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Corrigendum

Corrigendum to "Radiative generation of the Higgs potential" [Phys. Lett. B 725 (1–3) (2013) 158–163]

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In the original paper [1], we first suggested the idea of generating the full scalar potential radiatively starting from the vanishing potential at an UV scale and considered the minimal $B-L$ extension of the Standard Model as a concrete example. A key ingredient was that an "order-one" Yukawa coupling of the right-handed neutrino y_N generates a non-vanishing quartic coupling λ_Φ in the $B-L$ sector while fulfilling the Coleman–Weinberg minimization condition. However, there was an error in the coefficient of the y_N^4 term in the beta function of λ_Φ in Eq. (A.9) of Ref. [1], which has been recently noticed by Hashimoto et al [2]. Correcting the factor of 16 in the y_N^4 term, we find that the minimization condition cannot be met for the original $B-L$ charge assignment, in agreement with the results of Ref. [2].

Let us generalize the $B-L$ symmetry to $U(1)_X$ by taking the X charge to be a linear combination of the original $B-L$ charge, Y_{B-L}, and the hypercharge, Y:

$$X = Y_{B-L} - xY$$

to implement the dynamical generation of the Higgs potential. We can freely choose a charge mixing parameter x within a range satisfying a certain criterion that will be discussed below. In Table 1, we show Y and Y_{B-L} charges as well as X charges for a representative $U(1)_X$ with $x=4/5$.

For this generalized $B-L$ symmetry $U(1)_X$, we denote the gauge coupling and gauge boson mass by g_X and M_X, which replace g_{B-L} and M_{B-L}, respectively, in Ref. [1]. Correcting the factor 16 in the beta function of λ_Φ in Eq. (A.9) and adopting new $U(1)$ charges, the key equations, (8) and (11)–(13), in Ref. [1], are changed to

Table 1
Y, Y_{B-L} and X charges in the generalized $B-L$ model with $x=4/5$.

	q_L	u_R	d_R	l_L	e_R	ν_R	H	Φ
Y	$\frac{1}{6}$	$\frac{2}{3}$	$-\frac{1}{3}$	$-\frac{1}{2}$	-1	0	$\frac{1}{2}$	0
Y_{B-L}	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{3}$	-1	-1	-1	0	2
$X_{\frac{4}{5}}$	$\frac{1}{5}$	$-\frac{1}{5}$	$\frac{3}{5}$	$-\frac{3}{5}$	$-\frac{1}{5}$	-1	$-\frac{2}{5}$	2

$$D_\mu = \partial_\mu + ig_S T^\alpha G^\alpha_\mu + igT^a W^a_\mu + ig_Y Y B_\mu + i(\tilde{g}Y + g_X X)B'_\mu, \tag{8}$$

$$V_X(\phi) = \frac{1}{4}\lambda_\Phi \phi^4 + \frac{\phi^4}{64\pi^4}\left(10\lambda_\Phi^2 + 48 g_X^2 - 8\sum_{i=1}^{3} y_{N_i}\right) \times \left(\ln\frac{\phi^2}{M^2} - \frac{25}{6}\right), \tag{11}$$

$$\lambda_\Phi(v_\phi) = \frac{11}{48\pi^2}\left(10\lambda_\Phi^2 + 48 g_X^4 - 8\sum_{i=1}^{3} y_{N_i}^4\right)(v_\phi), \tag{12}$$

$$v_\phi \simeq M_* e^{\frac{11}{6}} \exp\left(-\frac{\pi^2}{6}\frac{\lambda_\Phi(M_*)}{g_X^4(M_*) - \frac{16}{96} y_N^4(M_*)}\right). \tag{13}$$

Let us now rewrite all the renormalization group equations in the appendix of Ref. [1], accordingly also correcting some typographical errors as follows:

$$(4\pi)^2\beta_{g_Y} = \frac{41}{6}g_Y^3, \qquad (4\pi)^2\beta_g = -\frac{19}{6}g^3,$$
$$(4\pi)^2\beta_{g_S} = -7g_S^3, \tag{A.1}$$

