Right-Handed Sector Leptogenesis

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Outline

- Baryogenesis via leptogenesis
- Some limits of the usual leptogenesis scenario
- The role of a charged Higgs singlet δ^+
- Lepton asymmetry from right-handed leptons
- Leptogenesis at TeV scale: phenomenological signatures

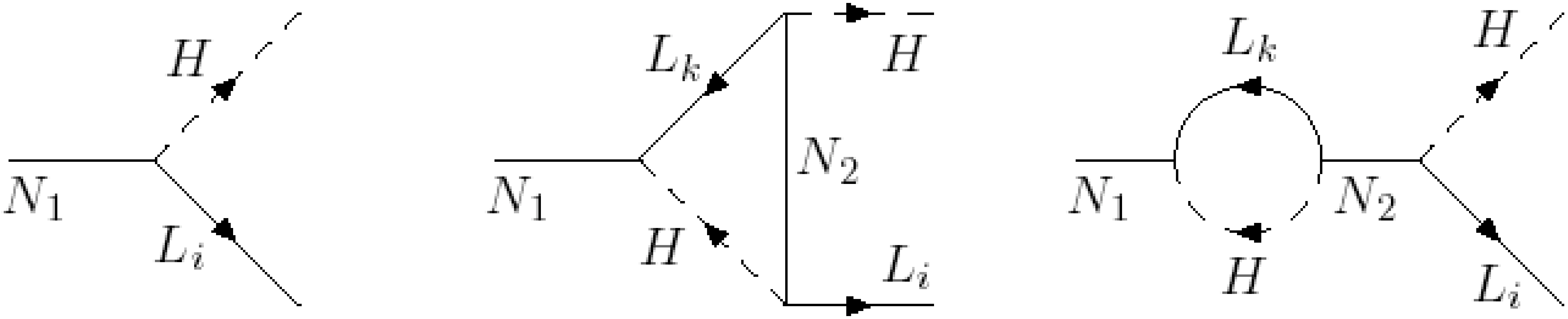
Baryogenesis via Leptogenesis

- Non-zero neutrino mass m_ν (if it is Majorana-type) points to high scale Lepton Number Violation
- Simplest mechanism to generate m_ν is the seesaw: the source of LNV is the mass term $M_N NN$ for a super-heavy sterile neutrino N: $m_\nu \approx v^2 / M_N$
- Possible origin of the matter-antimatter asymmetry of the Universe:

  (i) an heavy neutrino N decays at $T \approx M_N$ out-of-equilibrium generating a lepton asymmetry

  (ii) Standard Model B+L violating effects at $T > v$ convert lepton into baryon asymmetry

Quantifying lepton asymmetry



- From the interference between tree and loop diagrams: $\epsilon_L \sim [\ \Gamma(N_1 \to LH) - \Gamma(N_1 \to L^*H^*)\ ]$
- Baryon Asymmetry of the Universe requires $n_B/s \sim 10^{-10} \leq 10^{-3}\ \epsilon_L$ that is, one needs $\epsilon_L \geq 10^{-7}$
- 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: $m_\nu/v \approx 10^{-12}$ implies $M_1 > 10^6\,v \sim 10^8$ GeV >> TeV

Limits of the usual Leptogenesis

- No direct detection: the lepton asymmetry is generated at scale > 10^8 GeV
- Qualitatively the same lower bound on the scale is present in models which contain also an $SU(2)_L$ triplet Higgs (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's above 10^8 GeV may lead to gravitino overproduction

N_R Yukawa couplings

What Higgs multiplets couple RH neutrinos to SM leptons?

