DECAY WIDTH OF 3-3-1 MODEL CHARGED HIGGS AND GAUGE BOSONS

ANCHURA DE DECAIMIENTO DE LOS BOSONES DE HIGGS CARGADO Y DE CALIBRE DEL MODELO 3-3-1

Kelvin J. Ramos[1], Carlos A. Morgan[1], Jorge E. Cieza Montalvo[2], Antonio I. Rivasplata[1], Guillermo H. Ramírez[1], Carlos E. Rodríguez-Benites[1]

[1] Grupo de Física Teórica, Departamento Académico de Física, Universidad Nacional de Trujillo, Perú.

[2] Instituto de Física, Universidade do Estado de Rio do Janeiro, Brazil.

(Recibido: 08/2021. Aceptado: 11/2021)

Abstract

The total decay widths of the charged Higgs boson ($H_2^{\pm}$) and gauge ($V^{\pm}$) have been calculated in the version of the 3-3-1 Model with heavy leptons. In each case, we analyze the decay rates and determine the most likely channels to occur in order to identify the most relevant final events.

Keywords: decay width, Higgs boson, gauge boson, 3-3-1 Model.

Resumen

Se calculan las anchuras totales de decaimiento de los bosones de Higgs cargado ($H_2^{\pm}$) y de calibre ($V^{\pm}$) en la versión del Modelo 3-3-1 con leptones pesados. En cada caso, se analizan las razones de decaimiento y se determinan los canales más probables, lo que consecuentemente hace posible la identificación de los eventos finales más admisibles.

Palabras clave: anchura de decaimiento, bosón de Higgs, bosón de calibre, Modelo 3-3-1.

Kelvin J. Ramos: kramosv@unitru.edu.pe doi: 10.15446/mo.n64.97711

Introduction

The confirmation of the Higgs boson with a mass of 126 GeV in July 2012 has marked a milestone in Particle Physics, consolidating the standar model (SM) of elementary particles as one of the most successful models of Theoretical Physics [1–3]. The SM is based on the symmetry group $SU(3)_C \otimes SU(2)_L \otimes U(1)_Y$, which identifies elementary particles and explains their interactions. There is currently no experimental data that can decisively contradict their predictions; however, the description provided by the SM is incomplete, since there are experimental observations that it can not explain, such as: the violation of leptonic universality, the proliferation of fermionic generations and their mass spectrum, the CP violation mechanisms, symmetry breaking, the large number of arbitrary parameters and neutrino oscillation. Likewise, it does not include gravity and leaves out the explanation of dark matter and energy. For these reasons, it is important to study extensions of the SM such as Technicolor [4], Supersymmetric Models, or 3-3-1 Model and their different mechanisms to try to respond to the aforementioned problems.

Currently, research at TeV energy scales is of great importance for Particle Physics, because it can clarify many of the above-mentioned questions. In this sense, the 3-3-1 Model with heavy leptons [5], whose symmetry group is $SU(3)_C \otimes SU(3)_L \otimes U(1)_N$, is a good alternative, where the subgroup $SU(3)_L \otimes U(1)_N$ of the electroweak interactions is an extension of the symmetry group $SU(2)_L \otimes U(1)_Y$ of SM.

The 3-3-1 Model adds heavy charged leptons to the doublets of the SM, extending it to triplets [6] and in the Higgs sector it considers three scalar triplets, unlike the SM, which has only one doublet. The new particles generated in this model acquire mass through spontaneous symmetry breaking, being the Higgs sector the most extended, with: neutral Higgs (h^0, H_2^0, H_3^0), singly $(H_1^\pm,\ H_2^\pm)$ and doubly charged $(H^{\pm\pm})$ and, to a lesser extent, the gauge sector with simple bosons $(V^\pm)$ and doubly charged $(U^{\pm\pm})$ and an exotic neutral (Z'), which if they exist, will become one of the main objectives of high energy experimental physics.

In this present work a brief overview of the 3-3-1 Model with heavy leptons is presented, the total decay width of the charged Higgs boson $H_2^{\pm}$ and that of gauge $V^{\pm}$ is calculated and the most significant decay ratios are determined. It is necessary to identify the mean channels in order to have some guidance in the search for a new physics, wich must manifest itself in TeV's energy scales.

