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Production of the heaviest charged Higgs boson in 3-3-1 models

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We study the production cross section of the heaviest hypercharge-two Higgs boson ($H_2^{\pm}$) predicted by the 3-3-1 model. Taking into account intermediate vector bosons, including a new Z' neutral boson, we calculate the cross section of $H_2^{\pm}$ pair production at CERN-LHC hadron collider. Considering Z'-mass of the order of 1 TeV, we found that the cross sections decreases from 100 fb to 1×10^{-3} fb for the $H_2^{\pm}$-mass range 200 - 1000 GeV. We also found that for masses below the kinematic threshold (500 GeV), the cross section splits into three branches for $H_2^{\pm}$-boson, the hipercharge-one $H_1^{\pm}$ -boson, and the $H_{2HDM}^{\pm}$-boson from a two Higgs doublet model.

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1. Introduction

An interesting alternative to extend the SM are the models with gauge symmetry $SU(3)_c \otimes SU(3)_L \otimes U(1)_X$, also called 3-3-1 models, which introduce a family nonuniversal $U(1)$ symmetry [1, 2, 3]. These models have a number of phenomenological advantages. First of all, from the cancellation of chiral anomalies and asymptotic freedom in QCD, the 3-3-1 models can explain why there are three fermion families. Secondly, since the third family is treated under a different representation, the large mass difference between the heaviest quark family and the two lighter ones may be understood. Finally, these models contain a natural Peccei-Quinn symmetry, necessary to solve the strong-CP problem. In particular, these models extend the scalar sector of the SM into three $SU(3)_L$ scalar triplets. After the spontaneous breaking of the gauge symmetry and rotations into mass eigenstates, the model contains 4 massive charged Higgs ($H_1^{\pm}$, $H_2^{\pm}$), one neutral CP-odd Higgs (A^0), 3 neutral CP-even Higgs (h^0, H_1^0, H_2^0), and one complex neutral Higgs (H_3^0) bosons. In particular, the charged sector is composed of two types of Higgs bosons: hypercharge-one Higgs bosons $H_1^{\pm}$ which exhibit tree-level couplings with the SM particles [4], and hypercharge-two Higgs $H_2^{\pm}$ bosons which show couplings with the SM matter through mixing with non-SM particles. In this work we study the $H_{1,2}^{\pm}$-boson production at CERN-LHC in $pp \to H_2^+ H_2^-$ pair production. For comparison purposes, we include the $H_{2HDM}^{\pm}$-boson production from the two Higgs doublet model.

2. The 331 spectrum

We consider a 3-3-1 model where the electric charge is defined by:

$$Q = T_3 - \frac{1}{\sqrt{3}} T_8 + X, \tag{2.1}$$

with $T_3 = \frac{1}{2} Diag(1,-1,0)$ and $T_8 = (\frac{1}{2\sqrt{3}}) Diag(1,1,-2)$. In order to avoid chiral anomalies, the model introduces in the fermionic sector the following $(SU(3)_c, SU(3)_L, U(1)_X)$ left- and right-handed representations:

$$\begin{aligned}
Q_L^1 &= \begin{pmatrix} U^1 \\ D^1 \\ T^1 \end{pmatrix}_L : (3,3,1/3), \begin{cases} U_R^1 : (3^*,1,2/3) \\ D_R^1 : (3^*,1,-1/3) \\ T_R^1 : (3^*,1,2/3) \end{cases} \\
Q_L^{2,3} &= \begin{pmatrix} D^{2,3} \\ U^{2,3} \\ J^{2,3} \end{pmatrix}_L : (3,3^*,0), \begin{cases} D_R^{2,3} : (3^*,1,-1/3) \\ U_R^{2,3} : (3^*,1,2/3) \\ J_R^{2,3} : (3^*,1,-1/3) \end{cases} \\
L_L^{1,2,3} &= \begin{pmatrix} \nu^{1,2,3} \\ e^{1,2,3} \\ (\nu^{1,2,3})^c \end{pmatrix}_L : (1,3,-1/3), \begin{cases} e_R^{1,2,3} : (1,1,-1) \\ N_R^{1,2,3} : (1,1,0) \end{cases},
\end{aligned} \tag{2.2}$$