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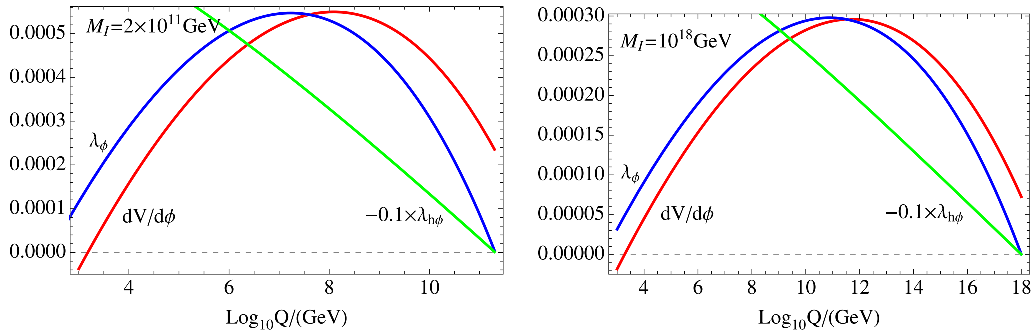

Fig. 1. Examples of running quartic coupling λ_Φ (blue), the minimization condition (12) (red), and $\lambda_{H\Phi}$ (green) (multiplied by −0.1 to fit in the plot) for the instability scale $M_I = 2 \times 10^{11}$ GeV on the left and $M_I = 10^{18}$ GeV on the right. Successful electroweak symmetry breaking occurs in both examples with the charge mixing parameter, $x = 4/5$. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

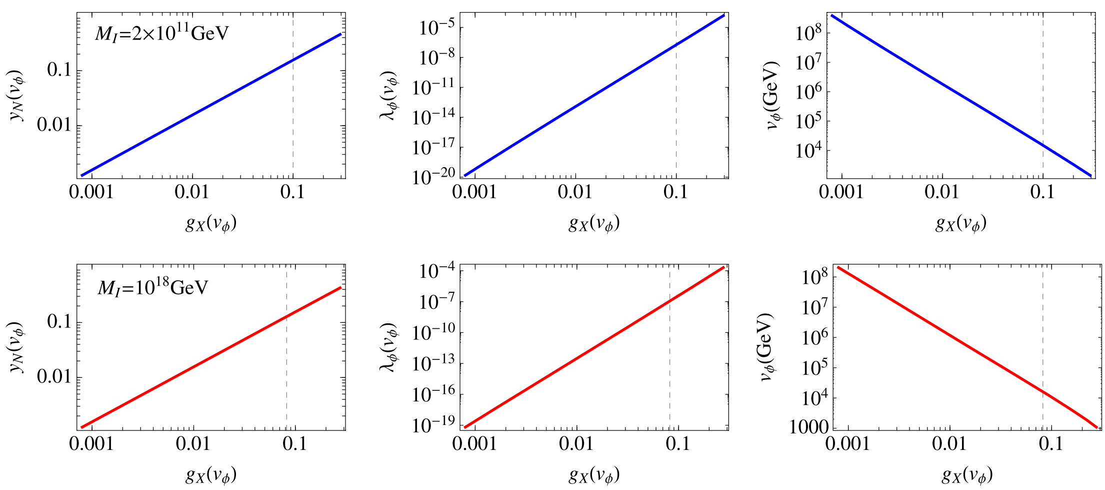

Fig. 2. The values of the gauge coupling g_X *vs.* the right-handed neutrino Yukawa coupling y_N (left), the quartic coupling λ_Φ (middle), and the $U(1)_X$ breaking scale v_ϕ (right) realizing successful electroweak symmetry breaking. We have chosen the charge mixing parameter to $x = 4/5$, the Higgs mass at 126 GeV and the instability scale, $M_I = 2 \times 10^{11}$ GeV and 10^{18} GeV, in the upper and lower panels, respectively. We get $M_X > 3$ TeV in the region left to the vertical dashed line.

$$(4\pi)^2\beta_{g_X} = \left(12 - \frac{32}{3}x + \frac{41}{6}x^2\right)g_X^3 + \left(\frac{32}{3} - \frac{41}{3}x\right)g_X^2\tilde{g} + \frac{41}{6}g_X\tilde{g}^2, \tag{A.2}$$

$$(4\pi)^2\beta_{\tilde{g}} = \frac{41}{6}\tilde{g}\left(\tilde{g}^2 + 2g_Y^2\right) + \left(\frac{32}{3} - \frac{41}{3}x\right)g_X\left(\tilde{g}^2 + g_Y^2\right) + \left(12 - \frac{32}{3}x + \frac{41}{6}x^2\right)g_X^2\tilde{g}, \tag{A.3}$$

$$(4\pi)^2\beta_{y_t} = y_t\left[\frac{9}{2}y_t^2 - 8g_S^2 - \frac{9}{4}g^2 - \frac{17}{12}g_Y^2 - \left(\frac{2}{3} - \frac{5}{3}x + \frac{17}{12}x^2\right)g_X^2 - \left(\frac{5}{3} - \frac{17}{6}x\right)g_X\tilde{g} - \frac{17}{12}\tilde{g}^2\right], \tag{A.4}$$

