Neutrino Mass in the effective theory of the strongly-coupled supersymmetric $SU(2)_H$ gauge theory

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Introduction

Problems in the SM

- Baryonasymmetry of the Universe
- Dark matter
- Neutrino mass

Our model can explain these problems simultaneously.

I focus on neutrino mass in this talk.

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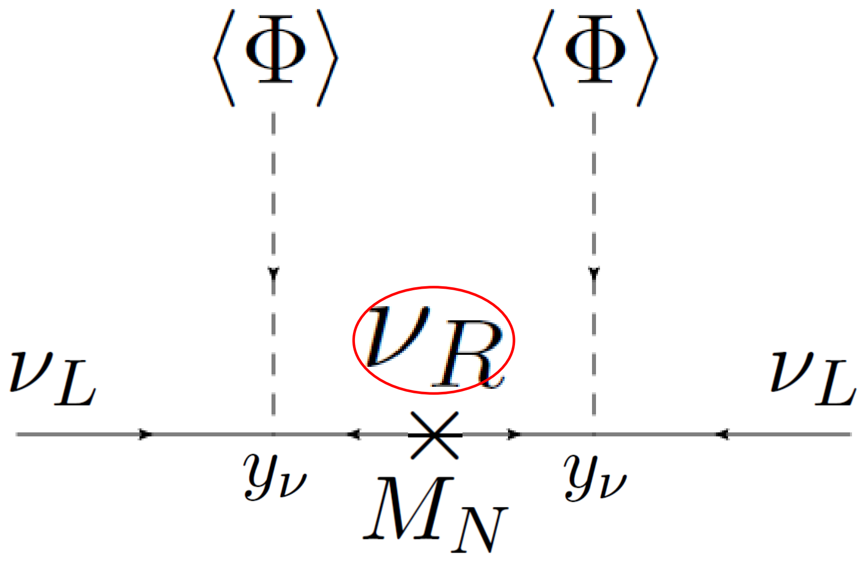
Type-I Seesaw Mechanism



Right-handed neutrino: ν_R

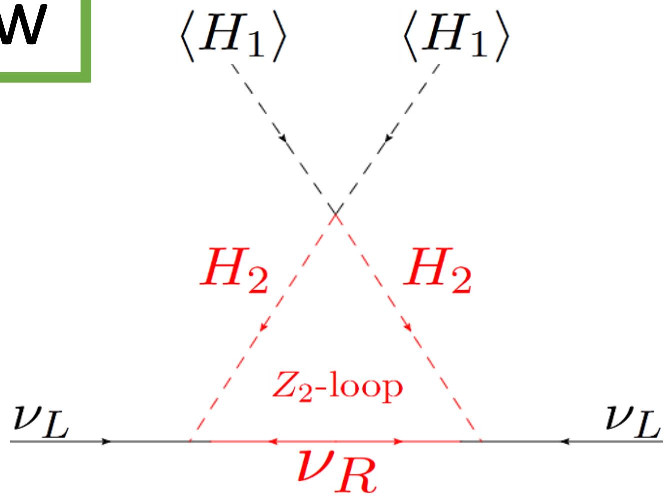
Neutrino mass: $M = \dfrac{v^2}{M_N} y_\nu^T y_\nu$

$$y_\nu = O(1) \rightarrow M_N = O(10^{12})\mathrm{GeV}$$

The right-handed neutrino masses are too large to measure at the collider experiments.

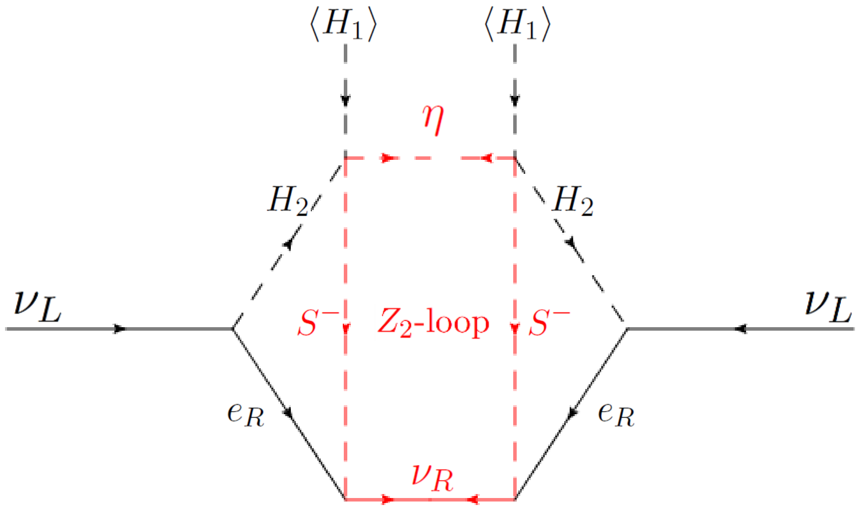
Alternative scenario for neutrino masses