Additionally, to verify the existence of the particles postulated by 3-3-1 Model, either in high energy hadronic accelerators such as the Large Hadron Collider(LHC), which is expected to reach energies of up to 28 and 100 TeV, and which could be able to obtain signals from Higgs sector and non-standard gauge particles, or in linear colliders of the e^+e^- type such as the Compact Linear Collider (CLIC), which has its simpler initial states and leads to easier final states to identify. For example, when the production of heavy leptons ($e^+e^- \to c\ \bar{c},\ b\ \bar{b},\ t\ \bar{t}$) is analyzed, the final states are cleaner than in $p\ p$ ($p\ \bar{p}$) machines; however, energy loss due to initial state radiation (ISR) and beamstrahlung limit the energy that can be achieved.

Particles of 3-3-1 Model

Quarks Sector

In 3-3-1 Model, quarks and leptons are treated in a different way. In the quark sector we have the following left-hand particles:

$$Q_{1L} = \begin{pmatrix} u'_1 \\ d'_1 \\ J_1 \end{pmatrix}_L \sim (\mathbf{3}, +2/3);\ Q_{\alpha L} = \begin{pmatrix} J'_\alpha \\ u'_\alpha \\ d'_\alpha \end{pmatrix}_L \sim (\mathbf{3^*}, -1/3) \quad (1)$$

where the first family of quarks belongs to the fundamental representation of $SU(3)_L$, while the second and third belong to the adjoint representation. The particles J_1 and J_α ($\alpha = 2, 3$) are exotic quarks and have a charge of $(5e/3)$ and $(-4e/3)$, respectively [7, 8]. Right-handed quarks

$$\begin{gathered} U'_R \sim (\mathbf{1}, 2/3),\ D'_R \sim (\mathbf{1}, -1/3), \\ J_{1R} \sim (\mathbf{1}, +5/3),\ J'_{\alpha R} \sim (\mathbf{1}, -4/3) \end{gathered} \quad (2)$$

with $U = u; c; t$ and $D = d; s; b$, are transformed as singlets under the $SU(3)_L$ group.

Leptons Sector

The leptonic sector is made up of the following left-hand particles:

$$\psi_{l_L} = \begin{pmatrix} \nu_l \\ l' \\ P'_l \end{pmatrix}_L \sim (\mathbf{3}, 0) \tag{3}$$

where $l = e; \mu; \tau$ and $P_l = E; M; T$.

Unlike quarks, in leptons all families belong to the same representation of the $SU(3)_L$ group. This sector also presents its right-handed counterpart:

$$l_R \sim (\mathbf{1}, -1), \qquad P_R \sim (\mathbf{1}, 1) \tag{4}$$

Like quarks, right-handed leptons also transform as singlets under the $SU(3)_L$. The values 0, 2/3 and $-1/3$ presented in the description of quarks and leptons represent the charge of the group $U(1)_N$ [5].

Higgs Sector

It is the most abundant sector, apart from containing the Higgs H_1^0 which is similar to Higgs H^0 of SM. 3-3-1 Model presents new Higgs such as:

$$H_1^0,\ H_2^0,\ H_3^0,\ h^0,\ H_1^{\pm},\ H_2^{\pm} \text{ and } H^{\pm\pm}.$$

The minimal scalar sector of 3-3-1 Model contains the following triplets, η, ρ and χ [5, 7]:

$$\eta = \begin{pmatrix} \eta^0 \\ \eta_1^- \\ \eta_2^+ \end{pmatrix} \sim (\mathbf{3}, 0); \ \rho = \begin{pmatrix} \rho^+ \\ \rho^0 \\ \rho^{++} \end{pmatrix} \sim (\mathbf{3}, 1);$$

$$\chi = \begin{pmatrix} \chi^- \\ \chi^{--} \\ \chi^0 \end{pmatrix} \sim (\mathbf{3}, -1) \tag{5}$$

whose expected vacuum values of its neutral components are:

$$\langle\eta^0\rangle = v_\eta,\ \ \langle\rho^0\rangle = v_\rho,\ \ \langle\chi^0\rangle = v_\chi$$

and satisfy:

$$v_\eta^2 + v_\rho^2 = v_W^2 = (246\,\mathrm{GeV})^2$$

where v_W is the expectation value of vacuum (VEV) or Weinberg value of vacuum. The pattern of the symmetry breaking is given by [6]:

$$SU(3)_L \otimes U(1)_N \xrightarrow{\langle\chi\rangle} SU(2)_L \otimes U(1)_Y \xrightarrow{\langle\rho,\eta\rangle} U(1)_{em}$$

