LEPTOGENESIS FROM RIGHT-HANDED NEUTRINO DECAYS TO RIGHT-HANDED LEPTONS

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We investigate what would be the consequences for leptogenesis of the existence of a charged $SU(2)_L$ singlet scalar $\delta^+$. If such a scalar particle exists it allows the right-handed neutrinos to couple not only to left-handed lepton and Higgs doublets as in ordinary leptogenesis, but also to a right-handed charged lepton and a $\delta^+$. This provides a new source of leptogenesis which can be successful in a non-resonant way at scales as low as TeV. The incorporation of this scenario in left-right symmetric and unified models is discussed.

1 Introduction

The leptogenesis mechanism\cite{1} provides a particularly simple and well motivated explanation for the origin of the baryon asymmetry of the universe. Its motivation is based on the recent discovery of the neutrino masses and the fact that these masses are most presumably associated with lepton number violation. The lepton number violation associated to the neutrino masses can create a lepton number asymmetry at high temperature in the universe. This results in the creation of a baryon asymmetry from the lepton to baryon conversion induced by the Standard Model sphalerons associated to the $B + L$ anomaly. The most straightforward and presumably most attractive way to induce the neutrino masses and leptogenesis is the type-I seesaw model\cite{2} in which the lepton asymmetry can be produced from the effect of the L violating right-handed (RH) neutrino Majorana masses in the RH neutrino decays.

In a generic way leptogenesis from decay of RH neutrinos can easily lead to the observed baryon asymmetry of the universe, i.e. to a baryon to entropy density of the universe equal to $n_B/s = 9 \cdot 10^{-11}$. However there are at least two criticisms one could make on this framework. The first is more pragmatic than theoretical: due to the smallness of the neutrino masses, in a generic way type-I leptogenesis can work only at a very high scale\cite{3} (i.e. if $M_{N_1} \gtrsim 4 \cdot 10^8$...
GeV where $N_1$ is the lightest RH neutrino). Beside the fact that this bound is in tension with the gravitino constraint in supergravity theories, basically it implies that leptogenesis could never be tested directly. The second criticism is more theoretical: at such scale far beyond the reach of present accelerators we have of course no guarantee at all that the right-handed neutrinos exist and that they provide the only source of lepton number violation. It turns out that there are quite a few other ways to induce successful leptogenesis at a high scale. Leptogenesis is a mechanism which in this sense works even too easily. For example, an alternative source of neutrino masses which can lead to successful leptogenesis, and which is well motivated in unified theories such as SO(10), Pati-Salam or left-right model, is the type II seesaw. It involves the interactions of a heavy $SU(2)_L$ triplet Higgs $\Delta_L$. Other seesaw possibilities of successful leptogenesis arise if there are two or more heavy Higgs triplets or if self-conjugate triplets of fermions $\Sigma$ exist. These models also work generically only at a high scale, i.e. if $M_{\Delta_L} \gtrsim 2.5 \cdot 10^{10} \text{GeV}$ or if $M_{\Sigma} \gtrsim 1.5 \cdot 10^{10} \text{GeV}$.

Beside looking at the various leptogenesis possibilities at a high scale, in the absence of any real possibilities to distinguish these models experimentally, another important question to investigate is to see more phenomenologically what are the basic mechanisms and interactions which could induce successful leptogenesis at a directly testable low scale, even if in this case there is always a price to pay in terms of assumptions to be made (particle content extended and/or fine-tuning assumed, naturalness in grand unified theories, relaxation of the links between neutrino mass constraints and leptogenesis). At low scale too, it turns out that there are several possibilities to induce leptogenesis, resonant ones or non-resonant ones. In this talk I want to emphasize the fact that low scale leptogenesis doesn’t necessarily require to assume a quasi-degeneracy of the heavy particle mass spectrum or to assume two sources of lepton number violation, one for neutrino masses and a different one for leptogenesis. I present a new mechanism of leptogenesis which can work at low scale, where a) neutrino masses are induced as in the type-I model, b) the source of lepton number violation remains the same (i.e. the Majorana masses of RH neutrinos $N_i$), and c) the decays of the RH neutrinos are also at the origin of leptogenesis, but where d) the interactions driving dominantly the decays of the right-handed neutrinos, instead of involving the left-handed Standard Model (SM) leptons, involve the right-handed SM leptons. The price to pay with respect to high energy models is that, in order that the right-handed neutrinos can decay to right-handed leptons, a new particle has to be assumed to exist, a $SU(2)_L$ singlet charged scalar $\delta^+$. I show that if this particle exists leptogenesis can be implemented in a very simple way even at scales as low as $\sim \text{TeV}$. This work is based on a collaboration with Michele Frigerio and Ernest Ma.

