chi_e \end{pmatrix}_L \sim (4,2,1);$$

$$\chi_R = \begin{pmatrix} \chi_u^r & \chi_u^b & \chi_u^g & \chi_\nu \\ \chi_d^r & \chi_d^b & \chi_d^g & \chi_e \end{pmatrix}_R \sim (4,1,2);$$

Potential

- The general Higgs potential is given by:

$$V = -\mu_L^2 \mathrm{Tr}(\chi_L^\dagger \chi_L) - \mu_R^2 \mathrm{Tr}(\chi_R^\dagger \chi_R) + \lambda_0[(\mathrm{Tr}(\chi_L^\dagger \chi_L))^2 + (\mathrm{Tr}(\chi_R^\dagger \chi_R))^2]+ \\ \lambda_1[\mathrm{Tr}(\chi_L^\dagger \chi_L \chi_L^\dagger \chi_L) + \mathrm{Tr}(\chi_R^\dagger \chi_R \chi_R^\dagger \chi_R)] + \lambda_2 \mathrm{Tr}(\chi_L^\dagger \chi_L)\mathrm{Tr}(\chi_R^\dagger \chi_R)+ \\ \lambda_3 \mathrm{Tr}(\chi_L^\dagger \chi_L \chi_R^\dagger \chi_R) + \lambda_4(\mathrm{Tr}(\chi_L^T \tilde{\chi}_L^* \chi_R^\dagger \tilde{\chi}_R) + \mathrm{h.c.}).$$

- V invariant with respect to parity operation, except for the scalar mass terms for $\chi_{L/R}$ which breaks the symmetry softly.
- No CP-violating term is arising from the Higgs sector.
- $\epsilon_{\alpha\beta\gamma\delta}\ \epsilon_{ab}\epsilon_{cd}\ \chi_L^{\alpha a}\chi_L^{\beta b}\chi_R^{\gamma c}\chi_R^{\delta d}$ term will be there. This type of pfaffian structure leads to neutron oscillation $(\Delta B = 2)$ but doesn't play a role in the mass spectrum of physical Higgs.

Higgs Mass Mixing Matrix

- **Two Neutral Higgs:** The mixing matrix between $\sigma_L \equiv \mathrm{Re}(\chi_{\nu L})$ and $\sigma_R \equiv \mathrm{Re}(\chi_{\nu R})$:

$$M^2_{\text{neutral}} = \begin{pmatrix} 2(\lambda_0+\lambda_1)\kappa_L^2 & (\lambda_2+\lambda_3)\kappa_L\kappa_R \\ (\lambda_2+\lambda_3)\kappa_L\kappa_R & 2(\lambda_0+\lambda_1)\kappa_R^2 \end{pmatrix} .$$

- **Six up-type Higgs**: The mixing matrix between χ^i_{uL} and χ^i_{uR}:

$$M^2_{\text{up}} = \frac{1}{2}\begin{pmatrix} -\lambda_3\kappa_R^2 & \lambda_3\kappa_L\kappa_R \\ \lambda_3\kappa_L\kappa_R & -\lambda_3\kappa_L^2 \end{pmatrix},$$

with $M^2_{Hu1} = -\dfrac{1}{2}\lambda_3(\kappa_L^2+\kappa_R^2)$ and $M^2_{Hu2} = 0$.

- **Twelve down-type Higgs:** The mixing matrix between χ^i_{dL} and χ^i_{dR}:

$$M^2_{\text{down}} = \begin{pmatrix} -\lambda_1\kappa_L^2 - \frac{1}{2}\lambda_3\kappa_R^2 & -\lambda_4\kappa_L\kappa_R \\ -\lambda_4\kappa_L\kappa_R & -\lambda_1\kappa_R^2 - \frac{1}{2}\lambda_3\kappa_L^2 \end{pmatrix}.$$

Charged Gauge Boson Masses

- The gauged Higgs sector Lagrangian, without the scalar potential, is simply:

$$\mathcal{L} = (D_\mu \chi_L)^\dagger (D_\mu \chi_L) + (D_\mu \chi_R)^\dagger (D_\mu \chi_R)$$

- We get 12 massive gauge bosons which is equal to the number of broken generators

$$SU(4)_C \times SU(2)_L \times SU(2)_R \to SU(3) \times U(1)_{\text{EM}}$$

- The charged gauge bosons don't mix at tree level and their masses are:

$$m^2_{W_L^{\mu\pm}} = \frac{1}{4} g_L^2 \kappa_L^2 \ ,$$
$$m^2_{W_R^{\mu\pm}} = \frac{1}{4} g_R^2 \kappa_R^2 \ ,$$
$$m^2_{Y^{\mu\pm}_{i=1,2,3}} = \frac{1}{4} g_4^2 (\kappa_L^2 + \kappa_R^2) \ .$$

