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POSSIBLE EXISTENCE OF NEUTRAL BOSONS WITH SPINS 0 AND 2 IN THE MASS RANGE FROM 160.77 GeV TO 227.36 GEV

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Abstract

The questions connected with the possible existence of new neutral bosons with the spins 0, 2 and 3 in the mass range from 160.77 GeV to 227.36 GeV are discussed. We investigate the decay of an arbitrary neutral boson with the mass heavier than 160.77 GeV to a pair of charged vector bosons in a uniform magnetic field when the spins of the W-bosons are longitudinally polarized. We also assume that these arbitrary neutral bosons can decay to the two photons. The possible existence of the new neutral bosons with the spins 0, 2, 3 and with the charge conjugation $C = +1$ in the mass range from 160.77 GeV to 227.36 GeV is predicted. The analyses show that the existence of the neutral bosons with the spins 0 and 2 in the mass range from 160.77 GeV to 227.36 GeV is more promising and realistic.

Keywords: Higgs boson, W-boson in a magnetic field, spin 2 particle, spin 3 particle, parity, charge conjugation, neutral boson with the mass 126 GeV

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1. INTRODUCTION

In 2012 the ATLAS and CMS Collaborations reported on the discovery of a new neutral boson (NB) at a mass around 126 GeV [1, 2]. This NB has properties compatible with the Standard Model Higgs boson [3-8] that is described with $J^{PC} = 0^{++}$ where P is the parity, C is the charge conjugation, J is the spin. Plenty of background phenomena were observed in the pp-collisions in the LHC experiments. From this point of view it is difficult to distinguish the signals from the background phenomena in pp-collisions. Therefore the production of new particles in the pp-collisions in the energy (mass) range $2m_W \le m < \infty$ ($m_W \cong 80.385\ GeV$ [9] is the W-boson mass) is not excluded in the future improved LHC experiments. Here we investigate the possibility of the existence of the NBs with the spins 0, 2 and higher than 2 in the mass range $2m_W \le m < \infty$. The following natural questions arise. Are there any other NBs with the spins 0, 2 and higher than 2 except the 126 GeV NB? How is realistic and promising the existence of the NB with the spins 0, 2 and higher than 2 in the mass range $2m_W \le m < \infty$? Search for the answers to these questions determines the motivation for the presented investigation. We investigate the decay of an arbitrary NB (we call it a neutral Y-boson) with the mass heavier than $2m_W$ into an on shell W-boson pair in a magnetic field (MF) provided that our arbitrary NB also decays into the two photons. The main purpose of this work is to predict the existence of new NBs in the mass range $2m_W \le m < \infty$ and to determine their spins.

2. BASIC IDEA IN THIS WORK

First of all, let us consider the energy spectrum of a $W^{\mp}$-boson in an external uniform MF [10-14]. We will use the formula [10, 11]

$$E^2 = p_{\mp z}^2 + \left(2n_{\mp} + 1 - 2q_{\mp}s_{\mp z}\right)eB + m_W^2 , \qquad (1)$$

that was written in the $\hbar = c = 1$ system of units where $B = \left|\vec{B}\right|$ is the strength of a MF whose intensity vector $\vec{B}$ is directed along the Oz-axis, $p_{\mp z}$ and $s_{\mp z}$ are the third component of the momentum and the third component of the spin of a $W^{\mp}$-boson, respectively, $n_{\mp} = 0,1,2,...$ enumerates the Landau energy levels of a $W^{\mp}$-boson, $q_+ = +1$ ($q_- = -1$) is the sign of the electric charge of a W^+ $\left(W^-\right)$-boson. A $W^{\mp}$-boson has three polarization states:

$\left|W^{\mp}(s_{\mp}=1,\, s_{\mp z}=+1)\right\rangle = \left|1,+1\right\rangle$, $\left|W^{\mp}(s_{\mp}=1,\, s_{\mp z}=0)\right\rangle = \left|1,0\right\rangle$, $\left|W^{\mp}(s_{\mp}=1,\, s_{\mp z}=-1)\right\rangle = \left|1,-1\right\rangle$, where $s_{\mp}$ is the spin of a $W^{\mp}$-boson. Hereafter we will consider the case $n_{\mp}=0,\ p_{\mp z}=0$ and the longitudinal polarization of the spin of a $W^{\mp}$-boson, i.e. $s_{\mp z}=0$. When the $W^{+}\left(W^{-}\right)$-boson spin is perpendicular ($s_{\mp z}=0$) to the MF direction, the $W^{\mp}$-boson energy satisfies the inequality

$$E=\sqrt{m_W^2+eB}\geq m_W \qquad (2)$$

for an arbitrary B taken from the range $0\leq B\leq B_{0W}$ where $B_{0W}=m_W^2/e$.

