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A version of the SU(3)$_L \otimes$U(1)$_N$ electroweak model predicts charged heavy-leptons which do not belong to any class of heavy-leptons proposed up to now. The phenomenology of these new leptons are however still not studied. We investigate the production and signatures of pairs of these heavy-leptons *via* the Drell-Yan process and the gluon-gluon fusion at the CERN Large Hadron Collider (LHC).

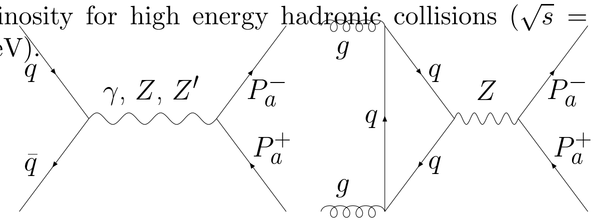
I. INTRODUCTION

Measurements of the total width of the Z neutral gauge boson of the standard model at CERN and SLAC colliders provide an indisputable evidence for only three neutrino flavors [1]. Reasons based on CP-violation mechanism and big-bang nucleosynthesis in the framework of the standard model allow to apply this experimental result to conclude that in the Nature there are only three families of fermions.

However, since the standard model must be only a low energy effective electroweak theory, there are several motivations to consider the possibility of additional quarks and leptons. For example, grand unified theories such as SO(10) and E(6) incorporate new fermions naturally [2]. In some extensions of the standard model anomalies cancel out through additional fermions [3]. Also, new fermions can play a role in CP-violation schemes [4]. Heavy-leptons phenomenology are widely studied in many extended electroweak models, such as supersymmetric [5], grand unified theories [6], technicolor [7], superstring-inspired models [8], mirror fermions [9], etc. All these models predict the existence of new particles with masses around of the scale of 1 TeV and they consider the possible existence of new generations of fermions.

The standard electroweak model provides a very satisfactory description of most elementary particle phenomena up to the presently available energies. However, there are some unsatisfactory features as the family number and their complex pattern of masses and mixing angles which are not predicted by the model. Searches of new fermions can reveal some directions for the solution of these problems.

In this paper we addresses to a new class of heavy-fermions, *i.e.*, the heavy-leptons which are predicted by a strong and electroweak model based on the SU(3)$_C \otimes$-SU(3)$_L \otimes$U(1)$_N$ (3-3-1 for short) semi simple symmetry group [10]. In this model the new leptons require not new generations, as occur in the most of the heavy-lepton models [11]. It is a chiral electroweak model whose left-handed charged heavy-leptons, which we denote by $P_a = E$, M and T, together the associated ordinary charged leptons and its respective neutrinos, are accommodate in SU(3)$_L$ triplets. We study the production of these charged heavy-lepton pairs in hadronic collisions at the CERN Large Hadron Collider (LHC). This process is studied here through the well known Drell-Yan mechanism, *i. e.*, the quark-antiquark fusion $q\bar{q} \to P^+P^-$ (Fig. 1a) and the gluon-gluon fusion mechanism $gg \to P^+P^-$ (Fig. 1b), which dominate for lepton masses over 200 GeV [12]. Here we take advantage of the high gluon luminosity for high energy hadronic collisions ($\sqrt{s} = 14$ TeV).



(a) (b)

FIG. 1. Feynman diagrams for production of charged heavy-lepton pairs *via* (a) Drell-Yan and (b) gluon-gluon fusion processes.

As we mentioned above there are very motivations to search heavy-leptons in electroweak extensions of the standard model. However, in 3-3-1 model we have in addition two particular motivations. At first, should be notice that the heavy-leptons appearing in the literature up to now can be classified in four kinds [1]: (a) Sequential leptons, in that the new leptons are associated with new neutrinos, forming new SU(2)$_L$ doublets. This new leptons and its neutrinos have the same leptonic numbers which are conserved in all interactions; (b) paraleptons, in that the new leptons have the same leptonic numbers of the associated ordinary charged leptons of opposite charge; (c) ortholeptons, in that the new leptons have the same leptonic numbers of the associated ordinary charged leptons of the same charge and (d) long-lived penetrating particles. As we will see in the next section the 3-3-1 heavy-leptons do not belong to any of these types of new leptons. Consequently, the existing experimental bounds on heavy-lepton parameters do not apply to them. Secondly, there is nothing on the 3-3-1 heavy-lepton phenomenology.