Neutral Gauge Boson Mixing

- The mass part of the Lagrangian is:

$$\mathcal{L}^{Neutral}_{mass} = \frac{1}{8} \begin{pmatrix} W^0_{\mu L} & W^0_{\mu R} & G_{\mu 15} \end{pmatrix} \; M_0^2 \; \begin{pmatrix} W^{\mu 0}_L \\ W^{\mu 0}_R \\ G^{\mu 15} \end{pmatrix}.$$

where the mass matrix square is given by

$$\begin{pmatrix} g_L^2 \kappa_L^2 & 0 & -\sqrt{\frac{3}{2}} g_4 g_L \kappa_L^2 \\ 0 & g_R^2 \kappa_R^2 & -\sqrt{\frac{3}{2}} g_4 g_R \kappa_R^2 \\ -\sqrt{\frac{3}{2}} g_4 g_L \kappa_L^2 & -\sqrt{\frac{3}{2}} g_4 g_R \kappa_R^2 & \frac{3}{2} g_4^2 (\kappa_L^2 + \kappa_R^2) \end{pmatrix}.$$

Neutral Gauge Boson Mixing (Continued)

- Matching condition:

$$\frac{1}{e^2} = \frac{1}{g_L^2} + \frac{1}{g_R^2} + \frac{2}{3g_4^2}.$$

- After decoupling the photon, the massive gauge boson mixing matrix looks like:

$$M^2_{Z_L - Z_R} = \frac{1}{4} \begin{pmatrix} (g_Y^2 + g_L^2)\,\kappa_L^2 & g_Y^2 \sqrt{\frac{g_Y^2 + g_L^2}{g_R^2 - g_Y^2}}\,\kappa_L^2 \\ g_Y^2 \sqrt{\frac{g_Y^2 + g_L^2}{g_R^2 - g_Y^2}}\,\kappa_L^2 & \frac{g_Y^4}{g_R^2 - g_Y^2}\,\kappa_L^2 + \frac{g_R^4}{g_R^2 - g_Y^2}\,\kappa_R^2 \end{pmatrix}.$$

- The mixing angle β given approximately by

$$\beta \simeq \frac{g_Y^2}{g_R^4} \sqrt{(g_L^2 + g_Y^2)(g_R^2 - g_Y^2)}\, \frac{\kappa_L^2}{\kappa_R^2}.$$

Realizing Universal Seesaw Mechanism

- We see, at this point, no Yukawa couplings are allowed.
- That motivates us to introduce $SU(4)_C$ charged vector-like fermions to give consistent mass to fermions and help realize the Universal Seesaw mechanism in this model.

$$\Psi^i_{10}(10,1,1) \rightarrow \Omega(6_{1/3}) \oplus D(3_{-\frac{1}{3}}) \oplus E(1_{-1}).$$

Both handedness $((10,1,1) \oplus (\overline{10},1,1))$ are required for mass generation which helps in anomaly cancellation as well.

- And we have the adjoint representation as well:

$$\Psi^i_{15}(15,1,1) \rightarrow \Sigma(8_0) \oplus U(3_{\frac{2}{3}}) \oplus \bar{U}(\bar{3}_{-\frac{2}{3}}) \oplus N(1_0).$$

where i runs on three generations of fermions.

Charged Fermion Mass Matrices

- The Yukawa Lagrangian gives 6×6 mass matrices for up-type quarks (u, U), down-type quarks (d, D) and charged leptons (e, E). With parity symmetry:

$$M_u = \begin{pmatrix} 0 & y_{15}\kappa_L \\ y_{15}^\dagger \kappa_R & M_{15} \end{pmatrix}$$

$$M_d = \begin{pmatrix} 0 & y_{10}\kappa_L \\ y_{10}^\dagger \kappa_R & M_{10} \end{pmatrix}$$

$$M_e = \begin{pmatrix} 0 & \sqrt{2} y_{10}\kappa_L \\ \sqrt{2} y_{10}^\dagger \kappa_R & M_{10} \end{pmatrix}$$

- The overall non-degeneracy factor in the down and electron sector may not have the necessary flexibility to generate masses accurately for all three generations.