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

$$\mathcal{L} \ni -Y_N H^\dagger \bar{N} L - Y_R \delta^+ N^T C l_R - Y_L \delta^+ L^T C i\tau_2 L$$

Usual leptogenesis employs only the coupling Y_N

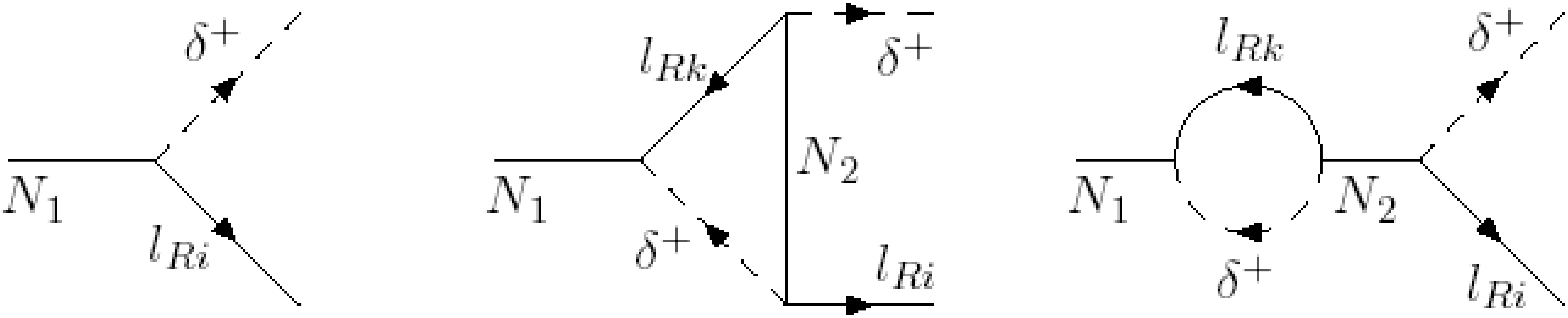
However natural extensions of the SM may contain δ^+

- 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] $\Delta_R(1,3,2) = (\Delta_R^{++}, \Delta_R^+, \Delta_R^0)$, in this case Y_L is forbidden
- SO(10) models: [i] $\delta^+ \in 120_H$ [ii] $\Delta_R \in 126_H$

Due to the coupling Y_R, N's have an alternative decay channel:

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

New source of lepton asymmetry



- We assume always $M_{\delta+} < M_{Ni}$: otherwise asymmetry from δ^+ decays is washed out by N_i interactions (as well as gauge scattering)
- In ordinary leptogenesis H has zero lepton number. Here δ^+ has $L = -2$ if Y_L is present ($\delta^+ \to l^+$ anti-ν) or $L=0$ if Y_L is forbidden ($\delta^+ \to l^+ l^- H^+$)
- N_l decays proceed through Y_R as well as Y_N (but Y_N produces negligible asymmetry for $M_{Nl} << 10^8$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

- If a δ^+ is produced at colliders (e.g. from a photon in Drell-Yan processes), RH leptogenesis would become as plausible as the LH one.
- δ^+ decays into (l^+ + anti-ν) if it is $SU(2)_R$ singlet or decays into ($l^+ l^- H^+$) if it is part of a triplet
- If $N_{2,3}$ is produced at few TeVs (through $Y_R^{(2,3)} > 10^{-3}$), this would generically imply low scale baryogenesis
- Lepton Flavor Violation by δ^+ exchange: a sizable contribution may come from Y_L couplings to LH leptons:

$$\mathrm{Br}(\mu \to e\gamma) \approx \frac{\alpha}{48\pi} \frac{|(Y_L)_{e\tau}(Y_L)_{\mu\tau}|^2}{M_\delta^4 G_F^2}$$

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 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

- Usual leptogenesis relates the baryon asymmetry to neutrino masses, but there is a price to pay: it works only at super-heavy scales
- If RH neutrinos decay into RH charged leptons, leptogenesis may work at for masses M_N and M_δ at scales as low as TeV
- One needs to introduce a scalar singlet δ^+, which appears naturally in minimal Grand Unified Theories
- δ^+ can be produced in colliders e.g. from a photon and it may also mediate sizable $\mu \to e\gamma$; N_2 can be produced through the large coupling which generates also ϵ_L