After breaking of symmetry, the masses of scalar fields are given by:

$$\begin{aligned}
m_{H_1^0}^2 \approx& 4\frac{\lambda_2 v_\rho^4 - 2\lambda_1 v_\eta^4}{v_\eta^2 - v_\rho^2}; \qquad m_{H_2^0}^2 \approx \frac{v_W^2}{2v_\eta v_\rho}v_\chi^2\\
m_{H_3^0}^2 \approx& -4\lambda_3 v_\chi^2; \qquad m_h^2 \approx -\frac{f v_\chi}{v_\eta v_\rho}\left[v_W^2 + \left(\frac{v_\eta v_\rho}{v_\chi}\right)^2\right]\\
m_{H_1^\pm}^2 =& \frac{v_W^2}{2v_\eta v_\rho}(f v_\chi - 2\lambda_7 v_\eta v_\rho); \quad m_{H_2^\pm}^2 = \frac{v_\eta^2 + v_\chi^2}{2v_\eta v_\chi}(f v_\rho - 2\lambda_8 v_\eta v_\chi)\\
m_{H^{\pm\pm}}^2 =& \frac{v_\rho^2 + v_\chi^2}{2v_\rho v_\chi}(f v_\eta - 2\lambda_9 v_\rho v_\chi)
\end{aligned} \tag{6}$$

where f is a constant with dimension of mass and the $\lambda_i(i = 1, 2..., 10)$ are dimensionless constants. In addition, it is considered that $v_\chi \gg v_{\rho,\eta}$ and the condition is imposed by $f \approx -v_\chi$ [6].

Gauge Sector

In addition to the intermediate particles of SM (γ, $W^\pm$ and Z), the 3-3-1 Model predicts the existence of the neutral boson Z', two singly charged bosons $V^\pm$ and two doubly charged bosons $U^{\pm\pm}$. The interaction between gauge and Higgs bosons results from the lagrangian:

$$\mathcal{L}_{GH} = \sum_\varphi (\mathcal{D}_\mu\varphi)^\dagger(\mathcal{D}^\mu\varphi) \tag{7}$$

where the covariant derivative is given by:

$$\mathcal{D}_\mu\varphi_i = \partial_\mu\varphi_i - ig\left(\vec{W}_\mu.\frac{\vec{\lambda}}{2}\right)_i^j\varphi_j - ig'N_\varphi\varphi_i B_\mu \tag{8}$$

where N_φ are the charges of the group $U(1)_N$ for the triplets ($\varphi = \eta, \rho, \chi$), $\vec{W}_\mu$ and B_μ are the gauge fields of $SU(2)$ and $U(1)$, $\vec{\lambda}$ are the Gell-Mann matrices, and g and g' are the coupling constants for $SU(2)$ and $U(1)$, respectively [7–9].

The masses of the new bosons as a function of the Weinberg angle θ_W, of the expected values of the vacuum and the elemental charge e of the electron, are:

$$\begin{aligned}&m_{Z'}^2 \approx \left(\frac{ev_\chi}{s_W}\right)^2\frac{2(1-s_W^2)}{3(1-4s_W^2)}; \quad m_V^2 = \left(\frac{e}{s_W}\right)^2\frac{v_\eta^2+v_\chi^2}{2};\\ &m_U^2 = \left(\frac{e}{s_W}\right)^2\frac{v_\rho^2+v_\chi^2}{2}\end{aligned} \tag{9}$$

where:

$$s_W^2 = sin^2\theta_W = \frac{t^2}{1+4t^2}; \quad t = \frac{g'}{g}$$

Decay of Higgs $H_2^\pm$ and gauge bosons $V^\pm$ of the 3-3-1 Model

The production of charged Higgs $H_2^\pm$ and gauge bosons $V^\pm$ can occur through the processes $e^-e^+ \to H_2^-H_2^+$ and $e^-e^+ \to V^-V^+$ respectively, through the intermediation of the bosons Z, Z', γ.

The $H_2^-(H_2^+)$ decays in $u(\bar{u})$ and $\bar{J}_1(J_1)$, in heavy leptons $P^-(P^+)$ and neutrinos $\nu_l(\bar{\nu}_l)$, in simply charged gauge bosons $V^-(V^+)$ and a photon γ, in $W^-(W^+)$ and doubly charged Higgs $H^{--}(H^{++})$, in $V^-(V^+)$ and Z, Z', in $V^-(V^+)$ and neutral Higgs H_1^0, H_2^0, H_3^0, h^0.