Correct Mass Hierarchy For All Generations

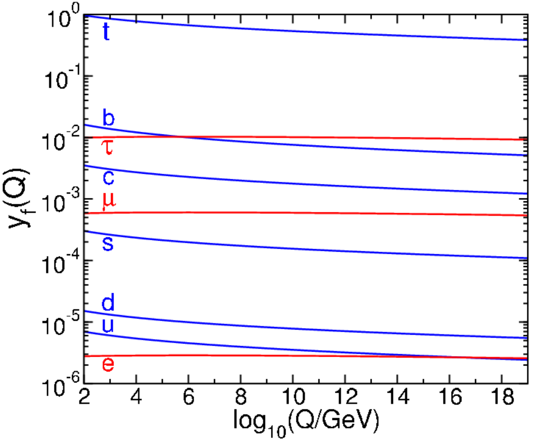


Figure: Standard model parameters in the tadpole-free pure $\overline{MS}$ scheme.

(S.P.Martin, D.G.Robertson, 2019)

Finite Radiative Corrections To The Seesaw Mechanism

- The Seesaw mass matrix:

$$M_f = \begin{pmatrix} 0 & y_f\,\kappa_L \\ y_f^\dagger\,\kappa_R & M_F \end{pmatrix} ,$$

- One-loop contribution can be decomposed as

$$(\delta M)_{\text{1-loop}} = \begin{pmatrix} \delta M_{LL} & \delta M_{LH} \\ \delta M_{HL} & \delta M_{HH} \end{pmatrix}$$

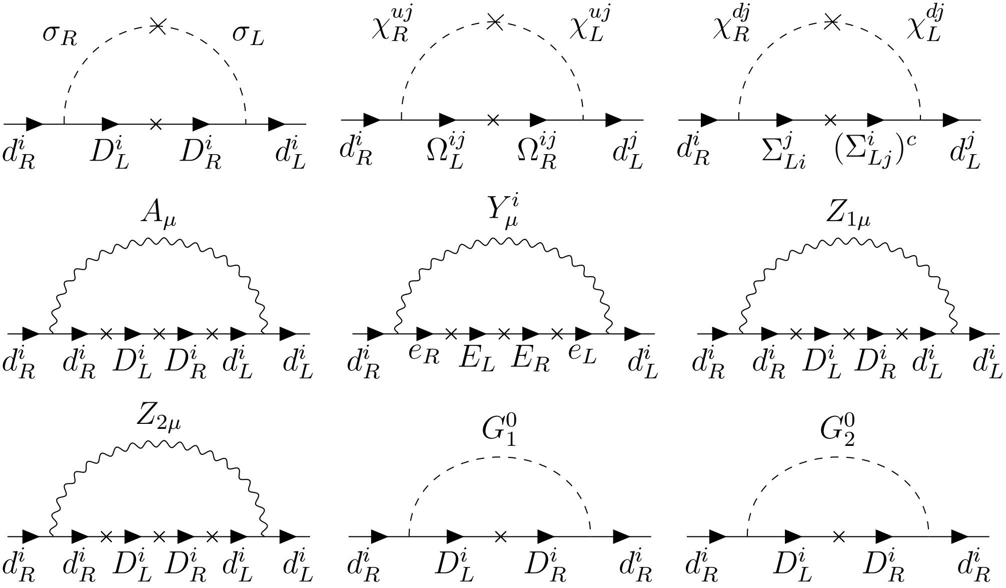
- Effective light fermion mass matrix, up to one-loop order:

$$m_f^{\text{light}} \simeq -y_f M_F^{-1} y_f^\dagger \kappa_L \kappa_R + \delta M_{LL} - \delta M_{LH} M_F^{-1} y_f^\dagger \kappa_R - y_f \kappa_L M_F^{-1} \delta M_{HL} + y_f \kappa_L M_F^{-1} \delta M_{HH} M_F^{-1} y_f^\dagger \kappa_R$$

