Electroweak baryogenesis in the three-loop neutrino mass model with dark matter

Sora Taniguchi (U. of Osaka) JHEP06(2025)036, and recent work with M. Aoki, K. Enomoto, S. Kanemura

Introduction

Higgs was found in 2012, but **the structure of Higgs sectors is still unknown**

Related to BSM phenomena

Testable with various experiments

Approaching new physics from Higgs physics

BSM phenomena

- **Neutrino Oscillation**
- **Dark matter**
- **Baryon asymmetry of the Universe**

$$\eta_B = \frac{n_B}{n_\gamma} = (6.04 - 6.20)\times 10^{-10}$$

n_B :Baryon number density

n_γ :Photon number density

From CMB Planck (2018)

Q. Can we explain these 3 BSM phenomena simultaneously at TeV scale?

Related to extended Higgs sector

Testable energy scale

We build a complete model by improving the 3-loop radiative seesaw model M. Aoki, S. Kanemura and O. Seto (2009)

Model

SM + **Extended Higgs** + **Right-handed ν**

- **Extended Higgs**→additional Higgs doublet ϕ_2 + singlet η, S^+
- **Softly broken $\tilde{Z}_2$ symmetry**→suppress FCNC (Type-X)
- **Exact Z_2** symmetry { Tiny ν mass via radiative correction; Guarantees DM stability

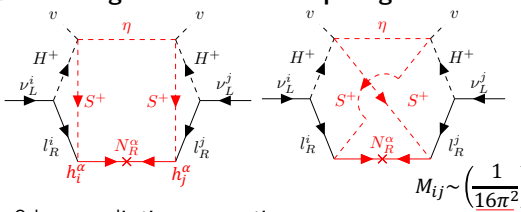
	$SU(2)_L$	$U(1)_Y$	Z_2	$\tilde{Z}_2$ (Softly broken)
ϕ_2	2	1/2	+	−
N_R^α	1	0	−	+
S^+	1	1	−	+
Dark matter η	1	0	−	+

- **CP Violation** $\mathcal{L} \supset -\frac{\lambda_5}{2}(\phi_1^\dagger\phi_2)^2 - h_i^\alpha (N_R^\alpha)^c l_R^i S^+ + \text{h.c.}$

CP phase θ_5 ($\lambda_5 = |\lambda_5| e^{i\theta_5}$) $\alpha = 1,2,3, i = 1,2,3$

Tiny neutrino mass & Dark matter

ν mass is generated via 3 loop diagrams



$$M_{ij} \sim \left(\frac{1}{16\pi^2}\right)^3 \times \left(\frac{m_l}{v}\right)^2 \times \frac{v^2}{m_N}$$

$\sim 10^{-6}$ $\sim 10^{-4}$

3 loop radiative correction

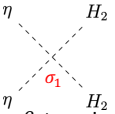
→**Natural size Yukawa $h_e^\alpha \sim O(1)$ and $m_N \sim O(1)$ TeV**

The scalar η is the dark matter

$$V \supset \sum_{a=1}^{2}\left(\frac{1}{2}\sigma_a |\phi_a|^2 \eta^2\right)$$

DM-Higgs interaction

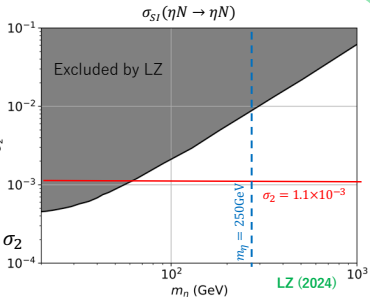
Dominant contribution to $\Omega_{\rm DM}h^2$



σ_{SI} **depends on** $(\sigma_1 \cos\beta + \sigma_2 \sin\beta) \simeq \sigma_2$

$\tan\beta = 18$

→ $\sigma_1 = 0.084$, $\sigma_2 = 1.1\times 10^{-3}$



K. Enomoto, S. Kanemura, ST (2024)

Baryon asymmetry

Electroweak baryogenesis (EWBG) Kuzmin, Rubakov and Shaposhnikov (1985)

