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Probing doubly charged Higgs bosons in e^+e^- colliders at the ILC and the CLIC in a 3-3-1 model

J. E. Cieza Montalvo,[1] Nelson V. Cortez,[2] and M. D. Tonasse[3]

[1]*Instituto de Física, Universidade do Estado do Rio de Janeiro, Rua São Francisco Xavier 524, 20559-900 Rio de Janeiro, RJ, Brazil*
[2]*Rua Justino Boschetti 40, 02205-050 São Paulo, SP, Brazil*
[3]*Unidade de Registro, Campus Experimental de Registro, Universidade Estadual Paulista, Rua Nelson Brihi Badur 430, 11900-000 Registro, SP, Brazil*

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The $SU(3)_L \otimes U(1)_N$ electroweak model predicts new Higgs bosons beyond the one of the standard model. In this work we investigate the signature and production of doubly charged Higgs bosons in the e^-e^+ International Linear Collider and in the CERN Linear Collider. We compute the branching ratios for the doubly charged gauge bosons of the model.

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I. INTRODUCTION

The usual way to understanding the symmetry breaking in particle physics is through the scalars. These particles protect the unitarity of the theory by moderating the cross section of divergent processes at high energies, allowing the building of a renormalizable gauge theory of massive vector fields. Studies about the consequences of the extended scalar sector on the perturbative unitarity have been done in Ref. [1]. The discovery of these scalars will be crucial for the standard model (SM) or beyond it. Some extensions of the SM have two Higgs doublets as the supersymmetric ones or a Higgs triplet as $SU(3)_L \otimes U(1)_N$ models (3-3-1) [2–4], left-right symmetric models [5,6], Higgs triplet models [7], and little Higgs models [8]; all these models predict the doubly charged Higgs bosons (DCHBs). In some cases these particles can be relatively light, leading to interesting phenomenology [9].

In several models the DCHBs do not couple to quarks, and their coupling to leptons breaks the lepton number by two units [6]. As a result, these new scalar particles have a distinct experimental signature, namely, lepton pairs of same electric charges. In addition, DCHBs can be the key to implement seesaw schemes [10], to generate tiny neutrino masses [9,11]. Searches for DCHBs have been made lastly in several laboratories, and a lower limit of 141(114) GeV for the mass is obtained at the 95% confidence level [12] for HERA (FERMILAB) using the left-right symmetric models.

It is well known that the SM is not expected to be the ultimate theory of the microworld; therefore it suggests that there may be deeper symmetries underlying the SM. In the electroweak sector the immediate quiral extension is a 3-3-1 model [2–4]. In a 3-3-1 model, DCHBs can also appear in a sextet representation of SU(3) [2,3]. In this class of electroweak models DCHBs can have a role in the mass generation schemes, and they can be used to generate lepton masses *via* a seesaw mechanism and therefore contribute to an improvement in understanding the charged lepton mass hierarchy problem [13].

The main motivation of this work is to show that in the context of the 3-3-1 model [2–4], the signatures for DCHBs can be significant in the International Linear Collider (ILC) and in the CERN Linear Collider (CLIC). Our results indicate a satisfactory number of events to establish the signal, and analyzing it we can make inferences about the existence of doubly charged gauge bosons and heavy lepton. The outline of this paper is the following. In Sec. II we give a brief overview of the version of the 3-3-1 model with heavy lepton in triplet representation of $SU(3)_L$ [4]. In Sec. III we discuss the cross section and production of the DCHBs, and in Sec. IV we summarize our results and give the conclusions.

II. OVERVIEW OF THE MODEL

The underlying eletroweak symmetry group is $SU(3)_L \otimes U(1)_N$, where N is the quantum number of the U(1) group. Therefore, the left-handed lepton matter content is $(\nu'_a \quad l'_a \quad \mathtt{L}'_a)^{\mathtt{T}}_L$ transforming as $(\mathbf{3}, 0)$, where $a = e, \mu, \tau$ is a family index (we are using primes for the interaction eigenstates). $\mathtt{L}'_{aL}$ are lepton fields which can be the charge conjugates l'^{C}_{aR} [2,3] or the antineutrinos ν'^{C}_{La} [14] or heavy leptons P'^{+}_{aL} ($P'^{+}_{aL} = E'^{+}_L, M'^{+}_L, T'^{+}_L$) [4].

The model of Ref. [4] has the simplest scalar sector of the class of 3-3-1 models. In this version the charge operator is given by

$$\frac{Q}{e} = \frac{1}{2}(\lambda_3 - \sqrt{3}\lambda_8) + N, \qquad (1)$$

where λ_3 and λ_8 are the diagonal Gell-Mann matrices and e is the elementary electric charge. The right-handed charged leptons are introduced in singlet representation of $SU(3)_L$ as $l'^{-}_{aR} \sim (\mathbf{1}, -1)$ and $P'^{+}_{aR} \sim (\mathbf{1}, 1)$.

The quark sector is given by

$$Q_{1L} = \begin{pmatrix} u'_1 \\ d'_1 \\ J_1 \end{pmatrix}_L \sim \left(\mathbf{3}, \tfrac{2}{3}\right), \qquad Q_{\alpha L} = \begin{pmatrix} d'_\alpha \\ u'_\alpha \\ J'_\alpha \end{pmatrix}_L \sim \left(\mathbf{3}^*, -\tfrac{1}{3}\right), \tag{2}$$

where $\alpha = 2, 3$, J_1 and J_α are exotic quarks with electric charge $5/3$ and $-4/3$, respectively. It must be noticed that the first quark family transforms differently from the two others under the gauge group, which is essential for the anomaly cancellation mechanism [2,3].

The physical fermionic eigenstates rise by the transformations

$$l'^-_{aL(R)} = A^{L(R)}_{ab} l^-_{bL(R)}, \qquad P'^+_{aL(R)} = B^{L(R)}_{ab} P^+_{bL(R)}, \tag{3a}$$

$$U'_{L(R)} = \mathcal{U}^{L(R)} U_{L(R)}, \qquad D'_{L(R)} = \mathcal{D}^{L(R)} D_{L(R)}, \qquad J'_{L(R)} = \mathcal{J}^{L(R)} J_{L(R)}, \tag{3b}$$

where $U_{L(R)} = (u \quad c \quad t)_{L(R)}$, $D_{L(R)} = (d \quad s \quad b)_{L(R)}$, $J_{L(R)} = (J_1 \quad J_2 \quad J_3)_{L(R)}$, and $A^{L(R)}$, $B^{L(R)}$, $\mathcal{U}^{L(R)}$, $\mathcal{D}^{L(R)}$, $\mathcal{J}^{L(R)}$ are arbitrary mixing matrices.

The minimal scalar sector contains the three scalar triplets

$$\eta = \begin{pmatrix} \eta^0 \\ \eta_1^- \\ \eta_2^+ \end{pmatrix} \sim (\mathbf{3}, 0), \qquad \rho = \begin{pmatrix} \rho^+ \\ \rho^0 \\ \rho^{++} \end{pmatrix} \sim (\mathbf{3}, 1), \qquad \chi = \begin{pmatrix} \chi^- \\ \chi^{--} \\ \chi^0 \end{pmatrix} \sim (\mathbf{3}, -1). \tag{4}$$

The most general, gauge invariant, and renormalizable Higgs potential, which conserves the leptobaryon number [15], is

$$V(\eta, \rho, \chi) = \mu_1^2 \eta^\dagger \eta + \mu_2^2 \rho^\dagger \rho + \mu_3^2 \chi^\dagger \chi + \lambda_1 (\eta^\dagger \eta)^2 + \lambda_2 (\rho^\dagger \rho)^2 + \lambda_3 (\chi^\dagger \chi)^2 + (\eta^\dagger \eta)[\lambda_4 (\rho^\dagger \rho) + \lambda_5 (\chi^\dagger \chi)] + \lambda_6 (\rho^\dagger \rho)(\chi^\dagger \chi) + \lambda_7 (\rho^\dagger \eta)(\eta^\dagger \rho) + \lambda_8 (\chi^\dagger \eta)(\eta^\dagger \chi) + \lambda_9 (\rho^\dagger \chi)(\chi^\dagger \rho) + \tfrac{1}{2}(f \epsilon^{ijk} \eta_i \rho_j \chi_k + \text{H.c.}). \tag{5}$$