2 The Model

The minimal implementation of our mechanism requires that, in addition to the SM particles, there exist two or more RH neutrinos $N_i$ and a charged scalar $SU(2)_L$ singlet $\delta^+$. From this particle content one can write down the most general lagrangian and the interactions involving the $\delta^+$:

$$\mathcal{L} \supset -M_\delta^2 \delta^+ \bar{\delta}^+ + \left[ -\frac{1}{2} M_{N_i} N_{iR}^T C N_{iR} - H^\dagger \bar{N}_i (Y_N)_{ij} \psi_{jL} ight. \\
- (Y_R)_{ij} N_{iR}^T C \delta^+ l_{jR} - (Y_L)_{ij} \psi_{iL}^T C i \tau_2 \delta^+ \psi_{jL} + h.c. \right], \quad (1)$$

with $\psi_{iL} = (\nu_{iL}, l_{iL})^T$ and $H = (H^0, H^-)^T$.

We consider the possibility that the scalar singlet is lighter than the RH neutrinos and we neglect, at this stage, the effects of the $Y_N$ couplings, which are not relevant to achieve our main results. We neglect their effects at this stage. In this case leptogenesis can be induced simply
by replacing in the diagrams of the standard leptogenesis model, both in the loop and in the final state, the left-handed lepton doublet with the RH charged lepton, $e_R$, $\mu_R$ or $\tau_R$ and the Higgs doublet with the scalar singlet, as shown in Fig. 1. For the lightest RH neutrino $N_1$, the CP asymmetry, that is to say the average $\Delta L$ which is produced each time a $N_1$ decays in the thermal bath of the universe at a temperature of order its mass $M_{N_1}$, is:

$$\varepsilon_{N_1} = \sum_i \frac{\Gamma(N_1 \to l_{iR} + \delta^+) - \Gamma(N_1 \to \bar{l}_{iR} + \delta^-)}{\Gamma_{N_1}} \cdot C_L,$$

(2)

with its tree level decay width given by

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

(3)

In Eq. (2), $C_L$ is the lepton number produced in the decay $N_1 \to l_{iR} + \delta^+$. Unlike the Higgs doublet in the standard leptogenesis case, $\delta^+$ does not have a vanishing lepton number. Once produced from the decay of the RH neutrinos, it decays to 2 left-handed antileptons, via the $Y_L$ couplings, so that it has $L = -2$ which gives $C_L = -1$. Calculating the one loop diagrams of Fig. 1 one finds

$$\varepsilon_{N_1} = \frac{1}{8\pi} C_L \sum_j \frac{\mathcal{I}_m[(Y_RY_R^\dagger)_{1j}]}{\sum_i |(Y_R)_{1i}|^2} \sqrt{x_j} \left[ 1 - (1 + x_j) \log \left( 1 + \frac{1}{x_j} \right) + \frac{1}{2} \frac{1}{1 - x_j} \right],$$

(4)

where $x_j = M_{N_j}^2/M_{N_1}^2$. For this calculation we neglected $(M_\delta/M_{N_1})^2$ corrections which are small as soon as the $\delta^+$ is a few times lighter than $N_1$ as we assume here. In the limit where we also neglect the $M_{N_1}^2/M_{N_{2,3}}^2$ corrections, we get

$$\varepsilon_{N_1} = -C_L \frac{1}{8\pi} \sum_j \frac{\mathcal{I}_m[(Y_RY_R^\dagger)_{1j}]}{\sum_i |(Y_R)_{1i}|^2} \frac{M_{N_1}}{M_{N_j}},$$

(5)

Apart for the $C_L$ factor and for a combinatoric factor of two in the self-energy contribution, this asymmetry is the same as in the standard case, replacing the ordinary Yukawa couplings $Y_N$ by the $Y_R$ scalar singlet ones. Contrary to the standard case, however, the RH Yukawa couplings $Y_R$ do not induce any neutrino masses and so are not constrained by them. As a result this mechanism may easily lead to successful leptogenesis and may also work at a much lower scale, as explained below, which is phenomenologically interesting.