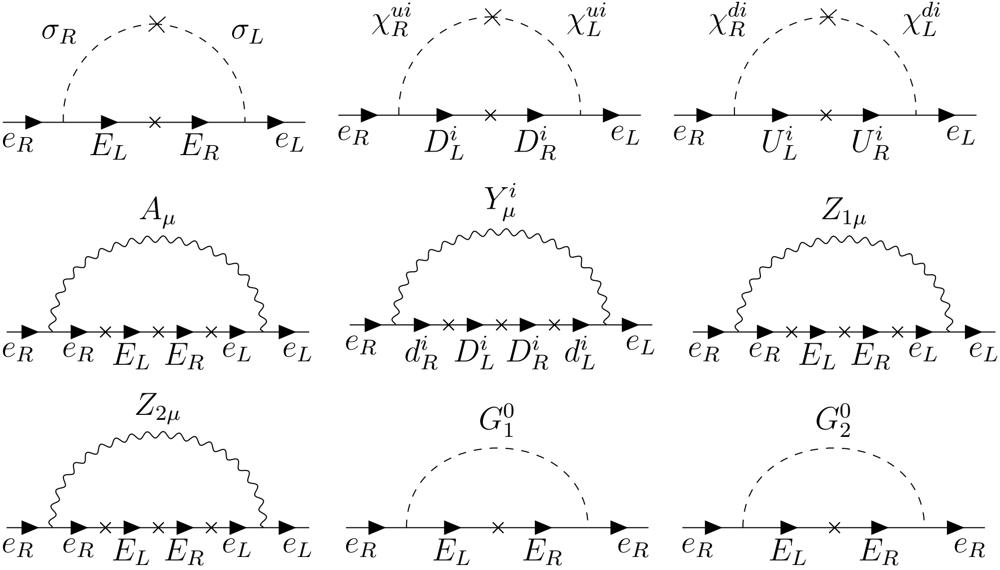
- In a renormalizable theory, δM_{LL} has to be finite and gauge independent through radiative corrections since no counter-term is associated.

(Gerard 't Hooft, 1971.)

One-Loop Corrections To Light Down-Quark Mass

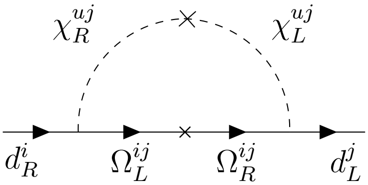


One-Loop Corrections To Light Electron Mass



Example With One Diagram

- Unlike charged lepton, the down sector can get one-loop radiative mass corrections through heavy sextet and up-type Higgs.



$$m_d^i \sim \frac{2y_{10}^2 M_{10}^i \sin\theta\ \cos\theta}{(4\pi)^2}\left[\frac{M_{Hu1}^2}{(M_{10}^i)^2 - M_{Hu1}^2}\ln\left(\frac{(M_{10}^i)^2}{M_{Hu1}^2}\right) - \frac{M_Y^2}{(M_{10}^i)^2 - M_Y^2}\ln\left(\frac{(M_{10}^i)^2}{M_Y^2}\right)\right]$$

- Hierarchy in bare mass terms can give rise to hierarchical radiative corrections throughout the three generations.

Neutrino Mass Matrix

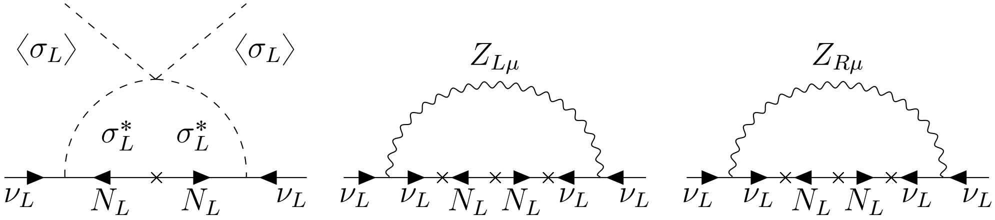
- The Lagrangian gives 9×9 mass matrix for neutrinos.

$$\mathcal{L}_{\nu N} \supset \frac{1}{2}\ \overline{F^{\nu}_{L}} \begin{pmatrix} 0 & 0 & -\frac{3}{2\sqrt{6}} y_{15}\kappa_L \\ 0 & 0 & -\frac{3}{2\sqrt{6}} y_{15}\kappa_R \\ -\frac{3}{2\sqrt{6}} y^T_{15}\kappa_L & -\frac{3}{2\sqrt{6}} y^T_{15}\kappa_R & M_{15} \end{pmatrix} F^{\nu}_{R}$$

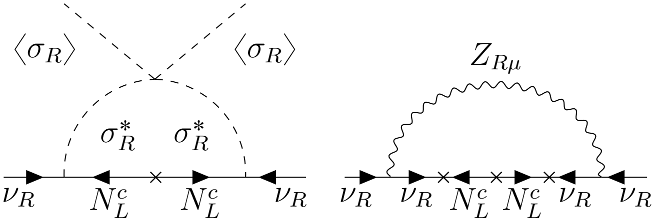
- The basis is written in $F^{\nu}_{L} \equiv (\nu_L, \nu^c_R, N_L), \quad F^{\nu}_{R} \equiv (\nu^c_L, \nu_R, N^c_L)$
- This mass matrix leads to the lightest neutrino being massless.
- In our case, neutrinos will get Dirac and Majorana mass contributions at one loop.