The neutral components of the scalar triplets (4) develop nonzero vacuum expectation values $\langle \eta^0 \rangle = v_\eta$, $\langle \rho^0 \rangle = v_\rho$, and $\langle \chi^0 \rangle = v_\chi$, with $v_\eta^2 + v_\rho^2 = v_W^2 = (246\ \text{GeV})^2$. The pattern of symmetry breaking is $\text{SU}(3)_L \otimes \text{U}(1)_N \overset{\langle \chi \rangle}{\longmapsto} \text{SU}(2)_L \otimes \text{U}(1)_Y \overset{\langle \eta, \rho \rangle}{\longmapsto} \text{U}(1)_{\text{em}}$. Therefore, we can expect $v_\chi \gg v_\eta, v_\rho$. In the potential (5), f and μ_j ($j = 1, 2, 3$) are constants with dimension of mass, and the λ_i ($i = 1, \ldots, 9$) are adimensional constants. The masses of the Higgs bosons were calculated by shifting the neutral fields of the potential (5) around its minimum as $\varphi = v_\varphi + \xi_\varphi + i\zeta_\varphi$, with $\varphi = \eta^0, \rho^0, \chi^0$, and diagonalizing the bilinear terms. These procedures are shown in Ref. [16] under the conditions $v_\chi \approx -f$, leading to the following results for the masses of the neutral physical scalars,

$$m^2_{H_1^0} \approx 4 \frac{\lambda_2 v_\rho^4 - 2\lambda_1 v_\eta^4}{v_\eta^2 - v_\rho^2}, \qquad m^2_{H_2^0} \approx \frac{v_W^2 v_\chi^2}{2 v_\eta v_\rho}, \qquad m^2_{H_3^0} \approx -\lambda_3 v_\chi^2, \qquad m_h^2 = -\frac{f v_\chi}{v_\eta v_\rho}\left[v_W^2 + \left(\frac{v_\eta v_\rho}{v_\chi}\right)^2\right], \tag{6a}$$

for the singly charged ones,

$$m^2_{\pm 1} = \frac{v_W^2}{2 v_\eta v_\rho}(f v_\chi - 2\lambda_7 v_\eta v_\rho), \qquad m^2_{\pm 2} = \frac{v_\eta^2 + v_\chi^2}{2 v_\eta v_\chi}(f v_\rho - 2\lambda_8 v_\eta v_\chi), \tag{6b}$$

and for the doubly charged Higgs bosons,

$$m^2_{\pm\pm} = \frac{v_\rho^2 + v_\chi^2}{2 v_\rho v_\chi}(f v_\eta - 2\lambda_9 v_\rho v_\chi). \tag{6c}$$

After the process of diagonalization of the Higgs potential (5) we obtain the physical neutral scalar eigenstates H_i^0 ($i = 1, 2, 3$) and h which are related to the shifted fields as

$$\begin{pmatrix} \xi_\eta \\ \xi_\rho \end{pmatrix} \approx \frac{1}{v_W} \begin{pmatrix} c_\omega & s_\omega \\ s_\omega & c_\omega \end{pmatrix} \begin{pmatrix} H_1^0 \\ H_2^0 \end{pmatrix}, \qquad \xi_\chi \approx H_3^0, \qquad \zeta_\chi \approx ih, \tag{7a}$$

where $c_\omega = \cos\omega = v_\eta / \sqrt{v_\eta^2 + v_\rho^2}$ and $s_\omega = \sin\omega$. For the charged physical eigenstates $H_1^\pm$, $H_2^\pm$, and $H^{\pm\pm}$ we have

$$\eta_1^+ = s_\omega H_1^+, \qquad \eta_2^+ = s_\varphi H_2^+, \qquad \rho^+ = c_\omega H_1^+, \qquad \chi^+ = c_\varphi H_2^+, \tag{7b}$$

$$\rho^{++} = s_\phi H^{++}, \qquad \chi^{++} = c_\phi H^{++}, \tag{7c}$$

with $c_\varphi = \cos\varphi = v_\eta / \sqrt{v_\eta^2 + v_\chi^2}$, $s_\varphi = \sin\varphi$, $c_\phi = \cos\phi = v_\rho / \sqrt{v_\rho^2 + v_\chi^2}$, and $s_\phi = \sin\phi$.

The Yukawa interactions for leptons and quarks are, respectively,

$$-\mathcal{L}_l = G_{ab}\bar{\psi}_{aL}l'_{bR}\rho + G'_{ab}\bar{\psi}_{aL}P'_{bR}\chi + \text{H.c.}, \tag{8a}$$

$$\begin{aligned}-\mathcal{L}_Q = \bar{Q}_{1L}\sum_i\Big[&G^u_{1i}U'_{iR}\eta + G^d_{1i}D'_{iR}\rho \\ &+ \sum_\alpha \bar{Q}_{\alpha L}(F^u_{\alpha i}U'_{iR}\rho^* + F^d_{\alpha i}D'_{iR}\eta^*)\Big] \\ &+ G^j\bar{Q}_{1L}J_{1R}\chi + \sum_{\alpha\beta}G^j_{\alpha\beta}\bar{Q}_{\alpha L}J'_{\beta R}\chi^* + \text{H.c.}\end{aligned} \tag{8b}$$

In Eq. (8) $a, b = e, \mu, \tau$ and $\alpha = 2, 3$. We are assuming the masses of exotic fermions are of the order of v_χ.

Beyond the standard particles γ, Z, and $W^\pm$ the model predicts, in the gauge sector, one neutral (Z'), two single-charged ($V^\pm$), and two double-charged ($U^{\pm\pm}$) gauge bosons. The interactions between the gauge and Higgs bosons are given by the covariant derivative

$$\mathcal{D}_\mu\varphi_i = \partial_\mu\varphi_i - ig\Big(\vec{W}_\mu\cdot\frac{\vec{\lambda}}{2}\Big)^j_i\varphi_j - ig'N_\varphi\varphi_i B_\mu, \tag{9}$$

where N_φ are the U(1) charges for the φ Higgs triplets ($\varphi = \eta, \rho, \chi$). $\vec{W}_\mu$ and B_μ are field tensors of SU(2) and U(1), respectively, $\vec{\lambda}$ are Gell-Mann matrices, and g and g' are coupling constants for SU(2) and U(1), respectively. Diagonalization of the covariant derivative (9), after symmetry breaking, furnishes the masses of the exotic gauge bosons, i.e.,

$$m^2_{Z'} \approx \Big(\frac{ev_\chi}{s_W}\Big)^2\frac{2(1-s^2_W)}{3(1-4s^2_W)}, \qquad m^2_V = \Big(\frac{e}{s_W}\Big)^2\frac{v^2_\eta + v^2_\chi}{2},$$
$$m^2_U = \Big(\frac{e}{s_W}\Big)^2\frac{v^2_\rho + v^2_\chi}{2}, \tag{10}$$

where $s_W = \sin\theta_W$.

Introducing the eigenstates (3) and (7) in the Lagrangians (8) we obtain the Yukawa interactions as a function of the physical eigenstates, i.e.,

$$\begin{aligned}-\mathcal{L}_{lp} = \frac{1}{2}\Big\{&\frac{1}{v_\rho}[c_\omega\bar{\nu}\mathcal{U}^{\nu e}H^+_1 + (v_\rho + s_\omega H^0_1 - c_\omega H^0_2)\bar{e}^- + s_\phi\bar{P}^+\mathcal{U}^{Pe}H^{++}]M^eG_Re^- \\ &+ \frac{1}{v_\chi}[c_\omega\bar{\nu}\mathcal{V}^{\nu P}H^-_2 + c_\phi\bar{e}^-\mathcal{V}^{eP}H^{--} + (v_\chi + H^0_3 + ih)\bar{P}^+]M^EG_RP^+\Big\} + \text{H.c.},\end{aligned} \tag{11a}$$