Considering for simplicity only 2 RH neutrinos $N_{1,2}$ (the effect of $N_3$ can be straightforwardly incorporated), numerically to have successful leptogenesis there are essentially 3 constraints:

- The total baryon asymmetry produced is given by:

$$\frac{n_B}{s} = -\frac{28}{79} \frac{n_L}{s} = -\frac{135\zeta(3) 28}{4\pi^2 g_*} \varepsilon_{N_1} \eta = -1.36 \cdot 10^{-3} \varepsilon_{N_1} \eta,$$

(6)
The factor $-28/79$ is the lepton to baryon number conversion factor due to the effects of the sphalerons of the Standard Model. $n_B$, and $n_L$ and $s$ are the baryon number, lepton number and entropy densities. The factor $g_* = 108.75$ appears to take into account the fact that only a fraction $\sim 1/g_*$ of the entropy is due to the decaying $N_1$. $\eta$ is the efficiency factor to take into account the thermalization effects. $\eta = 1$ if all $N_1$ decay perfectly out of equilibrium and if there are no fast L violating scatterings occurring after the $N_1$ decays. $\eta < 1$ if the $N_1$ decay partly in thermal equilibrium with the thermal bath. For a maximal efficiency, $\eta = 1$, the requirement to reproduce the data (i.e. $\frac{\eta}{g_*} = 9 \cdot 10^{-11}$) implies that

$$Y_R^{(2)} \equiv \sqrt{\frac{Im \left[ \sum_i (Y_R)_{1i} (Y_R^*)_{2i} \right]^2}{\sum_i (Y_R)_{1i} (Y_R^*)_{1i}}} \geq 1.3 \cdot 10^{-3} \sqrt{\frac{M_{N_2}}{M_{N_1}}}, \quad (7)$$

which means that at least one of the $(Y_R)_{2i}$ coupling needs to be of order $10^{-3} \sqrt{M_{N_2}/M_{N_1}}$ or larger.

- To avoid a suppression of the efficiency associated to the inverse decay of a $l_R$ and a $\delta^+$ into a $N_1$, the decay width has to be smaller than the expansion rate of the universe:

$$\Gamma_{N_1} < H(T)|_{T=M_{N_1}} = \frac{4\pi^2 g_*}{45} \frac{T^2}{M_{Planck}}|_{T=M_{N_1}}. \quad (8)$$

Using Eq. (3), the corresponding upper bound on the $(Y_R)_{1i}$ couplings reads

$$Y_R^{(1)} \equiv \sqrt{\sum_i |(Y_R)_{1i}|^2} < 3 \cdot 10^{-4} \sqrt{\frac{M_{N_1}}{10^9 \text{GeV}}}. \quad (9)$$

Larger values of $Y_R^{(1)}$ lead to suppression of the efficiency which, for successful leptogenesis, has to be compensated by larger values of the $(Y_R)_{2i}$ couplings in the numerator of the asymmetry $\epsilon_{N_1}$.

- If Eq. (8) is satisfied, the lepton number washout from $\Delta L = 2$ scattering mediated by a $N_1, l_R \delta^+ \leftrightarrow l_R \delta^-$, is negligible, because its rate is also smaller than the Hubble rate, see e.g. (7). Taking values for $(Y_R)_{2i}$ consistent with Eq. (7), the washout from the same $\Delta L = 2$ scattering mediated by a $N_2$ is generically negligible, except possibly for $M_{N_1}$ as low as a few TeV (because for fixed values of the Yukawa couplings, the Hubble rate decreases faster than the scattering rate when $T \simeq M_{N_1}$ decreases). In fact, this effect depends on the interplay of $Y_R^{(1)}$, $M_{N_1}$, $M_{N_2}/M_{N_1}$ as well as of the $(Y_R)_{2i}$ couplings. This interplay can be determined from the Boltzmann equations. Considering them explicitly, we have checked that even at scales as low as a few TeV, an efficiency of order one can be obtained easily (see (151, 172)).

Combining the 3 constraints above, successful leptogenesis can be achieved in a large region of parameter space. The scale at which the lepton asymmetry may be produced depends on the hierarchy between the $Y_R$ couplings of $N_2$ and $N_1$. This can be quantified by combining Eqs. (7) and (9): 

$$\frac{Y_R^{(1)}}{Y_R^{(2)}} < 0.2 \cdot \sqrt{\frac{M_{N_1}}{M_{N_2}}} \frac{M_{N_1}}{10^9 \text{GeV}}. \quad (10)$$

