Right-Handed Sector Leptogenesis

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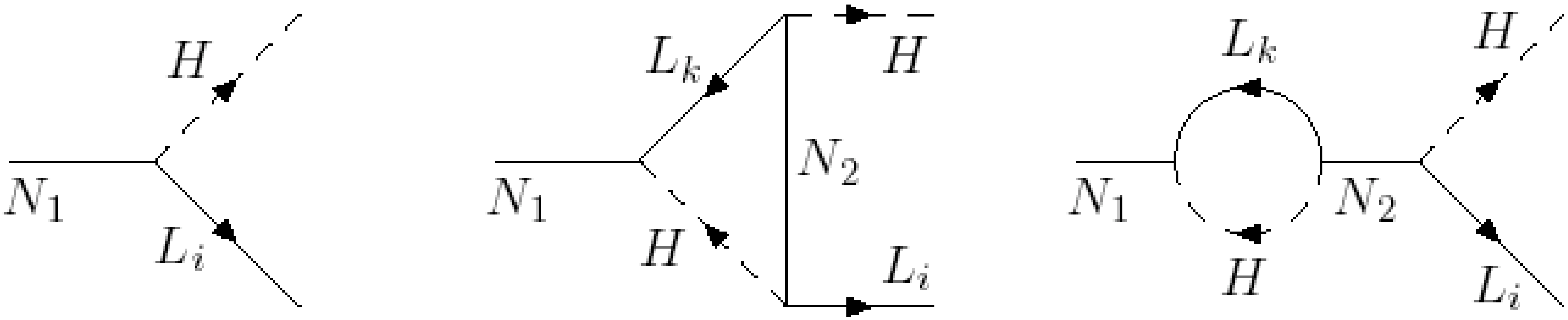
Outline

- Baryogenesis via leptogenesis:
  shortcomings of the usual scenario
- Alternative: right-handed neutrino decays into right-handed charged leptons
- Leptogenesis at scales as low as TeV
- Possible phenomenological tests

Baryogenesis via Leptogenesis

- Majorana mass term $M_i N_i N_i$ for super-heavy sterile neutrinos N_i violates Lepton Number and induces a small active neutrino mass $m_\nu \approx v^2 / M_i$
- N_1 decays at $T \approx M_1$ out-of-equilibrium generating a lepton asymmetry by the interference between tree and loop diagrams: $\epsilon_L \sim [\, \Gamma(N_1 \to LH) - \Gamma(N_1 \to L^*H^*) \,]$
- Standard Model B+L violating effects at $T > v$ convert lepton into baryon asymmetry.
  Since $[n_B/s]_{exp} \sim 10^{-10} \leq 10^{-3}\, \epsilon_L$, one needs $\epsilon_L \geq 10^{-7}$



Quantifying lepton asymmetry

- Quick estimate:

$$\epsilon_L \sim [Y_N^{(2)}]^2 \frac{M_1}{M_2} \qquad \frac{m_\nu}{v} \sim \sum_i [Y_N^{(i)}]^2 \frac{v}{M_i}$$

- Leptogenesis is viable only at super-heavy scale: $m_\nu/v \approx 10^{-12}$ and $\epsilon_L \geq 10^{-6}$ imply $M_1 > 10^6 v \approx 10^8$ GeV >> TeV, so that no direct test is conceivable

- Qualitatively the same lower bound on the scale holds even if an $SU(2)_L$ triplet Higgs is added (type I + II seesaw)

- If neutrino Yukawas Y_N are hierarchical (as in most unified models), ϵ_L is further suppressed: leptogenesis may not work even at super-heavy scale

- In supergravity models, the large reheating temperature needed to produce N_1 above 10^8 GeV may lead to gravitino overproduction

N_i Yukawa couplings

What Higgs multiplets couple RH neutrinos to SM leptons?

