



Baryon-lepton duplicity as the progenitor of long-lived dark matter

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ABSTRACT

In an $SU(2)_R$ extension of the standard model, it is shown how the neutral fermion N in the doublet $(N, e)_R$ may be assigned baryon number $B = 1$, in contrast to its $SU(2)_L$ counterpart ν in the doublet $(\nu, e)_L$ which has lepton number $L = 1$. This baryon-lepton duplicity allows a scalar σ which couples to $N_L N_L$ to be long-lived dark matter.

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1. Introduction

In the conventional $SU(2)_R$ extension of the standard model (SM) of quarks and leptons, the neutral fermion N in the doublet $(N, e)_R$ is identified with the Dirac mass partner of ν in the $SU(2)_L$ doublet $(\nu, e)_L$. Hence N has lepton number $L = 1$. However, it is also possible that N is not the mass partner of ν , and that it has $L = 0$ [1] or $L = 2$ [2]. As such N may be considered a dark-matter candidate using [3] $(-1)^{L+2j}$ as the stabilizing dark symmetry. In the following, it will be shown how N may be assigned baryon number $B = 1$ instead [4], in which case a scalar σ coupling to $N_L N_L$ may become long-lived dark matter.

2. Model

The basic framework for considering $(N, e)_R$ differently from $(\nu, e)_R$ is originally inspired by E_6 models with the decomposition $E_6 \rightarrow SU(3)_C \times SU(3)_L \times SU(3)_R \rightarrow SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)_X$, where the $SU(2)_R$ is not [5] the one contained in $SO(10) \rightarrow SU(5)$ in the conventional left-right model. Consider the fermion particle content of the basic model given in Table 1.

The electric charge is $Q = I_{3L} + I_{3R} + X$. The discrete Z_5 symmetry ($\omega^5 = 1$) serves to forbid the terms $\bar{N}_L \nu_R$ and $\bar{h}_L d_R$ and others to be discussed. The scalar particle content of the proposed model of baryon-lepton duplicity is given in Table 2.

In the above, η is a bidoublet, with $SU(2)_L$ acting vertically and $SU(2)_R$ acting horizontally, i.e.

Table 1
Basic fermion content of model with unconventional $SU(2)_R$.

Fermion	$SU(3)_C$	$SU(2)_L$	$SU(2)_R$	$U(1)_X$	Z_5
$(\nu, e)_L$	1	2	1	-1/2	1
ν_R	1	1	1	0	1
$(N, e)_R$	1	1	2	-1/2	ω^{-1}
N_L	1	1	1	0	ω^3
$(u, d)_L$	3	2	1	1/6	ω
d_R	3	1	1	-1/3	ω
$(u, h)_R$	3	1	2	1/6	ω^2
h_L	3	1	1	-1/3	ω^{-2}

Table 2
Scalar content defining the model of baryon-lepton duplicity.

Scalar	$SU(3)_C$	$SU(2)_L$	$SU(2)_R$	$U(1)_X$	Z_5
(ϕ_L^+, ϕ_L^0)	1	2	1	1/2	1
(ϕ_R^+, ϕ_R^0)	1	1	2	1/2	ω^{-1}
η	1	2	2	0	ω
ζ	3	1	1	-1/3	ω^{-2}
σ	1	1	1	0	ω

$$\eta = \begin{pmatrix} \eta_1^0 & \eta_2^+ \\ \eta_1^- & \eta_2^0 \end{pmatrix}, \quad (1)$$

$$\tilde{\eta} = \sigma_2 \eta^* \sigma_2 = \begin{pmatrix} \tilde{\eta}_2^0 & -\eta_1^+ \\ -\eta_2^- & \tilde{\eta}_1^0 \end{pmatrix}. \quad (2)$$

The Z_5 symmetry distinguishes η from $\tilde{\eta}$. The resulting Yukawa interactions are