The outline of this paper is the following. In Sec. II we present the relevant features of the model. The production of a pair of 3-3-1 heavy-leptons for pp colliders are discussed in Sec. III and in Sec. IV we summarize our results and conclusions.

II. THE 3-3-1 HEAVY-LEPTON MODEL

In 3-3-1 model the strong and electroweak interactions are described by a gauge theory based on the $\mathrm{SU}(3)_C\otimes\mathrm{SU}(3)_L\otimes\mathrm{U}(1)_N$ semi simple symmetry group. In its original version new leptons are not required, since the lepton representation content of each $\mathrm{SU}(3)_L$ triplet is one charged lepton, its charge conjugated counterpart and the associated neutrino field [13,14]. However, the version of the model which we work here differs from the original one in that in the $\mathrm{SU}(3)_L$ lepton triplets the charged conjugated lepton fields of the original model are replaced by heavy-leptons [10]. The most interesting feature of this class of models is that the anomaly cancellations occur only when the three fermion families are considered together and not family by family as in the standard model. This implies that the number of families must be a multiple of the color number and, consequently, the 3-3-1 model suggests a route towards the response of the flavor question [13]. The model have also a great phenomenological interest since the related new physics can be expected in a scale near of the Fermi one [15].

Let us summarize the most relevant points of the model (for details see Refs. [10,13,14]). In its heavy-lepton version the left-handed leptons and quarks transform under the $\mathrm{SU}(3)_L$ group as the triplets

$$\psi_{aL} = \left(\begin{array}{c} \nu_{\ell_a} \\ \ell'_a \\ P'_a \end{array}\right)_L \sim (\mathbf{3}, 0)\,, \tag{1a}$$

$$Q_{1L} = \left(\begin{array}{c} u'_1 \\ d'_1 \\ J_1 \end{array}\right)_L \sim \left(\mathbf{3}, \frac{2}{3}\right), \tag{1b}$$

$$Q_{\alpha L} = \left(\begin{array}{c} J'_\alpha \\ u'_\alpha \\ d'_\alpha \end{array}\right)_L \sim \left(\mathbf{3}^*, -\frac{1}{3}\right), \tag{1c}$$

where $P'_a = E'$, M', T' are the new leptons, $\ell'_a = e'$, μ', τ' and $\alpha = 2$, 3. The J_1 exotic quark carries 5/3 units of elementary charge, while J_2 and J_3 carry $-4/3$ each. In Eqs. (1) the numbers 0, 2/3 and $-1/3$ are the $\mathrm{U}(1)_N$ charges. Except the neutrino fields, which we are considering massless here, each left-handed fermion has its right-handed counterpart transforming as singlet of the $\mathrm{SU}(3)_L$ group, *i. e.*,

$$l'_R \sim (\mathbf{1}, -1)\,, \qquad P'_R \sim (\mathbf{1}, 1)\,, \tag{1d}$$

$$U'_R \sim (\mathbf{1}, 2/3)\,, \qquad D'_R \sim (\mathbf{1}, -1/3)\,, \tag{1e}$$

$$J_{1R} \sim (\mathbf{1}, 5/3)\,, \qquad J'_{2,3R} \sim (\mathbf{1}, -4/3)\,. \tag{1f}$$

We are defining the ordinary quark fields as $U = u, c, t$ and $D = d, s, b$. In order to avoid anomalies one of the quark families must transform in a different way with respect to the two others. In Eqs. (1) all the primed fields are linear combinations of the mass eigenstates. The charge operator is defined by

$$\frac{Q}{e} = \frac{1}{2}\left(\lambda_3 - \sqrt{3}\lambda_8\right) + N, \tag{2}$$

where the λ's are the usual Gell-Mann matrices.

The fermions and gauge bosons masses are generated in the model by the three Higgs scalar triplets

$$\eta = \left(\begin{array}{c} \eta^0 \\ \eta_1^- \\ \eta_2^+ \end{array}\right) \sim (\mathbf{3}, 0)\,, \qquad \rho = \left(\begin{array}{c} \rho^+ \\ \rho^0 \\ \rho^{--} \end{array}\right) \sim (\mathbf{3}, 1)\,, \tag{3a}$$

$$\chi = \left(\begin{array}{c} \chi^- \\ \chi^{--} \\ \chi^0 \end{array}\right) \sim (\mathbf{3}^*, -1)\,. \tag{3b}$$