Radiative Seesaw



Ma model

Ma(2006)



Aoki-Kanemura-Seto model (AKS model)

Aoki, Kanemura, Seto (2009)

Neutrino mass
Dark matter } Z_2 symmetry

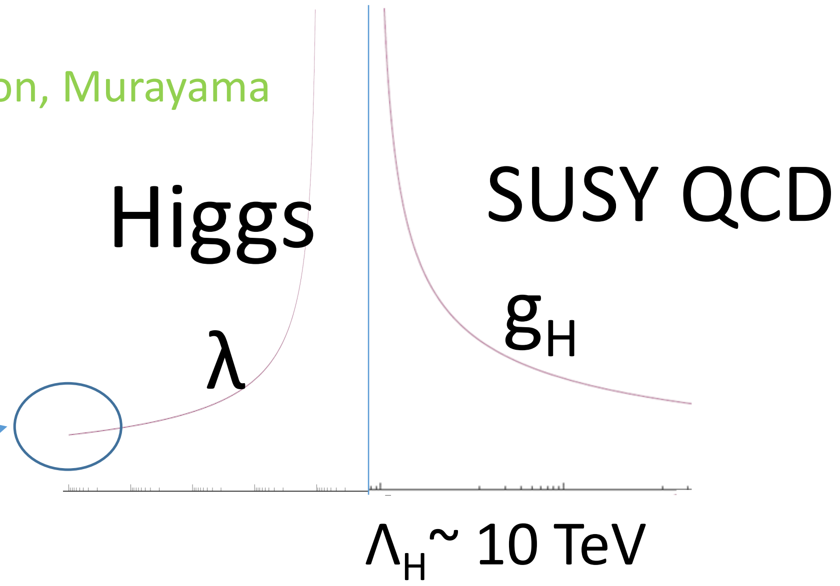
Especially, the AKS model is very interesting since coupling constants are of O(1).

Aoki, Kanemura, Yagyu(2011)

Motivation

The O(1) coupling is good for electroweak first order phase transition.
Such coupling leads Landau pole between 10- 100 TeV. Aoki, Kanemura, Yagyu(2011)
We want to know a fundamental theory above Landau pole.

The fat Higgs model is an example. Harnik, Kribs, Larson, Murayama (2004)
This is a SUSY theory with asymptotic free.



We consider a new model along this line.

- Baryogenesis ➔ O(1) coupling at EW scale
- Neutrino mass ➔ Radiative seesaw mechanism
- Dark matter ➔ Z_2-odd and/or R-parity odd particle(s)

with 126 GeV SM-like Higgs boson.

SUSY $SU(2)_H$ gauge theory

$N_f=N_C+1$ → Confinement

$N_C=2,\ N_f=3$ The Simplest

Intrigator, Seiberg (1996)

$$SU(2)_H \times SU(2)_L \times U(1)_Y \times Z_2$$

Harnik, Kribs, Larson, Murayama (2004)

$SU(2)_H$ doublets

Field	$SU(2)_L$	$U(1)_Y$	Z_2
$\begin{pmatrix} T_1 \\ T_2 \end{pmatrix}$	2	0	+
T_3	1	+1/2	+
T_4	1	−1/2	+
T_5	1	+1/2	−
T_6	1	−1/2	−

Confinement →

$M_{ij} \sim T_i T_j$

Kanemura, Shindou, Yamada (2012)

Kanemura, Senaha , Shindou, Yamada(2013)

MSSM doublets: H_u, H_d

Field	$SU(2)_L$	$U(1)_Y$	Z_2
H_u	2	+1/2	+
H_d	2	−1/2	+
Φ_u	2	+1/2	−
Φ_d	2	−1/2	−
Ω^+	1	+1	−
Ω^-	1	−1	−
$N,\ N_\Phi,\ N_\Omega$	1	0	+
$\zeta,\ \eta$	1	0	−