The total width of decay of the Higgs $H_2^\pm$ is given by:

$$\begin{aligned}\Gamma(H_2^\pm \to \text{all}) = \quad &\Gamma_{\bar{u}J_1(u\bar{J}_1)} + \Gamma_{E^+\bar{\nu}_e(E^-\nu_e)} + \Gamma_{M^+\bar{\nu}_\mu(M^-\nu_\mu)}\\ &+ \Gamma_{T^+\bar{\nu}_\tau(T^-\nu_\tau)} + \Gamma_{V^\pm\gamma} + \Gamma_{ZV^\pm} + \Gamma_{Z'V^\pm}\\ &+ \Gamma_{W^\mp H^{\pm\pm}} + \Gamma_{V^\pm H_1^0} + \Gamma_{V^\pm H_2^0} + \Gamma_{V^\pm H_3^0} + \Gamma_{V^\pm h^0}\end{aligned} \tag{10}$$

where $\Gamma_{XY} = \Gamma(H_2^\pm \to XY)$.

The contribution of each term is given by:

$$\Gamma_{u\bar{J}_1} = \frac{3\mathcal{B}(H_2^\pm, u, \bar{J}_1)}{16\pi m_{H_2^\pm}} \frac{v_\chi^2}{v_W^2(v_\rho^2+v_\chi^2)} m_u^2(m_{H_2^\pm}^2 - m_u^2 - m_{J_1}^2) \tag{11}$$

$$\Gamma_{E^\pm\bar{\nu}_e} = \frac{\mathcal{B}(H_2^\pm, E, \bar{\nu}_e)}{16\pi m_{H_2^\pm}} \frac{v_\rho^2}{v_\chi^2(v_\rho^2+v_\chi^2)} m_E^2(m_{H_2^\pm}^2 - m_E^2) \tag{12}$$

$$\Gamma_{M^\pm\bar{\nu}_\mu} = \frac{\mathcal{B}(H_2^\pm, M, \bar{\nu}_\mu)}{16\pi m_{H_2^\pm}} \frac{v_\rho^2}{v_\chi^2(v_\rho^2+v_\chi^2)} m_M^2(m_{H_2^\pm}^2 - m_M^2) \tag{13}$$

$$\Gamma_{T^\pm\bar{\nu}_\tau} = \frac{\mathcal{B}(H_2^\pm, T, \bar{\nu}_\tau)}{16\pi m_{H_2^\pm}} \frac{v_\rho^2}{v_\chi^2(v_\rho^2+v_\chi^2)} m_T^2(m_{H_2^\pm}^2 - m_T^2) \tag{14}$$

$$\Gamma_{V^\pm\gamma} = \frac{3e^4}{32\pi m_{H_2^\pm}} (\frac{v_\rho^2 v_\chi^2}{v_\rho^2+v_\chi^2}) \mathcal{B}(H_2^\pm, V, \gamma) \tag{15}$$

$$\Gamma_{ZV^\pm} = \frac{e^4}{32\pi m_{H_2^\pm}} \frac{(1+s_W^2)^2}{s_W^4 c_W^2} \frac{v_\rho^2 v_\chi^2}{v_\rho^2+v_\chi^2} (3 + \frac{\mathcal{A}(H_2^\pm, Z, V)}{m_V^2}) \times \mathcal{B}(H_2^\pm, Z, V) \tag{16}$$

$$\Gamma_{Z'V^\pm} = \frac{e^4}{96\pi m_{H_2^\pm}} \frac{(7s_W^2-1)^2}{s_W^4 c_W^2(4s_W^2-1)} \frac{v_\rho^2 v_\chi^2}{v_\rho^2+v_\chi^2} (3 + \frac{\mathcal{A}(H_2^\pm, Z', V)}{m_V^2}) \tag{17}$$

$$\Gamma_{W^\mp H^{\pm\pm}} = \frac{e^2\mathcal{C}(H_2^\pm, W, H^{\pm\pm})}{128\pi m_{H_2^\pm}} \frac{v_\rho^2 v_\eta^2}{s_W^2(v_\rho^2+v_\chi^2)(v_\eta^2+v_\chi^2)} \tag{18}$$