The NB at a mass around 126 GeV observed at the LHC is produced in the pp-collisions at $\sqrt{s}=7TeV$ and $\sqrt{s}=8TeV$ via the one of the following main reaction channels: the gluon-gluon fusion channel, the vector boson fusion channel, the Higgs-strahlung channel and the channel of the associated production with a $t\bar{t}$ quark-antiquark pair [15-19]. We assume that the production of the other new NBs via the above indicated channels is not excluded in the pp-collisions in the future improved LHC experiments or in other planned collider experiments. The possible new NBs can decay via the one of the main decay channels: $Y\to\gamma\gamma$, $Y\to ZZ^*\to 4l$, $Y\to WW^*\to l\nu l\nu$, $Y\to\tau^-\tau^+$, $Y\to b\bar{b}$ like the NB at a mass around 126 GeV .

Let us consider the decay of an arbitrary NB with the mass heavier than $2m_W$ into the W^-W^+-boson pair. For instance, the NB at a mass around 126 GeV observed at the ATLAS and CMS experiments decays via the $H\to WW^*\to l\nu l\nu$ channel [20]. One of these $W^{\mp}$-bosons is on-shell, the other one (W^*) is off-shell. According to the energy conservation law the decay of this NB into the on-shell W^-W^+-boson pair is impossible. Therefore, this NB decays into one on-shell W-boson and one off-shell W^*-boson. However, if we place this NB or any other neutral Y-boson with the mass $m\geq 2m_W$ in a uniform MF, the MF will affect on the W^+- and W^--bosons that are the products of the decay $Y\to W^-W^+$. If we consider the decaying neutral Y-boson in the rest frame and take into account the relation (2) for the W^+ (W^-)-boson with $s_{\mp z}=0$ in the energy conservation law $m=E_Y=E_{W^-}+E_{W^+}$, we can see that in a MF with the strength B_Y the equality $m=2\sqrt{m_W^2+eB_Y}$ is satisfied and the NB with the mass $m\geq 2m_W$ can easily decay into the two on-shell longitudinally polarized $W^{\mp}$-bosons. So, as a result of the decay reaction

$Y \to W^-W^+$ in a MF we have the final diboson system Y' that consists of the on-shell W^-- and W^+-bosons situating in a MF.

3. POSSIBLE POLARIZATION STATES OF W-BOSON PAIR SYSTEM

We denote an arbitrary polarization state of the system Y' as $|S_{Y'}, S_{Y'_z}\rangle$ where $S_{Y'} = S_{W^-W^+}$ is the total spin of the system Y' and $S_{Y'_z}$ is the third component of the total spin vector $\vec{S}_{Y'} = \vec{S}_{W^-W^+}$. In general, the quantum states of the system Y' can have the spin equal to 0, 1, 2. Using the three possible polarization states of $W^{\mp}$-bosons, the addition rule of spins and the Clebsch-Gordan coefficients [9, 21] we obtain nine polarization states $|S_{Y'}, S_{Y'_z}\rangle$ of the system Y': $|2,+2\rangle$, $|2,+1\rangle$, $|2,0\rangle$, $|2,-1\rangle$, $|2,-2\rangle$, $|1,+1\rangle$, $|1,0\rangle$, $|1,-1\rangle$, $|0,0\rangle$. The total angular momentum vector $\vec{J}$ of the W^-W^+-system is determined with the total spin vector $\vec{S}_{W^-W^+}$ of the W^-W^+-system and the orbital angular momentum vector $\vec{L}_{W^-W^+}$ of the relative motion performed by the W^-- and W^+-bosons on the plane perpendicular to the MF intensity vector which is oriented along the Oz-axis. In case of the longitudinal polarization the states $|W^{\pm}(s_{\pm} = 1,\ s_{\pm z} = 0)\rangle = |1,0\rangle$ only contributes to the final polarization state of the system Y'. Using the polarization states $|W^-(s_- = 1,\ s_{-z} = 0)\rangle = |1,0\rangle$ and $|W^+(s_+ = 1,\ s_{+z} = 0)\rangle = |1,0\rangle$ of $W^{\mp}$-bosons, the addition rule of spins and the Clebsch-Gordan coefficients [9, 21] we obtain $|1,0;1,0\rangle = \sqrt{\frac{2}{3}}|2,0\rangle - \frac{1}{\sqrt{3}}|0,0\rangle$. So, in case of longitudinal polarization of spins of $W^{\mp}$-bosons the system Y' has two different polarization states: $|2,0\rangle$, $|0,0\rangle$. The states $|2,\ 0\rangle$ and $|0,\ 0\rangle$ are formed from $|W^-(s_- = 1,\ s_{-z} = 0)\rangle = |1,0\rangle$ and $|W^+(s_+ = 1,\ s_{+z} = 0)\rangle = |1,0\rangle$ as a result of the transition reactions $Y \to Y'(S_{Y'} = 2,\ S_{Y'_z} = 0)$, $Y \to Y'(S_{Y'} = 0,\ S_{Y'_z} = 0)$, respectively. According to the energy conservation law the energy of the final W^+W^--system $E_{W^-W^+}$ is to be in the range $2m_W \le E_{W^-W^+} \le 2\sqrt{2}m_W$ if we assume that the MF strength changes in the range $0 \le B \le B_{0W}$.