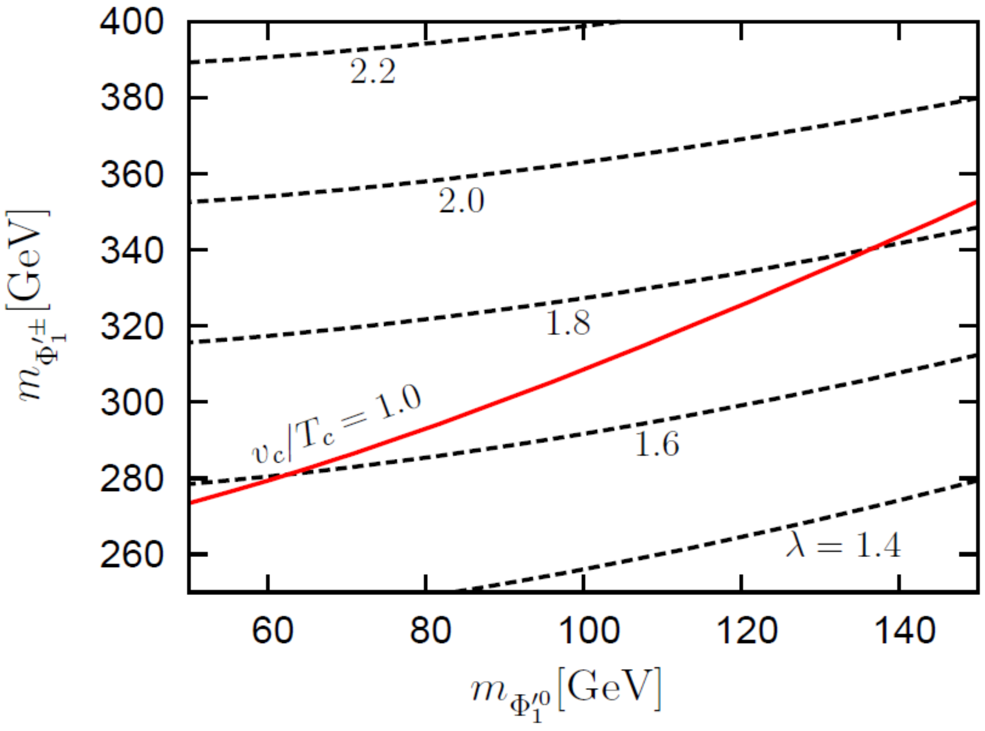
Below the cut-off scale Λ_H , fields in the low energy effective theory are mesonic fields $M_{ij} \sim T_i T_j$.
This model contains the Higgs sector of the AKS model.
Low-energy effective theory can explain electroweak first order phase transition, neutrino mass and dark matter simultaneously.

