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

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Abstract

We study the production cross section of the heaviest hypercharge-two Higgs boson ($H_2^{\pm}$) predicted by the $SU(3)_c \otimes SU(3)_L \otimes U(1)_X$ gauge model (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 500 GeV, the cross section of the $H_2^{\pm}$-boson and the hipercharge-one $H_1^{\pm}$ -boson also predicted by the same model, are different.

Introduction

An interesting alternative to extend the Standard Model (SM) are the models with gauge symmetry $SU(3)_c \otimes SU(3)_L \otimes U(1)_X$ (3-3-1 models) [1], which introduce a family non-universal $U(1)$ symmetry. Some typical features are :

✔ From cancellation of chiral anomalies, can explain why there are three fermion families.

✔ The large mass difference between the $[b, t]$ quark family and the $[u(c), d(s)]$ may be understood.

✔ The quantization of electric charge and the vectorial character of the electromagnetic interactions can be predicted.

✔ Introduces new types of matter relevant to the next generation of colliders at the TeV energy scales without spoiling the low energy limits at the electroweak scale.

The 331 spectrum

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

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

with $T_3 = \frac{1}{2} Diag(1, -1, 0)$ and $T_8 = (\frac{1}{2\sqrt{3}}) Diag(1, 1, -2)$. The table in figure 1 show the sector of the spectrum we are interested in. In summary the model contains:

➠ Three phenomenological SM-fermion families plus new fermions E, T, J. The right-handed sector are $SU(3)_L$ singlets with $U(1)_X$ quantum numbers equal to the electric charge.

➠ One heavy scalar triplet χ with a VEV ν_χ at large scales, which produces the breaking:

$$SU(3)_L \otimes U(1)_X \to SU(2)_L \otimes U(1)_Y$$

➠ Two light scalar triplets ρ and η with VEVs $v_{\rho(\eta)}$, which produces the breakdown

$$SU(2)_L \otimes U(1)_Y \to U(1)_Q.$$

➠ Three electroweak neutral gauge bosons.

The ρ and η triplets contains the hipercharge-Y structures shown in Figure 2. After the symmetry breaking, the charged weak eigenstates rotate into the following mass eigenstates:

$$\begin{aligned} &\textbf{Hipercharge-one Higgs}: \quad H_1^{\pm} = -S_{\beta_T} \rho_1^{\pm} + C_{\beta_T} \eta_2^{\pm} \\ &\textbf{Hipercharge-two Higgs}: \quad H_2^{\pm} \approx \rho_3^{\pm} \end{aligned} \tag{2}$$

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

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

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.

The couplings

For the interaction between the SM-quarks and neutral gauge bosons [2]:

$$\mathcal{L}_D^{NC} = eQ_q \bar{q} A\!\!\!/ q + \frac{g_L}{2C_W} \bar{q} \left[\gamma_\mu \left(g_v^q - g_a^q \gamma_5 \right) Z^\mu + \gamma_\mu \left(\tilde{g}_v^q - \tilde{g}_a^q \gamma_5 \right) Z'^\mu \right] q, \tag{4}$$

where $g_v^q = g_a^q - 2Q_q S_W^2$, $2g_a^q = 1(-1)$ for up-(down-)type quarks, $\tilde{g}_v^q = \tilde{g}_a^q - 2Q_q n S_W^2$, $\tilde{g}_a^q = n(-n)[1/2 - S_W^2]$ for the s, b-(u-)quarks and $\tilde{g}_a^q = n(-n)/2$ for the c, t-(d-)quarks. The Z' couplings contains the normalization factor $n = 1/\sqrt{3 - 4S_W^2}$.

For the cubic interaction between the charged Higgs bosons and the gauge bosons:

$$\begin{aligned} i\mathcal{L}^{HHV} &= -ie \left[H_1^+ H_1^- + H_2^+ H_2^- \right] (p-q)^\mu A_\mu \\ &- \frac{ig_L}{2C_W} \left[C_{2W} H_1^+ H_1^- + 2S_W^2 H_2^+ H_2^- \right] (p-q)^\mu Z_\mu \\ &+ \frac{ig_X}{2\sqrt{3} T_W} \left[\left(C_{2\beta_T} + T_W^2 \right) H_1^+ H_1^- + 2 \left(1 + T_W^2 \right) H_2^+ H_2^- \right] (p-q)^\mu Z'_\mu \end{aligned} \tag{5}$$

The above couplings allow the pair production mode shown in Figure 3.