The neutral scalar fields develop the vacuum expectation values $\langle\eta^0\rangle = v_\eta$, $\langle\rho^0\rangle = v_\rho$ and $\langle\chi^0\rangle = v_\chi$, with $v_\eta^2 + v_\rho^2 = v_W^2 = (246\ \mathrm{GeV})^2$. The pattern of symmetry breaking is

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

and so, we can expect $v_\chi \gg v_\eta, v_\rho$. The η and ρ scalar triplets give masses to the ordinary fermions and gauge bosons, while the χ scalar triplet gives masses to the new fermions and contributes to the new gauge boson masses. Notice that due the transformation properties of the fermion and Higgs fields under $\mathrm{SU}(3)_L$ [see Eqs. (1) and (3)] the Yukawa interactions in the model are

$$\mathcal{L}_\ell^Y = -G_{ab}\bar{\psi}_{aL}\ell'_{bR}\rho - G'_{ab}\bar{P}'_{aL}P'_{bR}\chi + \text{H. c.}, \tag{4a}$$

$$\begin{aligned}\mathcal{L}_q^Y = &\sum_\alpha \Big[\bar{Q}_{1L}\left(G_{1\alpha}U'_{\alpha R}\eta + \tilde{G}_{1\alpha}D'_{\alpha R}\rho\right) + \\ &\sum_i \bar{Q}_{iL}\left(F_{i\alpha}U'_{\alpha R}\rho^* + \tilde{F}_{i\alpha}D'_{\alpha R}\eta^*\right)\Big] + \\ &\sum_{im} F^J_{im}\bar{Q}_{iL}J'_{mR}\chi^* + G^J\bar{Q}_{1L}J_{1R}\chi + \text{H. c.}\end{aligned} \tag{4b}$$

The interaction eigenstates appearing in Eqs. (4) can be transformed in corresponding physical eigenstates by appropriated rotations. However, since the cross section calculations imply summation on flavors (see Sec. III) and the rotation matrix must be unitary, the mixing parameters have not essential effect for our purpose here. So, thereafter we suppress the primes notation for the interaction eigenstates.

Symmetry breaking is initiated when the scalar neutral fields are shifted as $\varphi = v_\varphi + \xi_\varphi + i\zeta_\varphi$, with $\varphi = \eta^0$, ρ^0, χ^0. Thus, the physical neutral scalar eigenstates H_1^0, H_2^0, H_3^0 and h^0 are related with the shifted fields as

$$\begin{pmatrix} \xi_\eta \\ \xi_\rho \end{pmatrix} \approx \frac{1}{v_W} \begin{pmatrix} v_\eta & v_\rho \\ v_\rho & -v_\eta \end{pmatrix} \begin{pmatrix} H_1^0 \\ H_2^0 \end{pmatrix}, \qquad \xi_\chi \approx H_3^0, \quad (5a)$$

$$\zeta_\chi \approx h^0, \quad (5b)$$

in the condition $v_\chi \gg v_\eta, v_\rho$ [18]. So, from Eqs. (1) to (5b) it is easy to see that in this regime there are not Higgs contribution with diagrams analogous to ones of the Figs. 1a and 1b, since the ordinary quarks couple only through H_1^0 and H_2^0 and the heavy-leptons couple only through H_3^0 and h^0 in the scalar sector.

In the gauge sector the single charged $V^\pm$ and the double charged $U^{\pm\pm}$ vector bileptons, together with a new neutral gauge boson Z' complete the particle spectrum with the charged $W^\pm$ and the neutral standard gauge bosons Z. The relevant neutral vector current interactions are given by

$$\mathcal{L}_{AP} = -e\bar{P}_a\gamma^\mu P_a A_\mu, \quad (6a)$$

$$\mathcal{L}_{ZP} = -\frac{g}{2\cos\theta_W}\left[a_L(P_a)\bar{P}_a\gamma^\mu(1-\gamma_5)P_a + a_R(P_a)\bar{P}_a\gamma^\mu(1-\gamma_5)P_a\right]Z_\mu^0, \quad (6b)$$

$$\mathcal{L}_{Z'P} = -\frac{g}{2\cos\theta_W}\left[a'_L(P_a)\bar{P}_a\gamma^\mu(1-\gamma_5)P_a + a'_R(P_a)\bar{P}_a\gamma^\mu(1-\gamma_5)P_a\right]Z'_\mu, \quad (6c)$$