$$\begin{aligned}-\mathcal{L}_{Qp} = \frac{1}{2}\Big\{&\bar{U}G_R\Big[1 + \Big[\frac{s_\omega}{v_\rho} + \Big(\frac{c_\omega}{v_\eta} + \frac{s_\omega}{v_\rho}\Big)\mathcal{V}^u\Big]H^0_1 + \Big[-\frac{c_\omega}{v_\rho} + \Big(\frac{s_\omega}{v_\eta} - \frac{c_\omega}{v_\rho}\Big)\mathcal{V}^u\Big]H^0_2\Big]M^uU \\ &+ \bar{D}G_R\Big[1 + \Big[\frac{c_\omega}{v_\eta} + \Big(\frac{s_\omega}{v_\rho} - \frac{c_\omega}{v_\eta}\Big)\mathcal{V}^D\Big]H^0_1 + \Big[\frac{s_\omega}{v_\eta} - \Big(\frac{c_\omega}{v_\rho} + \frac{s_\omega}{v_\eta}\Big)\mathcal{V}^D\Big]H^0_2\Big]M^dD \\ &+ \bar{U}G_R\Big[\frac{s_\omega}{v_\eta}V^\dagger_{\text{CKM}}H^-_1 + \Big(\frac{c_\omega}{v_\eta} - \frac{s_\omega}{v_\rho}\Big)\mathcal{V}^{ud}H^+_1\Big]M^dD + \bar{D}G_R\Big[\frac{c_\omega}{v_\rho}V_{\text{CKM}}H^+_1 + \Big(\frac{s_\omega}{v_\eta} - \frac{c_\omega}{v_\rho}\Big)\mathcal{V}^{ud\dagger}H^-_1\Big]M^uU\Big\} \\ &+ \text{H.c.},\end{aligned} \tag{11b}$$

$$-\mathcal{L}_J = \frac{1}{2}[\bar{J}G_R\mathcal{J}^{L\dagger}(\mathcal{N}\mathcal{U}^LM^uU + \mathcal{R}\mathcal{D}^LM^dD) + (\bar{U}\mathcal{U}^{L\dagger}\mathcal{X}_1 + \bar{D}\mathcal{D}^{L\dagger}\mathcal{X}_2 + \bar{J}\mathcal{J}^{L\dagger}\mathcal{X}_0)\mathcal{J}^LM^JG_RJ] + \text{H.c.}, \tag{11c}$$

where $G_R = 1 + \gamma_5$, $V^U_LV^D_L = V_{\text{CKM}}$ is the Cabibbo-Kobayashi-Maskawa mixing matrix, $\mathcal{U}^{\nu e}$, $\mathcal{U}^{Pe}$, $\mathcal{V}^{\nu e}$, $\mathcal{V}^{eP}$, $\mathcal{V}^u = V^U_L\Delta V^{U\dagger}_L$, $\mathcal{V}^d = V^D_L\Delta V^{D\dagger}_L$, and $\mathcal{V}^{ud} = V^U_L\Delta V^{D\dagger}_L$ are arbitrary mixing matrices, $M^e = \text{diag}(m_e \quad m_\mu \quad m_\tau)$, $M^P = \text{diag}(m_E \quad m_M \quad m_T)$, $M^u = \text{diag}(m_u \quad m_c \quad m_t)$, $M^d = \text{diag}(m_d \quad m_s \quad m_b)$, and $M^J = \text{diag}(m_{J_1} \quad m_{J_2} \quad m_{J_3})$. In Eq. (11c) we have defined

$$\mathcal{N} = \begin{pmatrix} s_\omega H^+_2/v_\eta & 0 & 0 \\ 0 & s_\phi H^{--}/v_\rho & s_\phi H^{--}/v_\rho \\ 0 & s_\phi H^{--}/v_\rho & s_\phi H^{--}/v_\rho \end{pmatrix}, \qquad \mathcal{X}_0 \approx \frac{v_\chi + H^0_3 + ih}{v_\chi}\begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 1 \\ 0 & 1 & 1 \end{pmatrix}, \tag{12a}$$

$$\mathcal{R} = \begin{pmatrix} s_\phi H^{++}/v_\rho & 0 & 0 \\ 0 & s_\omega H^-_2/v_\eta & s_\omega H^-_2/v_\eta \\ 0 & s_\omega H^-_2/v_\eta & s_\omega H^-_2/v_\eta \end{pmatrix}, \qquad \mathcal{X}_1 = \frac{1}{v_\chi}\begin{pmatrix} c_\omega H^-_2 & 0 & 0 \\ 0 & c_\phi H^{++} & c_\phi H^{++} \\ 0 & c_\phi H^{++} & c_\phi H^{++} \end{pmatrix}, \tag{12b}$$

$$\mathcal{X}_2 = \frac{1}{v_\chi}\begin{pmatrix} c_\phi H^{--} & 0 & 0 \\ 0 & c_\omega H^+_2 & c_\omega H^+_2 \\ 0 & c_\omega H^+_2 & c_\omega H^+_2 \end{pmatrix}. \tag{12c}$$

It should be noticed that nonstandard field interactions violate the leptonic number, as can be seen from the Lagrangians (8) and (9). However the total leptonic number is conserved [2,3].

III. CROSS SECTION PRODUCTION

The production of DCHBs in e^+e^- collisions occurs in association with the bosons γ, Z, Z', H_1^0, and H_2^0 in the s channel. This production mechanism can be studied through the analysis of the reactions $e^-e^+ \rightarrow H^{\pm\pm}H^{\mp\mp}$, provided there is enough available energy ($\sqrt{s} \geq 2m_{\pm\pm}$). There is another contribution coming from $e^-e^+ \rightarrow H^{++}H^{--}$ via t-channel heavy lepton exchange; these contributions are 3 to 4 orders of magnitude smaller than that of the s channel, because the coupling $e^+P^+H^{++}$ is directly proportional to electron mass (11a). Using the interaction Lagrangians (5) and (11) we evaluate the differential cross section for this reaction:

$$\begin{aligned}
\frac{d\hat{\sigma}}{d\cos\theta} &= \frac{\beta\alpha^2\pi\Lambda_\gamma^2}{8s^3}[8m_{\pm\pm}^4 - 8m_{\pm\pm}^2(t+u) + 16m_{\pm\pm}^2m_e^2 + 2t^2 + 4tu - 8m_e^2(t+u) + 2u^2 - 2s^2 + 8m_e^2] \\
&+ \frac{\beta\alpha^2\pi\Lambda_{Z(Z')}^2}{32ss_W^2c_W^2[(s-m_{Z,Z'}^2)^2 + m_{Z,Z'}^2\Gamma_{Z,Z'}^2]}[-8m_{\pm\pm}^2s[(g_V^{l(l')})^2 + (g_A^{l(l')})^2] + 32m_{\pm\pm}^2m_e^2(g_A^{l(l')})^2 \\
&- 2t^2[(g_V^{l(l')})^2 + (g_A^{l(l')})^2] + 4tu[(g_V^{l(l')})^2 + (g_A^{l(l')})^2] - 2u^2[(g_V^{l(l')})^2 + (g_A^{l(l')})^2] + 2s^2[(g_V^{l(l')})^2 + (g_A^{l(l')})^2] \\
&- 8sm_e^2(g_A^{l(l')})^2] + \frac{\beta m_e^2\Lambda_1^2}{128\pi v_W^2 s[(s-m_{H_1^0}^2)^2 + m_{H_1^0}^2\Gamma_{H_1^0}^2]}(s-2m_e^2) \\
&+ \frac{\beta m_e^2 v_\rho^2\Lambda_2^2}{128\pi v_W^2 v_\eta^2 s[(s-m_{H_2^0}^2)^2 + m_{H_2^0}^2\Gamma_{H_2^0}^2]}(s-2m_e^2) - \frac{\beta m_e^2 v_\rho\Lambda_1\Lambda_2}{64\pi v_W^2 v_\eta s(s-m_{H_1^0}^2 + im_{H_1^0}\Gamma_{H_1^0})(s-m_{H_2^0}^2 + im_{H_2^0}\Gamma_{H_2^0})} \\
&\times (s-2m_e^2) + \frac{\beta\alpha^2\pi\Lambda_\gamma\Lambda_{Z'}}{8s_Wc_Ws(s-m_{Z'}^2)}[-8m^{\pm\pm2}sg_V^{l'} - 2t^2g_V^{l'} + 4tug_V^{l'} - 2u^2g_V^{l'} + 2s^2g_V^{l'}]. \qquad (13)
\end{aligned}$$

The primes ($'$) concern the Z' boson, $\Gamma_{Z,Z'}$ are the total width of the boson Z and Z' [17,18], β is the velocity of the DCHB in the center of mass (c.m.) of the process, α is the fine structure constant, which we take equal to $\alpha = 1/128$, $g_{V,A}^l$ are the standard coupling constants, $g_{V,A}^{l'}$ are the 3-3-1 lepton coupling constants, m_Z is the mass of the Z boson, $\sqrt{s}$ is the c.m. energy of the e^-e^+ system, $t = m_{\pm\pm}^2 - (1 - \beta\cos\theta)s/2$ and $u = m_{\pm\pm}^2 - (1 + \beta\cos\theta)s/2$, where θ is the angle between the heavy DCHBs and the incident electron, in the c. m. frame.

