Osaka Particle Physics Group
in Wakayama, Nov. 06, 2011

Invitation to Yukawaon Museum

-- Evolution of Yukawaon Models --

from an early one to recent (preliminary) ones

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This museum was founded
by Dr. Y. Koide on 6th Nov. 2011

The tour time takes 14 min
with question time 30 sec.

Exhibition Rooms

Room 1: Standard model

Room 2: Yukawaon model in the early stage

Room 3: MNS and CKM mixings

Room 4: Sumino mechanism (2009)

Room 5: SU(5) compatible yukawaon model

Room 6: The future

Room 1: Standard model

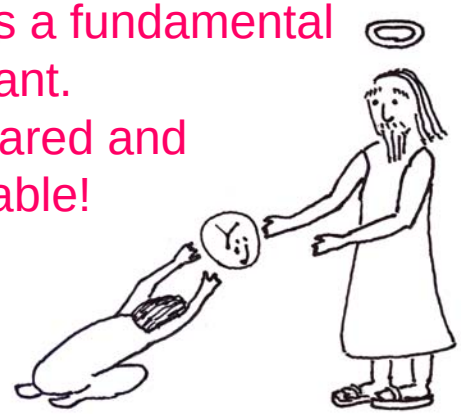
These are Yukawa interaction terms in the standard model

$$H_Y = (Y_u)_{ij}\bar{q}_{Li}u_{Rj}H_u + (Y_d)_{ij}\bar{q}_{Li}d_{Rj}H_d + \cdots$$

Ancient people had believed that mass spectra and mixings of quarks and leptons originate in the so-called "Yukawa coupling constants" Y_f .

Y_f are fundamental constants which are given by God, so that we must never intend to calculate values of Y_f .

This is a fundamental constant.
Be scared and inviolable!



Room 2-1: Yukawaon model in the early stage (1990)

This is a prototype of the yukawaon model, where the charged lepton mass formula (1983)

$$m_e + m_\mu + m_\tau = \frac{2}{3}(\sqrt{m_e} + \sqrt{m_\mu} + \sqrt{m_\tau})^2$$

was tried to derive from a minimization of

$$V = \mu^2 \mathrm{Tr}[\Phi\Phi] + \frac{1}{2}\lambda \mathrm{Tr}^2[\Phi\Phi] + \frac{1}{2}\lambda' \mathrm{Tr}^2[\Phi]\mathrm{Tr}[\hat{\Phi}\hat{\Phi}]$$

Φ: **8+1** of U(3)

"Nonet assumption"

$\hat{\Phi} = \Phi - \frac{1}{3}\mathrm{Tr}[\Phi]$: **8** of U(3)

YK, MPL A5, 2319 (1990),

Room 2-2: Yukawaon model in the early stage (2008)

This is an early yukawaon model, where Y_f are not constants, but fields. We call them yukawaons. Therefore, we can consider non-Abelian family symmetry without an explicit symmetry breaking terms.

$$W_Y = \frac{y_u}{\Lambda} q_i Y^u_{ij} u^c_j H_u + \frac{y_d}{\Lambda} q_i Y^d_{ij} d^c_j H_d$$
$$+ \frac{y_\nu}{\Lambda} \ell_i Y^\nu_{ij} \nu^c_j H_u + \frac{y_e}{\Lambda} \ell_i Y^e_{ij} e^c_j H_d + y_R \nu^c_i Y^R_{ij} \nu^c_j$$

SUSY and O(3)-family symmetry have been assumed.

Y_f are distinguished from each other by "sector charges" Q_X .

(**Nowadays, R charges are used instead of Q_X.**) YK., PLB565, 227 (2008)

Room 3: MNS and CKM mixings

This is a first model which could give a unified description of MNS and CKM mixings in terms of a fundamental VEV matrix $<\Phi_e>$:

$$W_Y = \frac{y_u}{\Lambda} q_i Y^u_{ij} u^c_j H_u + \frac{y_d}{\Lambda} q_i Y^d_{ij} d^c_j H_d$$
$$+ \frac{y_\nu}{\Lambda} \ell_i Y^e_{ij} \nu^c_j H_u + \frac{y_e}{\Lambda} \ell_i Y^e_{ij} e^c_j H_d + y_R \nu^c_i Y^R_{ij} \nu^c_j$$

Note that the yukawaon Y_ν is replaced with Y_e.

