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THE ESTIMATION OF THE Z' GAUGE BOSON MASS IN E_6 MODELS

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The aim of this study is to estimate the Z' boson mass by using the calculations of the decay width of $Z'(\theta)$ boson. So, the decay width of the extra Z boson is calculated numerically in effective rank 5 models for different mixing angles θ of the model and for different mass values of the extra Z boson. The decay width of Z' boson to the Standard Model (SM) fermions is found to be between 4.42 and 19.36 GeV and the full decay width of Z' boson to all particles is found to be between 20.88 and 37.15 GeV. We calculated the full decay width at the angle $\theta \approxeq 0$ for Z' and $Z_2 \longrightarrow Z'$. The full decay width of Z' boson is written in a single equation according to our calculations. By using these calculations and the previous works the mass of Z' boson and the number of generations of the exotic particles are estimated.

Целью данного исследования является оценка массы Z'-бозона с помощью вычисления ширины распада $Z'(\theta)$-бозона. То есть ширина распада экстра-Z-бозона находится численно в эффективных моделях ранга 5 с различными углами смешивания θ и различными значениями массы экстра-Z-бозона. Ширина распада Z'-бозона на фермионы Стандартной модели (СМ) находится в интервале между 4,42 и 19,36 ГэВ, а полная ширина распада Z'-бозона на все возможные частицы находится в интервале между 20,88 и 37,15 ГэВ. Нами вычислена полная ширина распада для угла $\theta \approxeq 0$ для Z' и $Z_2 \to Z'$. В соответствии с нашими вычислениями полная ширина распада Z'-бозона может быть выражена одним уравнением. Опираясь на приведенные расчеты и предыдущие работы, можно оценить массу Z'-бозона и число поколений экзотических частиц.

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INTRODUCTION

Although the Standard Model (SM) is consistent with most of the experimental results, there are some discrepancies at high energy experiments [1]. The SM deals with nature at low energies. Extended gauge bosons seem in many extensions of the SM, like left-right symmetric models and GUTs (Grand Unified Theories), etc. Extra gauge bosons have not been discovered experimentally yet. They will be searched for at LHC experiments [2, 3] starting this year. Hence, the decay widths of Z' boson are calculated here, and using the results of these calculations and also the previous works the mass of Z' is estimated.

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The simplest possible extension of the SM gauge group suggested by a gauge group of larger rank involves the introduction of one extra $U(1)$ factor. This produces an extra neutral gauge boson, Z', in the particle spectrum. By the charges and gauge couplings of the extra $U(1)$ factor, the decay widths of the extra neutral gauge boson to the particles under consideration can be calculated in some energy ranges. The low energy phenomenology of Z' bosons has been extensively discussed in the literature [4]. Recently, particularly strong motivation for having the Z' mass below one TeV has been emphasized by Cvetic and Langacker [5, 6].

In the breakdown of the extended gauge groups such as E_6 there can be at most two additional gauge bosons in the low energy spectrum. Since the popular examples of the extended gauge theories are based on supersymmetric GUT groups such as $SO(10)$ and E_6, it is decided to study the additional Z bosons originating from E_6. GUTs with larger gauge groups than $SO(10)$ predict more than one extra neutral gauge boson and exotic particles. The mass of Z' is estimated to be between electroweak scale and GUT scale. It is hoped that Z' boson can be observed experimentally at LHC experiments. In our calculations we used the particle content of E_6 model in the electroweak breaking of $U(1)$ symmetry [7]. However, for simplicity we will consider an effective rank 5 low energy theory with only one additional gauge boson associated with an extra $U(1)$ and parameterized by

$$Z'(\theta) = Z_\psi \cos\theta - Z_\chi \sin\theta, \tag{1}$$

where θ is the mixing angle in the E_6 group [4], and

(i) Z_ψ occurs when

$$E_6 \to SO(10) \times U(1)_\psi, \tag{2}$$

(ii) Z_χ occurs when

$$SO(10) \to SU(5) \times U(1)_\chi. \tag{3}$$

The orthogonal combination to $Z'(\theta)$ given in Eq. (1) is assumed to have a mass at the intermediate or Planck scale. When E_6 breaks directly to a rank 5 group [SM $\times\, U(1)_\eta$] as in superstring inspired models via Wilson line breaking, the extra Z boson is denoted by $Z_\eta \equiv \sqrt{5/8}Z_\psi - \sqrt{3/8}Z_\chi$ [4].