Radiative Majorana Mass Through One-Loop Correction

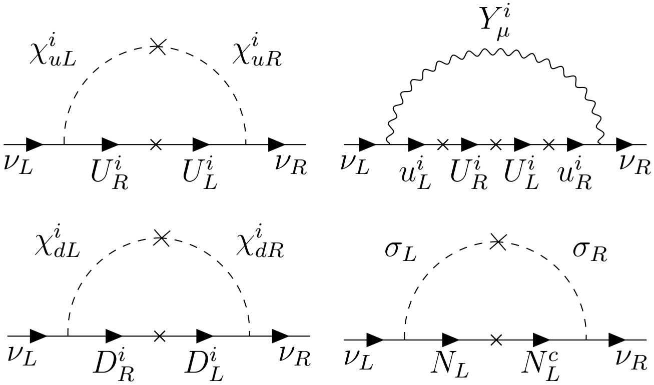
- (1,1) block:



- (2,2) block:



Radiative Dirac Mass Through One-Loop Correction



$$(m_\nu^D)^i_{1+2} = \frac{3y_{15}^2 M_{15}^i \sin\theta\ \cos\theta}{16\pi^2}\left[\frac{M^2_{Hu1}}{(M^i_{15})^2 - M^2_{Hu1}}\ln\left(\frac{(M^i_{15})^2}{M^2_{Hu1}}\right) - \frac{M_Y^2}{(M^i_{15})^2 - M_Y^2}\ln\left(\frac{(M^i_{15})^2}{M_Y^2}\right)\right] + \frac{3g_4^2 y_{15}^2 \kappa_L \kappa_R M^i_{15}}{16\pi^2}\left[\frac{(M^i_{15})^2}{(M^i_{15})^2 - M_Y^2}\ln\left(\frac{(M^i_{15})^2}{M_Y^2}\right)\right]$$

Lightest Neutrino Mass

Now the mass matrix looks like this:

$$\mathcal{L}_{\nu N} \supset \frac{1}{2}\,\overline{F_L^\nu}\begin{pmatrix} m_L & m_\nu^D & -\frac{3}{2\sqrt{6}}y_{15}\kappa_L \\ (m_\nu^D)^T & m_R & -\frac{3}{2\sqrt{6}}y_{15}\kappa_R \\ -\frac{3}{2\sqrt{6}}y_{15}^T\kappa_L & -\frac{3}{2\sqrt{6}}y_{15}^T\kappa_R & M_{15}\end{pmatrix}F_R^\nu$$

The lightest neutrino mass:

$$M_\nu^\ell \approx -m_L + \begin{pmatrix} m_\nu^D & -\frac{3}{2\sqrt{6}}y_{15}\kappa_L\end{pmatrix}\begin{pmatrix} m_R & -\frac{3}{2\sqrt{6}}y_{15}\kappa_R \\ -\frac{3}{2\sqrt{6}}y_{15}^T\kappa_R & M_{15}\end{pmatrix}^{-1}\begin{pmatrix}(m_\nu^D)^T \\ -\frac{3}{2\sqrt{6}}y_{15}^T\kappa_L\end{pmatrix}$$

$$\approx \frac{\kappa_L}{\kappa_R}\left(m_\nu^D + (m_\nu^D)^T\right) + \frac{\kappa_L^2}{\kappa_R^2}\,m_R - m_L$$

The Strong CP Problem

- The Strong CP Problem is related to the presence of this term in Lagrangian (a consequence of non-perturbative effects):

$$\mathcal{L}_\theta = \theta \frac{g_s^2}{32\pi^2} G^a_{\mu\nu} \tilde{G}^{a\mu\nu}$$

- Violates P and T but conserves C, so it violates CP.