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$$\begin{aligned}
\mathcal{L}_Y = & f_\nu(\bar{\nu}_L\bar{\phi}_L^0 - \bar{e}_L\bar{\phi}_L^-)\nu_R + f_d(\bar{u}_L\bar{\phi}_L^+ + \bar{d}_L\bar{\phi}_L^0)d_R \\
& + f_N(\bar{N}_R\bar{\phi}_R^0 - \bar{e}_R\bar{\phi}_R^-)N_L + f_h(\bar{u}_R\bar{\phi}_R^+ + \bar{h}_R\bar{\phi}_R^0)h_L \\
& + f_e[(\bar{\nu}_L\eta_1^0 + \bar{e}_L\eta_1^-)N_R + (\bar{\nu}_L\eta_2^+ + \bar{e}_L\eta_2^0)e_R] \\
& + f_u[(\bar{u}_L\bar{\eta}_2^0 - \bar{d}_L\bar{\eta}_2^-)u_R + (-\bar{u}_L\eta_1^+ + \bar{d}_L\bar{\eta}_1^0)h_R] \\
& + f_1\sigma^*N_LN_L + f_2\bar{N}_Ld_R\zeta^* + f_3\bar{\nu}_Rh_L\zeta^* \\
& + f_4\epsilon_{ijk}(u_{iL}d_{jL} - d_{iL}u_{jL})\zeta_k + H.c., \quad (3)
\end{aligned}$$

where each f is a 3×3 matrix for the three families of quarks and leptons and the last term is the product of three color triplets. Note that ν and d masses come from $\langle\phi_L^0\rangle$, e and u masses come from $\langle\eta_2^0\rangle$, N and h masses come from $\langle\phi_R^0\rangle$. This structure guarantees the absence of tree-level flavor-changing neutral currents.

If the scalar color triplet ζ and singlet σ are absent, the model of Ref. [2] is recovered with $L = 2$ for N and $L = -1$ for h . As it is, a very different outcome is obtained with $B = 1$ for N and $B = 2$ for σ as well as $B = -2/3$ for h , as shown below. The first thing to realize is that even though the input symmetry is Z_5 , the Lagrangian of Eq. (3) actually has a larger symmetry due to the chosen particle content under the gauge symmetry. It is an $U(1)$ symmetry S under which

$$\begin{aligned}
(u, d)_L, d_R & \sim 1/3, \quad h_L \sim -2/3, \quad (u, h)_R \sim -1/6, \\
N_L & \sim 1, \quad (N, e)_R \sim 1/2, \quad (4) \\
\Phi_R & \sim 1/2, \quad \eta \sim -1/2, \quad \sigma \sim 2, \quad \zeta \sim -2/3. \quad (5)
\end{aligned}$$

This S symmetry is broken by $\langle\phi_R^0\rangle$ as well as $\langle\eta_2^0\rangle$, but not the combination $S + I_{3R}$. Indeed this residual symmetry is just baryon number, i.e. $1/3$ for the known quarks and zero for the known leptons. There is another residual symmetry, i.e. lepton parity under which the known leptons are odd. Note that ν_R is allowed a Majorana mass, hence the canonical seesaw mechanism for neutrino mass is applicable.

As for the new particles beyond the SM, their baryon number and lepton parity assignments are

$$\begin{aligned}
\zeta & \sim (-2/3, +), \quad N \sim (1, +), \quad \sigma \sim (2, +), \quad h \sim (-2/3, -), \quad (6) \\
W_R^\pm & \sim (\pm 1, -), \quad Z' \sim (0, +), \quad (\eta_1^0, \eta_1^-) \sim (-1, -). \quad (7)
\end{aligned}$$

Hence ζ is a scalar diquark, h is a fermion diquark with odd lepton parity, N is a fundamental $B = 1$ fermion, σ is a fundamental $B = 2$ scalar, W_R^\pm is a fundamental $B = 1$ vector boson with odd lepton parity, and $(\eta_1^+, -\bar{\eta}_1^0)$ is a fundamental $B = 1$ scalar $SU(2)_L$ doublet with odd lepton parity. Underlying this exotic scenario is the duplicity between N and ν in their $SU(2)_R/SU(2)_L$ interactions. Two symmetries are conserved: baryon number and lepton parity. The lightest lepton, i.e. the lightest neutrino, is stable. The lightest baryon, i.e. the proton, is stable. However, just as the heavier neutrinos are very long-lived, the heavier $B = 2$ σ may also be very long-lived and become dark matter.

