

BACKGROUND AND MOTIVATION

- Beyond the standar model (SM): **neutrinos** have a small masses and **another (heavy) Higgs particle?**
- By considering the effective theory, we may observe the effect of the heavy particle with the present accelerator energy.
- The SM has only one Higgs particle, but there is no reason why we only have one Higgs particle → Two Higgs Model (THM)
- One of example THM is **Davidson and Logan model (PRD 80, 2009)**
- In this work, we construct an effective field theory of THM in the low energy region by integrating the heavy particles that are not observed on the low energy.
- We look for observable effects in the low energy experiments and discuss up to one-loop level.

A (TOY) MODEL

We present a simple toy model which leads to a tiny Dirac neutrino mass due to small vacuum expectation value (VEV) of the second scalar. The action is written in terms of bare fields ρ_{0i} and bare masses m_{0i} and bare couplings λ_{0i} :

$$S = \int d^d x \left(-\frac{1}{2} \sum_{i=1}^2 \rho_{0i} \left(\square + m_{0i}^2 + \frac{\lambda_{0i}}{2} \rho_{0i}^2 \right) \rho_{0i} - \frac{\lambda_{03}}{4} \rho_{01}^2 \rho_{02}^2 - (y_0 \bar{n}_0 n_0 + m_{012}^2 \rho_{01}) \rho_{02} \right)$$

where m_{012}^2 is the bare mixing mass and y_0 is the Yukawa coupling of the neutrino and the second scalar. The model is renormalizable by imposing the two Z_2 symmetries (Z_2, Z_2'). By considering Z_2 and Z_2' , only heavy Higgs couples to neutrino. To forbid Majorana neutrino, we impose a symmetry that transforms neutrino n to in .

Table 1: The charge assignment under Z_2 and Z_2' symmetries.

Symmetry	ρ_1	ρ_2	n_L	n_R
Z_2	−	−	+	−
Z_2'	−	+	+	+

Note that in the action we actually have the cosmological constants which consist of the mass parameters of the model. But those terms are not written explicitly. In addition, we also do not include the kinetic term for neutrino and its quantum correction is not considered.

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Next, we will write the action in terms of renormalized quantities. The relations between bare quantity and renormalized one are introduced as follows;

$$\begin{aligned} \rho_{0i} &= \sqrt{Z_i} \rho_i, \quad n_0 = \sqrt{Z_n} n, \quad y_0 Z_n \sqrt{Z_2} = Z_y y \mu^\eta, \\ m_{0i}^2 Z_i &= \sum_{j=1}^2 Z_{mij} m_j^2, \quad m_{012}^2 \sqrt{Z_1 Z_2} = m_{12}^2 Z_{12}, \\ \lambda_{0i} Z_i^2 &= \sum_{I=1}^3 Z_{\lambda_{iI}} \lambda_I \mu^{2\eta}, \quad \lambda_{03} Z_1 Z_2 = \sum_{I=1}^3 Z_{\lambda_{3I}} \lambda_I \mu^{2\eta}, \end{aligned}$$

where the index i is not summed ($i = 1, 2$), μ is the renormalization scale and η is $2 - \frac{d}{2}$. Then the action becomes,

$$\begin{aligned} S[\rho_1, \rho_2, n] &= -\frac{1}{2} \int d^d x \sum_{i=1}^2 (Z_i \rho_i \square \rho_i + \rho_i^2 Z_{mij} m_j^2 \\ &\quad + \frac{\mu^{2\eta}}{2} \sum_{I=1}^3 (\rho_i^4 Z_{\lambda_{iI}} \lambda_I + \rho_1^2 \rho_2^2 Z_{\lambda_{3I}} \lambda_I)) \\ &\quad - \int d^d x (Z_y y \mu^\eta \bar{n} n + Z_{12} m_{12}^2 \rho_1) \rho_2 \end{aligned}$$

LOW-ENERGY EFFECTIVE ACTION

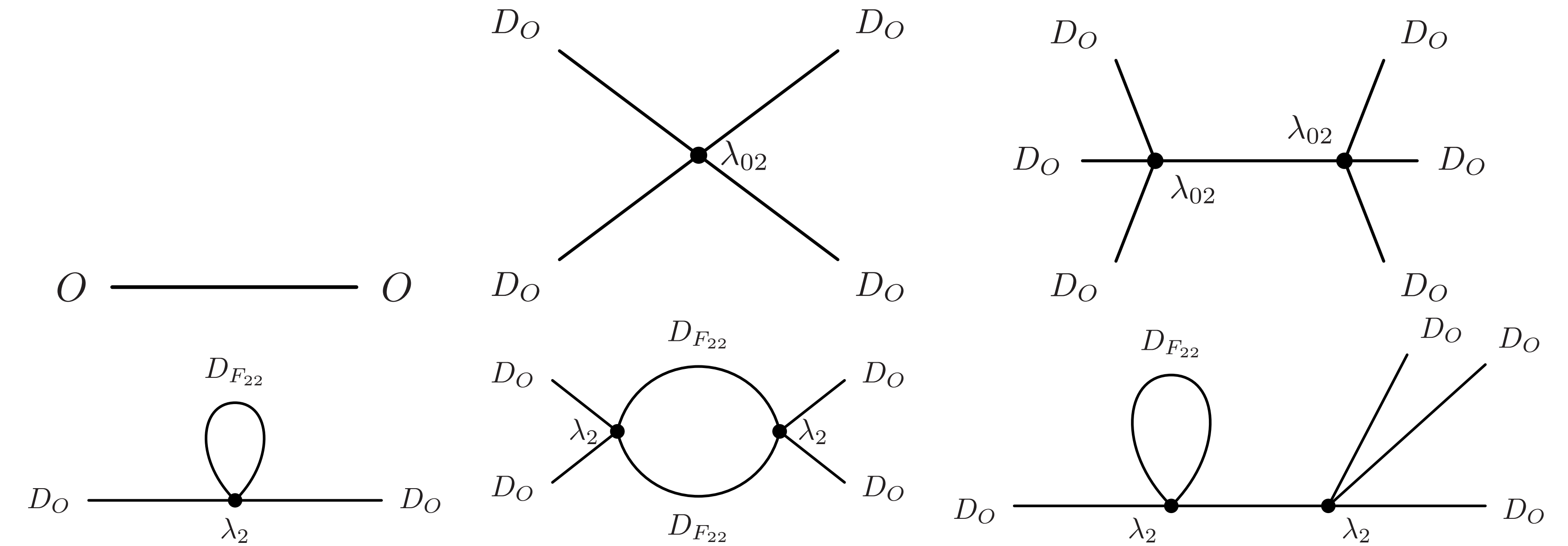
The effective action is constructed with a Legendre transformation introducing a source term J_1 for the lighter field ρ_1 ,