The Λ_i, where i stands for H_1^0, H_2^0, are the coupling constants of these bosons to $H^{--}H^{++}$, the Λ_γ is the coupling constants of the photon to $H^{--}H^{++}$, and the $\Lambda_{Z(Z')}$ are of the bosons Z and Z' to $H^{--}H^{++}$. The analytical expressions for these coupling constants are

$$\Lambda_\gamma = \frac{v_\chi^2 - v_\eta^2}{v_\chi^2 + v_\eta^2}, \qquad (14a)$$

$$\Lambda_Z = -i\frac{(1-4s_W^2)v_\eta^2 + 4s_W^2v_\chi^2}{4s_Wc_W(v_\chi^2 + v_\eta^2)}, \qquad (14b)$$

$$\Lambda_{Z'} = -\frac{2(1-7s_W^2)v_\chi^2 - (1-10s_W^2)v_\eta^2}{4s_Wc_W\sqrt{3(1-4s_W^2)}(v_\chi^2 + v_\eta^2)}, \qquad (14c)$$

$$\Lambda_1 = -i\left(\frac{2[(2\lambda_6 + \lambda_9)v_\eta^4 + 2(2\lambda_2 + \lambda_9)v_\eta^2v_\chi^2 + 2(\lambda_4v_\chi^2 + \lambda_5v_\eta^2)v_\rho^2 - fv_\eta v_\rho v_\chi]}{v_W(v_\eta^2 + v_\chi^2)}\right), \qquad (14d)$$

$$\Lambda_2 = i\frac{v_\eta[2(-\lambda_5 + \lambda_6 + \lambda_9)v_\eta^2v_\rho + 2(2\lambda_2 - \lambda_4 + \lambda_9)v_\chi^2v_\rho + fv_\eta v_\chi]}{v_W(v_\eta^2 + v_\chi^2)}. \qquad (14e)$$

The Higgs parameters λ_i ($i = 1\ldots 9$) must run from -3 to $+3$ in order to allow perturbative calculations. For H_2^0 we take $m_{H_2^0} = (0.2 - 3.0)$ TeV. It must be noticed that here there is no contribution from the interference between the scalar particle $H_{1(2)}^0$ and a vectorial one (γ, Z, or Z') such as between the photon and the boson Z.

Concerning the signal $H^{\pm\pm} \rightarrow U^{\pm\pm}Z$, it is necessary to compute the decay of the doubly charged gauge bosons $U^{\pm\pm}$, for which total width into $J_{2,3}\bar{q}_{u,c,t}(\bar{J}_{2,3}q_{u,c,t})$ and $q_d\bar{J}_1(\bar{q}_dJ_1)$ quarks, $e^{\pm}P^{\pm}$ leptons, $\gamma H^{\pm\pm}$ photon and doubly charged Higgs, $Z(Z')H^{\pm\pm}$ gauge boson and doubly charged Higgs, $H_1^{\pm}H_2^{\pm}$, $H_1^0H^{\pm\pm}$, $H_2^0H^{\pm\pm}$, $H_3^0H^{\pm\pm}$, and $h^0H^{\pm\pm}$ Higgs bosons are, respectively, given by

$$\Gamma(U^{\pm\pm} \rightarrow \text{all}) = \Gamma_{U^{\pm\pm}\rightarrow J_{2,3}\bar{q}_{u,c,t}(\bar{J}_{2,3}q_{u,c,t})} + \Gamma_{U^{\pm\pm}\rightarrow q_d\bar{J}_1(\bar{q}_dJ_1)} + \Gamma_{U^{\pm\pm}\rightarrow l^{\pm}P^{\pm}} + \Gamma_{U^{\pm\pm}\rightarrow \gamma H^{\pm\pm}} + \Gamma_{U^{\pm\pm}\rightarrow ZH^{\pm\pm}} + \Gamma_{U^{\pm\pm}\rightarrow Z'H^{\pm\pm}} + \Gamma_{U^{\pm\pm}\rightarrow H_1^{\pm}H_2^{\pm}} + \Gamma_{U^{\pm\pm}\rightarrow H_1^0H^{\pm\pm}} + \Gamma_{U^{\pm\pm}\rightarrow H_2^0H^{\pm\pm}} + \Gamma_{U^{\pm\pm}\rightarrow H_3^0H^{\pm\pm}} + \Gamma_{U^{\pm\pm}\rightarrow h^0H^{\pm\pm}},$$

where the widths are given by

$$\Gamma_{U^{\mp\mp}\rightarrow J_{2,3}\bar{q}_{u,c,t}(\bar{J}_{2,3}q_{u,c,t})} = \frac{\sqrt{1-(\frac{m_{J_{2,3}}+m_{\bar{q}_{u,c,t}}}{m_{U^{\mp\mp}}})^2}\sqrt{1-(\frac{m_{J_{2,3}}-m_{\bar{q}_{u,c,t}}}{m_{U^{\mp\mp}}})^2}}{48\pi m_{U^{\mp\mp}}}(\Lambda^2_{UJq_u})(8m^2_{U^{\pm\pm}} - 4m^2_{J_{2,3}} - 4m^2_{\bar{q}_{u,c,t}}), \tag{15a}$$

$$\Gamma_{U^{\mp\mp}\rightarrow q_d\bar{J}_1(\bar{q}_dJ_1)} = \frac{\sqrt{1-(\frac{m_{q_d}+m_{\bar{J}_1}}{m_{U^{\mp\mp}}})^2}\sqrt{1-(\frac{m_{q_d}-m_{\bar{J}_1}}{m_{U^{\mp\mp}}})^2}}{48\pi m_{U^{\mp\mp}}}(\Lambda^2_{UJq_d})(8m^2_{U^{\mp\mp}} - 4m^2_{\bar{J}_1} - 4m^2_{q_d}), \tag{15b}$$

$$\Gamma_{U^{\mp\mp}\rightarrow l^-P^-(l^+P^+)} = \frac{\sqrt{1-(\frac{m_l+m_P}{m_{U^{\mp\mp}}})^2}\sqrt{1-(\frac{m_l-m_P}{m_{U^{\mp\mp}}})^2}}{48\pi m_{U^{\mp\mp}}}(\Lambda^2_{UlP})(8m^2_{U^{\mp\mp}} - 4m^2_l - 4m^2_P), \tag{15c}$$

$$\Gamma_{U^{\mp\mp}\rightarrow \gamma H^{\mp\mp}} = \frac{(1-\frac{m^2_{\mp\mp}}{m^2_{U^{\mp\mp}}})}{16\pi m_{U^{\mp\mp}}}(\Lambda^2_{UAH^{\mp\mp}}), \tag{15d}$$

$$\Gamma_{U^{\mp\mp}\rightarrow ZH^{\mp\mp}} = \frac{\sqrt{1-(\frac{m_Z+m_{\mp\mp}}{m_{U^{\mp\mp}}})^2}\sqrt{1-(\frac{m_Z-m_{\mp\mp}}{m_{U^{\mp\mp}}})^2}}{48\pi m_{U^{\mp\mp}}}\left(2+\frac{m^2_{U^{\mp\mp}}}{4m^2_Z}\right)(\Lambda^2_{UZH^{\mp\mp}}), \tag{15e}$$

$$\Gamma_{U^{\mp\mp}\rightarrow Z'H^{\mp\mp}} = \frac{\sqrt{1-(\frac{m_{Z'}+m_{\mp\mp}}{m_{U^{\mp\mp}}})^2}\sqrt{1-(\frac{m_{Z'}-m_{\mp\mp}}{m_{U^{\mp\mp}}})^2}}{48\pi m_{U^{\mp\mp}}}\left(2+\frac{m^2_{U^{\mp\mp}}}{4m^2_{Z'}}\right)(\Lambda^2_{UZLH^{\mp\mp}}), \tag{15f}$$