3. Gauge boson masses and interactions

Let

$$\langle\phi_L^0\rangle = v_1, \quad \langle\eta_2^0\rangle = v_2, \quad \langle\phi_R^0\rangle = v_R, \quad (8)$$

then the $SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)_X$ gauge symmetry is broken to $SU(3)_C \times U(1)_Q$, with residual baryon number and lepton parity as discussed in the previous section. Consider now the masses of the gauge bosons. The charged ones, W_L^\pm and W_R^\pm , do

not mix because of B and $(-1)^L$, as in the original alternative left-right models. Their masses are given by

$$M_{W_L}^2 = \frac{1}{2}g_L^2(v_1^2 + v_2^2), \quad M_{W_R}^2 = \frac{1}{2}g_R^2(v_R^2 + v_2^2). \quad (9)$$

Since $Q = I_{3L} + I_{3R} + X$, the photon is given by

$$A = \frac{e}{g_L}W_{3L} + \frac{e}{g_R}W_{3R} + \frac{e}{g_X}X, \quad (10)$$

where $e^{-2} = g_L^{-2} + g_R^{-2} + g_X^{-2}$. Let

$$Z = (g_L^2 + g_Y^2)^{-1/2} \left(g_L W_{3L} - \frac{g_Y^2}{g_R} W_{3R} - \frac{g_Y^2}{g_X} X \right), \quad (11)$$

$$Z' = (g_R^2 + g_X^2)^{-1/2} (g_R W_{3R} - g_X X), \quad (12)$$

where $g_Y^{-2} = g_R^{-2} + g_X^{-2}$, then the 2×2 mass-squared matrix spanning (Z, Z') has the entries:

$$M_{ZZ}^2 = \frac{1}{2}(g_L^2 + g_Y^2)(v_1^2 + v_2^2), \quad (13)$$

$$M_{Z'Z'}^2 = \frac{1}{2}(g_R^2 + g_X^2)v_R^2 + \frac{g_X^4 v_1^2 + g_R^4 v_2^2}{2(g_R^2 + g_X^2)}, \quad (14)$$

$$M_{ZZ'}^2 = \frac{\sqrt{g_L^2 + g_Y^2}}{2\sqrt{g_R^2 + g_X^2}}(g_X^2 v_1^2 - g_R^2 v_2^2). \quad (15)$$

Their neutral-current interactions are given by

$$\begin{aligned}
\mathcal{L}_{NC} = & eA_\mu j_Q^\mu + g_Z Z_\mu (j_{3L}^\mu - \sin^2\theta_W j_Q^\mu) \\
& + (g_R^2 + g_X^2)^{-1/2} Z'_\mu (g_R^2 j_{3R}^\mu - g_X^2 j_X^\mu), \quad (16)
\end{aligned}$$

where $g_Z^2 = g_L^2 + g_Y^2$ and $\sin^2\theta_W = g_Y^2/g_Z^2$. Assuming also that $g_R = g_L$, then $g_X^2/g_Z^2 = \sin^2\theta_W \cos^2\theta_W / \cos 2\theta_W$. In that case, setting $v_1^2/v_2^2 = \cos 2\theta_W / \sin^2\theta_W$ would result in zero $Z - Z'$ mixing which is constrained by precision data to be less than a few times 10^{-4} .

The present bound on $M_{Z'}$ from the Large Hadron Collider (LHC) is about 4 TeV. However, if the lightest N is considered as dark matter, then its gauge interaction through Z' with quarks would constrain $M_{Z'}$ to be above 10 TeV or higher from direct-search experiments, depending on m_N . Here it will be assumed that σ is dark matter and since it does not couple to Z' , this constraint is not applicable.