$$\mathcal{L}_{Zq} = -\frac{g}{4\cos\theta_W}\sum_i \bar{q}_i\gamma^\mu\left(v^i + a^i\gamma^5\right)q_i Z_\mu, \quad (6d)$$

$$\mathcal{L}_{Z'q} = -\frac{g}{4\cos\theta_W}\sum_i \bar{q}_i\gamma^\mu\left(v'^i + a'^i\gamma^5\right)q_i Z'_\mu, \quad (6e)$$

where θ_W is the Weinberg mixing angle, q are the ordinary quarks U and D. The coefficients in Eqs. (6) are

$$a_L(P_a) = a_R(P_a) = -\sin^2\theta_W, \quad (7a)$$

$$a'_L(P_a) = -\frac{\sin\theta_W}{\sqrt{3}t_W}, \quad (7b)$$

$$a'_R(P_a) = \sqrt{3}t_W\sin\theta_W, \qquad v^U = \frac{3+4t_W^2}{3\left(1+4t_W^2\right)}, \quad (7c)$$

$$v^D = -\frac{3+8t_W^2}{3\left(1+4t_W^2\right)}, \qquad -a^U = a^D = 1, \quad (7d)$$

$$v'^u = -\frac{1+8t_W^2}{f(t_W)}, \qquad v'^c = v'^t = \frac{1-2t_W^2}{f(t_W)}, \quad (7e)$$

$$v'^d = -\frac{1+2t_W^2}{f(t_W)}, \qquad v'^s = v'^b = \frac{f(t_W)}{\sqrt(3)}, \quad (7f)$$

$$a'^u = \frac{1}{f(t_W)}, \qquad a'^c = a'^t = -\frac{1+6t_W^2}{f(t_W)}, \quad (7g)$$

$$a'^d = -a'^c, \qquad a'^s = a'^b = -a'^u \quad (7h)$$

with

$$t_W^2 = \frac{\sin^2\theta_W}{1-4\sin^2\theta_W} \quad (8)$$

and $f^2(t_W) = 3\left(1+4t_W^2\right)$. As we comment in Sec. I we stress here that an inspection in Eqs. (1), (6b), (6c) and (7a,7b,7c) tell us that the heavy-leptons P_a belong to another class of exotic particles differently of the preexisting heavy-lepton classes usually considered in the literature. Hence, the present experimental limits do not apply directly to them [1] (see also Ref. [10]). Therefore, the 3-3-1 heavy-leptons phenomenology deserves more detailed studies.

Should be notice that the t_W parameter in Eq. (8) has a Landau pole which imposes $\sin^2\theta_W < 1/4$. It is another good feature of the model since evolving $\sin^2\theta_W$ to high values it is possible to find an upper bound to the masses of the new charged gauge bosons [14,16]. It does not occurs in the popular extensions of the standard model. Another consequence of this pole is an enhancement of the couplings of the Z' to quarks relative to the lepton ones.

The charged lepton current interactions are

$$\mathcal{L}_\ell^{CC} = -\frac{g}{\sqrt{2}}\sum_a\left(\overline{\ell'}_{aL}\gamma^\mu\nu_{aL}W_\mu^- + \overline{P'}_{aL}\gamma^\mu\nu_{bL}V_\mu^+ + \overline{\ell'}_{aL}\gamma^\mu P'_{bL}U^{--}\right) + \text{H. c.} \quad (9a)$$

For the first and second quark generations we have

$$\mathcal{L}_{Q_1}^{CC} = -\frac{g}{\sqrt{2}}\left(\overline{u'}_L\gamma^\mu d'_L W_\mu^- + \overline{J}_{1L}\gamma^\mu u'_L V_\mu^+ + \overline{d'}_L\gamma^\mu J_{1L}U^{--}\right) + \text{H. c.}, \quad (9b)$$

$$\mathcal{L}_{Q_2}^{CC} = -\frac{g}{\sqrt{2}}\left(\overline{c'}_L\gamma^\mu d'_L W_\mu^- - \overline{s'}_L\gamma^\mu J'_{2L}V_\mu^+ + \overline{c'}_L\gamma^\mu J'_{2L}U^{--}\right) + \text{H. c.}, \quad (9c)$$

while the charged current interactions for the third quark generations are obtained from those of the second generation replacing $c \to t$, $s \to b$ and $J_2 \to J_3$. Thus, the main decay modes of the new leptons are among the exotic leptons themselves such as $T^+ \to E^+\nu_e\bar{\nu_\tau}$, considering that $M_T > M_E$. The heavy leptons can decay also *via* single or double charged bileptons in a standard lepton, a standard quark and an exotic quark (see Fig. 2). Detailed analysis of the 3-3-1 heavy-lepton decays will be given elsewhere [17].