where U_L^i and D_L^i for $i = 1,2,3$ are three up- and down-type quark components in the flavor basis, while ν_L^i and e_L^i are the neutral and charged lepton families. The right-handed sector transforms as singlets under $SU(3)_L$ with $U(1)_X$ quantum numbers equal to the electric charges. In addition, we see that the model introduces heavy fermions with the following properties: a single flavor quark T^1 with electric charge $2/3$, two flavor quarks $J^{2,3}$ with charge $-1/3$, three neutral Majorana leptons $(\nu^{1,2,3})^c_L$ and three right-handed Majorana leptons $N_R^{1,2,3}$. On the other hand, the scalar sector introduces one triplet field with VEV $\langle\chi\rangle_0 = \upsilon_\chi$, which provides the masses to the new heavy fermions, and two triplets with VEVs $\langle\rho\rangle_0 = \upsilon_\rho$ and $\langle\eta\rangle_0 = \upsilon_\eta$, which give masses to the SM fermions at the electroweak scale. The $(SU(3)_L, U(1)_X)$ group structure of the scalar fields are:

$$\begin{aligned}
\chi &= \begin{pmatrix} \chi_1^0 \\ \chi_2^- \\ \frac{1}{\sqrt{2}}(\upsilon_\chi + \xi_\chi \pm i\zeta_\chi) \end{pmatrix} : (3, -1/3) \\
\rho &= \begin{pmatrix} \rho_1^+ \\ \frac{1}{\sqrt{2}}(\upsilon_\rho + \xi_\rho \pm i\zeta_\rho) \\ \rho_3^+ \end{pmatrix} : (3, 2/3) \\
\eta &= \begin{pmatrix} \frac{1}{\sqrt{2}}(\upsilon_\eta + \xi_\eta \mp i\zeta_\eta) \\ \eta_2^- \\ \eta_3^0 \end{pmatrix} : (3, -1/3).
\end{aligned} \tag{2.3}$$

In particular, the ρ and η triplets contain hipercharge-one and hypercharge-two fields. After the symmetry breaking, the above weak eigenstates rotate into the following mass eigenstates [5, 6]:

$$\begin{aligned}
&\textit{Hipercharge-one Higgs} : H_1^\pm = -S_{\beta_T}\rho_1^\pm + C_{\beta_T}\eta_2^\pm \\
&\textit{Hipercharge-two Higgs} : H_2^\pm \approx \rho_3^\pm,
\end{aligned} \tag{2.4}$$

where $T_{\beta_T} = \upsilon_\eta/\upsilon_\rho$. The photon A, neutral weak boson Z and a new neutral boson Z' are [7]:

$$\begin{aligned}
A_\mu &= S_W W_\mu^3 + C_W \left(\frac{1}{\sqrt{3}} T_W W_\mu^8 + \sqrt{1 - \frac{1}{3}(T_W)^2} B_\mu \right), \\
Z_\mu &= C_W W_\mu^3 - S_W \left(\frac{1}{\sqrt{3}} T_W W_\mu^8 + \sqrt{1 - \frac{1}{3}(T_W)^2} B_\mu \right), \\
Z'_\mu &= -\sqrt{1 - \frac{1}{3}(T_W)^2} W_\mu^8 + \frac{1}{\sqrt{3}} T_W B_\mu,
\end{aligned} \tag{2.5}$$

where the Weinberg angle is defined as $S_W = \sqrt{3} g_X / \sqrt{3g_L^2 + 4g_X^2}$, with g_L and g_X the coupling constants of the groups $SU(3)_L$ and $U(1)_X$, respectively.

3. The couplings

For the interaction between the SM-quarks q and neutral gauge bosons, we found [7]:

$$\mathscr{L}^{NC} = eQ_q \overline{q} \not{A} q + \frac{g_L}{2C_W} \overline{q} \left[\gamma_\mu (g_v^q - g_a^q \gamma_5) Z^\mu + \gamma_\mu (\tilde{g}_v^q - \tilde{g}_a^q \gamma_5) Z'^\mu \right] q, \tag{3.1}$$

Fermion	g_v^q	g_a^q	$\widetilde{g}_v^q$	$\widetilde{g}_a^q$
D^1	$-\frac{1}{2}+\frac{2}{3}S_W^2$	$-\frac{1}{2}$	$\frac{-1}{6}\sqrt{3-4S_W^2}$	$\frac{-1}{2\sqrt{3-4S_W^2}}$
D^m	$-\frac{1}{2}+\frac{2}{3}S_W^2$	$-\frac{1}{2}$	$\frac{3-2S_W^2}{6\sqrt{3-4S_W^2}}$	$\frac{1-2S_W^2}{2\sqrt{3-4S_W^2}}$
U^1	$\frac{1}{2}-\frac{4}{3}S_W^2$	$\frac{1}{2}$	$\frac{-3-2S_W^2}{6\sqrt{3-4S_W^2}}$	$\frac{-1+2S_W^2}{2\sqrt{3-4S_W^2}}$
U^m	$\frac{1}{2}-\frac{4}{3}S_W^2$	$\frac{1}{2}$	$\frac{3-8S_W^2}{6\sqrt{3-4S_W^2}}$	$\frac{1}{2\sqrt{3-4S_W^2}}$

Table 1: Vector and Axial couplings of SM quarks and Neutral Gauge Bosons. The index $m = 2,3$ labels the 3^* multiplets.