$$(4\pi)^2\beta_{y_{N_i}} = y_{N_i}\left(4y_{N,i}^2 + 2\,\mathrm{Tr}\left(y_N^2\right) - 6g_X^2\right), \tag{A.5}$$

$$(4\pi)^2\gamma_{m_H^2} = m_H^2\left(12\lambda_H + 6y_t^2 - \frac{9}{2}g^2 - \frac{3}{2}g_Y^2 - \frac{3}{2}(\tilde{g} - g_X x)^2\right) + 2\lambda_{H\Phi}m_\Phi^2, \tag{A.6}$$

$$(4\pi)^2\gamma_{m_\Phi^2} = m_\Phi^2\left(8\lambda_\Phi + 4\,\mathrm{Tr}\left(y_N^2\right) - 24g_X^2\right) + 4\lambda_{H\Phi}m_H^2, \tag{A.7}$$

$$(4\pi)^2\beta_{\lambda_H} = 24\lambda_H^2 - 6y_t^4 + \frac{9}{8}g^4 + \frac{3}{8}g_Y^4 + \frac{3}{4}g^2g_Y^2 + \frac{3}{4}(\tilde{g} - g_X x)^2\left(g^2 + g_Y^2\right) + \frac{3}{8}(\tilde{g} - g_X x)^4 + \lambda_H\left(12y_t^2 - 9g^2 - 3g_Y^2 - 3(\tilde{g} - g_X x)^2\right) + \lambda_{H\Phi}^2, \tag{A.8}$$

$$(4\pi)^2\beta_{\lambda_\Phi} = 20\lambda_\Phi^2 - 16\,\mathrm{Tr}\left(y_N^4\right) + 96g_X^4 + 8\lambda_\Phi\,\mathrm{Tr}\left(y_N^2\right) - 48\lambda_\Phi g_X^2 + 2\lambda_{H\Phi}^2, \tag{A.9}$$

$$(4\pi)^2\beta_{\lambda_{H\Phi}} = \lambda_{H\Phi}\left(12\lambda_H + 8\lambda_\Phi + 4\lambda_{H\Phi} + 6y_t^2 - \frac{9}{2}g^2 - \frac{3}{2}g_Y^2 - \frac{3}{2}(\tilde{g} - g_X x)^2 + 4\,\mathrm{Tr}\left(y_N^2\right) - 24g_X^2\right) + 12(\tilde{g} - g_X x)^2 g_X^2. \tag{A.10}$$

Making the above changes and including a single right-handed neutrino Yukawa coupling only, one gets the K factor [2]: $K = (108 - 64x + 41x^2)/36\sqrt{6}$ which becomes less than 1 for $0.43 < x < 1.13$ to allow the dynamical breaking of $U(1)_X$ symmetry with a vanishing potential in the UV. We can now repeat our previous analysis in Ref. [1] taking a representative $U(1)_X$ symmetry with $x = 4/5$ whose charge assignment is shown in the above table. Our results are summarized in the new Figs. 1–3.

First, the running quartic coupling of the singlet scalar Φ and the minimization condition $V'(\Phi) = 0$ are shown as a function of