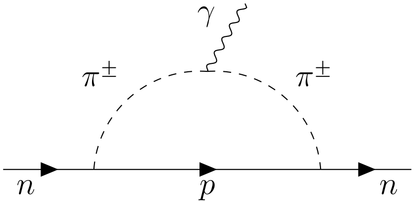
(J.Schwinger, 1951)

- θ carries the information of CP violation in strong interactions.
- θ is shifted by the chiral transformation needed to diagonalize the quark mass matrix M.
- The invariant physical parameter $\bar{\theta}$ is

$$\bar{\theta} = \theta + \text{ArgDet}(M_Q)$$

Constraints on $\bar{\theta}$ from Neutron EDM

- The Feynman diagram giving the leading-order contribution to the neutron EDM



$$d_n \simeq \frac{e\,\bar{\theta}\,g_A\,c_+\,\mu}{8\pi^2 f_\pi^2} \log\left(\frac{\Lambda^2}{m_\pi^2}\right) \simeq 3\times 10^{-16}\bar{\theta}\,e\,cm$$

$$\mu = \frac{m_u m_d}{m_u + m_d}, g_A \simeq 1.27, c_+ \simeq 1.6, \Lambda = 4\pi f_\pi$$

(A.Hook,2018)

- Experimental bound, $d_n < 10^{-26}$e cm$\Longrightarrow \bar{\theta} < 10^{-10}$

(C.Abel et al.2020)

- Extreme smallness in this dimensionless parameter $\bar{\theta}$, is the strong CP problem.

$\bar{\theta}$ At The Tree Level

$$\bar{\theta} = \theta + \mathrm{ArgDet}(M_u M_d) + 5\ \mathrm{ArgDet}(M_{\text{sextet}}) + 6\ \mathrm{ArgDet}(M_{\text{octet}})$$

$$M_u = \begin{pmatrix} 0 & y_{15}\kappa_L \\ y_{15}^{\dagger}\kappa_R & M_{15} \end{pmatrix}; \qquad M_d = \begin{pmatrix} 0 & y_{10}\kappa_L \\ y_{10}^{\dagger}\kappa_R & M_{10} \end{pmatrix}$$

- Anomaly coefficients are different for different representations of $SU(3)_C$
- It is clear that $\mathrm{Det}(M_u)$ and $\mathrm{Det}(M_d)$ are separately real.
- $M_{\text{sextet}} \equiv M_{10}$ and $M_{\text{octet}} \equiv M_{15}$ are the hermitian bare mass matrices realized in left-right symmetric Lagrangian. Parity is only softly broken in dimension 2 terms.
- Therefore, we have $\bar{\theta}$=0 at the tree level.

$\bar{\theta}$ At The One-Loop For Up- And Down-type Quark

- We choose to work on the weak basis rather than the mass eigenstate.
- Radiatively corrected quark ($q = u, d$) mass matrix:

$$M^q = M_0^q(1 + C).$$

- So $\bar{\theta}$ can be expressed as

$$\bar{\theta} = \mathrm{ArgDet}(1 + C) = \mathrm{ImTr}\ln(1 + C) = \mathrm{ImTr}C_1 + \mathrm{ImTr}(C_2 - \tfrac{1}{2}C_1^2) + \ldots$$

Using the loop expansion: $C = C_1 + C_2 + C_3 + ..$

- The correction matrix for up- and down-type quark can be denoted by

$$\delta M^q = \begin{pmatrix} \delta M^q_{LL} & \delta M^q_{LH} \\ \delta M^q_{HL} & \delta M^q_{HH} \end{pmatrix}$$

$\bar{\theta}$ At The One-Loop Level(continued)

- Elements of correction matrix enter into $\bar{\theta}$ in the following manner

$$\bar{\theta} = \mathrm{Im}\mathrm{Tr}[-\left(\frac{1}{\kappa_L \kappa_R}\right)\delta M^q_{LL}(y_q^\dagger)^{-1} M_P y_q^{-1} +$$

