Non-Thermal Leptogenesis in Peccei-Quinn Inflation

Theoretical High Energy Physics Group
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What is leptogenesis?

- Leptogenesis is a model that can explain baryon asymmetry of the current universe through the seesaw model

What is different about using the PQ inflation model?

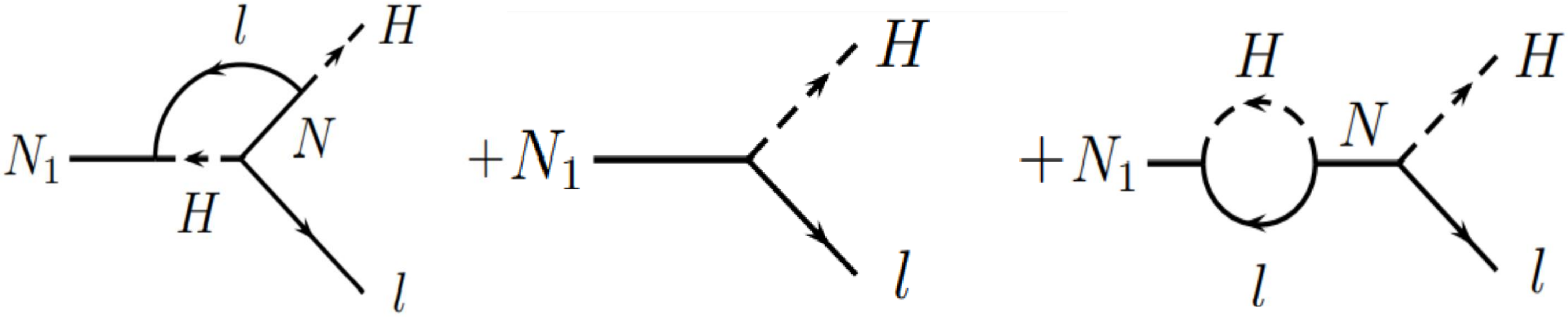
- Non zero Initial number density of RHN!

Leptogenesis

$$\mathcal{L} \supset i\overline{N}_R \gamma^\mu \partial_\mu N_R + h\bar{l}_L H N_R + M_N \overline{N}^c_R N_R + h.c$$

Seesaw Type-1

$\Gamma(N_1 \to \bar{l}_L H) =$



$$i\mathcal{M} = h_{1i} + h^*_{ij} h_{kj} h_{ki} F_N$$

$$\epsilon_1 = \frac{\Gamma(N_1 \to \bar{l}_L H) - \Gamma(N_1 \to l_L H^*)}{\Gamma(N_1 \to \bar{l}_L H) + \Gamma(N_1 \to l_L H^*)} \simeq -\frac{3}{16\pi} \frac{1}{(hh^\dagger)_{11}} \sum_{j=2,3} \mathrm{Im}[(hh^\dagger)^2_{1j}] \frac{M_{N_1}}{M_{N_j}}$$