$$\Gamma_{U^{\mp\mp}\rightarrow H_1^-H_2^-} = \frac{\sqrt{1-(\frac{m_{H_1^-}+m_{H_2^-}}{m_{U^{\mp\mp}}})^2}\sqrt{1-(\frac{m_{H_1^-}-m_{H_2^-}}{m_{U^{\mp\mp}}})^2}}{48\pi m_{U^{\mp\mp}}}(m^2_U - 2m^2_{H_1^-} - 2m^2_{H_2^-})(\Lambda^2_{UH_1H_2}), \tag{15g}$$

$$\Gamma_{U^{\mp\mp}\rightarrow H_i^0H^{\mp\mp}} = \frac{\sqrt{1-(\frac{m_{H_i^0}+m_{\mp\mp}}{m_{U^{\mp\mp}}})^2}\sqrt{1-(\frac{m_{H_i^0}-m_{\mp\mp}}{m_{U^{\mp\mp}}})^2}}{48\pi m_{U^{\mp\mp}}}(m^2_U - 2m^2_{H_i^0} - 2m^2_{\mp\mp})(\Lambda^2_{UH_i^0H^{\mp\mp}}), \tag{15h}$$

where H_i^0 denote the H_1^0, H_2^0, H_3^0, and h^0. The coupling constants in Eq. (15) are given by

TABLE I. Values of the masses for $v_\eta = 195$ GeV and the sets of parameters given in the text. All the values in this table are given in GeV.

v_χ	m_E	m_M	m_T	$m_{H_1^0}$	$m_{H_2^0}$	$m_{H_3^0}$	m_V	m_U	$m_{Z'}$	m_{J_1}	m_{J_2}	m_{J_3}
1000	148.9	875.0	2000	873.7	1017.2	2000	467.5	464.0	1707.6	1000	1410	1410
1500	223.3	1312.5	3000	873.7	1525.8	3000	694.1	691.8	2561.3	1500	2115	2115

$$\Lambda_{UJq_{u(d)}} = -i\frac{e}{2\sqrt{2}s_W}, \tag{16a}$$

$$\Lambda_{UlP} = -i\frac{e}{2\sqrt{2}s_W}, \tag{16b}$$

$$\Lambda_{UAH^{\mp\mp}} = ie^2\frac{\sqrt{2}v_\rho v_\chi}{s_W\sqrt{v_\rho^2 + v_\chi^2}}, \tag{16c}$$

$$\Lambda_{UZH^{\mp\mp}} = ie^2\frac{\sqrt{2}v_\rho v_\chi}{c_W\sqrt{v_\rho^2 + v_\chi^2}}, \tag{16d}$$

$$\Lambda_{UZ'H^{\mp\mp}} = -ie^2\frac{\sqrt{2(1-4s_W^2)}v_\rho v_\chi}{s_W c_W\sqrt{3(v_\rho^2 + v_\chi^2)}}, \tag{16e}$$

$$\Lambda_{UH_1H_2} = -e\frac{v_\rho v_\chi}{2\sqrt{2}s_W v_W\sqrt{v_\eta^2 + v_\chi^2}}, \tag{16f}$$

$$\Lambda_{UH_1^0H^{\mp\mp}} = -e\frac{v_\rho v_\chi}{2\sqrt{2}s_W v_W\sqrt{v_\rho^2 + v_\chi^2}}, \tag{16g}$$

$$\Lambda_{UH_2^0H^{\mp\mp}} = e\frac{v_\eta v_\chi}{2\sqrt{2}s_W v_W\sqrt{v_\rho^2 + v_\chi^2}}, \tag{16h}$$

$$\Lambda_{UH_3^0H^{\mp\mp}} = -e\frac{v_\rho}{2\sqrt{2}s_W\sqrt{v_\rho^2 + v_\chi^2}}, \tag{16i}$$

$$\Lambda_{UhH^{\mp\mp}} = ie\frac{v_\rho}{2\sqrt{2}s_W\sqrt{v_\rho^2 + v_\chi^2}}. \tag{16j}$$

For Z' boson we take $m_{Z'} = (0.6 - 3)$ TeV, since $m_{Z'}$ is proportional to the v_χ [2,3]. For the standard model parameters we assume Particle Data Group values, i.e., $m_Z = 91.19$ GeV, $\sin^2\theta_W = 0.2315$, and $m_W = 80.33$ GeV [11].

IV. RESULTS AND CONCLUSIONS

In the following we present the cross section for the process $e^+e^- \to H^{\pm\pm}H^{\mp\mp}$ for the ILC (1.5 TeV) and CLIC (3 TeV), where we have chosen for the parameters, masses, and vacuum expectation value the following representative values: $\lambda_1 = -1.2$, $\lambda_2 = \lambda_3 = -\lambda_6 = \lambda_8 = -1$, $\lambda_4 = 2.98$, $\lambda_5 = -1.57$, $\lambda_7 = -2$, $\lambda_9 = -0.8$, $v_\eta = 195$ GeV, and with other particles masses as given in Table I, it is noticeable that the value of λ_9 was chosen this way in order to guarantee the approximation $-f \simeq v_\chi$ [4,19] and because the masses of m_{h^0}, $m_{\pm 1}$, and $m_{\pm 2}$ depend on the parameter f [see (6a) and (6b)]. Therefore they cannot be fixed by any value of v_χ [19,20]. So when we have $m_{\pm\pm} = 500(700)$ GeV, $v_\chi = 1000$ GeV, the masses of $H_2^\pm$ and h are $m_{\pm 2} = 834.8(917.1)$ GeV, and $m_h = 1339.1(1017.6)$ GeV, and in the case of $v_\chi = 1500$ GeV for $m_{\pm\pm} = 500(700)$ GeV, the values of the mass of $H_2^\pm$ and h are $m_{\pm 2} = 1163.7(1223.6)$ GeV and $m_h = 2229.9(2052.2)$ GeV, respectively.

In Table I the $m_{Z'}$ is in accordance with the estimated values of the CDF and D0 experiments, which probe the Z' masses in the 500–800 GeV range [21]. In Figs. 1 and 2, we show the cross section $e^+e^- \to H^{\pm\pm}H^{\mp\mp}$; these processes are studied in two cases, the one where $v_\chi = 1000$ GeV and the other one where $v_\chi = 1500$ GeV.

A. ILC—Events

Considering that the expected integrated luminosity for the ILC will be of order of 3.8×10^5 pb^{-1}/yr, then the statistics we are expecting are the following. The ILC gives a total of $\simeq 9.1 \times 10^4$ events per year, if we take the mass of the boson $m_{\pm\pm} = 500$ GeV and $v_\chi = 1000$ GeV. Considering that the signals for $H^{\mp\mp}$ are $U^{--}\gamma$ and $U^{++}\gamma$ and taking into account that the branching ratios for these particles would be BR$(H^{\mp\mp} \to U^{\mp\mp}\gamma) = 49.5\%$ (see Figs. 3 and 4) for the mass of the Higgs boson $m_{\pm\pm} = 500$ GeV and $v_\chi = 1000$ GeV, and that the particles $U^{\mp\mp}$ decay into e^-P^- and e^+P^+, for which branching ratios for these particles would be BR$(U^{\mp\mp} \to e^\mp P^\mp) = 50\%$ (see Figs. 5 and 6), then we would have $\simeq 5.6 \times 10^3$ events per

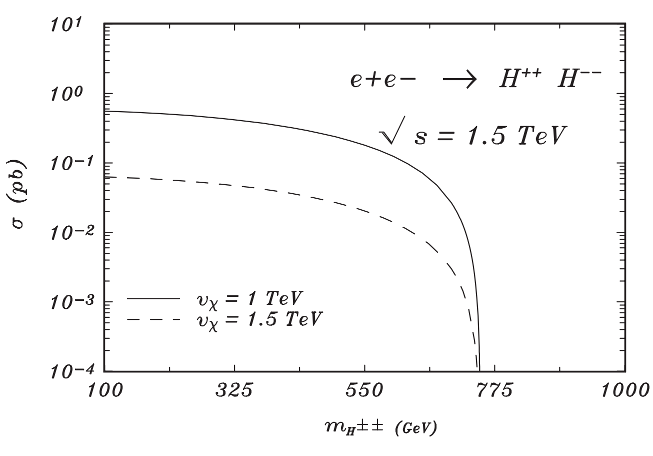

FIG. 1. Total cross section for the process $e^+e^- \to H^{++}H^{--}$ as a function of $m_{\pm\pm}$ at $\sqrt{s} = 1.5$ TeV: (a) $v_\chi = 1$ TeV (solid line) and (b) $v_\chi = 1.5$ TeV (dashed line).