$$\Gamma_{V^\pm H_1^0} = \frac{e^2\mathcal{C}(H_2^\pm, V, H_1^0)}{128\pi m_{H_2^\pm}} \frac{v_\rho^2 v_\chi^2}{s_W^2 v_W^2(v_\rho^2+v_\chi^2)} \tag{19}$$

$$\Gamma_{V^\pm H_2^0} = \frac{e^2\mathcal{C}(H_2^\pm, V, H_2^0)}{128\pi m_{H_2^\pm}} \frac{v_\eta^2 v_\chi^2}{s_W^2 v_W^2(v_\rho^2+v_\chi^2)} \tag{20}$$

$$\Gamma_{V^\pm H_3^0} = \frac{e^2\mathcal{C}(H_2^\pm, V, H_3^0)}{128\pi m_{H_2^\pm}} \frac{v_\rho^2}{s_W^2(v_\rho^2+v_\chi^2)} \tag{21}$$

$$\Gamma_{V^\pm h^0} = \frac{e^2\mathcal{C}(H_2^\pm, V, h^0)}{128\pi m_{H_2^\pm}} \frac{v_\rho^2}{s_W^2(v_\rho^2+v_\chi^2)} \tag{22}$$

The $V^-(V^+)$ decays in $u(\bar{u})$ and in $\bar{J}_1(J_1)$, in heavy leptons $P^-(P^+)$ and neutrinos $\nu_l(\bar{\nu}_l)$, in $W^-(W^+)$ and γ, in $H_2^-(H_2^+)$ and Z, γ, in $W^+(W^-)$ and $U^{--}(U^{++})$, in $H_2^-(H_2^+)$ and neutral Higgs bosons H_1^0, H_2^0, H_3^0, h^0.

The total width of decay of boson $V^\pm$ is given by:

$$\begin{aligned}\Gamma(V^\pm \to \text{all}) = \quad & \Gamma_{\bar{u}J_1(u\bar{J}_1)} + \Gamma_{E^+\bar{\nu}_e(E^-\nu_e)} + \Gamma_{M^+\bar{\nu}_\mu(M^-\nu_\mu)} \\ & + \Gamma_{T^+\bar{\nu}_\tau(T^-\nu_\tau)} + \Gamma_{H_2^\pm Z} + \Gamma_{H_2^\pm\gamma} + \Gamma_{W^\pm\gamma} + \Gamma_{W^\pm Z} \\ & + \Gamma_{W^\mp U^{\pm\pm}} + \Gamma_{H_2^\pm H_1^0} + \Gamma_{H_2^\pm H_2^0} + \Gamma_{H_2^\pm H_3^0} + \Gamma_{H_2^\pm h^0}\end{aligned} \tag{23}$$

where $\Gamma_{XY} = \Gamma(V^\pm \to XY)$.

The contribution of each term is given by:

$$\Gamma_{u\bar{J}_1} = \frac{e^2\mathcal{B}(V,u,J_1)}{48\pi m_V s_W^2}\left(\frac{3}{2}(m_V^2 - m_u^2 - m_{\bar{J}}^2) - 2\mathcal{A}(u,V,J_1)\right) \tag{24}$$

$$\Gamma_{E^\pm\bar{\nu}_e} = \frac{e^2\mathcal{B}(V,E,\bar{\nu}_e)}{96\pi m_V s_W^2}(-\frac{m_E^4}{m_V^2} - m_E^2 + 2m_V^2) \tag{25}$$

$$\Gamma_{M^\pm\bar{\nu}_\mu} = \frac{e^2\mathcal{B}(V,M,\bar{\nu}_\mu)}{96\pi m_V s_W^2}(-\frac{m_M^4}{m_V^2} - m_M^2 + 2m_V^2) \tag{26}$$

$$\Gamma_{T^\pm\bar{\nu}_\tau} = \frac{e^2\mathcal{B}(V,T,\bar{\nu}_\tau)}{96\pi m_V s_W^2}(-\frac{m_T^4}{m_V^2} - m_T^2 + 2m_V^2) \tag{27}$$

$$\Gamma_{H_2^\pm Z} = \frac{e^4\mathcal{B}(V,H_2^\pm,Z)}{96\pi m_V}\frac{(1+s_W^2)^2}{s_W^4 c_W^2}\frac{v_\rho^2 v_\chi^2}{v_\rho^2 + v_\chi^2}(3 + \frac{\mathcal{A}(V,Z,H_2^\pm)}{m_{H_2^\pm}^2}) \tag{28}$$