The cross section for $Z'(\theta)$ production at hadron colliders is inversely proportional to the $Z'(\theta)$ decay width. To avoid the cross section singularities at some special energies, the decay widths of neutral vector bosons should be known [8].

Here firstly the calculation of the decay width for E_6 boson $Z'(\theta)$ to the SM fermions is done for different mixing angles θ and masses. After that the gauge eigenstates Z' and Z_0 are written as a mixture of the mass eigenstates Z_1, Z_2 and the decay widths of Z' boson to $SU(2)$ bosons W^+W^- and $Z_1H_1^0$ are calculated. The full decay width for Z' boson to the SM particles and to their supersymmetric partners is calculated at the small mixing angle $\theta \approxeq 0$. By using these calculations and the previous works, the mass of Z' boson and the number of generations of the exotic fermions are estimated.

CALCULATION

In the extension of the SM the relevant neutral current (NC) Lagrangian is given as [9]

$$-L_{\mathrm{NC}} = g_1 J_{0\mu} Z_0^\mu + g_2 J_{\theta\mu} Z'^{\mu}(\theta), \tag{4}$$

where
$$J_{0\mu} = \sum_f \overline{f}\gamma_\mu(g_V - g_A\gamma_5)f, J_{\theta\mu} = \sum_f \overline{f}\gamma_\mu(g'_V - g'_A\gamma_5)f \tag{5}$$
and
$$g_1 = (g^2 + g'^2)^{1/2} = \frac{e}{2\sin\theta_W\cos\theta_W} = (\sqrt{2}G_\mu M_{Z_0}^2)^{1/2}, \tag{6}$$
$$g_2 = g_\theta = g_1\sqrt{\frac{5}{3}}\sin\theta_W = (\sqrt{2}G_\mu M_{Z_0}^2)^{1/2}\sqrt{\frac{5}{3}}\sin\theta_W, \tag{7}$$
here θ_W is the Weinberg angle.

The Feynman diagrams for $Z_0 \to f\overline{f}$ and $Z'(\theta) \to f\overline{f}$ are similar and given in Fig. 1.

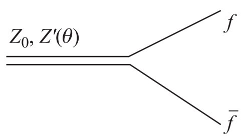

Fig. 1. The lowest order Feynman diagram for Z_0, $Z'(\theta)$

The matrix elements and the cross sections for $Z_0 \to f\overline{f}$ and $Z'(\theta) \to f\overline{f}$ are also the same formally. Firstly, the equations of Γ_{Z_0} are derived and after that $\Gamma_{Z'(\theta)}$ is found by using the same formalism. Here we take $f = \nu, e^-, u, d$; and $\nu = \nu_e, \nu_\mu, \nu_\tau$; $e = e, \mu, \tau$ leptons; $u = u, c, t$; $d = d, s, b$ quarks. The matrix element for the process $Z_0(p) \to f(p_2)\overline{f}(p_1)$ can be written as [10, 11]

$$M = \bar{u}(p_2)\gamma_\mu(g_V - g_A\gamma_5)v(p_1)Z_0^\mu. \tag{8}$$

Multiplying M with its hermitian conjugate $M^\dagger$ we obtain

$$\begin{aligned}|M|^2 &= g_1^2[\bar{v}(p_1)\gamma_\mu(g_V - g_A\gamma_5)u(p_2)] \times [\bar{u}(p_2)\gamma_\nu(g_V - g_A\gamma_5)v(p_1)]\varepsilon^\mu\varepsilon^\nu = \\ &= g_1^2\left(-g_{\mu\nu} + \frac{p_\mu p_\nu}{M_{Z_0}^2}\right) \times \text{Trace}\,[p_1\gamma_\mu p_2\gamma_\nu(g_V^2 + g_A^2 - 2g_V g_A\gamma_5)].\end{aligned} \tag{9}$$