The energy conservation law is as $m = 2\sqrt{m_W^2 + eB_Y}$ for the transition reactions $Y \to Y'(S_{Y'} = 2,\ S_{Y'_z} = 0)$, $Y \to Y'(S_{Y'} = 0,\ S_{Y'_z} = 0)$ when $|W^-(s_- = 1,\ s_{-z} = 0)\rangle = |1,0\rangle$ and $|W^+(s_+ = 1,\ s_{+z} = 0)\rangle = |1,0\rangle$ with $n_{\mp} = 0,\ p_{\mp z} = 0$ and $s_{\mp z} = 0$ are produced. In this case the mass of the neutral Y-boson is in the energy range $2m_W \le m_Y \le 2\sqrt{2}m_W$ ($160.77\ GeV \le m_Y \le 227.36\,GeV$) for an arbitrary B taken from the range $0 \le B \le B_{0W}$.

4. CHARGE CONJUGATION, PARITY, TOTAL ANGULAR MOMENTUM OF W^-W^+-PAIR AND SPIN OF NEUTRAL Y-BOSON

Introducing the intrinsic parity $P_{W^-}\left(P_{W^+}\right)$ for the $W^-\left(W^+\right)$-boson, the orbital quantum number $L_{W^-W^+}$ and the total spin $S_{W^-W^+}$ for the W^-W^+-system we can determine the charge conjugation $C_{W^-W^+}$, the parity $P_{W^-W^+}$ and the total angular momentum J for the W^-W^+-system by the following formulas, respectively:

$$C_{W^-W^+} = (-1)^{L_{W^-W^+}+S_{W^-W^+}}, \tag{3}$$

$$P_{W^-W^+} = (-1)^{L_{W^-W^+}} P_{W^-} P_{W^+} = (-1)^{L_{W^-W^+}}, \tag{4}$$

$$J = L_{W^-W^+} + S_{W^-W^+},\ L_{W^-W^+} + S_{W^-W^+} - 1, \ldots, \left|L_{W^-W^+} - S_{W^-W^+}\right|. \tag{5}$$

We accept that the initial NB can also decay into the two photons. Therefore its spin J can not be 1 according to the Landau-Yang theorem [22, 23] and the charge conjugation C of the initial decaying neutral Y-boson is $C = C_Y = 1$. The decay $Y \to W^-W^+$ is a weak process and C is not conserved in this process. It means that if the charge conjugation of the initial neutral Y-boson is $C_Y = 1$ before the reaction $Y \to W^-W^+$, the charge conjugation $C_{W^-W^+}$ might be $+1$ or -1 after the reaction, or it might also go to a state that is not a $C_{W^-W^+}$ eigenstate. Here we assume that $C_{W^-W^+}$ is either $+1$ or -1 after the reaction. We also assume that $P_{W^-W^+}$ is either $+1$ or -1 after the reaction. The following combinations of $C_{W^-W^+}$ and $P_{W^-W^+}$ for the W^-W^+-system are possible:

case A: $$C_{W^-W^+} = +1, \quad P_{W^-W^+} = +1, \tag{6}$$

case B: $$C_{W^-W^+} = +1, \quad P_{W^-W^+} = -1, \tag{7}$$

case C: $$C_{W^-W^+} = -1, \quad P_{W^-W^+} = +1, \tag{8}$$

case D: $$C_{W^-W^+} = -1, \quad P_{W^-W^+} = -1. \tag{9}$$

In case of the longitudinal polarization the spin of the W^-W^+-system can be either $S_{W^-W^+} = 0$ or $S_{W^-W^+} = 2$. If we take $S_{W^-W^+} = 0$ or $S_{W^-W^+} = 2$ in the formula (3) and compare the formulas (3) and (4), we obtain that

$$C_{W^-W^+} = P_{W^-W^+} = (-1)^{L_{W^-W^+}} . \qquad (10)$$

The last relation means that the cases B and C are not realized. So, we have only dealings with the cases A and D.