The neutrino mass matrix is given by a seesaw form

$$M_\nu = m_D M_R^{-1} m_D^T \propto \langle Y_e \rangle \langle Y_R \rangle^{-1} \langle Y_e \rangle$$

The model was intended to describe all VEV matrices of Yukawaons in terms of a VEV matrix $\langle \Phi_e \rangle$

Y.K., PLB680, 76 (2009).

$$M_e \propto \langle Y_e \rangle \propto \langle \Phi_e \rangle \langle \Phi_e \rangle$$
$$M_u \propto \langle Y_u \rangle \propto \langle \Phi_u \rangle \langle \Phi_u \rangle$$
$$M_u^{1/2} \propto \langle \Phi_u \rangle \propto \langle \Phi_e \rangle \langle S_u \rangle \langle \Phi_e \rangle$$
$$M_d \propto \langle Y_d \rangle \propto \langle \Phi_e \rangle \langle S_d \rangle \langle \Phi_e \rangle$$
$$\langle S_q \rangle_e \propto 1 + a_q X \equiv \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} + a_q \frac{1}{3} \begin{pmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{pmatrix}$$

The model has given reasonable fitting not only of MNS mixing but also of CKM mixing together with mass ratios by adjusting the parameters a_u and a_d and by using the input

$$\langle \Phi_e \rangle = k_e \mathrm{diag}(\sqrt{m_e} + \sqrt{m_\mu} + \sqrt{m_\tau})$$

For more accurate fitting, YK and Nishiura, PRD83, 035010 (2011).

Room 4: Sumino mechanism (2009)

Y.Sumino, PLB671, 477 (2009); JHEP 0905, 075 (2009).

Closed

I am sorry.

This room is excluded

from this short-time guide program.

Room 5: SU(5) compatible yukawaon model (2011)

Yukawaons are singlets under $SU(3)_c \times SU(2)_L \times U(1)_Y$, so that the yukawaon model will be compatible with GUT scenario.

He has proposed an SU(5) compatible model by adding vector-like (5*+5) and (10+10*) fields.

- **The main purpose of this model was to build a yukawaon model without a cutoff Λ.**
- **Another purpose was to know the scale of cutoff Λ.**

Room 5-1: SU(5) compatible yukawaon model with U(3) family symmetry

arXiv:1106.0971 [hep-ph]

$$W_{Yu} = y_u 10_i Y_u^{ij} \overline{10}'_j + M_{10} \overline{10}'_i 10'^i + y_{10} 10'^i 10_i 5_H$$

$$\Rightarrow \quad W_{Yu}^{eff} = \frac{y_u y_{10}}{\bar{M}_{10}} 10_i Y_u^{ij} 10_j 5_H$$

$$W_{Ye} = y_e \bar{5}_i Y_e^{ij} 5'_j + M_5 5'_i \bar{5}'^i + y_5 \bar{5}'^i 10_i \bar{5}_H$$

$$\Rightarrow \quad W_{Ye}^{eff} = \frac{y_e y_5}{\bar{M}_5} \bar{5}_i Y_e^{ij} 10_j \bar{5}_H$$

$$W_{Y\nu} = y_e \bar{5}_i Y_e^{ij} 5'_j + M_5 5'_i \bar{5}'^i + y_1 \bar{5}'^i 1_i 5_H$$

$$\Rightarrow \quad W_{Y\nu}^{eff} = \frac{y_e y_1}{\bar{M}_5} \bar{5}_i Y_e^{ij} 1_j 5_H$$

Note that $Y_\nu \Rightarrow Y_e$

Unfortunately, the model leads to

$$\Lambda_{U3} \geq \langle Y_u \rangle \sim M_{10} \geq 10^{12} \text{ GeV}$$

The value 10^{12} comes from the condition of no blowing up of the gauge c.c g_5.