$$\Gamma_{H_2^\pm\gamma} = \frac{e^4}{32\pi M_V}\frac{v_\rho^2 v_\chi^2}{v_\rho^2 + v_\chi^2}\mathcal{B}(V,H_2^\pm,\gamma) \tag{29}$$

$$\Gamma_{W^\pm\gamma} = \frac{e^2\mathcal{B}(V,W,\gamma)}{24\pi m_V}(\frac{5}{2}\frac{m_V^4}{m_W^2} - \frac{17}{2}m_V^2 - \frac{17}{2}m_W^2 + \frac{5}{2}\frac{m_W^4}{m_V^2}) \tag{30}$$

$$\begin{aligned}\Gamma_{W^{\pm}Z} = &\frac{e^2 s_W^2 \mathcal{B}(V,W,Z)}{24\pi m_V (1-4s_W^2)}\left(\frac{1}{4}\frac{m_V^6}{m_W^2 m_Z^2} + 2\frac{m_V^4}{m_W^2} - \frac{9}{2}\frac{m_Z^2 m_V^2}{m_W^2} + 2\frac{m_Z^4}{m_W^2}\right.\\ &+ \frac{1}{4}\frac{m_Z^6}{m_W^2 m_V^2} + 2\frac{m_V^4}{m_Z^2} - 8m_V^2 - 8m_Z^2 + 2\frac{m_Z^4}{m_V^2} - \frac{9}{2}\frac{m_W^2 m_V^2}{m_Z^2}\\ &\left.- 8m_W^2 - \frac{9}{2}\frac{m_W^2 m_Z^2}{m_V^2} + 2\frac{m_W^4}{m_V^2} + 2\frac{m_W^4}{m_Z^2} + \frac{1}{4}\frac{m_W^6}{m_Z^2 m_V^2}\right)\end{aligned} \tag{31}$$

$$\begin{aligned}\Gamma_{W^{\mp}U^{\pm\pm}} = &\frac{e^2 \mathcal{B}(V,W,U)}{48\pi m_V s_W^2}\left(\frac{1}{4}\frac{m_U^6}{m_W^2 m_Z^2} + 2\frac{m_U^4}{m_W^2} - \frac{9}{2}\frac{m_V^2 m_U^2}{m_W^2} + 2\frac{m_V^4}{m_W^2}\right.\\ &+ \frac{1}{4}\frac{m_V^6}{m_W^2 m_U^2} - 5m_V^2 - 5m_Z^2 + 4m_W^2 - \frac{m_U^4}{m_V^2} - \frac{m_V^4}{m_U^2}\\ &\left.+ \frac{3}{2}\frac{m_W^2 m_U^2}{m_V^2} + \frac{3}{2}\frac{m_W^2 m_V^2}{m_U^2} - \frac{m_W^4}{m_V^2} - \frac{m_W^4}{m_U^2} + \frac{1}{4}\frac{m_W^6}{m_V^2 m_U^2}\right)\end{aligned} \tag{32}$$

$$\Gamma_{H_2^{\pm}H_1^0} = \frac{e^2 \mathcal{B}(V,H_2^{\pm},H_1^0)}{96\pi m_V}\frac{v_\rho^2 v_\chi^2}{s_W^2 v_W^2 (v_\rho^2 + v_\chi^2)}\mathcal{A}(H_1^0,V,H_2^{\pm}) \tag{33}$$

$$\Gamma_{H_2^{\pm}H_2^0} = \frac{e^2 \mathcal{B}(V,H_2^{\pm},H_2^0)}{96\pi m_V}\frac{v_\eta^2 v_\chi^2}{s_W^2 v_W^2 (v_\rho^2 + v_\chi^2)}\mathcal{A}(H_2^0,V,H_2^{\pm}) \tag{34}$$

$$\Gamma_{H_2^{\pm}H_3^0} = \frac{e^2 \mathcal{B}(V,H_2^{\pm},H_3^0)}{96\pi m_V}\frac{v_\rho^2}{s_W^2 (v_\rho^2 + v_\chi^2)}\mathcal{A}(H_3^0,V,H_2^{\pm}) \tag{35}$$