After trace calculations and averaging over 3 spin states of Z_0 boson

$$|M|^2 = \frac{g_1^2 M_{Z_0}^2 C}{3}(g_V^2 + g_A^2) \tag{10}$$

is obtained. Here C is the color factor and $C = 1$ for leptons and $C = 3(1 + \alpha_s(M_{Z_0})/\pi + 1.409(\alpha_s(M_{Z_0})/\pi)^2 - 12.77(\alpha_s(M_{Z_0})/\pi)^3)$ for quarks [12], $\alpha_s(M_{Z_0})$ is the strong coupling constant. For two-body decay, in the rest frame of the decaying particle $|\mathbf{p}_1| = |\mathbf{p}_2|$, the differential decay width is given by

$$d\Gamma = \frac{|\mathbf{p}_1|}{32\pi^2 M_{Z_0}^2}|M|^2\,d\Omega, \tag{11}$$

where the solid angle is
$$d\Omega = d\phi_1 d(\cos\theta_1). \tag{12}$$

Then the decay width is obtained as follows:

$$\Gamma = \frac{1}{16\pi M_{Z_0}}|M|^2 = \frac{CG_F M_{Z_0}^3}{6\sqrt{2}\pi}(g_V^2 + g_A^2). \tag{13}$$

For the SM Z_0 boson, the couplings g_V and g_A for $\nu\overline{\nu}$, e^+e^-, $u\overline{u}$, $d\overline{d}$ are calculated as below by using the equations [13]:

$$g_V = T_3^f - 2Q^f \sin^2\theta_W \tag{14}$$

and

$$g_A = T_3^f, \tag{15}$$

where T_3^f is the third component of the SM isospin, and Q^f is the charge of fermions in units of the electron charge, i.e., $Q^e = -1$.

In the same manner we can calculate $\Gamma_{Z'(\theta)}$. The matrix element for $Z'(\theta)$ decay and the decay width are given by the following formulas:

$$M = \frac{g_2}{2}\bar{u}(p_2)\,\gamma_\mu(g'_V - g'_A\gamma_5)\,u(p_1)\,Z'(\theta)^\mu, \tag{16}$$

$$\Gamma_{Z'(\theta)} = \frac{CM_{Z'}}{3\cdot 16\pi}g_2^2(g_V'^2 + g_A'^2), \tag{17}$$

where

$$g_2 = g_\theta = \sqrt{\frac{5}{3}}\frac{e}{\cos\theta_W} = \sqrt{\frac{5}{3}}\frac{8M_{Z'(\theta)}G_F\sin^2\theta_W}{\sqrt{2}}. \tag{18}$$

By putting Eq. (18) in Eq. (17) we get

$$\Gamma(Z'(\theta)\to f\overline{f}) = \frac{5CM_{Z'(\theta)}M_{Z_0}^2G_F\sin^2\theta_W}{18\pi\cdot\sqrt{2}}(g_V'^2 + g_A'^2). \tag{19}$$

For the calculation of $\Gamma_{Z'(\theta)}$ the couplings g'_V and g'_A for $\nu\overline{\nu}$, e^+e^-, $u\overline{u}$, $d\overline{d}$ should be known. These couplings can be calculated by the equations [13]:

$$g'_V = Q'^{f_L} + Q'^{f_R} + \frac{g_{12}}{g_{22}}(Y^{f_L} + Y^{f_R}) \tag{20}$$

and

$$g'_A = Q'^{f_L} - Q'^{f_R} + \frac{g_{12}}{g_{22}}(Y^{f_L} - Y^{f_R}). \tag{21}$$

In these equations the term with g_{12} can be eliminated because of not requiring any additional symmetry. The breaking of E_6 to $SU(5)$ under Eqs. (2) and (3) gives the charge values of Q_χ and Q_ψ of $U(1)_\chi$ and $U(1)_\psi$ as given in Table 1.