We take the physical eigenstates of the neutral gauge bosons of the Refs. [13],

$$A_\mu = \sqrt{\frac{3}{f(t_W)}}\left[\left(W_\mu^3 - \sqrt{3}W_\mu^8\right)t + B_\mu\right], \quad (10a)$$

$$Z_\mu \simeq -\sqrt{\frac{3}{f(t_W)}}\left(\sqrt{1+3t^2}W_\mu^3 + \right.$$

$$\sqrt{\frac{3}{1+3t^2}}t^2W^8_\mu - \frac{1}{\sqrt{1+3t^2}}B_\mu\Bigg), \tag{10b}$$

$$Z'_\mu \simeq \frac{1}{\sqrt{1+3t^2}}\left(W^8_\mu + \sqrt{3}tB_\mu\right), \tag{10c}$$

in the usual notation, where the Z and Z' eigenstates are valid in the approximation $w \gg v, u$.

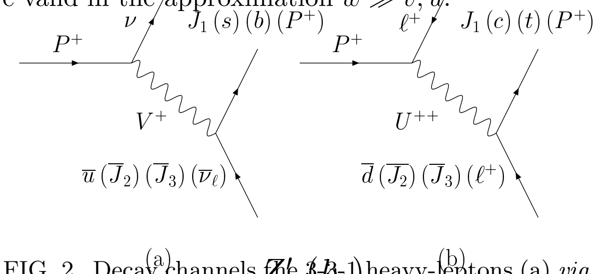


FIG. 2. Decay channels the 3-3-1 heavy-leptons (a) *via* V^+ and (b) *via* U^{++}.

From Eqs. (10) we have the trilinear interactions of the Z' with the $V^\pm$ and $U^{\pm\pm}$ bileptons in Fig. 3 whose strenght is

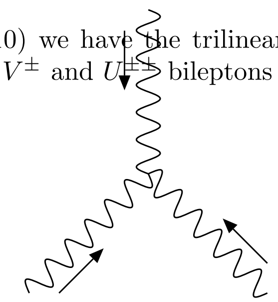


FIG. 3. Trilinear interaction among Z' and the exotic charged gauge bosons $\left(X^+_\mu = V^\pm_\mu, U^{\pm\pm}_\mu\right)$.

$$\mathcal{V}_{\mu\nu} \approx -\frac{ig}{2}\sqrt{\frac{3}{1+3t}}\left[(k_1-k_2)_\lambda\, g_{\mu\nu} + (k_2-k_3)_\mu\, g_{\nu\lambda} + (k_3-k_1)_\nu\, g_{\lambda\mu}\right], \tag{11}$$

where the k's are quadrimoments. We can see that in this approximation Z' does not interacts with the standard $W^\pm$ gauge bosons.

III. CROSS SECTION PRODUCTION

To calculate the cross-section we suppress the family indices of the Sec. II, *i. e.* and assume $P = E$, M, T and $\ell = e$, μ , τ. We begin at first our study with the mechanism of the Drell-Yan production of pair of heavy-leptons, that is, we study the process $pp \to q\bar{q} \to P^-P^+$ (Fig. 1a). This process take place through the exchange of the bosons Z, Z' and γ in the s channel. Using the interaction Lagrangians of the Eqs. (6) and the parameters of the Eqs. (7), we evaluate the differential cross section for the subprocess $q\bar{q} \to P^-P^+$ obtaining