Under $SU(2)_L \times U(1)_Y$: $N(1,0)$, $L(2,-1/2)$, $l_R(1,-1)$

$$\mathcal{L} \ni -Y_N H^\dagger \bar{N} L - Y_R \delta^+ N^T C l_R$$

Usual leptogenesis employs only the coupling Y_N

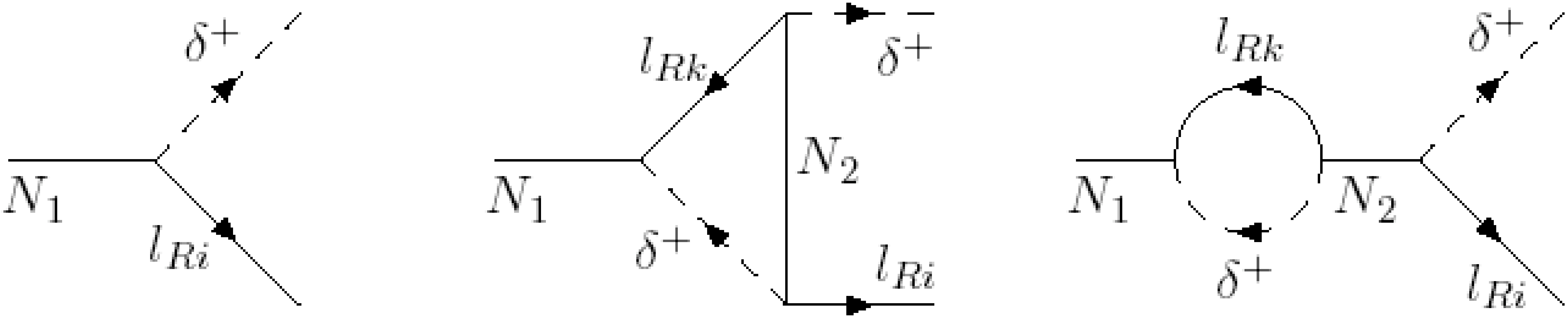
However natural extensions of the SM may contain δ^+:

- SU(5) models: $\delta^+ \in 10_H$
- $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$ models:
  [i] $\delta^+(1,1,2)$ [ii] $\Delta_R(1,3,2) = (\Delta_R^{++}, \Delta_R^+, \Delta_R^0)$
- SO(10) models: [i] $\delta^+ \in 120_H$ [ii] $\Delta_R \in 126_H$

Due to the coupling Y_R, N_i have an alternative decay channel:

$$N_i \to l_{Rj}\delta^+ \qquad N_i \to l_{Rj}\Delta_R^+$$

New source of lepton asymmetry



- We assume always $M_{\delta^+} < M_1$: otherwise asymmetry from δ^+ decays is washed out by N_1 interactions (as well as gauge scattering)
- In ordinary leptogenesis the Higgs has lepton number 0. Here δ^+ has $L = -2$ ($\delta^+ \rightarrow l^+$ anti-ν), while Δ_R^+ has $L=0$ ($\Delta_R^+ \rightarrow l^+ l^- H^+$).
- N_1 decays proceed through Y_R as well as Y_N (but Y_N produces negligible asymmetry for $M_1 << 10^8$GeV)

Constraints on Y_R couplings

$$\varepsilon_L = \frac{1}{8\pi} \boxed{\frac{\mathcal{I}m[(Y_R Y_R^\dagger)^2_{12}]}{\sum_i |(Y_R)_{1i}|^2}} \frac{M_{N_1}}{M_{N_2}}$$

$[Y_R^{(2)}]^2$

(1) To generate $\epsilon_L \geq 10^{-6}$:

$$Y_R^{(2)} \geq 1.3 \cdot 10^{-3} \sqrt{\frac{M_{N_2}}{M_{N_1}}}$$

$$\Gamma_{N_1} = \frac{1}{16\pi} M_{N_1} \boxed{\sum_i |(Y_R)_{1i}|^2}$$

$[Y_R^{(1)}]^2$

(2) To avoid washout from N_1 inverse decays, $\Gamma_{N1} \leq H(T=M_{N1})$:

$$Y_R^{(1)} \leq 0.3 \cdot 10^{-3} \sqrt{\frac{M_{N_1}}{10^9 \mathrm{GeV}}}$$

(3) $\Delta L=2$ scatterings due to N_2 are negligible for scales as low as few TeVs.