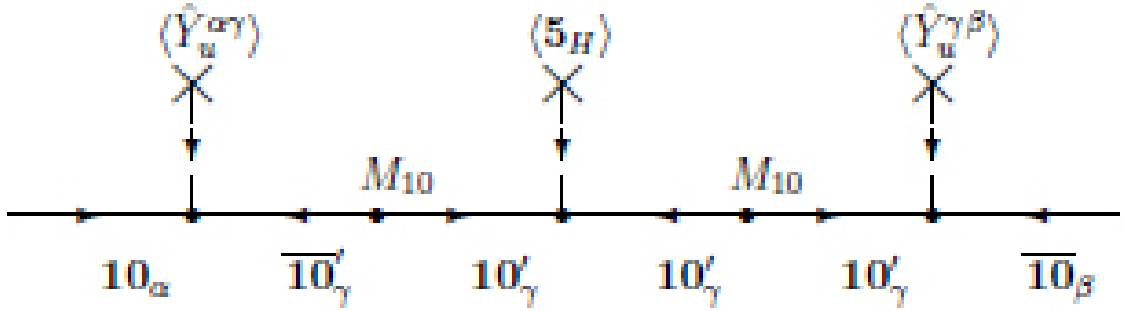
Room 5-2: $U(3)_{fam}$ x $O(3)_{fam}$ model

arXiv:1110.5413 [hep-ph]

This is a modified SU(5) compatible model.

We regards quarks and leptons as $(\bar{5}_i + 10_\alpha + 1_\alpha)$ **of** $U(3)_{fam}$ **x** $O(3)_{fam}$

$$W_{Yu} = y_u 10_\alpha \hat{Y}_u^{\alpha\beta} \overline{10}'_\beta + M_{10} \overline{10}'_\alpha 10'_\alpha + y_{10} 10'_\alpha 10'_\alpha 5_H$$



$$W_{Yu}^{eff} = \frac{y_u^2 y_{10}}{(\overline{M}_{10})^2} 10_\alpha \hat{Y}_u^{\alpha\gamma} \hat{Y}_u^{\gamma\beta} 10_\beta 5_H$$

We do't need Y_u**!**

We can take $\Lambda_{U3} \sim 1$ TeV **without blowing up of** g_5 **.**

Room 6: The Future

This room transports us to the future world.

This system was invented based on a discovery by OPERA on 2011.

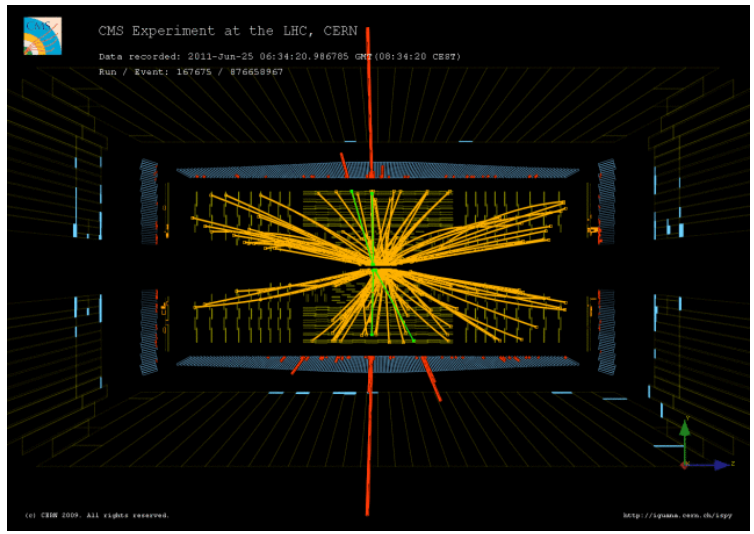
- **In 20XX, the family gauge boson was discovered at ILC.**

$$A_1^1 \to e^+e^- \text{ but no } \mu^+\mu^-$$

Ref.

Koide-Sumino-Yamanaka,

PLB695, 279 (2011)



- **In 20YY, QFD (Quantum Flavor Dynamics) was established.**

The charged lepton mass formula came clearly to be understood from QFD.

Thank you for your interests.

Please visit our museum again.

Next time, I hope that you have enough time.