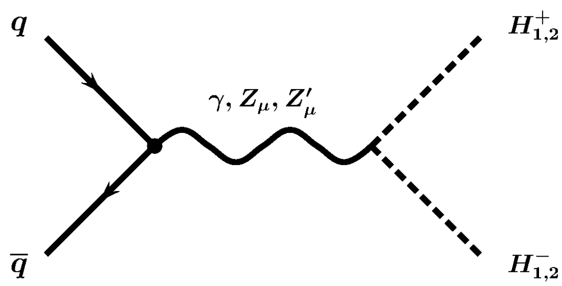

Figure 1: Charged Higgs boson pair production in pp collisions

where q is $U = (U^1, U^2, U^3)$ or $D = (D^1, D^2, D^3)$ for up- and down-type quarks, respectively, and Q_q the electric charge in units of the positron charge e. The vector and axial-vector couplings of the Z and Z' bosons are written in table 1 for each SM quark.

On the other hand, from the kinetic term of the Higgs Lagrangian, we obtain the following Higgs-Higgs-Vector interaction associated with the charged Higgs sector::

$$\begin{aligned} i\mathscr{L}^{HHV} &= -ie\left[H_1^+H_1^- + H_2^+H_2^-\right](p-q)^\mu A_\mu \\ &- \frac{ig_L}{2C_W}\left[C_{2W}H_1^+H_1^- + 2S_W^2H_2^+H_2^-\right](p-q)^\mu Z_\mu \\ &+ \frac{ig_X}{2\sqrt{3}T_W}\left[\left(C_{2\beta_T}+T_W^2\right)H_1^+H_1^- + 2\left(1+T_W^2\right)H_2^+H_2^-\right](p-q)^\mu Z'_\mu \end{aligned} \tag{3.2}$$

4. Results

For the pair production from figure 1, we use the couplings in (3.2). Figure 2 show the cross section for Higgs boson pair production $H_2^\pm$ for $M'_Z = 1$ TeV and pp collisions at CM energy of 14 GeV. For comparison purposes, we include the charged Higgs boson $H_1^\pm$ and $H_{2HDM}^\pm$ from a two

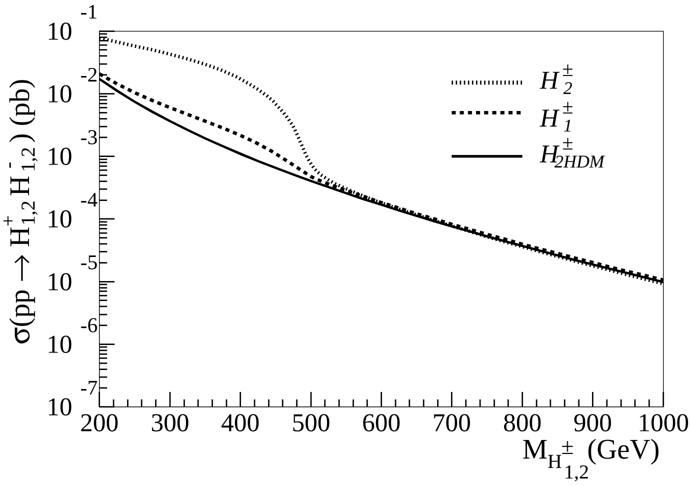

Figure 2: Pair production cross section of charged Higgs bosons

Higgs doublet model (2HDM). We observe the following behaviour:

- Below the kinematic threshold $M_H < 500$ GeV, the cross sections split into three branches, where $\sigma(H_2) > \sigma(H_1) > \sigma(H_{2HDM})$.

- The $H_2^\pm$ bosons exhibit larger contributions than $H_1^\pm$. This splits is due to the different contributions exhibits by the $H_1^\pm$ and $H_2^\pm$ bosons with the gauge bosons in Eqn. (3.2).

- For 2HDM model, we obtain smaller production ratios due to the fact that in this model the Z' contribution does not exist.

- For $M_H > 500$ GeV, the Z' contribution is suppressed by kinematic conditions ($M_Z' < 2M_H$). Thus, the cross section decreases, as shown.

- The $H_1^\pm$-Z' coupling is β_T-dependent as shown in Eq. (5). For numerical purposes we fix $T_{\beta_T} = 9$.

5. Acknowledgements

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