Table 1. **The charge values of Q_χ and Q_ψ of $U(1)_\chi$ and $U(1)_\psi$ from the breaking of E_6 under Eqs. (2) and (3)**

f, $\overline{f}$	$2\sqrt{10}Q_\chi$	$2\sqrt{6}Q_\psi$
$u, d, \overline{u}, \overline{e}$	-1	1
$\overline{d}, \nu, e$	3	1

By using Eqs. (22) and (23) with the equation

$$Q'^f = Q_\psi\cos\theta - Q_\chi\sin\theta \tag{22}$$

we can get the values of g'_V and g'_A of Z' boson. Thus, the decay widths

$$\Gamma(Z'(\theta) \to \nu\overline{\nu}) = 0.004570\, M_{Z'(\theta)} \left(\frac{\cos\theta}{2\sqrt{6}} - \frac{3\sin\theta}{2\sqrt{10}}\right)^2, \tag{23}$$

$$\Gamma(Z'(\theta) \to e^+e^-) = 0.002283\, M_{Z'(\theta)} \left(\frac{2\sin^2\theta}{5} + \left(\frac{\cos\theta}{\sqrt{6}} - \frac{\sin\theta}{\sqrt{10}}\right)^2\right), \tag{24}$$

$$\Gamma(Z'(\theta) \to u\overline{u}) = 0.007125\, M_{Z'(\theta)} \left(\frac{\cos\theta}{\sqrt{6}} + \frac{\sin\theta}{\sqrt{10}}\right)^2, \tag{25}$$

$$\Gamma(Z'(\theta) \to d\overline{d}) = 0.007125\, M_{Z'(\theta)} \left(\frac{2\sin^2\theta}{5} + \left(\frac{\cos\theta}{\sqrt{6}} - \frac{\sin\theta}{\sqrt{10}}\right)^2\right) \tag{26}$$

are obtained. The total decay width is

$$\Gamma_{\rm tot}(Z'(\theta) \to f\overline{f}) = 0.0214\, M_{Z'(\theta)} \left(\frac{\cos\theta}{\sqrt{6}} + \frac{\sin\theta}{\sqrt{10}}\right)^2 + \\ + 0.0137 M_{Z'(\theta)} \left(\frac{\cos\theta}{2\sqrt{6}} - \frac{3\sin\theta}{2\sqrt{10}}\right)^2 + 0.0282 M_{Z'(\theta)} \left(\frac{2\sin^2\theta}{5} + \left(\frac{\cos\theta}{\sqrt{6}} - \frac{\sin\theta}{\sqrt{10}}\right)^2\right). \tag{27}$$

Total decay width $\Gamma_{\rm tot}(Z'(\theta) \to f\overline{f})$ for certain values of $M_{Z'(\theta)}$ and θ is obtained numerically and is given in Table 2.

Table 2. **Total decay width $\Gamma_{\rm tot}(Z'(\theta) \to f\overline{f})$ for certain values of $M_{Z'(\theta)}$ and θ. Γ is used for $\Gamma(Z'(\theta) \longrightarrow f\overline{f})$. $\Gamma(Z'(\theta) \longrightarrow f\overline{f})$ and $M_{Z'(\theta)}$ are in GeV**

$M_{Z'(\theta)}$	500	600	700	800	900	1000
$\Gamma_{\rm tot}(\theta = 0)$	4.4217	5.3067	6.1905	7.0752	7.9581	8.8464
$\Gamma_{\rm tot}(\theta = 37.8)$	5.7825	6.9387	8.0961	9.2520	10.4088	11.5653
$\Gamma_{\rm tot}(\theta = 90)$	9.6768	11.6112	13.5465	15.4824	17.4462	19.3524
$\Gamma_{\rm tot}(\theta = 127.8)$	8.7723	10.5312	12.2805	14.0349	15.7896	17.5443