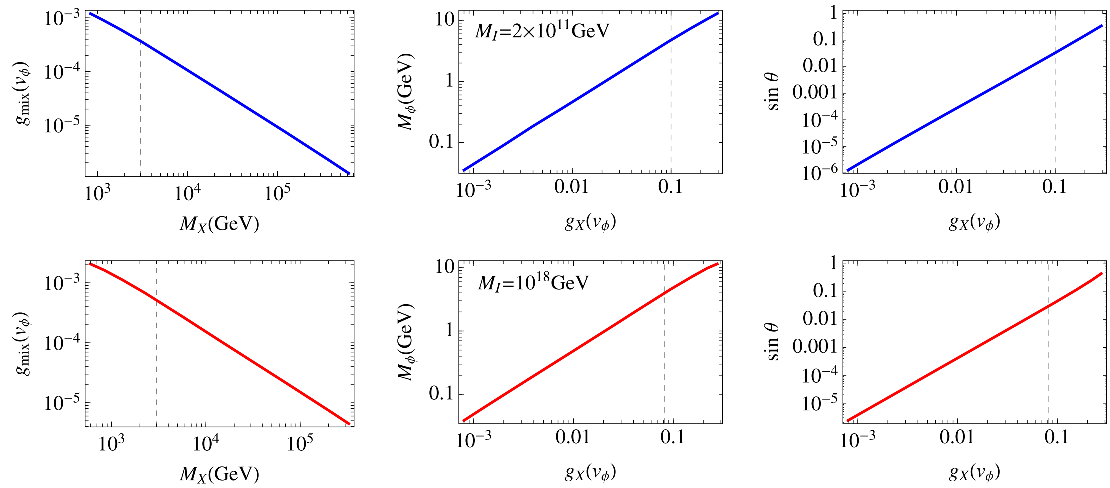

Fig. 3. The values of the $U(1)_X$ gauge boson mass *vs.* the kinetic mixing, $g_{mix} = \tilde{g}$ (left). The values of the gauge coupling g_X *vs.* singlet scalar mass M_ϕ (middle) and Higgs mixing parameter $\sin\theta$ (right). We have chosen the charge mixing parameter to $x = 4/5$, the Higgs mass at 126 GeV and the instability scale, $M_I = 2 \times 10^{11}$ GeV and 10^{18} GeV, in the upper and lower panels, respectively. The vertical dashed line corresponds to $M_X = 3$ TeV.

the renormalization scale in Fig. 1. Also shown is the running of the mixing quartic coupling between H and Φ, which is generated mainly by the g_X^4 term for $x \neq 0$ as can be seen from (A.10).

Fig. 2 shows the solution lines for successful electroweak symmetry breaking in the plane of the $U(1)_X$ gauge coupling g_X *vs.* the right-handed neutrino Yukawa coupling y_N, the $U(1)_X$ scalar quartic coupling λ_Φ and the $U(1)_X$ symmetry breaking scale v_ϕ where all the couplings are determined at v_ϕ. The $U(1)_X$ breaking scale lies in the range 10^4 GeV $\lesssim v_\phi \lesssim 10^8$ GeV for $10^{-3} \lesssim g_{B-L} \lesssim 0.1$ and it gets smaller for higher M_I. We note that v_ϕ as low as a few TeV can be obtained for $g_X(v_\phi) \gtrsim 0.2$ for which the $U(1)_X$ gauge boson signatures may be found in the future LHC run. One can see from Fig. 2 that the radiative breaking of the $U(1)_X$ and electroweak symmetries occurs appropriately in a reasonable range of the two input parameters y_N and g_X. However, one finds that $\lambda_\Phi \ll g_X^4$ which requires a fine cancellation between g_X^4 and y_N^4 contributions in the minimization condition. We note that from (A.8), the beta function of the Higgs quartic coupling acquires an additional contribution proportional to $x^4 g_X^4$ as compared to the standard $B - L$ symmetry. But, since the gauge coupling g_X is rather small, $g_X \lesssim 0.1$, for $U(1)_X$ symmetry breaking, the running of the Higgs quartic coupling is almost the same as in the SM.

In Fig. 3, we show the values of the kinetic mixing $\tilde{g}$ as a function of the $U(1)_X$ gauge boson mass M_X, and the values of the physical singlet scalar mass M_ϕ and the Higgs mixing angle $\sin\theta$ as a function of the gauge coupling g_X. All the values satisfy the electroweak symmetry breaking conditions. Note that the small kinetic mixing ($\tilde{g} \ll g_X$) plays an unimportant role in the $U(1)_X$ scheme with $x \sim 1$ as its contribution to the running of $\lambda_{H\Phi}$ is subdominant to that of g_X. In the case of $M_I = 2 \times 10^{11}$ GeV, the singlet scalar mass ranges between 0.1–8 GeV and the Higgs mixing is about $\sin\theta \sim 5 \times 10^{-4}$–$10^{-3}$ for $g_X(v_\phi) = 0.002$–0.2. On the other hand, in the case of $M_I = 10^{18}$ GeV, we obtain even lighter singlet scalar masses and relatively larger mixing. Thus, smaller v_ϕ successfully triggers electroweak symmetry breaking.

Note that the resulting λ_Φ and M_ϕ become much smaller than in the case with $x = 0$ [1]. For $g_X(v_\phi) \sim 0.1$, $M_X \approx 0.9 M_N$ can be multi-TeV while M_ϕ is only a few GeV. Such a light scalar can be produced by the Standard Model Higgs boson decay $h \to \phi\phi$ through small mixing $\sin\theta$ although being too small to observably affect Higgs decays. As ϕ decays mainly to $\tau\bar{\tau}$ or $c\bar{c}$, observing a very narrow resonance in these final states would provide an interesting signal of the radiative generation mechanism of the Higgs potential.

An updated version of this article incorporating all the above corrections can be found in Ref. [3].

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