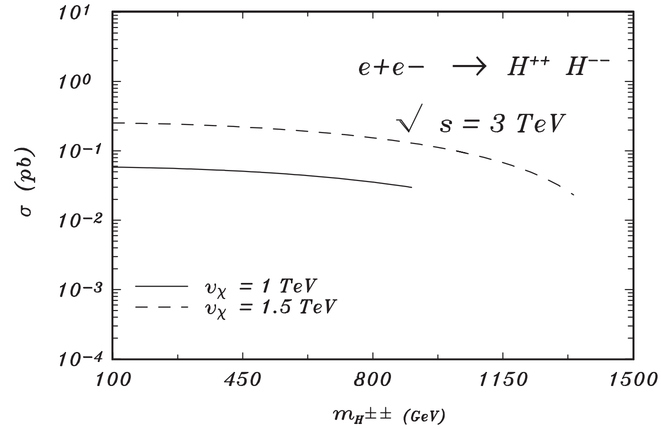

FIG. 2. Total cross section for the process $e^+e^- \longrightarrow H^{++}H^{--}$ as a function of $m_{\pm\pm}$ at $\sqrt{s} = 3$ TeV: (a) $\upsilon_\chi = 1$ TeV (solid line) and (b) $\upsilon_\chi = 1.5$ TeV (dashed line).

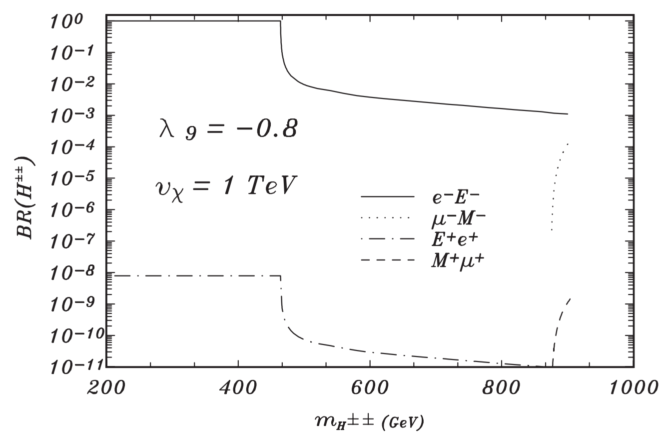

FIG. 3. Branching ratios for the DCHB decays as functions of $m_{\pm\pm}$ for $\lambda_9 = -0.8$ and $\upsilon_\chi = 1$ TeV for the leptonic sector.

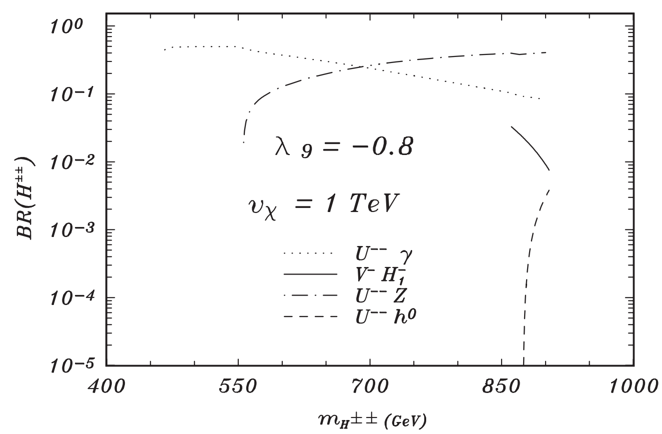

FIG. 4. Branching ratios for the DCHB decays as functions of $m_{\pm\pm}$ for $\lambda_9 = -0.8$, $\upsilon_\chi = 1$ TeV for the bosonic sector.

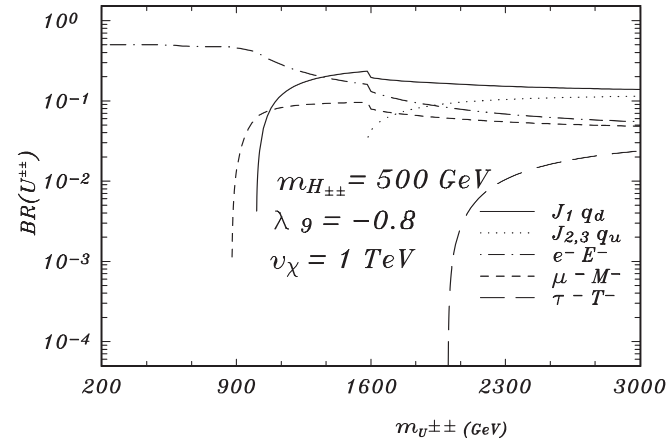

FIG. 5. Branching ratios for the DCHB decays as functions of $m_{\pm\pm}$ for $\lambda_9 = -0.8$, $\upsilon_\chi = 1.5$ TeV for the leptonic sector.

year for the ILC. Regarding the $\upsilon_\chi = 1500$ GeV it will not give any event because it is restricted by the values of $m_{U^{\pm\pm}}$ which in this case give $m_{U^{\pm\pm}} = 691.8$ GeV (see Table I).

Taking now $m_{\pm\pm} = 700$ GeV and $\upsilon_\chi = 1000$ GeV, we then have a total of $\simeq 10^4$ events per year. Considering again the same signal as above, for which branching ratios are equal to $\mathrm{BR}(H^{\mp\mp} \longrightarrow U^{\mp\mp}\gamma) = 23.7\%$ (see Figs. 3 and 4) for the mass of the Higgs boson $m_{\pm\pm} = 700$ GeV, $\upsilon_\chi = 1000$ GeV, and that the particles $U^{\mp\mp}$ decay into e^-P^- and e^+P^+, for which branching ratios for these particles would be $\mathrm{BR}(U^{\mp\mp} \longrightarrow e^{\mp}P^{\mp}) = 50\%$ (see Figs. 7 and 8), then we would have $\simeq 140$ events per year for the ILC, regarding the $\upsilon_\chi = 1500$ GeV then we will have $\simeq 1.1 \times 10^3$ events per year, and considering the same parameter signals as above, that is, $\mathrm{BR}(H^{\mp\mp} \longrightarrow U^{\mp\mp}\gamma) = 47.7\%$ (see Figs. 9 and 10), and $\mathrm{BR}(U^{\mp\mp} \longrightarrow e^{\mp}P^{\mp}) = 50\%$ (see Figs. 11 and 12), then we would have $\simeq 63$ events per year for the ILC. These results are shown in Table II.

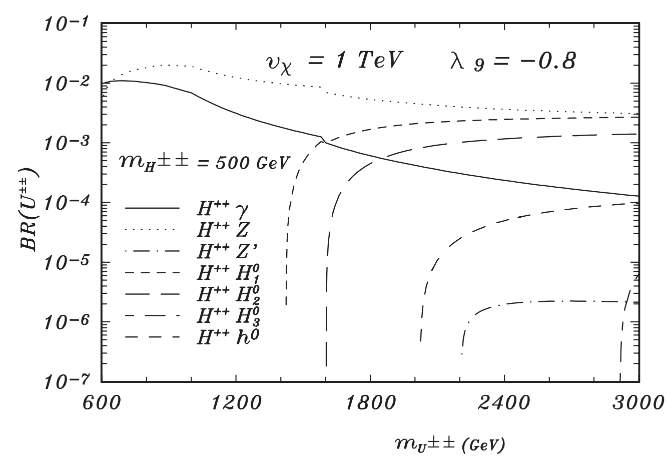

FIG. 6. Branching ratios for the DCHB decays as functions of $m_{\pm\pm}$ for $\lambda_9 = -0.8$, $\upsilon_\chi = 1.5$ TeV for the bosonic sector.