4. Scalar sector

Consider the most general scalar potential consisting of $\Phi_{L,R}$ and η , i.e.

$$\begin{aligned}
V = & -\mu_L^2 \Phi_L^\dagger \Phi_L - \mu_R^2 \Phi_R^\dagger \Phi_R - \mu_\eta^2 \text{Tr}(\eta^\dagger \eta) + [\mu_3 \Phi_L^\dagger \eta \Phi_R + H.c.] \\
& + \frac{1}{2}\lambda_L(\Phi_L^\dagger \Phi_L)^2 \\
& + \frac{1}{2}\lambda_R(\Phi_R^\dagger \Phi_R)^2 + \frac{1}{2}\lambda_\eta[\text{Tr}(\eta^\dagger \eta)]^2 + \frac{1}{2}\lambda'_\eta \text{Tr}(\eta^\dagger \eta \eta^\dagger \eta) \\
& + \lambda_{LR}(\Phi_L^\dagger \Phi_L)(\Phi_R^\dagger \Phi_R) \\
& + \lambda_{L\eta} \Phi_L^\dagger \eta \eta^\dagger \Phi_L + \lambda'_{L\eta} \Phi_L^\dagger \tilde{\eta} \tilde{\eta}^\dagger \Phi_L + \lambda_{R\eta} \Phi_R^\dagger \eta \eta^\dagger \Phi_R \\
& + \lambda'_{R\eta} \Phi_R^\dagger \tilde{\eta} \tilde{\eta}^\dagger \Phi_R. \quad (17)
\end{aligned}$$

Note that

$$2|\det(\eta)|^2 = [\text{Tr}(\eta^\dagger \eta)]^2 - \text{Tr}(\eta^\dagger \eta \eta^\dagger \eta), \quad (18)$$

$$(\Phi_L^\dagger \Phi_L) \text{Tr}(\eta^\dagger \eta) = \Phi_L^\dagger \eta \eta^\dagger \Phi_L + \Phi_L^\dagger \tilde{\eta} \tilde{\eta}^\dagger \Phi_L, \quad (19)$$

$$(\Phi_R^\dagger \Phi_R) \text{Tr}(\eta^\dagger \eta) = \Phi_R^\dagger \eta^\dagger \eta \Phi_R + \Phi_R^\dagger \tilde{\eta}^\dagger \tilde{\eta} \Phi_R. \quad (20)$$

The minimum of V satisfies the conditions

$$\mu_L^2 = \lambda_L v_1^2 + \lambda_{L\eta} v_2^2 + \lambda_{LR} v_R^2 + \mu_3 v_2 v_R / v_1, \quad (21)$$

$$\mu_\eta^2 = (\lambda_\eta + \lambda'_\eta) v_2^2 + \lambda_{L\eta} v_1^2 + \lambda_{R\eta} v_R^2 + \mu_3 v_1 v_R / v_2, \quad (22)$$

$$\mu_R^2 = \lambda_R v_R^2 + \lambda_{LR} v_1^2 + \lambda_{R\eta} v_2^2 + \mu_3 v_1 v_2 / v_R. \quad (23)$$

The 3×3 mass-squared matrix spanning $\sqrt{2} \text{Im}(\phi_L^0, \eta_2^0, \phi_R^0)$ is then given by

$$\mathcal{M}_I^2 = \mu_3 \begin{pmatrix} -v_2 v_R / v_1 & v_R & v_2 \\ v_R & -v_1 v_R / v_2 & -v_1 \\ v_2 & -v_1 & -v_1 v_2 / v_R \end{pmatrix}, \quad (24)$$

and that spanning $\sqrt{2} \text{Re}(\phi_L^0, \eta_2^0, \phi_R^0)$ is

$$\begin{aligned} \mathcal{M}_R^2 = \mu_3 & \begin{pmatrix} -v_2 v_R / v_1 & v_R & v_2 \\ v_R & -v_1 v_R / v_2 & v_1 \\ v_2 & v_1 & -v_1 v_2 / v_R \end{pmatrix} \\ & + 2 \begin{pmatrix} \lambda_L v_1^2 & \lambda_{L\eta} v_1 v_2 & \lambda_{LR} v_1 v_R \\ \lambda_{L\eta} v_1 v_2 & (\lambda_\eta + \lambda'_\eta) v_2^2 & \lambda_{R\eta} v_2 v_R \\ \lambda_{LR} v_1 v_R & \lambda_{R\eta} v_2 v_R & \lambda_R v_R^2 \end{pmatrix}. \end{aligned} \quad (25)$$