$N_1(t_e < t < t_{RH}) \cong 0,$

t_e: end of inflation

Initial number density of RHN

$$N_1(t_e < t < t_{RH}) \cong 0,$$

t_e: end of inflation

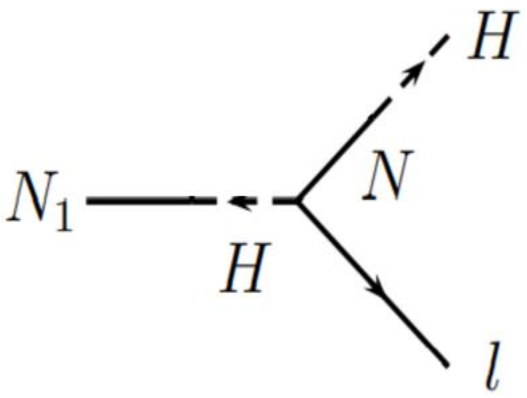
Thermal leptogenesis scenario

$$N_1(t_e < t < t_{RH}) \neq 0,$$

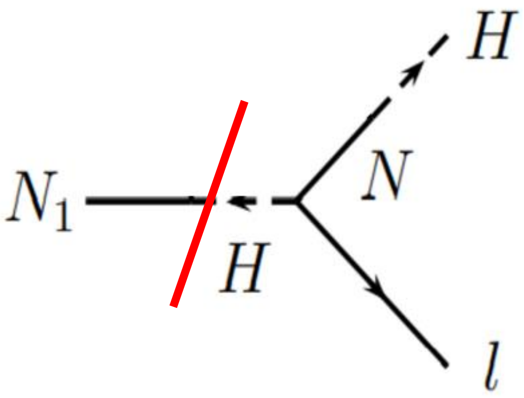
t_e: end of inflation

Non-Thermal leptogenesis scenario
(Our assumption)

Decay



Inverse Decay



$$M_{RHN} \gg T_{RH}$$

Initial number density of RHN

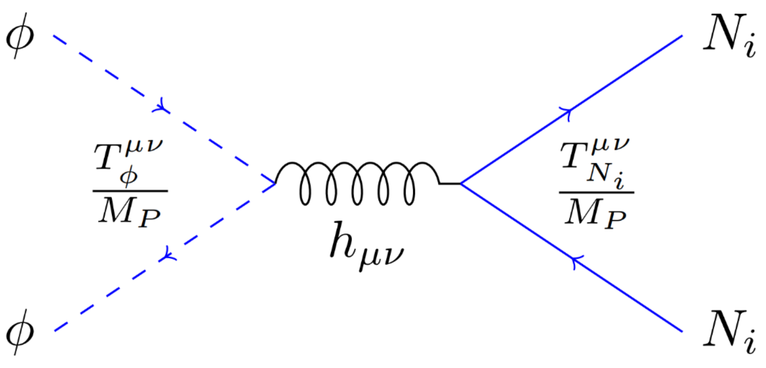
$$N_1(t_e < t < t_{RH}) \neq 0,$$

t_e: end of inflation

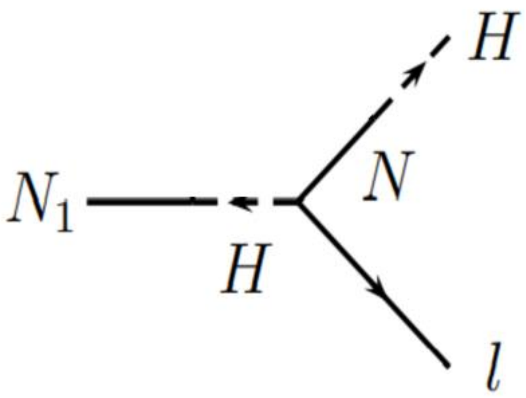
Non-Thermal leptogenesis scenario
(Our assumption)

