CP VIOLATION

FROM

DIMENSIONAL REDUCTION:

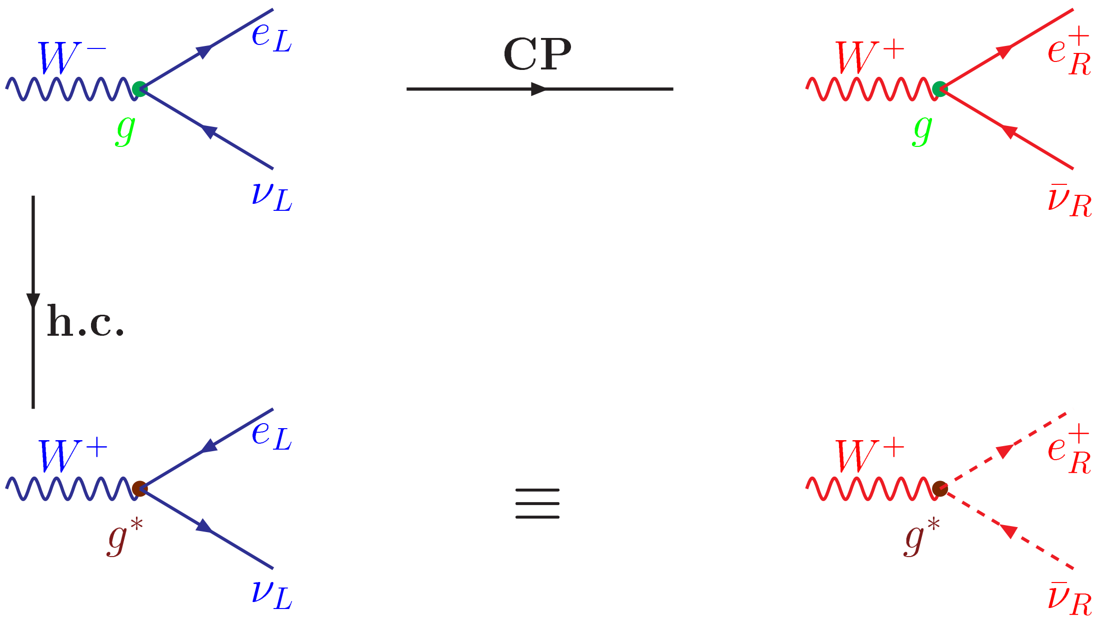
A SIMPLE EXAMPLE.

N.Cosme - J.M. Frère - L. Lopez Honorez.

Blois - June 2002.

Why?

1. CP NATURAL SYM. OF GAUGE INT.



2. $\not{C}P$ BY HAND IN THE SM

$$\lambda_{ij}\ \ \bar{u}_R^i\ \ \Phi^\dagger\ \ \begin{pmatrix} u \\ d \end{pmatrix}_L^j + h.c.$$

$\Rightarrow$ **arbitrary** $\lambda_{ij} \neq \lambda_{ij}^*$
induce $\not{C}P$ (CKM matrix).

If Yukawa is unified with gauge

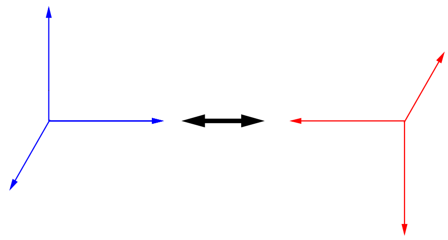
$\Rightarrow$ Need Dynamical $\not{C}P$ Mechanism.

P

d dimensions

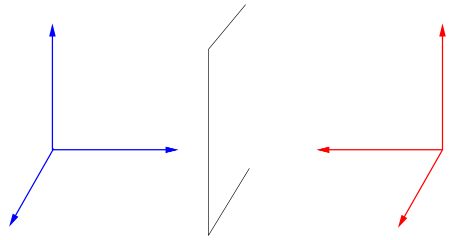
★ **$(d-1)$ odd:** e.g. (3+1)D

- $P_{(d-1)}: \vec{x} \rightarrow -\vec{x}$



$$|||$$

- $P_1 : x_1 \rightarrow -x_1, \qquad x_{2,3} \rightarrow x_{2,3}$



★ **$(d-1)$ even:**

- $P_{(d-1)} : \in \mathcal{L}_+^{\uparrow} \qquad det \begin{pmatrix} -1 & & & \\ & -1 & & \\ & & -1 & \\ & & & -1 \end{pmatrix} = 1$

$$\not\equiv$$

- P_1 : equivalent to $x_{d-1} \rightarrow -x_{d-1}$

Which one should we choose?

