Thermal Wash-in Leptogenesis via Heavy Higgs Decay

SOKENDAI/KEK M2 Hidenaga Watanabe

K. Mukaida, **H. Watanabe**, M. Yamada, "Thermal Wash-in Leptogenesis via Heavy Higgs Decay", arXiv:2405.14332 [hep-ph] Published in: JCAP 09 (2024), 063.

1. Introduction

In our universe, there exists the asymmetry between baryon and anti-baryon.

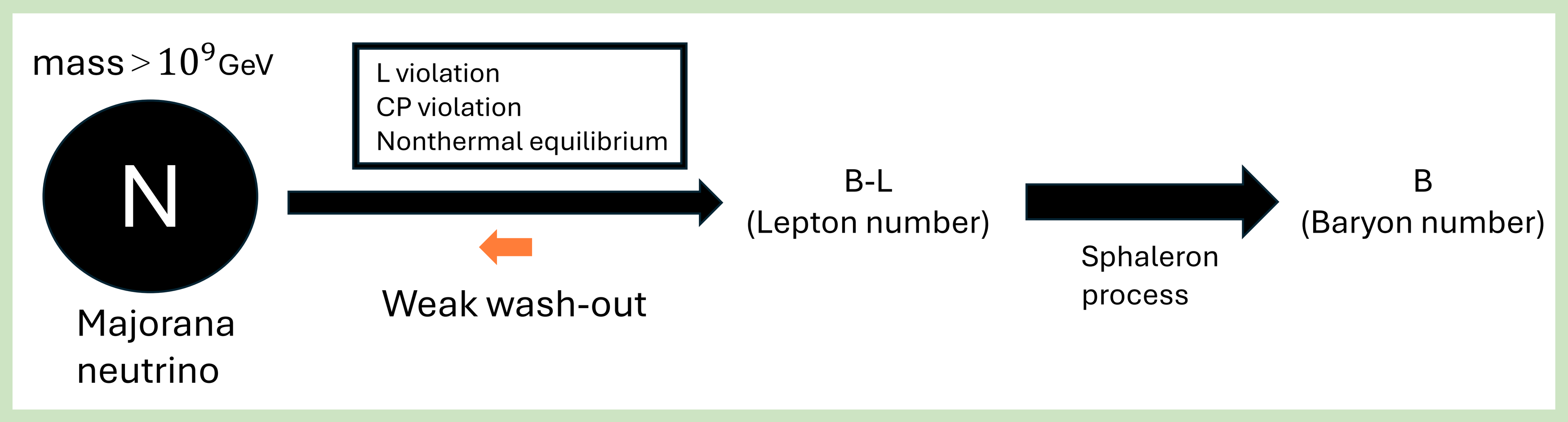
$$\frac{q_B}{s} := \frac{n_B - n_{\bar{B}}}{s} = 8.6\times10^{-11}$$

Because of inflation, we need to create this asymmetry after inflation.

2. Thermal Leptogenesis

M. Fukugita, T. Yanagida Phys.Lett.B 174 (1986) 45-47

Schematic picture of thermal leptogenesis



Need some conditions for successful leptogenesis

Conditions

- Weak wash-out and nonthermal equilibrium
- CP violation in the neutrino sector
- Large Majorana mass
- L violation when non-equilibrium decay