TABLE II. Branching ratios for the $H^{\pm\pm}$ decay and events per year for ILC and CLIC colliders, for which units of v_χ, m_{++}, $m_{\pm 2}$, and m_h are in GeV. The events for $v_\chi = 1500$ GeV and $m_{++} = 500$ GeV are prohibited by the cinematics.

v_χ	m_{++}	$m_{\pm 2}$	m_h	BR in % for $H^{\pm\pm} \rightarrow U^{\pm\pm}\gamma$	ILC total ev/yr	ILC signal ev/yr	CLIC total ev/yr	CLIC signal ev/yr
1000	500	834.8	1339.1	49.5	9.1×10^4	5.6×10^3	1.5×10^5	9.1×10^3
	700	917.1	1017.6	23.7	1.0×10^4	140	1.2×10^5	1.7×10^3
1500	500	1163.7	2229.9	...	...	...	...	...
	700	1223.6	2052.2	47.7	1.1×10^3	63	5.4×10^5	3.1×10^4

B. CLIC—Events

The cross section for the CLIC is restricted by the mass of the DCHBs, because for $v_\chi = 1000(1500)$ GeV and $\lambda_9 = -0.8$ the acceptable masses are for the DCHBs up to $m_{\pm\pm} \simeq 903(1346)$ GeV, as can be seen in Ref. [19]. Taking this into account and considering that the expected integrated luminosity for the CLIC collider will be of order of 3×10^6 pb^{-1}/yr, we obtain a total of $\simeq 1.5 \times 10^5$ events per year if we take the mass of the boson $m_{\pm\pm} = 500$ GeV and $v_\chi = 1000$ GeV. Considering the same signal as above for $H^{\mp\mp}$ production, that is, $U^{--}\gamma$ and $U^{++}\gamma$, and taking into account that the branching ratios for these particles would be $BR(H^{\mp\mp} \rightarrow U^{\mp\mp}\gamma) = 49.5\%$ (see Figs. 3 and 4) for the mass of the Higgs boson $m_{\pm\pm} = 500$ GeV and $v_\chi = 1000$ GeV, and that the particles $U^{\mp\mp}$ decay into $e^- P^-$ and $e^+ P^+$, for which branching ratios for

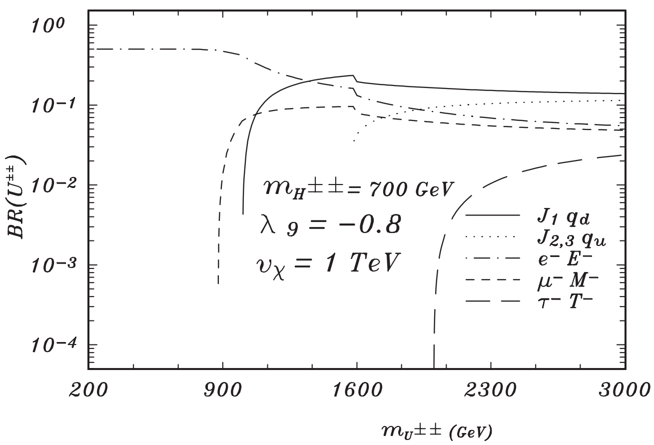

FIG. 7. Branching ratios for the DCHB decays as functions of $m_{U^{\pm\pm}}$ for $\lambda_9 = -0.8$, $v_\chi = 1$ TeV, and $m_{\pm\pm} = 500$ GeV for the leptonic sector.

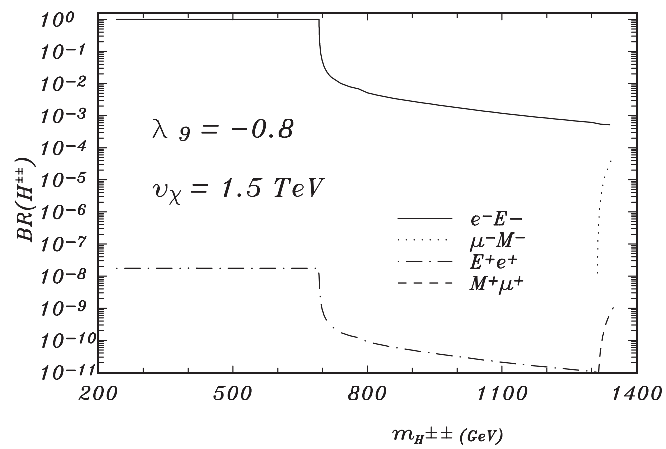

FIG. 9. Branching ratios for the doubly charged gauge boson decays as functions of $m_{U^{\pm\pm}}$ for $\lambda_9 = -0.8$, $v_\chi = 1$ TeV, and $m_{\pm\pm} = 700$ GeV for the leptonic sector.

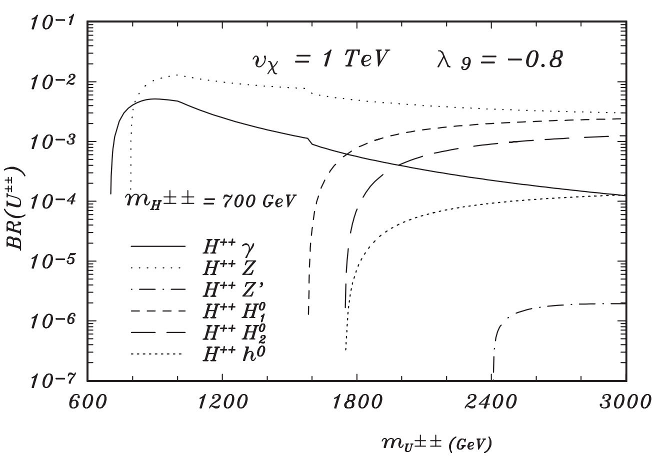

FIG. 8. Branching ratios for the doubly charged gauge boson decays as functions of $m_{U^{\pm\pm}}$ for $\lambda_9 = -0.8$, $v_\chi = 1$ TeV, and $m_{\pm\pm} = 500$ GeV for the bosonic sector.

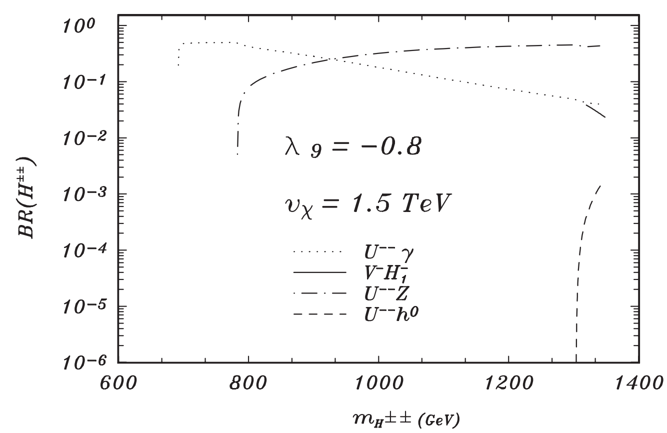

FIG. 10. Branching ratios for the doubly charged gauge boson decays as functions of $m_{U^{\pm\pm}}$ for $\lambda_9 = -0.8$, $v_\chi = 1$ TeV, and $m_{\pm\pm} = 700$ GeV for the bosonic sector.

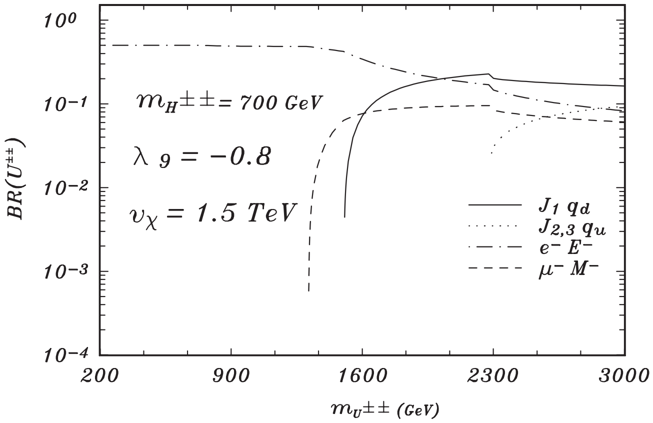

FIG. 11. : Branching ratios for the doubly charged gauge boson decays as functions of $m_{U^{\pm\pm}}$ for $\lambda_9 = -0.8$, $v_\chi = 1.5$ TeV, and $m_{\pm\pm} = 700$ GeV for the leptonic sector.