$$\Gamma_{H_2^{\pm}h^0} = \frac{e^2 \mathcal{B}(V,H_2^{\pm},h^0)}{96\pi m_V}\frac{v_\rho^2}{s_W^2 (v_\rho^2 + v_\chi^2)}\mathcal{A}(h^0,V,H_2^{\pm}) \tag{36}$$

where

$$\begin{aligned}\mathcal{A}(a,b,c) =& - m_c^2 + \frac{1}{4m_b^2}\left(m_a^2 - m_b^2 - m_c^2\right)^2\\ \mathcal{B}(a,b,c) =& \left[\left(1 - \frac{(m_b+m_c)^2}{m_a^2}\right)\left(1 - \frac{(m_b-m_c)^2}{m_a^2}\right)\right]^{1/2}\\ \mathcal{C}(a,b,c) =& \mathcal{A}(a,b,c) \times \mathcal{B}(a,b,c)\end{aligned}$$

Results and Conclusions

In this work we present the widths of the $H_2^{\pm}$ and $V^{\pm}$ for $v_\chi =$ 4.0 and 5.0 TeV. Then, for the $\lambda-$parameters and the VEV, we obtain: $\lambda_1 = 1.54 \times 10^{-1}$, $\lambda_2 = 1.0$, $\lambda_3 =$ -2.5 $\times 10^{-2}$, $\lambda_4 = 2.14$, $\lambda_5 =$-1.57, $\lambda_6 = 1.0$, $\lambda_7 =$-2.0, $\lambda_8 =$-5.0 $\times 10^{-1}$, $v_\eta = 195$ GeV, and $\lambda_9 = 0.0$. These parameters and the VEV's are used to estimate the masses of the particles, which are presented in Table 1. A mass of 125.5 GeV was obtained for H_1^0, since it is a standard particle whose mass does not depend on v_χ.

f	v_χ, m_{J_1}	m_E	m_M	$m_{H_3^0}$	m_{h^0}	$m_{H_2^0}$	m_V	m_U	$m_{Z'}$
-4000	4000	595.60	3500.02	1264.91	5756.99	4068.75	1837.72	1836.83	6830.21
-5000	5000	744.50	4375.00	1581.46	7198.47	5086.95	2296.63	2295.91	8539.47

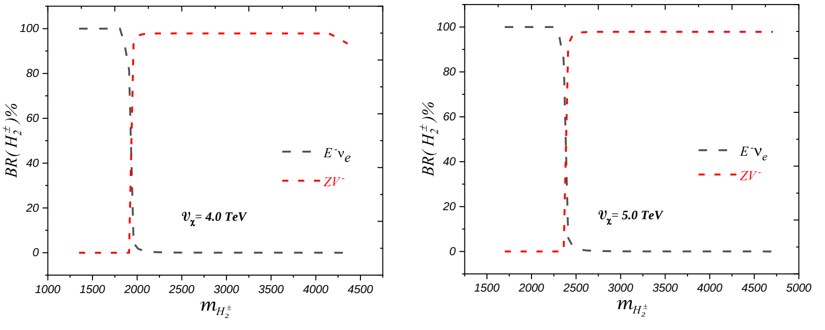
TABLE 1. *Masses of the particles used in this work in GeV.* $m_{H^{\pm\pm}}$ *= 3227.70(4035.50) GeV for* $v_\chi = 4.0(5.0)$ *TeV and* $m_T = 2v_\chi$.

Unlike other papers [7, 8, 10], in which arbitrary parameters were taken, in this work the representative values given above are considered for these parameters and the VEV's. This model, in particular, includes heavy leptons and also the condition $-f \simeq v_\chi$, different from other models, because of which the phenomenology must be different. Consequently, it should be noted that the decay widths of $H_2^{\pm}$ and $V^{\pm}$, depend on the parameters shown in Table 1, which also determine the size of various decay modes.

Since the Higgs $H_2^{\pm}$ and $V^{\pm}$ have greater masses than 1360.51(1698.72) GeV and 1837.72(2296.63) GeV for $v_\chi = 4.0(5.0)$ TeV, they can be considered heavy. Likewise, the mass of the exotic boson Z' is in agreement with the estimates of ATLAS [11, 12], also becoming a heavy particle.