In the case of non-zero mass mixing the Z, Z' gauge eigenstates which interact with $SU(2)$ W bosons are written in terms of the Z_1, Z_2 mass eigenstates as

$$\begin{bmatrix} Z \\ Z' \end{bmatrix} = \begin{bmatrix} \cos\theta_M & -\sin\theta_M \\ \sin\theta_M & \cos\theta_M \end{bmatrix} \begin{bmatrix} Z_1 \\ Z_2 \end{bmatrix}. \tag{28}$$

The decay width for $Z_2 \to W^+W^-$ occurs for the small mixing angle $\theta_M \to 1/M_{Z_2}$. This relation between θ_M and M_{Z_2} is called mass constraint [13]. For large M_{Z_2} the asymptotic Higgs-structure constraint on θ_M is that the mixing angle θ_M is proportional to $1/M_{Z_2}^2$ [14]. In the case $\theta_M \approx 1/M_{Z_2}^2$, $\sin\theta_M \to 0$ and $\cos\theta_M \to 1$. Therefore, $Z_1 \to Z_0$ and $Z_2 \to Z'$.

In this limit, the decay width for $Z_2 \to W^+W^-$ can be calculated by the equation [13, 14]:

$$\Gamma(Z_2 \to W^+W^-) = \frac{g_{ZWW}^2 M_{Z_2}}{192\pi} \sin^2\theta_M \left(\frac{M_{Z_2}}{M_{Z_0}}\right)^4 \left(1 - 4\frac{M_W^2}{M_{Z_2}^2}\right)^{3/2} \times \\ \times \left(1 + 20\frac{M_W^2}{M_{Z_2}^2} + 12\frac{M_W^4}{M_{Z_2}^4}\right), \quad (29)$$

where $g_{ZWW} = e\cot\theta_W$ [13], $M_{Z_0} = 91.2$ GeV, $M_W = 80.47$ GeV, and $\alpha = e^2/4\pi = 1/137$ is the fine structure constant. The factor $M_{Z_2}^4$ in Eq. (29) is too large. Therefore, the term $\sin^2\theta_M$ in this equation is taken as $1/M_{Z_2}^4$ because of the Higgs constraint. Then decay widths can be calculated for different masses.

In the large M_{Z_2} limit, the partial decay widths valid for $SU(2)_L \times U(1)_Y \times U(1)'$ model with two Higgs doublets and one Higgs singlet are given in [14]. When the branching fractions $Z_2 \to W^+W^-$ and $Z_2 \to Z_1H_1^0$ are the largest, then the decays $Z_2 \to H^+H^-$ and $Z_2 \to P^0H_2^0$, where H^+H^- and P^0 are the physical charged and the pseudoscalar Higgs bosons, respectively, are suppressed. Therefore, we can take $\Gamma(Z_2 \to Z_1H_1^0) = \Gamma(Z_2 \to W^+W^-)$.

Using the relation between the decay width for the fermionic SM particles and bosonic supersymmetric superpartners of them in one chiral supermultiplet in the massless limit given in [15] as

$$\Gamma(Z' \to bb^*) = \frac{1}{2}\Gamma(Z' \to f\overline{f}) = \Gamma(Z' \to \widetilde{f}\widetilde{\overline{f}}), \quad (30)$$

we can write the relationships between the decay widths for winos, zino and higgsino as

$$\Gamma(Z_2 \to \widetilde{W}^+\widetilde{W}^-) = 2\Gamma(Z_2 \to W^+W^-) = \Gamma(Z_2 \to \widetilde{Z}_0\widetilde{H}^0). \quad (31)$$