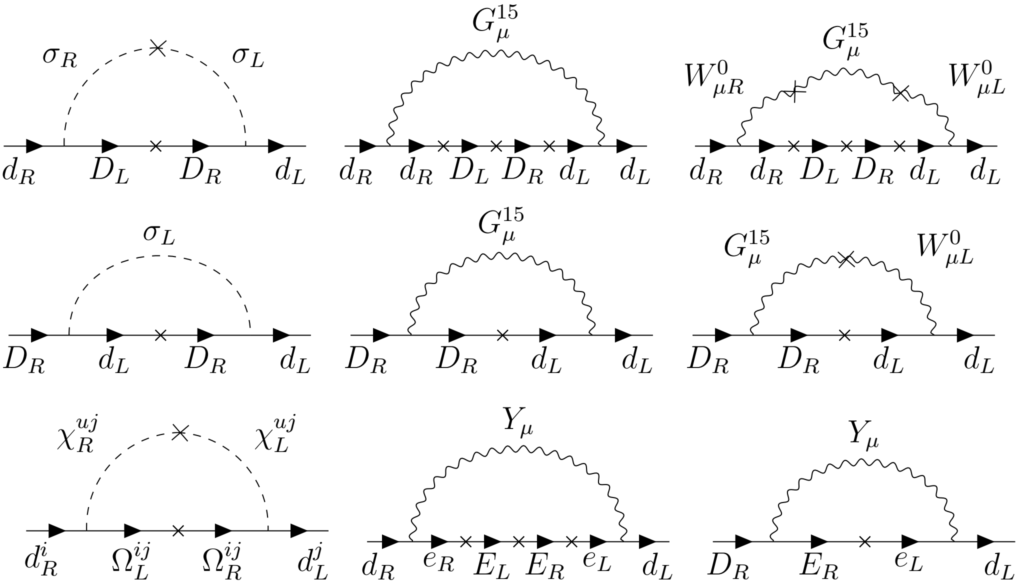
$$\left(\frac{1}{\kappa_L}\right)\delta M^q_{LH} y_q^{-1} + \left(\frac{1}{\kappa_R}\right)\delta M^q_{HL}(y_q^\dagger)^{-1}]$$

where $y_q = y_{15}(y_{10})$ and $M_P = M_{15}(M_{10})$ is for up (down) quark.

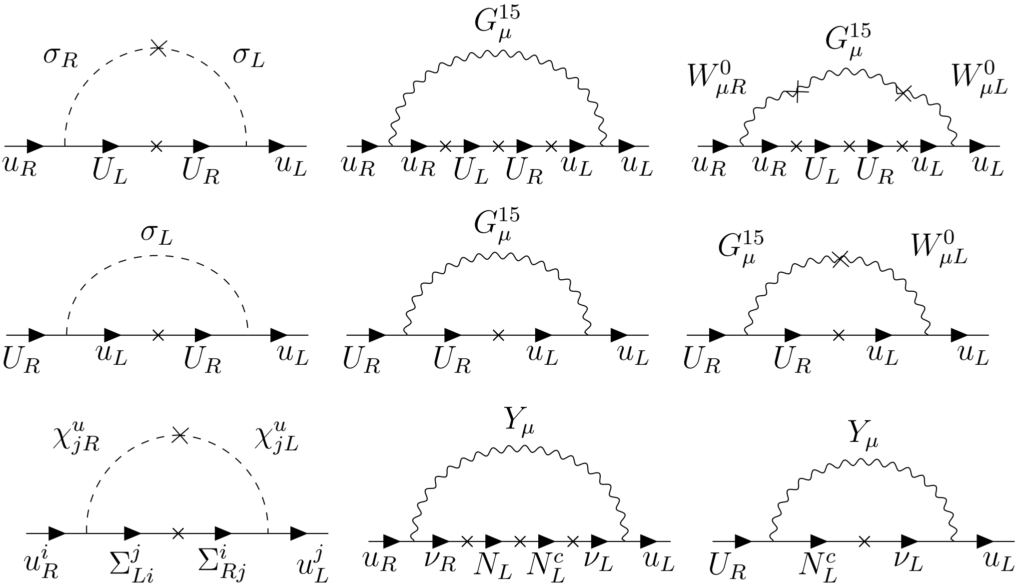
(K.S.Babu, R.N.Mohapatra,1989)

- δM^q_{HH} doesn't enter into the equation for $\bar{\theta}$. That means we need not compute one-loop correction to vector-like quark mass.

One-Loop Correction For Down Quark Mass



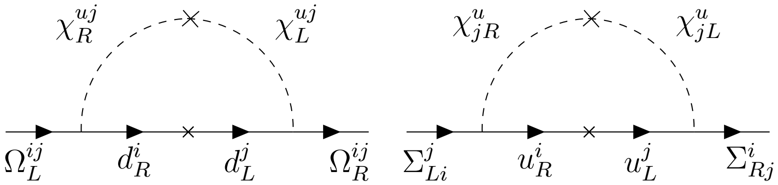
One-Loop Correction For Up Quark Mass



One-Loop Correction For Sextet and Octet Mass

- The induced $\bar{\theta}$ can be written considering upto one-loop:

$$\bar{\theta} = \text{Im Tr}[M_{10}^{-1}(\delta M_{\Omega})] + \text{Im Tr}[M_{15}^{-1}(\delta M_{\Sigma})]$$