Spin	Basis	$SU(3)_L \otimes U(1)_X$	Q
Quarks	$\begin{pmatrix} u,s,b \\ d,c,t \\ T,J_1,J_2 \end{pmatrix}_L = (Q_{1L}, Q_{2,3L})$	$Q_{1L}: (3,1/3)$ $Q_{2,3L}: (3^*,0)$	$\begin{pmatrix} \frac{2}{3}, \frac{-1}{3}, \frac{-1}{3} \\ \frac{-1}{3}, \frac{2}{3}, \frac{2}{3} \\ \frac{2}{3}, \frac{-1}{3}, \frac{-1}{3} \end{pmatrix}$
Leptons	$\begin{pmatrix} \nu_e, \nu_\mu, \nu_\tau \\ e, \mu, \tau \\ E_1, E_2, E_3 \end{pmatrix}_L = l_L$	$(3, -1/3)$	$\begin{pmatrix} 0 \\ -1 \\ 0 \end{pmatrix}$
Scalars	$\begin{pmatrix} \chi_1^0, \rho_1^+, \eta_1^0 \\ \chi_2^-, \rho_2^0, \eta_2^- \\ \chi_3^0, \rho_3^+, \eta_3^0 \end{pmatrix}_L = (\chi, \rho, \eta)$	$\chi: (3, -1/3)$ $\rho: (3, 2/3)$ $\chi: (3, -1/3)$	$\begin{pmatrix} 0,1,0 \\ -1,0,-1 \\ 0,1,0 \end{pmatrix}$
Neutral Gauge Bosons	$(W_\mu^3, W_\mu^8, B_\mu)$	$(8,0)$	0

Figure 1: 3-3-1 Spectrum

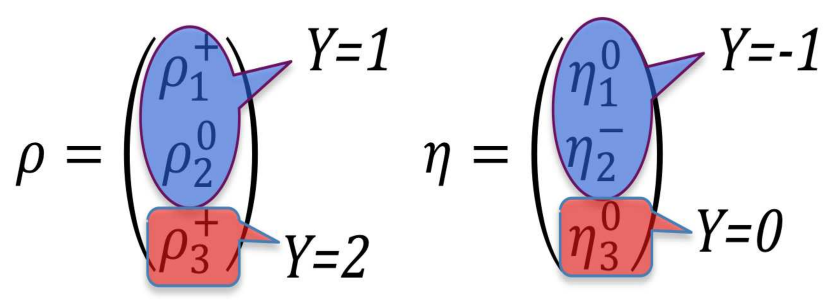

Figure 2: $SU(2)_L \otimes U(1)_Y$ structure of the ρ and η scalar triplets

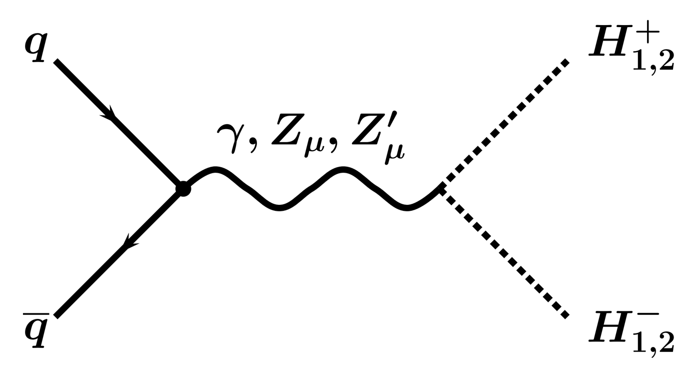

Figure 3: Pair Higgs production

Results

Figure 4 show the cross section for Higgs boson pair production $H_2^{\pm}$ for $M'_Z = 1$ TeV. For comparison purposes, we include the charged Higgs boson $H_1^{\pm}$ [3] and the charged Higgs from the two Higgs doublet model (2HDM).