Low energy effective theory

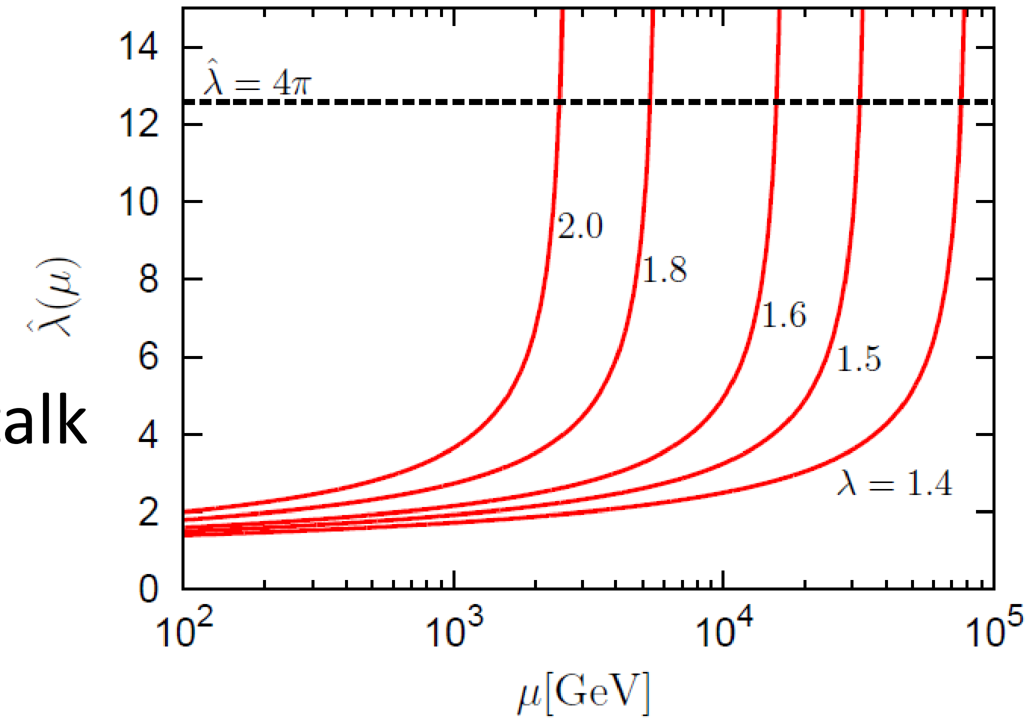
Low energy effective superpotential

$$W_{eff} = -\mu(H_u H_d - n_\Phi n_\Omega) - \mu_\Phi \Phi_u \Phi_d - \mu_\Omega(\Omega^+\Omega^- - \zeta\eta)$$
$$+ \lambda(H_d \Phi_u \zeta + H_u \Phi_d \eta - H_u \Phi_u \Omega^- - H_d \Phi_d \Omega^+)$$

Kanemura, Senaha , Shindou, Yamada(2013)



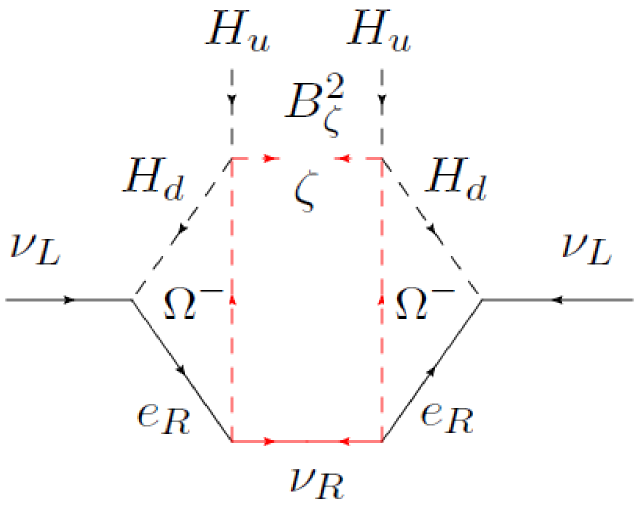
Prof. Shindo's talk

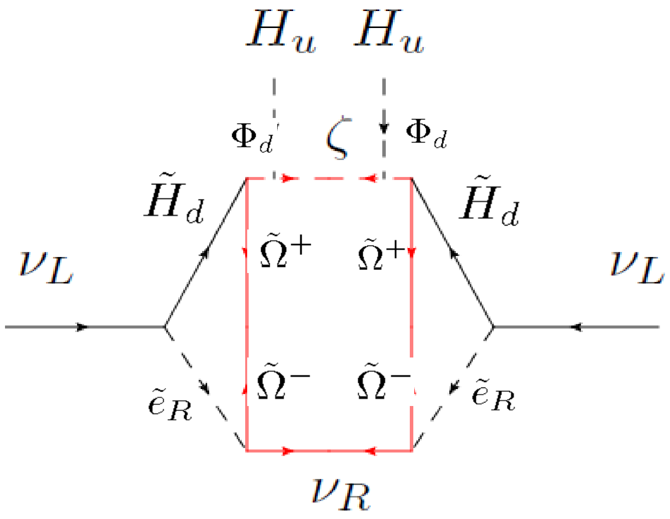


$\frac{v_c}{T_c} > 1$ leads $\lambda \sim O(1)$ → Landau pole at 10 TeV.

Neutrino mass generation mechanism

3-loop : SUSY AKS model





This 3-loop diagrams contain all low-energy fields.

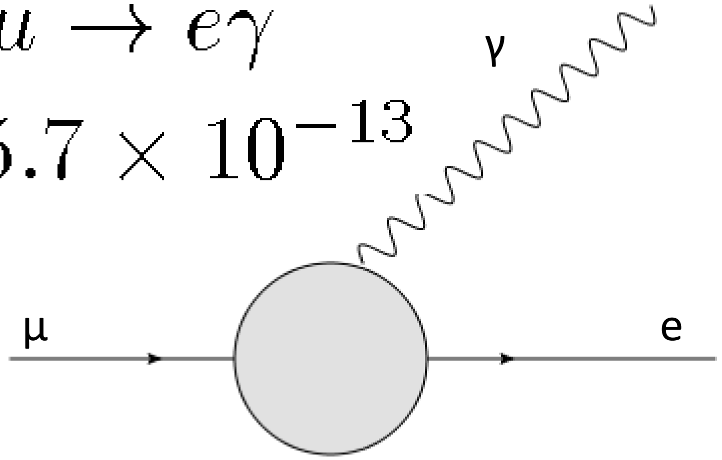
We investigate a parameter sets which satisfy neutrino oscillation data and lepton flavor violation experiments.