$$\begin{aligned}
\left(\frac{d\sigma}{d\cos\theta}\right)_{P^+P^-} = \frac{\beta\alpha^2\pi}{N_c s^2}\Bigg[&\frac{e_q^2}{s}\left(2sM_P^2 + \Theta_+\right) \\
&-\frac{e_q}{\Delta\Lambda_1}\left(2sM_P^2 g'^{PP}_V g^q_V + g'^{PP}_V g^q_V\Theta_+ + g'^{PP}_A g^q_A\Theta_-\right)\Bigg] \\
&+\frac{\beta\pi\alpha^2}{4\Delta^2\Lambda_1^2 sN_c}\Bigg\{\left[\left(g'^{PP}_V\right)^2 + \left(g'^{PP}_A\right)^2\right]\times \\
&\left[\left(g^q_V\right)^2 + \left(g^q_A\right)^2\right]\Theta_+ + 2sM_P^2\left[\left(g'^{PP}_V\right)^2 - \left(g'^{PP}_A\right)^2\right] \\
&\times\left[\left(g^q_V\right)^2 + \left(g^q_A\right)^2\right] + 4g'^{PP}_V g'^{PP}_A g^q_V g^q_A\Theta_-\Bigg\} \\
&+\frac{\beta\pi\alpha^2}{2\Lambda_2\Delta^2 N_c s}\Bigg\{2sM_P^2\left(g^q_V + g^q_A\right)\mathcal{G}_- + \left(M_P^2 - t\right)^2 \\
&\times\Big[\left(\left(g^q_V\right)^2 + \left(g^q_A\right)^2\right)g^{PP}_V g'^{PP}_V + g^{PP}_A g'^{PP}_A \\
&-2g^q_V g^q_A g^{PP}_V g'^{PP}_A - 2g^q_V g^q_A g^{PP}_A g'^{PP}_V\Big] \\
&+\left(M_P^2 - u\right)^2\Big[\left(\left(g^q_V\right)^2 + \left(g^q_A\right)^2\right)\mathcal{G}_+ \\
&+2g^q_V g^q_A g^{PP}_V g'^{PP}_A + 2g^q_V g^q_A g^{PP}_A g'^{PP}_V\Big]\Bigg\},
\end{aligned} \tag{12}$$

where

$$g^{PP}_{V,A} = \frac{a_L \pm a_R}{2}, \qquad g'^{PP}_{V,A} = \frac{a'_L \pm a'_R}{2}, \tag{13a}$$

$$\mathcal{G}_\pm = g^{PP}_V g'^{PP}_V \pm g^{PP}_A g'^{PP}_A, \tag{13b}$$

$$\Theta_\pm = \left(M_P^2 - u\right)^2 \pm \left(M_P^2 - t\right)^2, \tag{13c}$$

$$\Lambda_1 = s - M^2_{Z,Z'} + iM_{Z,Z'}\Gamma_{Z,Z'} \tag{13d}$$

$$\Lambda_2 = \left(s - M_Z^2 + iM_Z\Gamma_Z\right)\left(s - M^2_{Z'} + iM_{Z'}\Gamma_{Z'}\right), \tag{13e}$$

$$\Delta = 2\cos^2\theta_W \sin^2\theta_W. \tag{13f}$$

Here the primes ($'$) is for the case when we take a boson Z', $\Gamma_{Z,Z'}$ are the total width of the boson Z and Z', respectively. $\beta = \sqrt{1 - 4M_P^2/s}$ is the velocity of the heavy-lepton in the c. m. of the process, e^q are the quark electric charges, N_c is the number of colors, $g^q_{V,A}$ are the standard quark coupling constants, M_Z is the mass of the Z boson, $\sqrt{s}$ is the center of mass energy of the $q\bar{q}$ system, $t = M_P^2 - (1 - \beta\cos\theta)\,s/2$ and $u = M_P^2 - (1 + \beta\cos\theta)\,s/2$, where θ is the angle between the heavy-lepton and the incident quark in the c. m. frame. For Z' boson we take $M_{Z'} = (1-3)$ TeV, since $M_{Z'}$ is proportional to VEV v_χ [13,14]. For the standard model parameters we assume PDG values, *i. e.*, $M_Z = 91.02$ GeV, $\sin^2\theta_W = 0.2315$ and $M_W = 80.33$ GeV [1].

The total width of the Z' boson into exotic leptons, standard leptons, neutrinos, standard and exotic quarks and new vector bosons are

$$\Gamma\left(Z' \to \text{all}\right) = \Gamma_{Z'\to P^-P^+} + \Gamma_{Z'\to\ell^-\ell^+} + \Gamma_{Z'\to\nu\bar{\nu}} + \Gamma_{Z'\to q\bar{q}(Q\bar{Q})} + 2\Gamma_{Z'\to X^-X^+}, \tag{14}$$

where $X^\pm = V^\pm$ or $X^\pm = U^{\pm\pm}$ and we have for everyone

$$\Gamma_{Z'\to P^-P^+} = \frac{\alpha\sqrt{1-4M_P^2/s}}{12M_{Z'}\sin^2\theta_W\cos^2\theta_W}\Big[2M_P^2\left(g^{PP}_V\right)^2$$