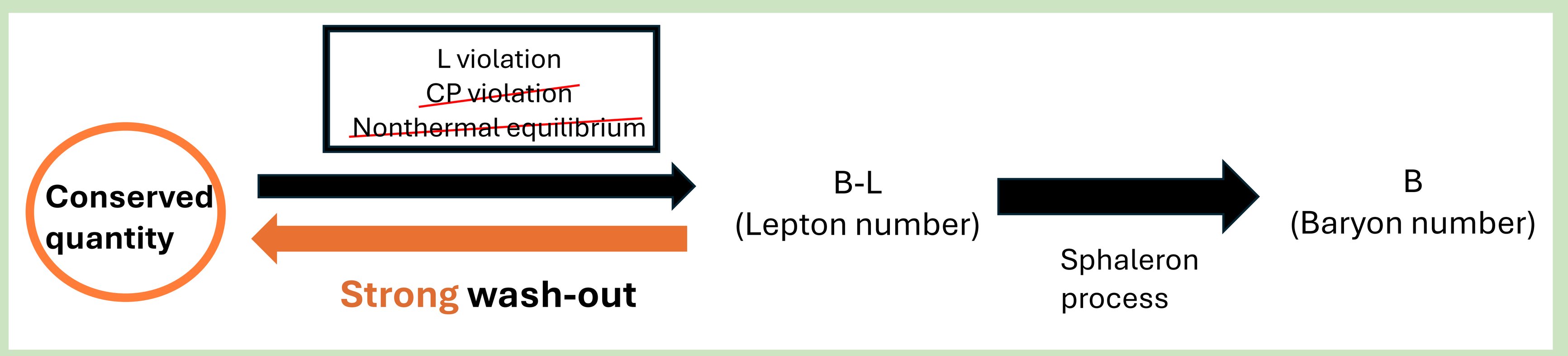
We probe baryon asymmetry without these conditions.

3. Wash-In Leptogenesis

V. Domcke *et al.*, Phys. Lev. Lett. 126 (2021) 201802.

produces B-L through strong wash-out regime

Schematic picture of wash-in leptogenesis



Thermal leptogenesis	Wash-in leptogenesis
Weak wash-out & nonthermal equilibrium	Strong wash-out & thermal equilibrium
CP violation in the neutrino sector	Independent of CP violation
Large Majorana mass	Small Majorana mass

4. Conserved quantity

Conserved quantity : Approximately conserved quantity by decoupling

Decoupling

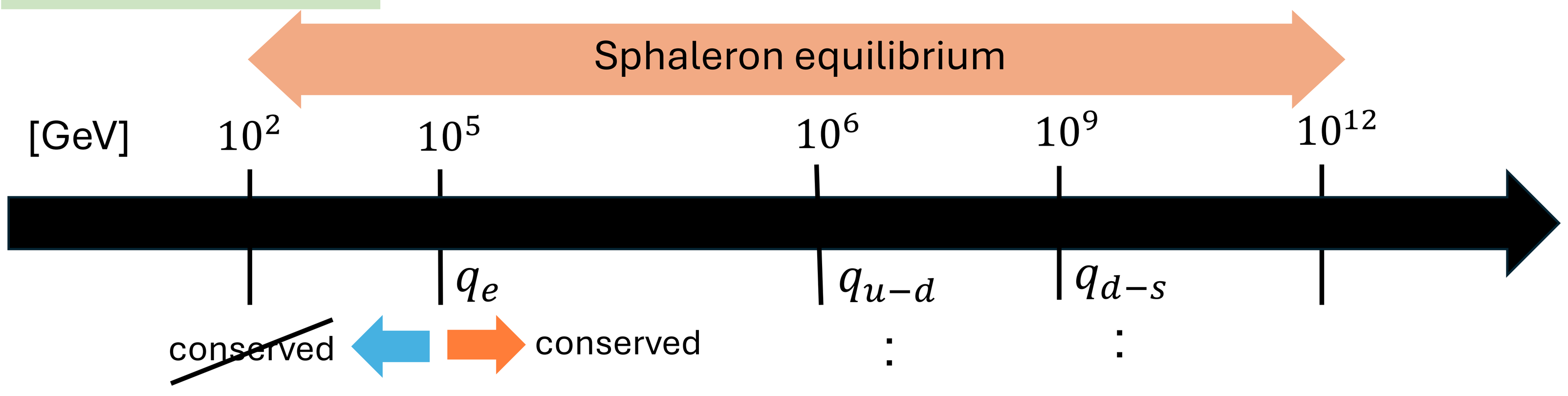
$$\frac{\Gamma}{H} < 1$$

Γ: reaction rate
H: Hubble parameter

For relativistic particles and radiation dominant era

$$\frac{\Gamma}{H} \propto \frac{g^2}{T}$$ { Weaker coupling / Higher temperature → Easier decoupling

g: coupling constant
T: temperature



The first conserved quantity : **q_e(right-handed electron asymmetry)** (b/c ; weak yukawa coupling)