This condition is easily satisfied for $M_{N_1} \simeq 10^{9-15}$ GeV. When, for example, $M_{N_1}/M_{N_2} \sim 0.1$ and $M_{N_1} = 10^7$ GeV, at least one of the $(Y_R)_{2i}$ couplings needs to be about two orders of magnitude larger than the $(Y_R)_{1i}$. At scale as low as 1-10 TeV the hierarchy needed is more
substantial, of about 4 orders of magnitude, but this is not unrealistic for Yukawa couplings (the hierarchy needed is of the order of the one in the SM Yukawa couplings). An example of a set of parameters leading to an efficiency of order one and to a baryon asymmetry in agreement with the observed one is: $M_{N_1} = 2$ TeV, $M_{N_2} = 6$ TeV, $(Y_R)^{max}_{2i} \simeq 4 \cdot 10^{-3}$, $(Y_R)^{(1)} \simeq 10^{-7}$ and $M_\delta \simeq 750$ GeV. We find that successful leptogenesis can be generated with $M_{N_1}$ as low as $\simeq 1$ TeV and with $M_{N_2}$ as low as $\simeq 4$ TeV.a

So far we have neglected the effects of the ordinary $Y_N$ Yukawa couplings which are necessary to induce the neutrino masses. Switching them on leads to more tree-level and one-loop diagrams, see more details in Ref. 20. At high scales, $M_{N_1} \gtrsim 4 \cdot 10^8$ GeV, these diagrams can induce successful leptogenesis just as in the ordinary scenario. At lower scales they can’t because the neutrino constraints require too small values of $Y_N$ couplings. But, still in this case, they can have a suppression effect on the asymmetry produced by the $Y_R$ couplings through the $Y_N$ contribution to the tree level decay width in the denominator

$$\Gamma_{N_1} = \frac{1}{16\pi} M_{N_1} \sum_i |(Y_R)_{1i}|^2 + \frac{1}{8\pi} M_{N_1} \sum_i |(Y_N)_{1i}|^2.$$  \hspace{1cm} (11)

entering in the denominator of Eq. 11. Just as in the standard leptogenesis mechanism, there will be no inverse decay washout effect if $N_1$ contributes to light neutrino masses by less than $10^{-3}$ eV, that is to say if the solar and atmospheric mass splittings are dominated by the contributions of $N_2$ and $N_3$. In fact, Eq. 11 now implies the constraint (9) as well as

$$\frac{v^2 \sum_i |(Y_N)_{1i}|^2}{M_{N_1}} < 10^{-3} \text{eV}.$$  \hspace{1cm} (12)

In the opposite case, larger $Y_R$ couplings to $N_2$ and/or $N_3$ are required for successful leptogenesis, in order to increase $\epsilon_{N_1}$ thus compensating for the washout factor $\eta < 1$.

### 3 Leptogenesis with a right-handed scalar triplet

As explained above, the $\delta^+$ must be a singlet of $SU(2)_L$ in order that the RH neutrinos can decay into it. It is important to note that this doesn’t necessarily mean that the $\delta^+$ must also be a singlet of any other gauge group. If the theory of particle interactions beyond the Standard Model contains left-right symmetry[21] based on the group $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$, one simple possibility is that the $\delta^+$ is the charge-one component of an $SU(2)_R$ triplet $\Delta_R$. In this case the leptogenesis mechanism discussed in section 2 is slightly modified. The relevant interactions are\(^b\)

$$\mathcal{L} \ni -M_\Delta^2 T_R \Delta_R^+ \Delta_R + \left[ -\frac{1}{2} M_{N_i} N^T_{Ri} C N_{Ri} - H^\dagger \bar{N}_{Ri} (Y_N)_{ij} \psi_{jL} \\
- (Y_\Delta)_{ij} \psi^T_{iR} C i\tau_2 \Delta_R \psi_{jR} + \text{h.c.} \right],$$  \hspace{1cm} (13)

with $\psi_{iL} = (\nu_{iL}, l_{iL})^T$, $\psi_{iR} = (N_i, l_{iR})^T$, $H = (H^0, H^-)^T$ and

$$\Delta_R = \left( \begin{array}{cc}
\frac{1}{\sqrt{2}} \delta^+ \\
\frac{\sqrt{\delta^0}}{\sqrt{2}} \delta^+ \\
\end{array} \right).$$  \hspace{1cm} (14)

The diagrams in Fig. 1, in this case, can also lead to successful leptogenesis. They lead to the same asymmetry as in Eq. 11, and same constraints, replacing everywhere the $(Y_R)_{ij}$ couplings

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*aIf there is an additional resonance effect, $M_{N_2}$ ($\simeq M_{N_1}$) can be lowered down to $\sim 1$ TeV as well.