$$M_{RHN} \gg T_{RH}$$

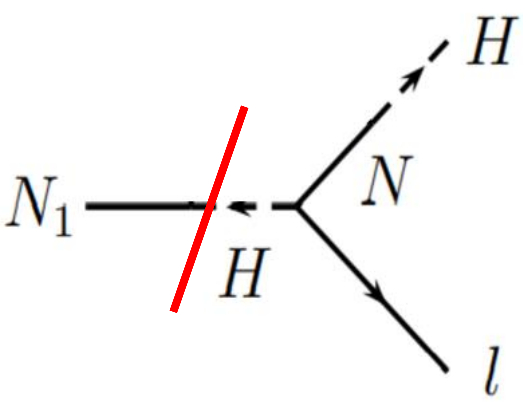
Inflaton scattering



RHN Decay



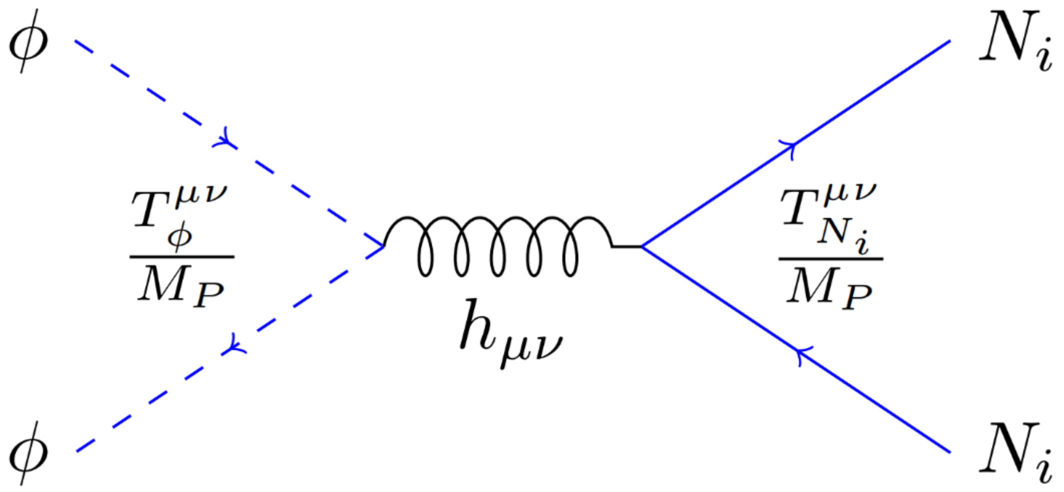
Inverse Decay



Gravitational Production of RHN

$$\sqrt{-g}L^1_{int} = \frac{1}{2M_P} h_{\mu\nu} \left(T^{\mu\nu}_{SM} + T^{\mu\nu}_{\phi} + T^{\mu\nu}_{N} \right).$$

$$g_{\mu\nu} \cong \eta_{\mu\nu} + \frac{h_{\mu\nu}}{M_P}$$

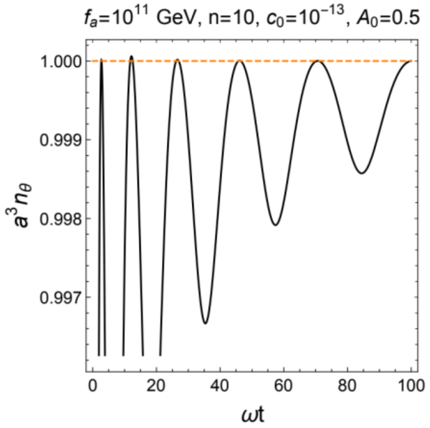


$$|\mathcal{M}^{\phi^k}_n|^2 = \frac{2\rho_\phi^2}{M_P^4} \frac{m_N^2}{s} \left[1 - \frac{4m_N^2}{s} \right] |(\mathcal{P}^k)_n|^2$$

$$\frac{dY^{\phi^k}_{N_1}}{da} = \frac{\sqrt{3}M_P}{\sqrt{\rho_{RH}}} a^2 \left(\frac{a}{a_{RH}} \right)^{\frac{3k}{k+2}} R^{\phi^k}_{N_1}(a)$$