$$\Gamma_{\text{eff}}[\bar{\rho}_1, n] = W[J_1, n] - \int J_1 \bar{\rho}_1 d^4 x = -i \log \int d\Delta_1 \int d\Delta_2 \times e^{iS[\bar{\rho}_1 + \Delta_1, \Delta_2, n] - i \int \Delta_1 \frac{\delta \Gamma_{\text{eff}}[\bar{\rho}_1, n]}{\delta \bar{\rho}_1(x)} d^4 x},$$

where $\bar{\rho}_1|_{J_1} = \frac{\delta W[J_1, n]}{\delta J_1}$, $J_1(x) = -\frac{\delta \Gamma_{\text{eff}}[\bar{\rho}_1, n]}{\delta \bar{\rho}_1(x)}$ and $\rho_1 \equiv \Delta_1 + \bar{\rho}_1$. Δ_1 is the quantum fluctuation from the expectation value $\bar{\rho}_1$. Next, we define a quantity $\tilde{\Gamma}_{\text{eff}}[\bar{\rho}_1, n] = \Gamma_{\text{eff}}[\bar{\rho}_1, n] - S[\bar{\rho}_1, 0, 0]$, by subtracting the classical action from the effective action and it is written as,

$$e^{i\tilde{\Gamma}_{\text{eff}}[\bar{\rho}_1, n]} = \int d\Delta_1 e^{i \left\{ \frac{1}{2} \int d^d x \int d^d y \Delta_1(x) \frac{\delta^2 S[\bar{\rho}_1, 0, n]}{\delta \bar{\rho}_1(x) \delta \bar{\rho}_1(y)} \Delta_1(y) + S_{1\text{int}}(\Delta_1, \bar{\rho}_1) - \int d^d x \Delta_1(x) \left(\frac{\delta \tilde{\Gamma}_{\text{eff}}[\bar{\rho}_1, n]}{\delta \bar{\rho}_1(x)} \right) \right\}} e^{iW_2[J_2, \Delta_1, n]},$$

in which $e^{iW_2[J_2, \Delta_1, n]}$ summarizes the contribution from the heavy field to the effective action.



In the up row, those Feynman diagrams correspond to $W_2^{c(\text{tree})}[J_2(\Delta_1 = 0), \bar{\rho}_1, 0]$. Whereas, in the down row, those Feynman diagrams correspond to $W_2^{c(1\text{ loop})}[-O(x), \bar{\rho}_1, 0]$. By integrating for Δ_1 and Δ_2 , we obtain the final form of effective action,

$$\begin{aligned} S_{\text{eff}} &= \int d^4 x \left[-\frac{m_{1\text{eff}}^2}{2} \bar{\rho}_1^2 + \frac{m_{12\text{eff}}^2}{2} \epsilon \bar{\rho}_1^2 - \frac{\lambda_{1\text{eff}}}{4} \bar{\rho}_1^4 - \frac{\lambda_{3\text{eff}}}{4} \epsilon^2 \bar{\rho}_1^4 \right. \\ &\quad \left. + y_{\text{eff}} \epsilon \bar{n} n \bar{\rho}_1 + \frac{\lambda_3^2}{8m_2^2} \epsilon^2 \bar{\rho}_1^6 - \frac{\lambda_3}{2m_2^2} \epsilon (\bar{n} n) \bar{\rho}_1^3 + \frac{y^2}{2m_2^2} (\bar{n} n)^2 \right] \end{aligned}$$

with $\epsilon = m_{12}^2/m_2^2$. Focusing on the neutrino mass, we have term

$$= \int d^4 x y \epsilon \bar{n} n \bar{\rho}_1 \left(1 + \frac{3\lambda_2 - \lambda_3}{16\pi^2} (1 - \log \frac{m_2^2}{\mu^2}) \right)$$

We note that the effective Yukawa coupling constant of neutrino mass term is $y \frac{m_{12}^2}{m_2^2}$, and it is naturally suppressed by the heavy mass Higgs m_2 ($m_2^2 \gg m_{12}^2$)

SUMMARY AND FUTURE WORK

- We have constructed low-energy effective theory by integrating heavy and light Higgs particles.
- By integrating heavy Higgs bosons in the model, the effective Yukawa coupling constant for neutrino mass is ym_{12}^2/m_2^2 , and it is naturally suppressed by the mass of heavy mass Higgs m_2^2 .
- The effective coupling constant of the quartic interaction of Higgs boson and the quartic interaction term of neutrino is given up to dimension six operator.
- For the future work, we will apply the effective theory in the low energy region for Davidson and Logan model. In addition, we will discuss the effects that can be verified by experiments.