CP_1T ✓	$CP_{(d-1)}T$ ✗

4+1D SCALAR VIOLATES P

$P = P_1$ **&** M **real**

$(\gamma_\mu, \quad i\gamma_5)$ $A = 0, 1, 2, 3, (4 = y)$ **&** $\mu = 0, 1, 2, 3.$

	(4+1)D
• $\bar{\Psi} \; i\partial_A \, \gamma^A \Psi$	**P** $\surd$**-even**
• $\bar{\Psi} M \Psi$	**"scalar"** ~~**P**~~**-odd, CP** $\surd$**-even**

4+1D SCALAR VIOLATES P

$P = P_1$ & M **real**

$(\gamma_\mu, \ i\gamma_5)$ $A = 0,1,2,3,(4=y)$ & $\mu = 0,1,2,3.$

	(4+1)D	(3+1)D
• $\bar{\Psi} \ i\partial_A \gamma^A \Psi$	P $\surd$-even	$\bar{\Psi}\gamma^\mu\Psi$ vector $\bar{\Psi}i\gamma^5\Psi$ ~~P~~- pseudoscalar
• $\bar{\Psi} M \Psi$	"scalar" ~~P~~-odd, CP $\surd$-even	P $\surd$- scalar C $\surd$- even

P $\surd$-scalar and ~~P~~-pseudoscalar $\longrightarrow$ ~~P~~

$(4+1)$D Gauge Theory:

$$\int dy \, (\, \bar{\Psi} \, W_A \, \, \gamma^A \, \Psi - \bar{\Psi} \, M \, \Psi \,)$$

$A = 0, 1, 2, 3, (4 = y)$ & $\mu = 0, 1, 2, 3.$

KK expansion:

$$\Psi = \frac{1}{\sqrt{V}} \sum_n \psi_n \, \, e^{i \frac{n}{R} y} \qquad W_A = \frac{1}{\sqrt{V}} \sum_k V_A^{(k)} \, e^{i \frac{k}{R} y}$$

$\Downarrow$

DIMENSIONAL REDUCTION:

$\Downarrow$

Zero Modes

$$\bar{\psi}_o V_\mu^{(o)} \gamma^\mu \psi_o + \bar{\psi}_o (V_4^{(o)} i \gamma_5 - M) \psi_o$$

$\rightsquigarrow$ **COMPLEX MASS.**

...but rotate away in the $U(1)$ case.

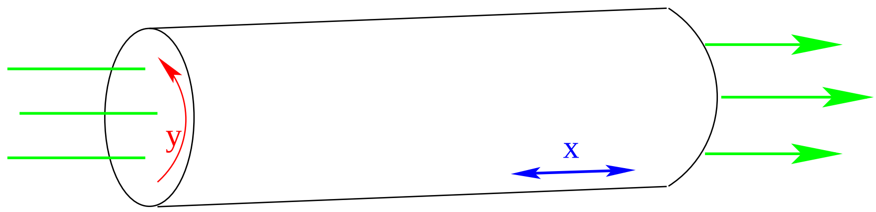
$V_4^{(o)}$??

$\langle V_4^{(o)} \rangle$ $\longrightarrow$ **not gauge invt.**

$V_4^{(o)} = \frac{1}{\sqrt{V}} \int dy \;\; W_4(y)$ $\longrightarrow$ **gauge invt!**

Hosotani Mech. - Wilson Loop

$\iint \bar{B}.d\bar{S}$



Rem.

Gauge trsf.: $\psi(y) \rightarrow \psi(y) e^{-i \int_0^y dy W_y}$

$$\Vert$$

Eliminates $V_4 \neq 0$ ***BUT*** ***non-periodical*** **B.C.**

$$\Downarrow$$

$$\psi(y + 2\pi R) \neq \pm \psi(y)$$

(cf. Hall & Nomura: hep-th/0107245)

TOY MODEL : $SU(2)$ IN $(4+1)D$

$$\Psi = \left(\Psi^1, \quad \Psi^2\right)$$

$$\bar{\Psi}(i\partial^A + W_a^A \tau^a)\gamma_A \Psi + \lambda \phi \bar{\Psi}\Psi$$

$$\int dy \;\; W^4 = \begin{pmatrix} v & \\ & -v \end{pmatrix}$$

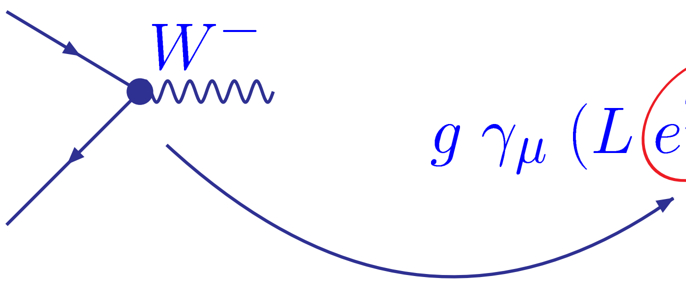
$(3+1)D \Rightarrow SU(2)$ **broken** ; $W^{\pm}$ **massive.**

$$\Rightarrow \bar{\Psi}_L^0 \begin{pmatrix} iv - \lambda\langle\phi\rangle & \\ & -iv - \lambda\langle\phi\rangle \end{pmatrix} \Psi_R^0 + h.c.$$