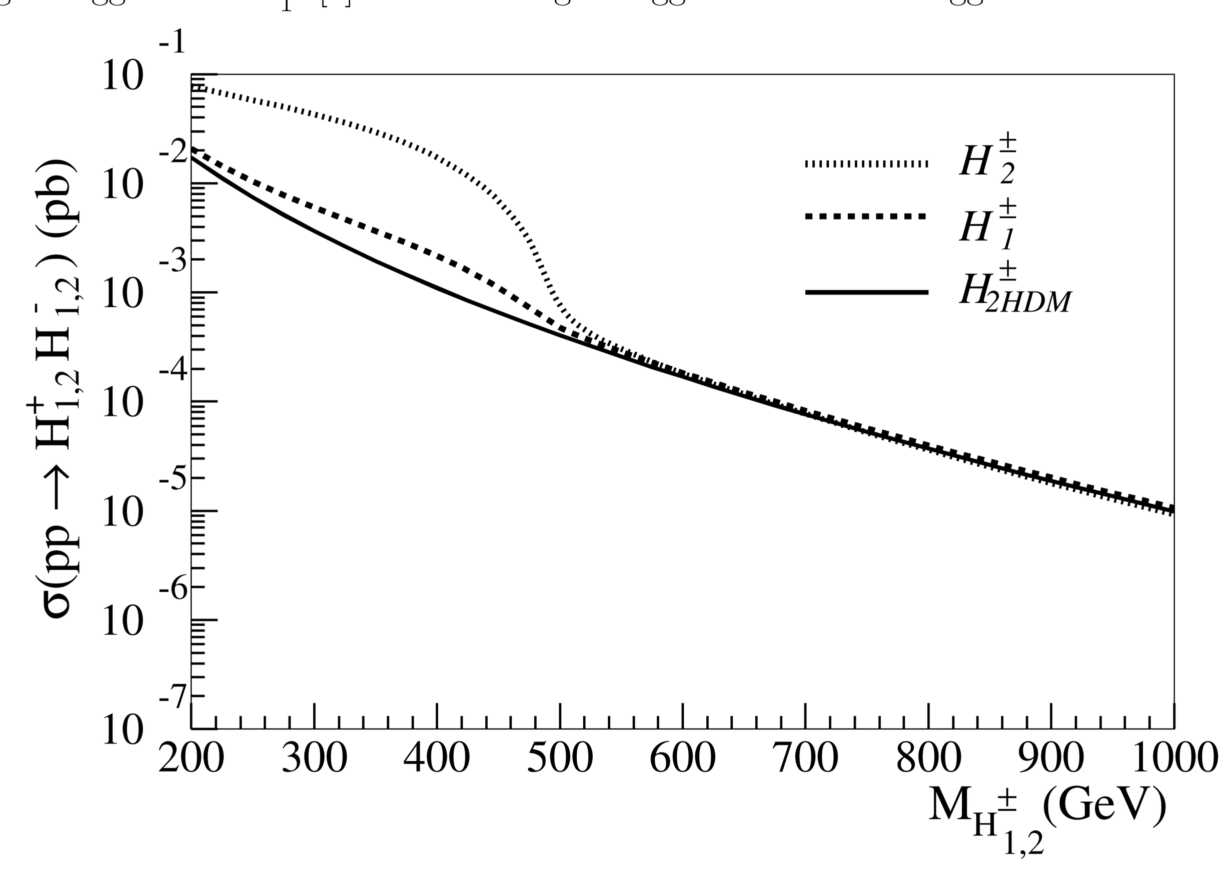

Figure 4: Pair production cross section of charged Higgs bosons

✔ For $M_H < 500$ GeV, the cross sections splits, with $\sigma(H_2) > \sigma(H_1) > \sigma(H_{2HDM})$ due to the Z' contribution.

✔ For $M_H > 500$ GeV, the Z' contribution is forbidden by the kinematic ($M'_Z < 2M_H$). Thus, the cross section drops, as shown.

✔ The $H_1^{\pm}$-Z' is β_T-dependent. We choose $T_{\beta_T} = 9$ in the above graph.

References

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