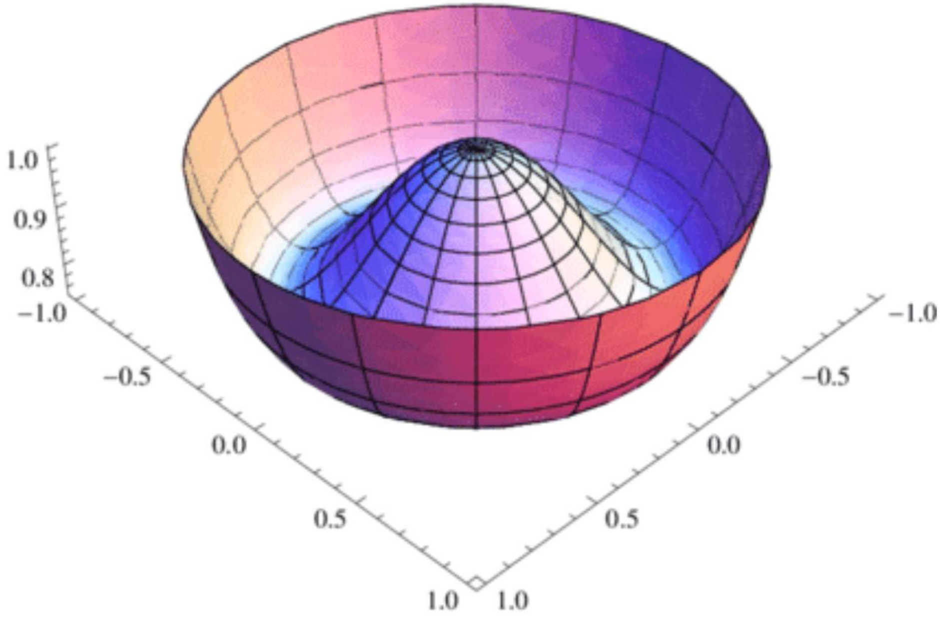
Peccei-Quinn inflation $U(1)_{PQ}$

$$\Phi = \frac{1}{\sqrt{2}}\rho\, e^{i\theta}$$



$$\frac{\mathcal{L}_E}{\sqrt{-g_E}} = -\frac{1}{2}M_P^2 R + \frac{1}{2}(\partial_\mu\phi)^2 + 3M_P^2\sinh^2\left(\frac{\phi}{\sqrt{6}M_P}\right)(\partial_\mu\theta)^2 - V_E(\phi,\theta)$$

$$V_E(\phi,\theta) = V_{\rm PQ}(\phi) + V_{\rm PQV}(\rho,\theta)$$



$$V_{\rm PQ}(\phi) = V_0 + \frac{1}{4}\lambda_\Phi\left(6M_P^2\tanh^2\left(\frac{\phi}{\sqrt{6}M_P}\right) - f_a^2\right)^2$$

$$V_{\rm PQV}(\rho,\theta) = 3^{n/2}M_P^4\tanh^n\left(\frac{\phi}{\sqrt{6}M_P}\right)\sum_{k=0}^{[n/2]}|c_k|\cos\Big((n-2k)\theta + A_k\Big)$$

Interaction

Sub-dominant about Reheating

$$\mathcal{L}_{Q,\text{int}} = -y_Q \Phi \bar{Q}_R Q_L + \text{h.c.}$$

$$\mathcal{L}_{\text{gluons}} = \frac{g_s^2}{32\pi^2}\left(\bar{\theta} + \xi \frac{a}{f_a}\right) G^a_{\mu\nu} \tilde{G}^{a\mu\nu}$$

Due to Strong CP problem!

dominant about Reheating

$$\Delta V_E = \lambda_{H\Phi} |\Phi|^2 |H|^2$$

$$\mathcal{L}_{\text{int}} = -\tfrac{1}{2}\lambda_\Phi \phi^2 a^2$$

$$\frac{\Gamma_{\phi\phi\to aa}}{\Gamma_{\phi\phi\to HH}} \simeq \frac{\lambda_\Phi^2}{2\lambda_{H\Phi}^2}$$

$$\lambda_{H\Phi} \gtrsim \frac{1}{\sqrt{2}}\lambda_\Phi$$

Reheating condition

Matching

Constraints

1. $M_{N_1} = 10^{13} GeV$ 2. $\epsilon_1 = 10^{-6}$ 3. $f_a = 10^{11} GeV$

$Y_B = \frac{n_B}{s} = \frac{28}{79}\epsilon_1 \frac{n_{N1(T_{RH})}}{s}$ ($s = \frac{2\pi^2 g_{RH} T_{RH}^3}{45}$, entropy density)

$Y_B^{Planck} \cong 8.7 \times 10^{-11}$.