$\Rightarrow 2 \neq$**phases**

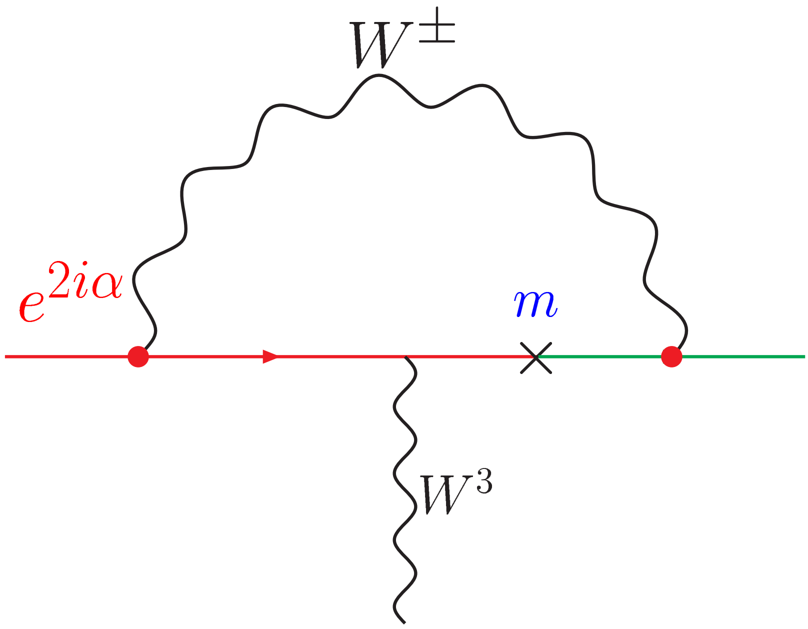
Re-define phases to get real masses:

- $U_L = \begin{pmatrix} e^{-i\alpha} & \\ & e^{i\alpha} \end{pmatrix}$
- $U_R = \mathbb{I}$



$$g\;\gamma_\mu\;(L\,e^{2i\alpha} + R)$$

$\Longrightarrow$ **Induce "EDM".**



$\Rightarrow$ ~~C~~P

BUT...

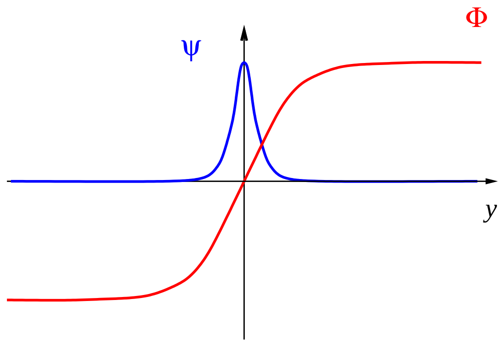
- **"vectorlike" interaction.**
- **masses degenerate,**

$$|\lambda\langle\phi\rangle + iv| = |\lambda\langle\phi\rangle - iv|$$

Toward more realistic models...

TO GET CHIRAL MODES

localize on a defect **(or orbifold)**



$$\Psi(4+1) \xrightarrow{\Phi} \psi_L(3+1)$$

or $$\xrightarrow{-\Phi} \psi_R(3+1)$$

(in $y = 0$**).**

However

$$\frac{\Psi\text{-components}}{2}$$

- $U(1) \longrightarrow \psi_L$

no $\bar{\psi}_L W^4 i\gamma_5 \psi_R$ **term.**

- $SU(2) \longrightarrow \psi_L^1, \psi_R^2$

$$\Phi \sim \begin{pmatrix} 1 & \\ & -1 \end{pmatrix} \qquad W^4 \sim \begin{pmatrix} & 1 \\ 1 & \end{pmatrix}$$

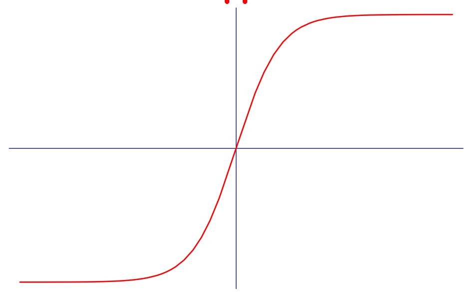
1! phase

NEED MORE SPINORS

e.g. SU(4)

$SU(4)_V$:

$\Vert$



$\Downarrow$

$SU(2)_L \times SU(2)_R \times U(1)_A$:

$\Vert \qquad \Vert$

$\chi \qquad \eta$

$\Downarrow \qquad \Downarrow$

$$\boxed{U(1)_V \;\; + W_L,\ W_R,\ Z_L\ , Z_R.}$$

$$\left(\Psi^1 \;\; \Psi^2 \;\; \Psi^3 \;\; \Psi^4 \right)$$

$\Vert$

$$\Phi = \begin{pmatrix} 1 & & & \\ & 1 & & \\ & & -1 & \\ & & & -1 \end{pmatrix}$$

$\Downarrow$

$$\left(\psi_L^1 \;\; \psi_L^2 \;\; \psi_R^3 \;\; \psi_R^4 \right)$$

$\Vert$

$H_1, \quad H_2$

$\Downarrow$

$$\bar{\psi}_L^1(\lambda_1 H_1 + iV_y)\psi_R^3$$
$$\bar{\psi}_L^2(\lambda_2 H_2 + iV_y)\psi_R^4$$