Hence there are two zero eigenvalues in \mathcal{M}_I^2 with one nonzero eigenvalue $-\mu_3[v_1 v_2 / v_R + v_R(v_1^2 + v_2^2) / v_1 v_2]$ corresponding to the eigenstate $A = (-v_1^{-1}, v_2^{-1}, v_R^{-1}) / \sqrt{v_1^{-2} + v_2^{-2} + v_R^{-2}}$. In \mathcal{M}_R^2 , the linear combination $H = (v_1, v_2, 0) / \sqrt{v_1^2 + v_2^2}$, is the standard-model Higgs boson, with

$$m_H^2 = 2[\lambda_L v_1^4 + (\lambda_\eta + \lambda'_\eta) v_2^4 + 2\lambda_{L\eta} v_1^2 v_2^2] / (v_1^2 + v_2^2). \quad (26)$$

The other two scalar bosons, i.e. $H' = (v_2, -v_1, 0) / \sqrt{v_1^2 + v_2^2}$ and $H_R = (0, 0, 1)$ are assumed not to mix with H and each other by fine-tuning the λ parameters to avoid further experimental constraints.

There are four charged scalars in the Higgs potential of Eq. (17). Two have $B = 1$, i.e. ϕ_R^+, η_1^+ . One linear combination becomes the longitudinal component of W_R^+ . The orthogonal combination, i.e. $(v_R \eta_1^+ - v_2 \phi_R^+) / \sqrt{v_R^2 + v_2^2}$ has a mass given by

$$m^2 = (\lambda'_{R\eta} - \lambda_{R\eta})(v_R^2 + v_2^2) - \frac{\mu_3 v_1 (v_R^2 + v_2^2)}{v_R v_2}. \quad (27)$$

The other two charged scalars have $B = 0$, i.e. ϕ_L^+, η_2^+ . One linear combination becomes the longitudinal component of W_L^+ . The orthogonal combination, i.e. $(v_1 \eta_2^+ - v_2 \phi_L^+) / \sqrt{v_1^2 + v_2^2}$ has a mass given by

$$m^2 = (\lambda'_{L\eta} - \lambda_{L\eta})(v_1^2 + v_2^2) - \frac{\mu_3 v_R (v_1^2 + v_2^2)}{v_1 v_2}. \quad (28)$$

The two physical charged scalars do not mix, for the same reason that W_R and W_L do not mix, because they have different B values. Note that in the limit $v_{1,2} \ll v_R$, the $B = 0$ charged scalar has the same mass as the $B = 0$ scalar H' and the $B = 0$ pseudoscalar A , as expected. As for the $B = 1$ neutral scalar η_1^0 , it has a mass given by

$$\begin{aligned} m^2(\eta_1^0) = & (\lambda'_{R\eta} - \lambda_{R\eta})v_R^2 + (\lambda'_{L\eta} - \lambda_{L\eta})v_1^2 - \lambda'_\eta v_2^2 \\ & - \mu_3(v_1/v_2)v_R. \end{aligned} \quad (29)$$

Note again that in the limit $v_{1,2} \ll v_R$, the $B = 1$ charged and neutral scalars have the same mass, as expected.

5. Diquark connection to dark matter

The scalar diquark ζ is crucial in assigning $B = 1$ to N and σ . The decay of N_L to d_R and a virtual ζ^* which converts to $u_L d_L$ means that N is long-lived if m_ζ is very large. The current LHC bound on m_ζ is about 2.5 TeV. On the other hand, if $m_\sigma < m_N$, then the former's decay is even more suppressed. It will be shown how σ may indeed be suitable as long-lived dark matter.