1 case :

$\lambda_{H\Phi} = 10^{-10.57}$

T_{reh}: $6.0 * 10^4 GeV$

initial axial velo... $:10^{-6} M_p$

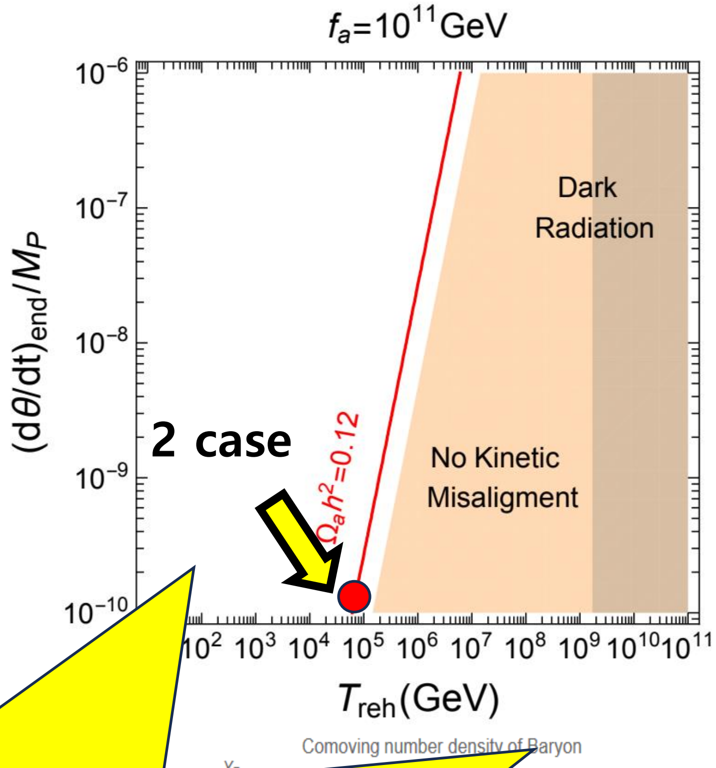
2 case :

$\lambda_{H\Phi} = 10^{-10.6}$

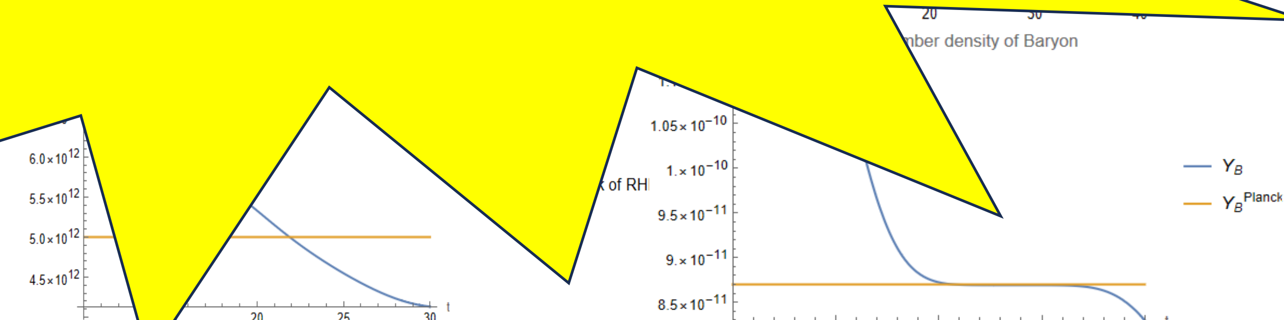
T_{reh}: $5.5 * 10^4 GeV$

initial axial velocity

$10^{-10} M_p$



baryon asymmetry, dark matter abundance, strong CP problem could be solved!



Thank you