*bHere for simplicity of notation we take the $\delta^0$ as vevless, that is, its contribution to RH neutrino masses is already reabsorbed in $M_{N_1}$.\"
by $\sqrt{2}(Y_\Delta)_{ij}$. In addition, as there is no coupling of the $\Delta_R$ to two left-handed leptons, the $\delta^+$ does not have $L = -2$ as above and $C_L$ is modified. Since we assume that the $\delta^+$ is lighter than the RH neutrinos, the $\delta^+$ cannot decay to two particles but instead to three, it decays predominantly to a Higgs doublet and a lepton-antilepton pair so that the $\delta^+$ has $L = 0$ with an intermediate RH neutrino, which gives $C_L = +1$.

4 Incorporating Right-handed Leptogenesis in Unified Gauge Theories

The case of a charged singlet $\delta^+$: in the presence of left-right symmetry, the leptogenesis mechanism above can be successful with a $SU(2)_L \times SU(2)_R$ singlet $\delta^+$ since it can couple in an antisymmetric way to 2 doublets of RH leptons $\psi_R = (N \ l_R)^T$. If the minimal left-right group is further extended to a Pati-Salam model, $\delta^+$ is accommodated into a $(1, 1, 10)$-multiplet under $SU(2)_L \times SU(2)_R \times SU(4)_c$, which couples bilinearly to RH fermions $\sim (1, 2, \bar{4})$. In these cases the presence of a $\delta^+$ is not better motivated than in the standard model case (i.e. it is not related to the breaking of the Pati-Salam or left-right symmetry, or contributing to fermion masses). The Pati-Salam group may be naturally embedded in unified models based on $SO(10)$, with all fermions in a 16-dimensional spinor representation. In this case $\delta^+$ is part of a 120 Higgs multiplet, which has renormalizable Yukawa couplings to fermions, contributing to fermion masses, see e.g. \[22\].

Alternatively, one can consider the $SU(5)$ option for gauge coupling unification. In this case, leptons are assigned as follows to $SU(5)$ representations: $\psi_L \in \bar{5}_f$, $l_R^c \in 10_f$ and $N_c \sim 1_f$. In order to introduce $\delta^+$, one needs to add to the model a 10-dimensional Higgs multiplet, which has the proper couplings required in section 2 to achieve RH leptogenesis: $Y_R l_f^{10} 10_H$ and $Y_L \bar{5}_f 5_f 10_H$. More details can be found in Ref.\[20\].

The case of a right-handed triplet $\Delta_R$: A RH triplet is naturally present in left-right models since the VEV of its neutral component $\delta^0$ provides the correct symmetry breaking to the Standard Model and, moreover, it gives a Majorana mass to the RH neutrinos. In fact, $\Delta_R \sim (1, 3, 2)$ couples symmetrically to two RH lepton doublets $\psi_R \sim (1, 2, -1)$. In Pati-Salam models, $\Delta_R$ is contained in the $(1, 3, 10)$ multiplet which, in turn, belongs to $126$ Higgs representation in $SO(10)$.

The minimal left-right model turns out to be able to satisfy all constraints which are necessary to lead to successful leptogenesis as in section 3 above, except an important one: it is well known that in order to get a non vanishing CP-asymmetry one must have 2 different sources of flavor breaking, one in the Yukawa couplings and a different one in the right-handed neutrino mass matrix. However in the minimal left-right model both matrices are proportional to each other since the RH neutrino masses are induced from the VEV of the $\delta^0$ through the $Y_\Delta$ couplings. As a result the CP asymmetry is simply vanishing. Therefore, for this leptogenesis mechanism to be effective we need to extend the minimal model in order to distinguish $M_R$ from $Y_\Delta$. For example, one may introduce a second RH triplet (a second $126$ in $SO(10)$), or consider extra (e.g. non-renormalizable) sources of RH neutrino mass. Alternatively, one could resort to the singlet leptogenesis mechanism, adding a $(1, 1, 2)$ Higgs multiplet ($120$ in $SO(10)$ context).