Of the new particles with $B \neq 0$, ζ is assumed to be the heaviest and N to be the lightest except σ . Now N decays to udd with a decay rate given by [6]

$$\Gamma(N \rightarrow udd) = \frac{f_2^2 f_4^2 m_N^5}{8(4\pi)^3 m_\zeta^4} \int_0^1 d\lambda_2 \lambda_2 (1 - \lambda_2)^2 = \frac{f_2^2 f_4^2 m_N^5}{96(4\pi)^3 m_\zeta^4}. \quad (30)$$

As an example, a lifetime of

$$\tau_N = (5 \times 10^{24} \text{ s}) \left(\frac{0.01}{f_2}\right)^2 \left(\frac{0.01}{f_4}\right)^2 \left(\frac{300 \text{ GeV}}{m_N}\right)^5 \left(\frac{m_\zeta}{10^{12} \text{ GeV}}\right)^4 \quad (31)$$

is obtained. Note that the age of the Universe is 4.35×10^{17} s, but the bound on decaying dark matter [7] is much greater, say about 10^{25} s, from the constraint of the cosmic microwave background (CMB). Hence N may be long-lived enough for it to be dark matter, with some adjustment of parameter values. However, because its interactions through the new gauge boson Z' are constrained by direct-search data as pointed out already, its resulting annihilation cross section is too small and would result in a thermal relic abundance exceeding what is observed. Hence it will be assumed from now on that N decays quickly, using for example $m_\zeta = 10^5$ GeV so that $\tau_N = 5 \times 10^{-4}$ s which is certainly short enough not to disturb Big Bang Nucleosynthesis (BBN).

Excepting σ , the other new particles with $B \neq 0$ all decay quickly to N . The vector gauge boson W_R^- decays to $e^- \bar{N}$. The fermion diquark h decays to $u W_R^-$ if $m_h > M_{W_R}$, or to $u e^- \bar{N}$ if $m_h < M_{W_R}$. The $B = -1$ scalar doublet (η_1^0, η_1^-) decays to the $B = 0$ scalar doublet (η_2^+, η_2^0) through W_R^- , again converting to $e^- \bar{N}$. In all these decays, N would appear as missing energy because its lifetime is long enough to escape detection in the experimental apparatus.

To estimate the decay rate of $\sigma \rightarrow NN$, let $p_{1,2}$ be the sum of the four-momenta of the three quark jets from each N . Then

$$\Gamma_\sigma \sim \frac{m_\sigma}{16\pi} \left[\frac{f_1 f_2^2 f_4^2}{96(4\pi)^3 m_\zeta^4} \right]^2 \int dp_1^2 dp_2^2 \frac{(m_\sigma - p_1^2 - p_2^2)^2 p_1^4 p_2^4}{(p_1^2 - m_N^2)^2 (p_2^2 - m_N^2)^2}, \quad (32)$$

where $p_{1,2}^2 > 0$ and $p_1^2 + p_2^2 < m_\sigma^2$. Letting $p_1^2 = p_2^2 = m_\sigma^2$ in the denominator, the integral is bounded from above by

$$\begin{aligned} & \frac{1}{(m_N^2 - m_\sigma^2)^4} \int_0^{m_\sigma^2} p_1^4 dp_1^2 \int_0^{m_\sigma^2 - p_1^2} p_2^4 (m_\sigma^2 - p_1^2 - p_2^2)^2 dp_2^2 \\ & = \frac{m_\sigma^{16}}{5040(m_N^2 - m_\sigma^2)^4}. \end{aligned} \quad (33)$$

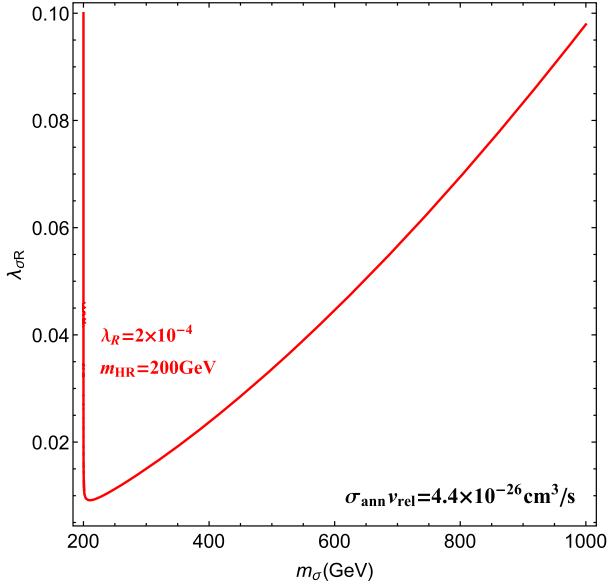


Fig. 1. $\lambda_{\sigma R}$ versus m_σ for σ relic abundance.