Case A: When $S_{W^-W^+} = 0$ or $S_{W^-W^+} = 2$ and $C_{W^-W^+} = P_{W^-W^+} = (-1)^{L_{W^-W^+}} = +1$, the minimal value for $L_{W^-W^+}$ is $L_{W^-W^+} = 0$. In this case we obtain $J = 0,2$ for the decaying NB. So, if $C_{W^-W^+} = +1, \quad P_{W^-W^+} = +1$, the NBs with the spins $J = 0$ and $J = 2$ can exist in the range $2m_W \le m_Y \le 2\sqrt{2}m_W$. The particle with $J = 0$ in the range $2m_W \le m_Y \le 2\sqrt{2}m_W$ corresponds to the Non-Standard Model Higgs boson. The calculations and analyses also show that if $C_{W^-W^+} = +1, \quad P_{W^-W^+} = +1$, the existence of the NBs with $J = 2$ is allowed in the mass range $2m_W \le m_Y \le 2\sqrt{2}m_W$.

Case D: When $S_{W^-W^+} = 0$, the minimal value for $L_{W^-W^+}$ is $L_{W^-W^+} = 3$ ($L_{W^-W^+} = 1$ is not allowed according to the Landau-Yang theorem) and we obtain $J = 3$ for the decaying NB. When $S_{W^-W^+} = 2$, the minimal value for $L_{W^-W^+}$ is $L_{W^-W^+} = 1$ and we obtain $J = 2,3$ for the decaying NBs. So, if $C_{W^-W^+} = -1, \quad P_{W^-W^+} = -1$, the NBs with $J = 2$ and $J = 3$ can exist in the mass range $2m_W \le m_Y \le 2\sqrt{2}m_W$.

5. DISCUSSION OF THE RESULTS

We have obtained that the NBs with the following spins can exist in the mass range $2m_W \le m_Y \le 2\sqrt{2}m_W$ and they can decay into the on-shell $W^-(s_- = 1, s_{-z} = -1)$ - and $W^+(s_+ = 1, s_{+z} = +1)$ -bosons in a MF:

Case A: if $C_{W^-W^+} = +1$ and $P_{W^-W^+} = +1$, $J = 0,2$ $(S_{W^-W^+} = 0,2; L_{W^-W^+} = 0)$, (11)

Case D: if $C_{W^-W^+} = -1$ and $P_{W^-W^+} = -1$, $J = 3$ $(S_{W^-W^+} = 0; L_{W^-W^+} = 3)$ and

$$J = 2,3 \quad (S_{W^-W^+} = 2; L_{W^-W^+} = 1). \qquad (12)$$

We have obtained $J = 0, 2$ for the spin of the neutral Y -boson if $C_{W^-W^+} = +1$, $P_{W^-W^+} = +1$ and $J = 2, 3$ for the spin of the neutral Y -boson if $C_{W^-W^+} = -1, \quad P_{W^-W^+} = -1$. The existence of the extra NB with the spin $J = 0$ and with the other mass is not excluded in the mass range $2m_W \le m_Y \le 2\sqrt{2}m_W$. When W^-W^+ -pair are produced on the ground Landau level, the orbital quantum number $L_{W^-W^+}$ should be minimal. $L_{W^-W^+}$ is minimal only in the case A. So, the case A is more suitable for the particle with the spins $J = 0$ and $J = 2$. The mass of the NBs with the spins $J = 0$ and $J = 2$ is in the range $2m_W \le m_Y \le 2\sqrt{2}m_W$. The existence of the particle with the spin 3 in the mass range $2m_W \le m_Y \le 2\sqrt{2}m_W$ is not excluded, if $C_{W^-W^+} = -1$ and $P_{W^-W^+} = -1$. The existence of the particle with the spin $J \ge 2$ would indicate that the world we live has additional dimensions besides known four ones [24, 25].