Correction To The Propagator Line

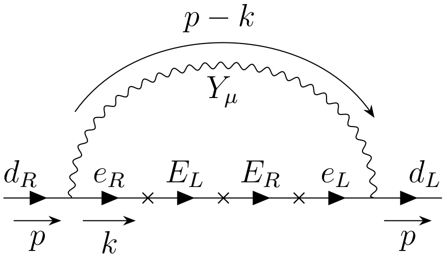
- Since we are treating mass as a part of the interaction, the cross on the fermion/boson line stands for all possible tree-level diagrams.
- Propagator with all possible mass insertion can be written as:

$$\overline{F_R}\left((M_F^0)^\dagger \frac{k^2}{k^2 - M_F^0 (M_F^0)^\dagger}\right) F_L$$

- Unique features of having Quark-lepton unification: Corrections coming from the SM lepton, sextet, and octet lines as well.
- $F^{\text{up}}_{L/R} \equiv (u, U)_{L/R}, \quad F^{\text{down}}_{L/R} \equiv (d, D)_{L/R}, \quad F^{\text{e}}_{L/R} \equiv (e, E)_{L/R}, \quad F^{\Omega}_{L/R} \equiv \Omega_{L/R}$
- $F^{\nu}_{L} \equiv (\nu_L, \nu_R^c, N_L), \quad F^{\nu}_{R} \equiv (\nu_L^c, \nu_R, N_L^c), \quad F^{\Sigma}_{L/R} \equiv \Sigma_L/\Sigma_L^C$

Example With Electron Propagator Line Correction

- Each diagram separately gives zero contribution to $\bar{\theta}$



- The amplitude with leptoquark in the loop is proportional to

$$\delta M^d_{LL} \supset \int \frac{d^4k}{(2\pi)^4} \left(\frac{g_4}{\sqrt{2}}\right)^2 \left(g_{\mu\nu} - \frac{(p-k)_\mu (p-k)_\nu}{M_Y^2}\right) \frac{\left((M_e^0)^\dagger \frac{k^2}{k^2 - M_e^0 (M_e^0)^\dagger}\right)}{(p-k)^2 - M_Y^2 + i\epsilon}$$

Electron Propagator Line Correction(continued)

- It's contribution to $\bar{\theta}$:

$$\mathrm{Im}\mathrm{Tr}\left[-\left(\frac{1}{\kappa_L \kappa_R}\right)\delta M^d_{LL}(y^\dagger_{10})^{-1} M_{10} y^{-1}_{10}\right]$$

- We can evaluate the trace before momentum integration.
- Expanding $(M^0_e(M^0_e)^\dagger - k^2)^{-1}$:

$$(M^0_e(M^0_e)^\dagger - k^2)^{-1} \equiv \begin{pmatrix} A_e(k^2) & B_e(k^2) \\ B^\dagger_e(k^2) & C_e(k^2) \end{pmatrix}$$

with $A_e = A^\dagger_e$, $C_e = C^\dagger_e$ and B_e are 3×3 block matrices

Electron Propagator Line Correction(continued)

- The term related to $\overline{e_L} e_R$ from $\left((M_e^0)^\dagger \frac{k^2}{k^2 - M_e^0 (M_e^0)^\dagger} \right)$ expansion:

$$\delta M_{LL}^d \supset k^2 \kappa_R B_e(k^2) y_{15}^\dagger$$

- So, the contribution to $\bar{\theta}$:

$$\begin{aligned}\bar{\theta} &\sim \mathrm{Im}\mathrm{Tr}\left[B_e(k^2) y_{10}^\dagger (y_{10}^\dagger)^{-1} M_{10} y_{10}^{-1} \right] \\ &= \mathrm{Im}\mathrm{Tr}\left[\left(\kappa_L^2 y_{10}^\dagger y_{10} - k^2 \right)^{-1} (M_{10})^\dagger C_e \left(k^2\right) M_{10} \right] = 0\end{aligned}$$

with C_e being hermitian.

Concluding Remarks

- This setup has the potential to solve the strong CP problem via parity along with some other appropriate symmetry.
- Fermion masses are generated by mixing usual fermions with vector-like fermions belonging to the "Universal Seesaw" class.

  (A Davidson, KC Wali,1987)
- All generation fermion mass can be realized through the one-loop radiative corrections.
- Lightest neutrino acquires Majorana and Dirac mass contribution at one-loop level.

Thank you