Hence

$$\Gamma_\sigma < \frac{m_\sigma^{17}}{35\pi(m_N^2 - m_\sigma^2)^4} \left[\frac{f_1 f_2^2 f_4^2}{9(32\pi)^3 m_\zeta^4} \right]^2. \quad (34)$$

For $m_\zeta = 10^5$ GeV, $f_{1,2,4} = 0.01$, $m_N = 300$ GeV, and $m_\sigma = 250$ GeV, $\tau_\sigma > 6 \times 10^{28}$ s is obtained. This shows that σ is long-lived enough to be dark matter.

6. Relic abundance of σ

The quartic interaction coupling $\lambda_{\sigma H}$ with the SM Higgs boson must be small ($< 10^{-3}$) to avoid the constraint of direct-search experiments. This means that the $\sigma\sigma^* \rightarrow HH$ cross section is not large enough to obtain the correct thermal relic abundance for σ as dark matter. However, if the H_R boson is lighter than σ , the latter's annihilation to the former (which does not couple to SM fermions) is a possible mechanism. Using

$$\sigma_{ann} \times v_{rel} = \frac{\lambda_{\sigma R}^2 r \sqrt{1-r}}{64\pi m_{H_R}^2} \left[1 + \frac{3r}{4-r} - \left(\frac{\lambda_{\sigma R}}{\lambda_R} \right) \frac{r}{2-r} \right]^2, \quad (35)$$

where $r = m_{H_R}^2/m_\sigma^2$ and assuming as an example $\lambda_R = 2 \times 10^{-4}$ with $v_R = 10$ TeV, so that $m_{H_R} = 200$ GeV, the allowed range of $\lambda_{\sigma R}$ is plotted versus $m_\sigma = 200$ GeV/ \sqrt{r} in Fig. 1 for $\sigma_{ann} \times v_{rel} = 4.4 \times 10^{-26}$ cm³/s.

7. Concluding remarks

In an $SU(2)_R$ extension of the SM, where an input Z_5 discrete symmetry is imposed with the particle content of Table 1 and Table 2, it has been shown that two conserved symmetries emerge. One is lepton parity $(-1)^L$ so that the known leptons are odd and other SM particles are even. Neutrino masses are obtained through the usual canonical seesaw mechanism. The other is baryon number B with the usual assignment of 1/3 for the SM quarks. The conservation of B and $(-1)^L$ separately implies that the proton is stable.

What is new and unconventional in this model is the nature of the neutral fermion N in the $SU(2)_R$ doublet $(N, e)_R$. It is not the Dirac mass partner of the neutrino ν in the $SU(2)_L$ doublet $(\nu, e)_L$. Instead of having $L = 1$, it actually has $B = 1$, as explained in the text because of the Z_5 symmetry and the chosen particle content. This baryon-lepton duality allows new particles to have nonzero B as well as odd $(-1)^L$. Whereas N itself decays into three quark jets and may have a long lifetime, a scalar σ with $B = 2$ and $m_\sigma < m_N$ is proposed instead as dark matter with a lifetime many orders of magnitude exceeding the age of the Universe. It has a correct thermal relic abundance from its interaction with the Higgs boson H_R associated with $SU(2)_R$ symmetry breaking. Its interaction with the $SU(2)_L$ Higgs boson H is however adjustable, so that present direct-search bounds are obeyed, but may reveal itself in the future if a positive signal is measured.

To test this model, the $SU(2)_R$ gauge sector has to be probed. If W_R or Z' can be produced, then N is predicted as a decay product. It will appear as an invisible massive particle. Another prediction is the existence of the fermion diquark h with odd lepton parity. It is produced readily by gluon interactions at the LHC and decays to $ue^- \bar{N}$ which looks like a fourth-family quark but again N appears as an invisible massive particle and not the expected light neutrino. As the LHC gathers more data, these processes may be searched for.

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