Three Higgs doublet model(3HDM) can produce q_e

5. 3HDM for producing q_e

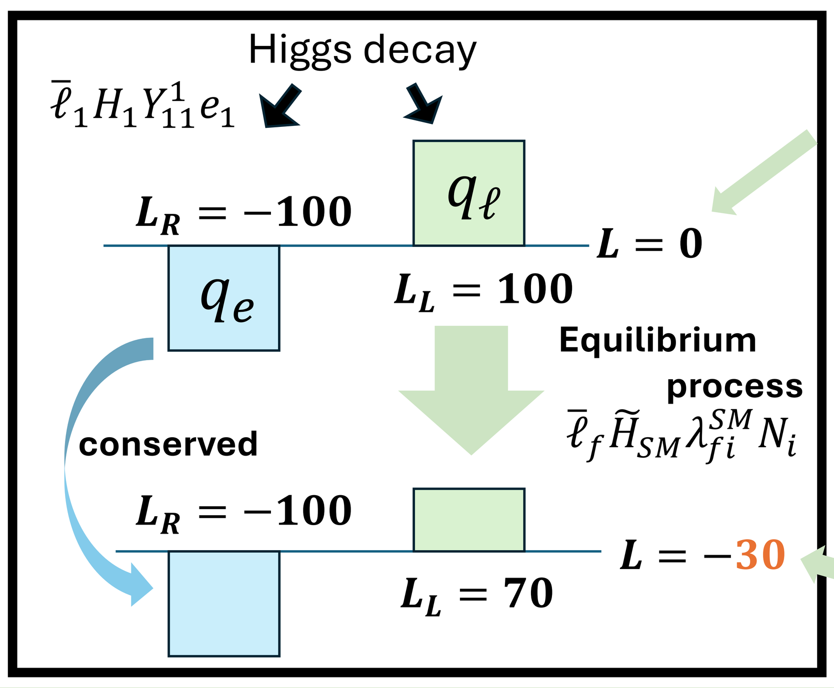
Lagrangian

$$\mathcal{L} = \mathcal{L}_{SM} + \mathcal{L}_{RH\nu} + \mathcal{L}_{HH}$$

$$\mathcal{L}_{RH\nu} = \bar{N}_i i\partial\!\!\!/ N_i - \frac{1}{2}M_i \bar{N}_i N_i - \left(\bar{\ell}_f \tilde{H}_{SM}\lambda^{SM}_{fi} N_i + \text{H.c.}\right)$$

$$\mathcal{L}_{HH} = |DH_\alpha|^2 - M^2_{H_\alpha}|H_\alpha|^2 - \left(\bar{\ell}_f H_\alpha Y^\alpha_{ff'} e_{f'} + \bar{\ell}_f \tilde{H}_\alpha \lambda^\alpha_{fi} N_i + \text{H.c.}\right)$$

Flow of B-L production



H_1 decays into q_e and q_ℓ
(This decay does not directly generate $B-L$)

10^5 GeV $< T_{B-L} < 10^6$ GeV
Only $q_\ell$is diluted by Majorana neutrino

$B-L$ asymmetry is generated

5.1 The amount of q_e for successful leptogenesis

Sphaleron equilibrium

$$q_B = \frac{28}{79}q_{B-L} = -\frac{42}{395}q_e$$

Neutrino yukawa equilibrium

$$q_{B-L} = -\frac{3}{10}q_e$$

observation

$$\frac{q_B}{s} = 8.6\times10^{-11}$$

$$q_e = -8.1\times10^{-10}$$

Need This!!

5.2 Calculation of q_e

Mass hierarchy

$$T_e < T_{B-L} \simeq M_1 < M_{H_1} \lesssim M_{H_2} \ll M_2, M_3$$ with $10^5 < M_1 < 10^6$ GeV.

cf : $M_1 > 10^9$GeV for thermal leptogenesis

Condition for sufficient q_e : Weak Wash-out of Higgs Decay

$$1 \gtrsim \left.\frac{\Gamma_{H_1\to\bar{e}_f\ell}}{H}\right|_{T=M_{H_1}} \Rightarrow M_{H_1} \gtrsim 10^{12}\,\text{GeV}\left(\frac{Y}{0.01}\right)^2$$