Lepton flavor violation (LFV)

MEG:arXiv:1303.0754v2 [hep-ex] 23 Apr 2013
PDG, Phys. Rev. D**86**, 010001 (2012)

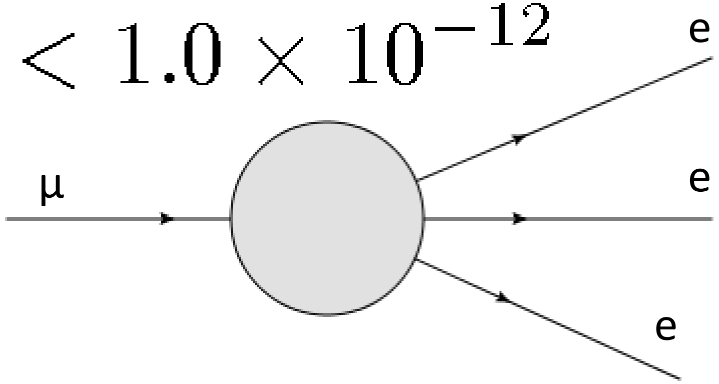
$\mu \to e\gamma$

$< 5.7 \times 10^{-13}$



$\mu \to 3e$

$< 1.0 \times 10^{-12}$



A benchmark point

Input parameters

$$\tan\beta = 30\,, \quad m_{H^\pm} = 350\text{GeV}\,, \quad M_{\tilde{W}} = 500\text{GeV}\,, \mu = 100\text{GeV}\,,$$
$$\bar{m}^2_{\Omega^+} = \bar{m}^2_{\Phi_d} = \bar{m}^2_{\Phi_u} = (1500\text{GeV})^2\,,$$
$$\bar{m}^2_{\zeta} = (1410\text{GeV})^2\,, \quad \bar{m}^2_{\eta} = (30\text{GeV})^2\,, \quad \bar{m}^2_{\Omega^-} = (30\text{GeV})^2\,,$$
$$\mu_\Phi = -\mu_\Omega = 550\text{GeV}\,, \quad (\text{A terms, B terms}) = 0\,,$$
$$\lambda = 1.8\,,$$
$$B^2_\zeta = (1400\text{GeV})^2\,, \quad B^2_\eta = m^2_{\zeta\eta} = 0\,,$$
$$M_k = (100\text{GeV}, 2000\text{GeV}, 4000\text{GeV})\,,$$
$$m_{\tilde{\nu}_R} = (100\text{GeV}, 4000\text{GeV}, 8000\text{GeV})\,, \quad m_{\tilde{e}_R} = (6000\text{GeV}, 6000\text{GeV}, 6000\text{GeV})\,,$$
$$h_N = \begin{pmatrix} 0.001 & 0 & 0 \\ -0.0624 + 0.16i & -0.0314 - 0.0016i & -0.0022 + 0.000297i \\ 0.902 + 2.46i & 0.000681 - 0.00126i & -0.000755 - 0.00161i \end{pmatrix}.$$

Output parameters

Neutrino masses and mixing

$$m_1 = 1.3 \times 10^{-10}\text{eV}\,, \quad m_2 = 0.0089\text{eV}\,, \quad m_3 = 0.050\text{eV}\,,$$
$$\sin^2\theta_{12} = 0.31\,, \quad \sin 2\theta^2_{23} = 1.0\,, \quad \sin\theta_{13} = 0.10\,,$$

LFV constrains

$$\text{B}(\mu \to e\gamma) = 5.2 \times 10^{-14}\,,$$
$$\text{B}(\mu \to eee) = 4.7 \times 10^{-13}\,,$$

Higgs boson mass

$$m_h = 126\text{GeV}$$

We find the parameter sets which satisfy electroweak phase transition, neutrino mass and dark matter.

Conclusion

- We have discussed neutrino mass generation mechanism by loop effect.

- We have discovered the benchmark point in the 3-loop case.

We could explain

・Electroweak baryogenesis (1st order phase transition)

・Neutrino mass (Radiative seesaw scenario)

・Dark matter (multi-component dark matter scenario)

in the framework of strongly dynamics of SUSY QCD.