So, the full decay width for Z' boson at the $\theta_M \approxeq 0$ is

$$\Gamma_{\text{full}}(Z', Z_2 \to f\overline{f}, \widetilde{f}\widetilde{\overline{f}}, W^+W^-, \widetilde{W}^+\widetilde{W}^-, Z_0H^0, \widetilde{Z}_0\widetilde{H}^0) = \\ = \frac{3}{2}\Gamma_{\text{tot}}(Z' \to f\overline{f}) + 6\Gamma(Z_2 \to W^+W^-). \quad (32)$$

From the last equation, it is obvious that the full decay width of Z' boson is increased at least by 50% when we consider the supersymmetric partners of the SM particles. The full decay width of Z' for the angle $\theta \approxeq 0$ is given in Table 3.

Table 3. **The full decay width of Z' for the angle $\theta \approxeq 0$. Γ_{full} and M_{Z_2} are in GeV**

M_{Z_2}	500	600	700	800	900	1000
$\Gamma_{\text{full}}(\theta \approxeq 0)$	20.8706	24.0341	27.2438	30.4968	32.0972	37.1436

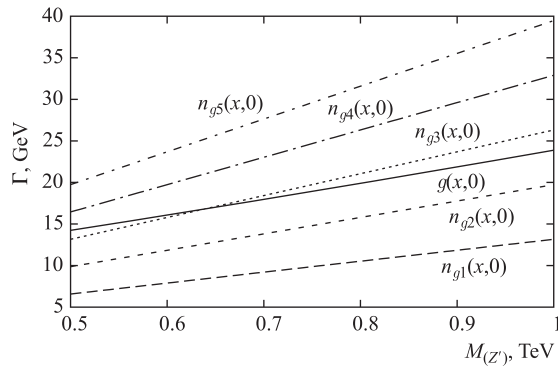

Fig. 2. The plot of decay width for $\Gamma(Z_2 \to W^+W^-,\ \widetilde{W}^+\widetilde{W}^-,\ Z_0H^0,\ \widetilde{Z}_0\widetilde{H}^0)$ defined by the line $g(x,0)$ as a function of different values of $M_{Z'(\theta)}$. The other five lines defined by $n_{g1}(x,0)$, $n_{g2}(x,0)$, $n_{g3}(x,0)$, $n_{g4}(x,0)$ and $n_{g5}(x,0)$ in the figure are for the number of generations of exotic fermions with values 1, 2, 3, 4 and 5, respectively, as seen in Eq. (33)

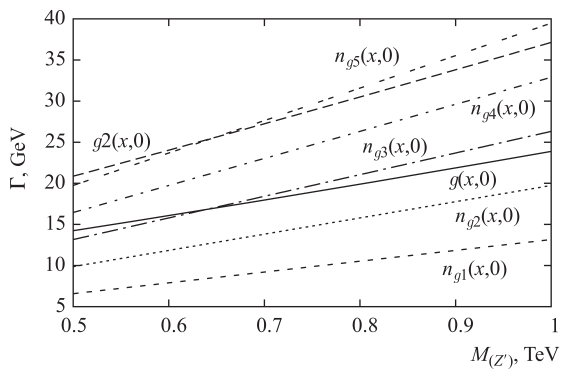

Fig. 3. The plot of $\Gamma_{\rm full}(Z', Z_2 \to f\overline{f}, \tilde{f}\bar{\tilde{f}}, W^+W^-, \widetilde{W}^+\widetilde{W}^-, Z_0H^0, \widetilde{Z}_0\widetilde{H}^0)$ decay widths defined by the line $g2(x,0)$ and $\Gamma(Z_2 \to W^+W^-,\ \widetilde{W}^+\widetilde{W}^-,\ Z_0H^0,\ \widetilde{Z}_0\widetilde{H}^0)$ defined by the line $g(x,0)$ as a function of different values of $M_{Z'(\theta)}$. The other five lines defined by $n_{g1}(x,0)$, $n_{g2}(x,0)$, $n_{g3}(x,0)$, $n_{g4}(x,0)$ and $n_{g5}(x,0)$ in the figure are for the number of generations of exotic fermions with values 1, 2, 3, 4 and 5, respectively, as seen in Eq. (33)