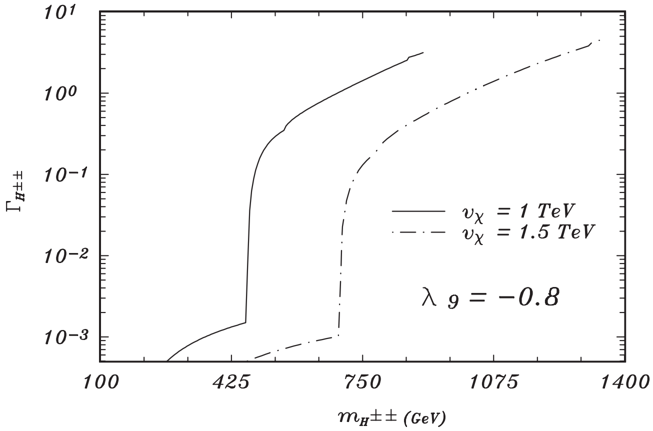

FIG. 13. The DCHB decay versus DCHB masses for (a) $v_\chi = 1$ TeV (solid line) and (b) 1.5 TeV (dash-dotted line).

these particles would be $\mathrm{BR}(U^{\mp\mp} \longrightarrow e^\mp P^\mp) = 50\%$ (see Figs. 5 and 6), then we would have $\simeq 9.1 \times 10^3$ events per year for the CLIC, regarding the $v_\chi = 1500$ GeV it will not give any event due to the same considerations given above.

Considering now the mass of the Higgs boson $m_{\pm\pm} = 700$ GeV and the $v_\chi = 1000$ GeV, we then have a total of $1.2 \simeq 10^5$ events per year. Taking the same signal as above, for which branching ratios are equal to $\mathrm{BR}(H^{\mp\mp} \longrightarrow U^{\mp\mp}\gamma) = 23.7\%$ (see Figs. 3 and 4) for $m_{\pm\pm} = 700$ GeV, $v_\chi = 1000$ GeV, and that the bosons $U^{\mp\mp}$ decay into e^-P^- and e^+P^+, for which branching ratios would be $\mathrm{BR}(U^{\mp\mp} \longrightarrow e^\mp P^\mp) = 50\%$ (see Figs. 7 and 8), then we would have $\simeq 1.7 \times 10^3$ events per year for the CLIC. Regarding $v_\chi = 1500$ GeV for $m_{\pm\pm} = 700$ GeV then we will have $\simeq 5.4 \times 10^5$ events per year, and considering the same signal parameters as above, that is, $\mathrm{BR}(H^{\mp\mp} \longrightarrow U^{\mp\mp}\gamma) = 47.7\%$ (see Figs. 9 and 10) and $\mathrm{BR}(U^{\mp\mp} \longrightarrow e^\mp P^\mp) = 50\%$ (see Figs. 11 and 12), then we would have $\simeq 3.1 \times 10^4$ events per year for the CLIC. These results are shown in Table II. Also given in Figs. 13 and 14 are the DCHBs and boson $U^{\pm\pm}$ total decay versus masses. We still mention that the initial state radiaton (ISR) and beamstrahlung (BS) strongly affect the behavior of the production cross section around the resonance peaks, modifying the shape and the size [22], so Fig. 15 shows the cross section with and without ISR + BS around the resonance point $m_{Z'} = 2561.3$ GeV for CLIC. As can be seen the peak of the resonance shifts to the right and is lowered as a result of the ISR + BS effects.

There are others signals such as $H^{\mp\mp} \longrightarrow U^{\pm\pm}Z \longrightarrow E^\pm e^\pm e^\pm e^\mp$ and a $H^{\mp\mp} \longrightarrow E^\pm e^\pm$. These signals occur with a small probability: the first one has a probability of $\simeq 10^{-2}$, and the second one has a probability of $\simeq 10^{-5}$ events per year for $v_\chi = 1500$ GeV, $m_{H^\pm} = 700$ GeV, $\lambda = -0.8$, and the other parameters listed above. So we have that the high energy electron-positron colliders can be a rich source for DCHBs [23]. Concerning the signals, $H^{\pm\pm} \longrightarrow U^{\pm\pm}\gamma$ and $U^{\pm\pm} \longrightarrow e^\pm P^\pm$, we conclude that there

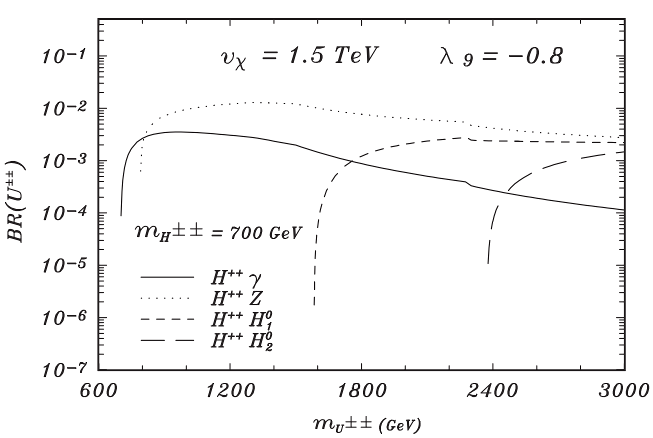

FIG. 12. Branching ratios for the doubly charged gauge boson decays as functions of $m_{U^{\pm\pm}}$ for $\lambda_9 = -0.8$, $v_\chi = 1.5$ TeV, and $m_{\pm\pm} = 700$ GeV for the bosonic sector.

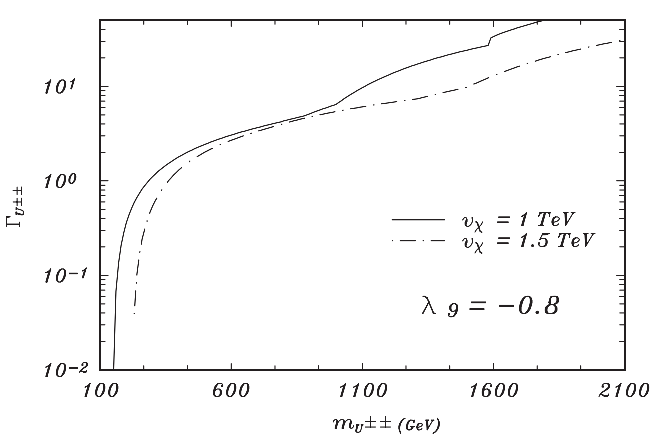

FIG. 14. The doubly charged gauge boson $U^{\pm\pm}$ decay versus its mass for (a) $v_\chi = 1$ TeV (solid line) and (b) 1.5 TeV (dash-dotted line).

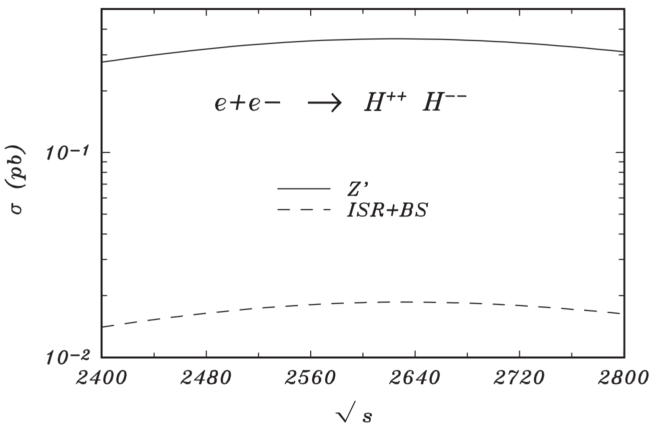

FIG. 15. The production cross section for the process $e^+e^- \rightarrow H^{++}H^{--}$ for the resonance point $m_{Z'} = 2561.3$ GeV. The solid line shows the cross section without the ISR + BS, and the dashed line represents the ISR + BS effect.

are very striking and important signals. The DCHBs will deposit 6 times the ionization energy than the characteristic single-charged particle; that is, if we see this signal, we will be seeing not only the DCHBs but also the heavy leptons. It is to notice that there are not SM backgrounds to this signal.

The discovery of a pair of DCHBs will be without any doubt of great importance for the physics beyond the SM, because of the confirmation of the Higgs triplet representation and indirect verification that there is asymmetry in decay rates between matter and antimatter. Our study indicates the possibility of obtaining a clear signal of these new particles with a satisfactory number of events.

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