5 Phenomenology of a TeV Scale $SU(2)_L$ Singlet Charged Scalar

The observation of a light $SU(2)_L$ singlet $\delta^+$ at colliders (produced from a photon, e.g. from Drell-Yan processes) would imply that, in the presence of RH neutrinos, the $Y_R$ interactions occur naturally. This would render our leptogenesis mechanism as plausible as the standard one. Notice that, as explained above, $\delta^+$ would decay predominantly into either a charged lepton and a neutrino (or eventually to two different Higgs bosons\[20\]). Moreover the fact that this model can work at scales as low as the TeV scale opens the possibility to produce directly
a RH neutrino through the relatively large $Y_R$ couplings of the $N_2$ and/or $N_3$, which can have a mass as low as few TeV. This would leave in general no other choice for leptogenesis (and baryogenesis) than to be produced at low scale below $M_{N_{2,3}}$, as allowed by our model.

Note also that the $\delta^+$ singlet can induce, through its $Y_L$ couplings, a $\mu \rightarrow e\gamma$ transition with branching ratio $\text{Br}(\mu \rightarrow e\gamma) \approx (\alpha/48\pi)(Y_L)_{e\tau}(Y_L)_{\mu\tau}/(M^2_{\delta}G^2_F)$ (see e.g. [20]). With $M_\delta$ below TeV, a branching ratio of the order of the experimental limit $\left(\text{Br}(\mu \rightarrow e\gamma) < 1.2 \cdot 10^{-11}\right)$ at 90% C.L. [27] can be easily obtained. Similarly the $Y_R$ couplings can induce this transition with $\text{Br}(\mu \rightarrow e\gamma) \approx (\alpha/192\pi)(Y_R)_{e\tau}(Y_R)_{i\mu}/M^2_{N_i}G^2_F$, where we assumed that the exchange of the RH neutrino $N_i$ gives the main contribution and we neglected $M_\delta/M_{N_i}$ corrections. In this case the sets of parameters which lead to successful leptogenesis give rise to a smaller branching ratio, below $\sim 10^{-17}$, therefore unobservable.

The case of the triplet $(\delta^0, \delta^+, \delta^{++})$ has a similar phenomenology for what concerns the production of the $\delta^+$ and $N_{2,3}$. However, here $\delta^+$ does not have 2-body decays. In this scenario a $\delta^{++}$ could also be produced electromagnetically in colliders. As there is no $Y_L$ couplings, the $\mu \rightarrow e\gamma$ process in this case can be induced only through the $Y_\Delta$ couplings, with suppressed branching ratios as for the singlet case with $Y_R$ couplings.

6 Summary

We have considered a new mechanism to induce leptogenesis successfully, by the decay of the RH neutrino $N_i$ to a RH charged lepton and a scalar $SU(2)_L$ singlet $\delta^+$. In the presence of left-right symmetry the $\delta^+$ may or may not be a member of an $SU(2)_R$ triplet. In both versions one achieves successful leptogenesis easily in a similar way. This mechanism can work at high scale just as ordinary leptogenesis and it can also work at scales as low as few TeV with no need of resonant enhancement of the asymmetry. Such a low scale realization requires that we do make 3 assumptions: RH neutrinos have to be assumed with masses of order $\sim T eV$, a lighter charged scalar $\delta^+$ has to exist and RH neutrinos Yukawa couplings to RH charged leptons must have a hierarchical structure.

In grand-unified theories this mechanism can be realized, for the singlet case, both in SO(10), if there exists a 120 scalar multiplet, and in SU(5) with a 10 scalar multiplet. The $SU(2)_R$ scalar triplet case can be incorporated in SO(10) models with a $T_{26}$ scalar multiplet. However, in this case, in order for leptogenesis to work, the model should contain a source of RH neutrino masses independent from this $T_{26}$ representation.

Phenomenologically, the observation of a light $SU(2)_L$ singlet $\delta^+$ at colliders would be a strong evidence in favor of our proposal. The additional production of a RH neutrino at few TeV scale, through the large couplings to RH charged leptons, would make the case for low scale leptogenesis.

References

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a The production of TeV scale RH neutrinos through the Yukawa couplings to left-handed leptons has been discussed e.g. [28] for LHC [29] for a high energy $e^+e^-$ linear collider and [30] for an $e\gamma$ collider.

b A possible exception is the case where the observed $N_i$ has suppressed couplings to a given flavor, so that it cannot washout any preexisting lepton asymmetry associated to that flavor.

c This can be compared with the resonant ordinary leptogenesis at low scale which to be testable must also be based on 3 assumptions [19]: RH neutrinos must be light in the same way, a hierarchical structure of Yukawa couplings has also to be assumed with in addition a special structure (with large (testable) Yukawa couplings which have to cancel each other to give small enough neutrino masses), and a large degeneracy of RH neutrino masses has to be assumed.
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