How to estimate q_e

$$\frac{q_{e_f}}{s} = \frac{n_{e_f}-n_{\bar{e}_f}}{s} \simeq \frac{\Gamma_{\bar{H}_1\to e_f\bar{\ell}}}{\Gamma^{(0)}_{H_1}}\frac{n_{\bar{H}_1}}{s} - \frac{\Gamma_{H_1\to\bar{e}_f\ell}}{\Gamma^{(0)}_{H_1}}\frac{n_{H_1}}{s} \simeq -\frac{2\Gamma^{(0)}_{H_1\to\bar{e}\ell}}{\Gamma^{(0)}_{H_1}}\epsilon_{\bar{e}_f}\times\frac{45\zeta(3)}{\pi^4}\frac{1}{g_*}$$

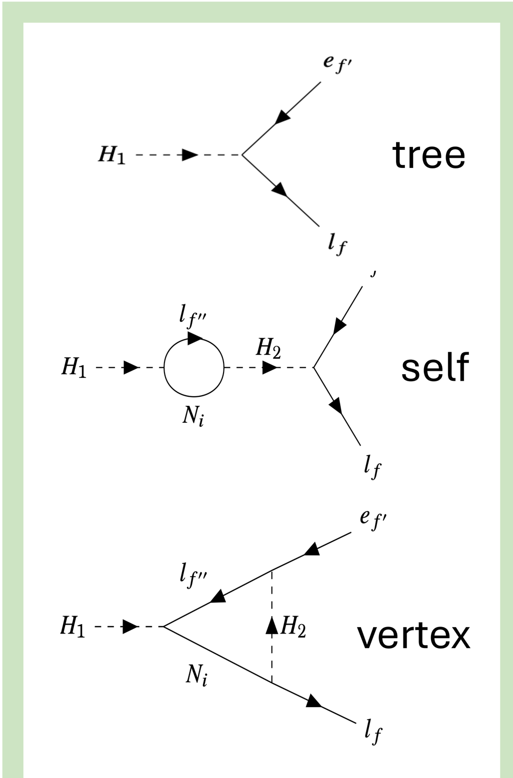
$\epsilon_{\bar{e}_f}$: the asymmetry parameter

$$\epsilon_{\bar{e}_f} \equiv \frac{\Gamma_{H_1\to\bar{e}_f\ell} - \Gamma_{\bar{H}_1\to e_f\bar{\ell}}}{\Gamma_{H_1\to\bar{e}\ell} + \Gamma_{\bar{H}_1\to e\bar{\ell}}}$$

$\epsilon_{\bar{e}_f}$ comes from interference between tree and one-loop diagram

$$\epsilon_{\bar{e}_1} \simeq \frac{1}{8\pi}\frac{\text{Im}\left(Y^1_{11}Y^{2\dagger}_{11}\lambda^1_{11}\lambda^{2\dagger}_{11}\right)}{\text{tr}\left(Y^{1\dagger}Y^1\right)} f(M_{H_2}/M_{H_1}).$$

$$f(x) \equiv f_{self}(x) + f_{vertex}(x), \quad f_{self}(x) \equiv \frac{1}{x^2-1}, \quad f_{vertex}(x) \equiv 1 - x^2\log\left(1+1/x^2\right).$$



Calculation result

$$\frac{q_e}{s} = \frac{q_{e_1}}{s} \simeq -\frac{\kappa}{4\pi}\frac{\text{Im}\left(Y^1_{11}Y^{2\dagger}_{11}\lambda^1_{11}\lambda^{2\dagger}_{11}\right)}{\text{tr}\left(Y^{1\dagger}Y^1\right)+\text{tr}\left(\lambda^{1\dagger}\lambda^1\right)} f(M_{H_2}/M_{H_1}) \times \frac{45\zeta(3)}{\pi^4}\frac{1}{g_*}$$

$$\sim -8\times10^{-10}\delta_{CP}\left(\frac{Y}{0.01}\right)^2,$$

The observed baryon asymmetry can be reproduced.

Summary and future prospect

- Leptogenesis is one of the most attractive scenarios to generate baryon asymmetry.
- We used the approximate conserved quantity(q_e) to generate the asymmetry.
- We will discuss more quantitatively in future work, solving the Boltzmann equation.