(1) B violation → Sphaleron Transition

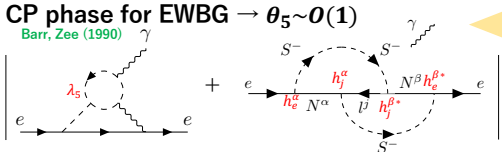
(2) C, CP violation → CP violation in extended Higgs sector

(3) Departure from thermal equilibrium → Sphaleron decoupling →Strongly 1st order EWPT

Sakharov (1967)

CP phase for EWBG → $\theta_5 \sim O(1)$

Barr, Zee (1990)



eEDM $< 4.1\times10^{-30}$ ecm

Barr-Zee contribution

Additional contribution in CPV AKS model K. Enomoto, S.Kanemura, ST (2024)

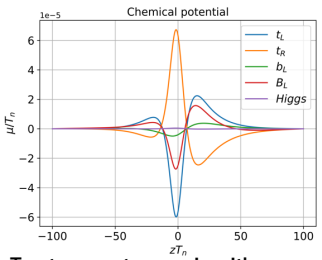
Strongly 1st order PT : $\frac{\varphi_n}{T_n} \geq 1$

←**Non-decoupling effect of additional scalars**

$m_{H^1} \simeq 125$ GeV, $m_{H^2} \simeq 209$ GeV, $m_{H^3} \simeq 371$ GeV
$m_{H^\pm} \simeq 371$ GeV, $m_S = 325$ GeV, $m_\eta = 250$ GeV
$m_{lightest} = 3.95$ meV, $M = 210$ GeV, $\mu_S \simeq 20$ GeV,
$(m_{N^1}, m_{N^2}, m_{N^3}) = (1000, 1200, 1400)$ GeV

$$\frac{\varphi_n}{T_n} = 1.4$$
$$\eta_B = 6.18\times10^{-10}$$
$$d_e = 8.1\times10^{-31} ecm$$

M. Aoki, K. Enomoto, S. Kanemura, ST (2025)



Top transport scenario with WKB approximation Fromme, Huber (2007)

Cline, Joyce, Kainulainen (2000)

Cline, Kainulainen (2007)

Result

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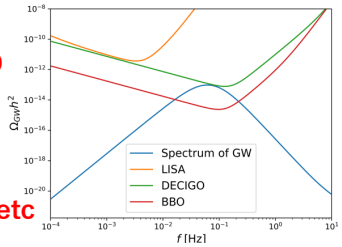
Gravitational wave signal

→**testable at BBO, DECIGO**



Deviation of λ_{hhh}

$$\Delta R \equiv \frac{\lambda_{hhh} - \lambda_{hhh}^{SM}}{\lambda_{hhh}^{SM}} \simeq 36\ \%$$

→**testable at HL-LHC, ILC, etc**

Collider signal from S^+S^-

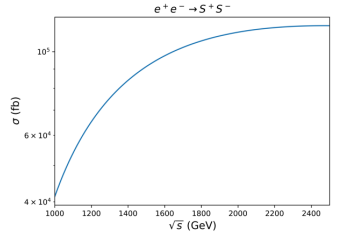
Production : Drell-Yan process and t-channel process with N^α mediation (for lepton collider)

$pp \to S^+S^-$ (MadGraph)

$\sqrt{s} = 13$ TeV : $\sigma = 0.976$ fb

$\sqrt{s} = 14$ TeV : $\sigma = 1.14$ fb

(Decay : $S^\pm \to H^{\pm *}\eta \to \tau\nu\eta$)



Future LFV, EDM experiments and other collider signals (ex. $H_2, H_3 \to \tau\tau$) can also test our benchmark scenario

Summary

- **We build a complete model by improving the 3-loop radiative seesaw model.**
- **We find the benchmark point which can explain 3 BSM phenomena with considering various constraints.**