By using the equation [14]

$$\Gamma_{Z_2}(\text{GeV}) = (0.6 + 0.6 n_g)(M_{Z'} - M_{Z_0}), \tag{33}$$

where n_g is the number of generations of exotic fermions, and Eq. (32) both in the full form and taking only the second term on the right of this equation, we plotted Figs. 2 and 3 for trying to guess the Z' mass at the intersections of the lines of these equations.

DISCUSSION AND CONCLUSION

As seen from the calculations, the Z' decays to the $SU(2)$ bosons are considered and the decay width for W^+W^-, Z_0H^0 and for the supersymmetric partners of these bosons is calculated numerically at the small mixing angle θ_M which is defined by Higgs mass constraint as well as the calculation of the Z' decays to the SM fermions and to the sparticles of the SM particles. The full decay width of Z' boson is written by Eq. (32) according to our calculations. By using the calculations of Z' boson decay widths, we drew Figs. 2 and 3. From Fig. 2, the mass of Z' boson can be decided to be about 630 GeV when we plot only the second term on the right of Eq. (32) with Eq. (33) for different values of n_g as a function of decay width versus different masses of Z' boson. The intersection occurs first for $n_g = 3$. Since the decaying particle is the same, it must have the same mass estimated by Fig. 2 when we plot a figure including the full decay of Z' boson to all particles. Therefore, in Fig. 3, we plotted Eq. (32) in the full form together with the second term on the right of this equation as we drew in Fig. 2. In this case, again the intersection occurs with the mass of Z' about 630 GeV for $n_g = 5$. Therefore, it is estimated that the mass of Z' boson is about 630 GeV and the number of generations of the exotic fermions is to be 3 or 5. The collider LHC is designed to collide the protons with a center-of-mass energy 14 TeV. Since the center-of-mass energy of proton–proton collisions at LHC is 14 TeV, the particle cascades coming from the collisions might contain Z' if the mass is below 1 TeV as calculated in this work. Therefore, we conclude that Z' boson can be discovered at LHC.

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REFERENCES

1. *Osland P., Pankov A. A.* // Phys. Lett. B. 1997. V. 403. P. 93.
2. *Bayatian G. L. et al.* (*CMS Collab.*) // J. Phys. G. 2007. V. 34. P. 995–1579.
3. http//atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/TDR/TDR.html.ATLAS Physics TDR
4. *Hewett J. L., Rizzo T. G.* // Phys. Rep. 1989. V. 183. P. 193.
5. *Cvetic M., Langacker P.* // Phys. Rev. D. 1996. V. 54. P. 3570.
6. *Cvetic M., Langacker P.* // Mod. Phys. Lett. A. 1996. V. 11. P. 1247.
7. *Cvetic M., Godfrey S.* hep-ph/9504216.
8. *Aydemir A., Sever R.* // Mod. Phys. Lett. A. 2001. V. 16. P. 457.
9. *Langacker P., Luo M., Mann A. K.* // Rev. Mod. Phys. 1992. V. 64. P. 105.
10. *Aitchison I. J. R., Hey A. J. G.* Gauge Theories in Particle Physics. Adam Hilger, 1982.
11. *Renton P.* Electroweak Interactions. Cambridge Univ. Press, 1990.
12. *Erler J., Langacker P.* Electroweak Model and Constraints on New Physics // Rev. Part. Phys. 2000. V. 95.
13. *Leike A.* hep-ph/9805494.
14. *Barger V., Whisnant K.* // Phys. Rev. D. 1987. V. 36.
15. *Kang Junhai, Langacker P.* // Phys. Rev. D. 2005. V. 71. P. 035014.

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