LEFT-RIGHT GAUGE SYMMETRY AND AN ISO-CONGUGATE MODEL OF CP VIOLATION

Rabindra Mohapatra & JCP (Phys. Rev. 1974)

$$G = SU(2)_L \times SU(2)_R \times U(1)_{B-L} \times SU(3)^C$$
$$\text{or}$$
$$= SU(2)_L \times SU(2)_R \times SU(4)^C$$

2 families $\left[\begin{pmatrix} u \\ d \end{pmatrix}_{L,R} + \begin{pmatrix} \nu_e \\ e \end{pmatrix}_{L,R}\right]$, $W_L \leftrightarrow W_R$, $g_L = g_R$;
+ one Higgs ~ (2,2,1,1)

Mohapatra, JCP (Phys. Rev, 1973) showed, Any Model

Satisfying $[I_3, P^{(-)}] = i\xi(\sin\delta) P^{(+)}$ → "ISO-CONJUGATE"

$\eta_{+-} = \eta_{00}$, Phase $\phi_{+-} \approx \tan^{-1}\left(2\frac{\Delta m}{\Gamma_S}\right)$

Holds exptly ✓

$K_L = (|K_2\rangle + \epsilon|K_1\rangle)/\sqrt{1+|\epsilon|^2}$; $K_S = (|K_1\rangle + \epsilon|K_2\rangle)/\sqrt{1+|\epsilon|^2}$

$$\eta_{ij} \equiv \frac{\langle \pi^i \pi^j | T | K_L \rangle}{\langle \pi^i \pi^j | T | K_S \rangle} \; ; \quad (i,j) = (+,-) \text{ or } (0,0)$$

$$\eta_{+-} = \epsilon + \epsilon'$$
$$\eta_{00} = \epsilon - 2\epsilon'$$

What we found is that the L-R Model Satisfies the Iso-Conj. Reln. with the CP-Violating parameter ϵ given by

$$|\epsilon| \approx (m_{W_L}/m_{W_R})^2 \cdot |\sin\delta| \quad \text{For } g_L = g_R$$

A Beautiful Reln, ϵ (CP-Viol) $\to 0$ as $m_{W_R} \to \infty$ (i.e. Parity Viol becomes maximal!)

CP Violation $\longleftrightarrow$ Parity Violation

Observed $K_1 - K_2$ mass-diff $\Rightarrow$

Beall, Bender & Soni (1982)

$$(m_{W_L}/m_{W_R})^2 < \frac{1}{430} \quad (\text{i.e. } m_{W_R} > 1.6\,\text{TeV})$$

But m_{W_R} can't be much heavier than 1.6 TeV for the L-R model to explain observed CPV because $|\epsilon| \approx 2.27 \times 10^{-3}$ (even with $\sin\delta \sim 1$)

$\Downarrow$

Turns out the model of CPV based on L-R Symm differs from SuperWeak (Wolfenstein) & KM model by $d_n^e \approx 10^{-26}$ e cm

I was quite hopeful that this model of CPV may well turn out to be right

$\Rightarrow$ **W_R should be discovered in the near future & also $(edm)_n$.**

Alas, Nature turned it down. The KM model based on SU(2)×U(1), one Higgs doublet & 3 families is now established by expts over the years.

How come?

$\Downarrow$

Have an answer for myself. Perhaps nature has an even prettier picture in mind which conflicts with the L-R model of CPV by Rabi & me, not as regards the idea of L-R Symmetry, but with (that of) relatively light W_R.

$\Rightarrow$ The picture of a GUT-Scale W_R with an underlying (SUSY) SO(10) or a string-derived $SU(2)_L \times SU(2)_R \times SU(4)^C$ → Gauge Coupling Unif + Predictive Weak angle + Higgs-Mass Naturalness + JUST THE RIGHT SCALE For ν-OSC. is VERY PRETTY

Perhaps Continuing Searches for SUSY at the upgraded LHC & that for p-decay at DUNE & HyperK will shed some light on this question.

That said, I keep an open mind & encourage searches for W_R, Z' etc at LHC.

I should add, while Nature has turned down the L-R model of CPV by Rabi & me, I still think highly of that paper & Rabi played the essential role in the development of that paper.

Since the 1970's Rabi has gone on to make some major contributions to our field over the last 5 decades, which have strong impact on the growth of theory & experiments. I will indicate by listing only some of his contribs:

(1) Feynman rules For The Yang-Mills Field - Canonical Quantization → 3 Papers

2. A major player in the growth of the idea of L-R Symmetry (with me, Senjanovic & many others)

3. Parity as the Soln. To Strong CP Problem, with (Senjanovic // Raisin // Babu // Datta & others)
→ To me, an attractive and viable soln. to the strong CP Problem.

4. ν Physics - See Saw (With Senjanovic // Among Many Others)

5. $n-\bar{n}$ Oscillation → With Marshak (// Babu //) & Many others → The major player in building viable models to confront with expts (Kamyshkov).

Rabi's Contribs (Contd.)

A Very Simple observation: In L-R or G(2,2,4) models: $Q_{em} = I_{3L} + I_{3R} + \frac{B-L}{2}$

$\Delta Q_{em} = 0$; I_{3L} Conserved upto EW scale $\rightarrow \Delta I_{3L} \simeq 0$

$\Rightarrow \quad \Delta I_{3R} = -\Delta\left(\frac{B-L}{2}\right)$

For High Energy Physics $\gg m_W$

For $\langle \text{Higgs} \rangle \sim \langle (1, 3_R, \bar{10}_c) \rangle$ under G(2,2,4)

$\Rightarrow \Delta I_{3R} = \pm 1 \Rightarrow \Delta(B-L) = \mp 2$

$\Rightarrow$ (a) $\Delta L = 0 \Rightarrow |\Delta B| = 2 \rightarrow n\text{-}\bar{n}$ OSC

(b) $\Delta B = 0 \Rightarrow |\Delta L| = 2 \rightarrow$ ν-less 2β decays; ν_R Majorana mass

(c) $\Delta B = -1 \not\Rightarrow \Delta L = +1$, $n \rightarrow e^- \pi^+$

6. **Mirror World** $\rightarrow$ Neutron Stars – Gravity Waves $\rightarrow$ Signals/Bounds (With Nussinov // Babu // Goldman // Zhang.

7. Many more $\rightarrow$ Too many To list, but interesting!

In Short MOST PROLIFIC & VERSATILE

8. Goes to Rabi's credit that a large fraction of the audience of this meeting (including the virtual Zoom attendees) ~~is~~ consists of Rabi's collaborators, like myself, or Rabi's students, spread all over the world.