The MF strength required for the decay of an arbitrary neutral Y-boson with the mass in the range $2m_W \le m_Y \le 2\sqrt{2}m_W$ into the on-shell $W^-(s_- = 1,\ s_{-z} = 0)$ and $W^+(s_+ = 1,\ s_{+z} = 0)$ bosons is calculated by the formula

$$B_Y = B_{0W}\left[\left(\frac{m_Y}{2m_W}\right)^2 - 1\right]. \qquad (13)$$

Let us perform the simple numerical estimations for the strength of the MF required for the decay of an arbitrary massive neutral Y-boson with the mass heavier than $2m_W$ into the on-shell $W^-(s_- = 1, s_{-z} = -1)$ - and $W^+(s_+ = 1, s_{+z} = +1)$ -bosons in a MF. When $m \cong 180\,GeV$, the required MF strength is $B \cong 2.5\times10^{23}\,G$ (or in Teslas it is $B \cong 2.5\times10^{19}\,T$). The strongest (pulsed) MF ever obtained in a laboratory is $28\,MG$ (or $2.8\times10^3\,T$) [26] that is much less than $\sim 10^{22}\,G$ (or $\sim 10^{18}\,T$). The maximum strength of the produced strong MF in noncentral heavy-ion collisions in the direction perpendicular to the reaction plane is estimated to be $\sim 10^{17}\,G(\sim 10^{13}\,T)$ at the RHIC and $\sim 10^{18}\,G(\sim 10^{14}\,T)$ at the LHC [27-33]. In lead-lead collisions at the LHC, the strength of the generated MF may reach $\sim 10^{20}\,G(\sim 10^{16}\,T)$ [28, 29]. We hope that in the future collider experiments, when the strength of the produced strong MF reaches the magnitude $\sim 10^{23}\,G$, the decay of the NBs with the spins $J = 0,2$ and with the mass heavier than $2m_W$ into the on shell W^- -and W^+-bosons having the polarization states $\left|W^-(s_- = 1,\ s_{-z} = 0)\right\rangle = \left|1,0\right\rangle$ and $\left|W^+(s_+ = 1,\ s_{+z} = 0)\right\rangle = \left|1,0\right\rangle$ can be observed experimentally. In the absence of a MF the NB with the mass heavier than $2m_W$ and with the spin $J = 0,2$ can easily decay into the pair of on-shell W-bosons. Consideration of the decay of an arbitrary NB into a pair of on-shell W-bosons in a MF with allowance for the longitudinal polarization of the spin of the $W^\pm$-

boson enables us to investigate the mass range above $2m_W$ and to predict possible existence of extra neutral bosons with spins 0 and 2 in this mass range.

6. CONCLUSIONS

We have investigated the decay of an arbitrary NB into the on-shell W^-W^+-pair in a uniform MF provided that this arbitrary NB also decays into the two photons and the W-bosons are longitudinally polarized. We have obtained that the neutral particles with the spins $J = 0, 2, 3$ and with the charge conjugation $C = +1$ can exist in the mass range $2m_W \leq m_Y \leq 2\sqrt{2}m_W$ ($160.77\ GeV \leq m_Y \leq 227.36\, GeV$). The NBs with the spins $J = 0, 2$ in the mass range $2m_W \leq m_Y \leq 2\sqrt{2}m_W$ are allowed if $C_{W^-W^+} = +1$ and $P_{W^-W^+} = +1$. The NB with the spins $J = 2$ in the mass range $2m_W \leq m_Y \leq 2\sqrt{2}m_W$ is also allowed if $C_{W^-W^+} = -1$ and $P_{W^-W^+} = -1$. The NB with the spin $J = 3$ in the mass range $2m_W \leq m_Y \leq 2\sqrt{2}m_W$ is allowed if $C_{W^-W^+} = -1$ and $P_{W^-W^+} = -1$. The analyses of the obtained results enable us to come to the conclusion that the existence of the NB with the spin $J = 2$ and the charge conjugation $C = +1$ in the mass range $2m_W \leq m_Y \leq 2\sqrt{2}m_W$ is allowed in all possible cases. Therefore its existence is more promising and realistic. We hope that the possible existence of the indicated NBs with the spins $J = 0, 2, 3$ and the charge conjugation $C = +1$, especially, the existence of the new NB with the spin $J = 2$ in the mass range from 160.77 GeV to 227.36 GeV will attract the experimental physicists' attention in future collider experiments.

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