M_1 as light as few TeVs

requires $Y_R^{(1)} / Y_R^{(2)} \sim 10^{-4}$

Low scale leptogenesis

Set of parameters for successful RH leptogenesis:

$$M_1 = 2\text{TeV} \ , \quad M_2 = 6\text{TeV} \ , \quad M_\delta \simeq 750\text{GeV} \ ,$$
$$Y_R^{(2)} \simeq 4 \cdot 10^{-3} \ , \quad Y_R^{(1)} \simeq 10^{-7}$$

Let us recall the crucial difference w.r.t. LH leptogenesis:

$$\epsilon_L \sim [Y_R^{(2)}]^2 \frac{M_1}{M_2} \qquad\qquad \frac{m_\nu}{v} \sim \sum_i [Y_N^{(i)}]^2 \frac{v}{M_i}$$

Light neutrino masses + TeV scale RH neutrinos:

very small Y_N couplings are needed, while $Y_R^{(2)}$ may be large

Low scale leptogenesis can also be obtained by resonant enhancement of ϵ_L. Here it is not needed: (i) no quasi-degenerate states (ii) no cancellations between $Y_N^{(i)}$

Phenomenological signatures

- A sufficiently light δ^+ is produced at colliders from photon (or Z^0) in Drell-Yan processes and it decays into l^+ and anti-ν (or $l^+ l^- H^+$ in the triplet case).
- If a δ^+ is observed as part of the EW Higgs sector, RH leptogenesis would become as plausible as the usual one.
- $N_{2,3}$ may be produced at few TeVs (through $Y_R^{(2,3)} > 10^{-3}$); this would generically imply low scale baryogenesis.
- Lepton Flavor Violation by δ^+ exchange: $\mu \to e\gamma$ may be around the corner due to couplings to LH leptons; however the couplings needed for leptogenesis are safe:

$$\mathrm{Br}(\mu \to e\gamma) \approx \frac{\alpha}{192\pi} \frac{|(Y_R)_{ie}(Y_R)_{i\mu}|^2}{M_i^4 G_F^2} \lesssim 10^{-17}$$

Minimal, but not minimal LR

- Minimal model in terms of particle content and assumptions: just add a charged scalar to SM + RHνs.
  Alternatives for low scale leptogenesis require (i) N_1 three-body decays (ii) L-violating soft-terms in MSSM+RHνs (iii) four neutrino generations.

- In the Minimal Left-Right model the charged scalar Δ_R^+ is part of the $SU(2)_R$ triplet Δ_R and may be lighter than N_1.
  Δ_R^{++} interactions do not violate L and Δ_R^0 is weakly coupled to N_1: no significant washout.

- But Minimal LR is too simple: $Y_R\,(N\,l_R)\,\Delta_R\,(N\,l_R)^T$
  (i) generates N masses (ii) mediates N decays.
  Each N_i mass eigenstate couples only to l_{Ri} :
  no interference and no production of lepton asymmetry!

- Non minimal solutions: (i) second triplet (ii) other sources of N masses (iii) singlet RH leptogenesis

Summary

- The lepton asymmetry related to neutrino masses is often insufficient to reproduce the correct amount of baryon asymmetry (in particular at scales < 10^8 GeV).

- In most extensions of the Standard Model, the RH neutrinos couple also to RH charged leptons, through the Higgs singlet δ^+.

- Extra lepton asymmetry is generated by $N_i \to l_{Rj}\, \delta^+$. RH leptogenesis is successful for masses M_i and M_δ at scales as low as TeV.

- δ^+ may be revealed in colliders and may mediate sizable $\mu \to e\gamma$; $N_{2,3}$ may be produced at few TeV scale through the same large Yukawa coupling which generates ϵ_L .