Decay of the $H_2^{\pm}$ and $V^{\pm}$

From Figures 1a and 1b it can be seen that, for $v_\chi = 4.0(5.0)$ TeV, depending on the effective cross section, the channel $H_2^- \to E^-\nu_e$ can give the greatest contribution to the signal in the $H_2^{\pm}$ mass range from 1362.00(1699.00) to 1927.00(2388.00) GeV.



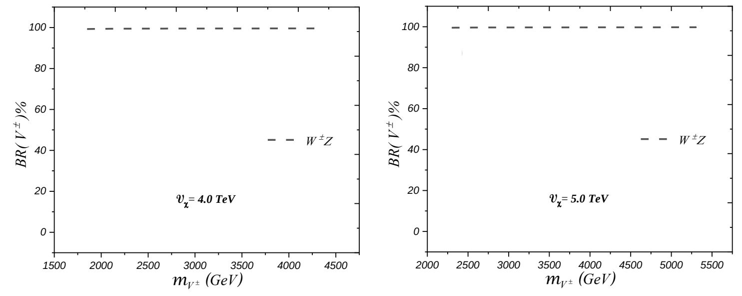
(a) (b)

FIGURE 1. *Branching decay ratio of $H_2^{\pm}$ for (a) v_χ =4.0 TeV and (b) v_χ =5.0 TeV*

These final two leptons E^-,ν_e are relatively easy to register on the detector, as charged heavy lepton leaves a trace. To record them, the invariant mass of the pair will be calculated, where the charged Higgs boson will be observed in the invariant mass distribution. With respect to $\bar{\nu}(\nu)$, the cut must be applied in the missing transverse moment $\not{p}_T > 20$ GeV, which allows a very strong reduction of backgrounds. It is necessary to clarify that the real events can only be calculated by estimating the effective cross section both in e^+e^- and in pp machines. However, all of these scenarios can only be solved by careful Monte Carlo analysis, to determine the signal size and the background.

From the same figures it is observed that for masses greater than or equal to 1930.00(2392.00) GeV for the $H_2^{\pm}$, the most promising channel will be $H_2^{\pm} \to V^{\pm}Z$, while channel $V^{\pm} \to W^{\pm}Z$ is the one that gives the greatest contribution to $V^{\pm}$ (see Figures 2a and 2b), but this would happen for masses of $m_{V^{\pm}}$ starting from 1850.00(2300.00) GeV for $v_\chi = 4.0(5.0)$ TeV.

Other less promising channels, which may give some contribution to the signal, depending on the effective cross section and the luminosity of the machine, would be: $H_2^{\pm} \to V^{\pm}\gamma$, $H_2^{\pm} \to V^{\pm}Z$, $H_2^{\pm} \to V^{\pm}H_1^0$. These channels would refer to $H_2^{\pm}$, while for the $V^{\pm}$ boson it would be: $V^{\pm} \to W^{\pm}\gamma$, $V^{\pm} \to W^{\pm}Z$ and $V^{\pm} \to W^{\mp}U^{\pm\pm}$.



(a) (b)

FIGURE 2. *Branching decay ratio of* $V^{\pm}$ *for (a)* v_χ *=4.0 TeV and (b)* v_χ *=5.0 TeV*

References

[1] G. Aad *et al.*, Physics Letters B **710**, 49 (2012).

[2] G. Aad *et al.*, Physics Letters B **716**, 1 (2012).

[3] S. Chatrchyan *et al.*, Physics Letters B **716**, 30 (2012).

[4] S. Dimopoulos, Nuclear Physics B **168**, 69 (1980).

[5] V. Pleitez and M. Tonasse, Physical Review D **48**, 2353 (1993).

[6] M. Tonasse, Physics Letters B **381**, 191 (1996).

[7] J. C. Montalvo and M. Tonasse, Nuclear Physics B **623**, 325 (2002).

[8] J. C. Montalvo and M. Tonasse, Physical Review D **67**, 075022 (2003).

[9] J. C. Montalvo, N. V. Cortez, and M. D. Tonasse, Physical Review D **78**, 116003 (2008).

[10] J. C. Montalvo and M. Tonasse, Physical Review D **71**, 095015 (2005).

[11] D. Hayden, R. Brock, and C. Willis, arXiv:1308.5874v1 [hep-ex] (2013).

[12] ATL-PHYS-PUB-2018-044 (ATLAS), "Prospects for searches for heavy Z' and W' bosons in fermionic final states with the ATLAS experiment at the HL-LHC," (2018).