$$-4M_P^2\left(g_A^{PP}\right)^2+M_{Z'}^2\left(g_V^{PP}\right)^2 +M_{Z'}^2\left(g_A^{PP}\right)^2\Big], \tag{15a}$$

$$\Gamma_{Z'\to\ell^-\ell^+}=\frac{\alpha M_{Z'}\left[\left(g_V^{\ell}\right)^2+\left(g_A^{\ell}\right)^2\right]}{12\sin^2\theta_W\cos^2\theta_W}, \tag{15b}$$

$$\Gamma_{Z'\to\nu\nu}=\frac{\alpha M_{Z'}}{18h\sin^2\theta_W\cos^2\theta_W}, \tag{15c}$$

$$\Gamma_{Z'\to q\bar{q}(Q\bar{Q})}=\frac{\alpha\sqrt{1-4M_q^2/s}}{16M_{Z'}\sin^2\theta_W\cos^2\theta_W}\Big[2M_q^2\left(g_{V_i}^{qq}\right)^2 -4M_q^2\left(g_{A_i}^{qq}\right)^2+M_{Z'}^2\left(g_{V_i}^{qq}\right)^2 +M_{Z'}^2\left(g_{A_i}^{qq}\right)^2\Big], \tag{15d}$$

$$\Gamma_{Z'\to Y_1^-Y_2^+}=\frac{\alpha\theta_+\theta_-}{8M_{Z'}\sin^2\theta_W\left(1+3t^2\right)} \times\left(\frac{M_{Z'}^6}{4M_{Y_1}^2M_{Y_2}^2}+\frac{2M_{Z'}^4}{M_{Y_1}^2}-\frac{M_{Z'}^4}{M_{Y_2}^2} +\frac{3M_{Z'}^2M_{Y_1}^2}{2M_{Y_2}^2}-\frac{9M_{Z'}^2M_{Y_2}^2}{2M_{Y_1}^2} -5M_{Z'}^2+\frac{M_{Y_1}^6}{4M_{Z'}^2M_{Y_2}^2}-\frac{M_{Y_1}^4}{M_{Z'}^2} +\frac{3M_{Y_1}^2M_{Y_2}^2}{2M_{Z'}^2}+\frac{M_{Y_2}^6}{4M_{Z'}^2M_{Y_1}^2} -\frac{M_{Y_2}^4}{M_{Z'}^2}-\frac{M_{Y_1}^4}{M_{Y_2}^2}+4M_{Y_1}^2+\frac{2M_{Y_2}^4}{M_{Y_1}^2} -5M_{Y_2}^2\right), \tag{15e}$$

with $h = 1+4\tan^2\theta_W$ and where $\theta_\pm = \sqrt{M_{Z'}^2-\left(M_{Y_1}\pm M_{Y_2}\right)^2}$. In Eq. (15e) Y_1 and Y_2 are any vector bosons. We take for our case $Y_1 = Y_2 = X$ and therefore we have

$$\Gamma_{Z'\to X^-X^+}=\frac{\alpha\sqrt{1-4M_X^2/s}}{8M_{Z'}\sin^2\theta_W\left(1+3t^2\right)}\times \left(\frac{M_{Z'}^6}{4M_X^4}+\frac{M_{Z'}^4}{M_X^2}-8M_{Z'}^2\right). \tag{16}$$

The total cross section for the process $pp\to qq\to P^-P^+$ is related to the subprocess $qq\to P^-P^+$ total cross section $\hat{\sigma}$, through

$$\sigma=\int_{\tau_{min}}^{1}\int_{\ln\sqrt{\tau_{min}}}^{-\ln\sqrt{\tau_{min}}} d\tau dy q\left(\sqrt{\tau}e^{y},Q^2\right)q\times \left(\sqrt{\tau}e^{-y},Q^2\right)\hat{\sigma}\left(\tau,s\right), \tag{17}$$

where $\tau = \left(\tau_{min}=4M_P^2/s\right)s/\hat{s}$ and $q\left(x,Q^2\right)$ is the quark structure function.

Another form to produce a pair of heavy-leptons is *via* the gluon-gluon fusion, namely through the reaction of the type $pp\to gg\to P^-P^+$ with

$$\hat{\sigma}_Z^q=\frac{\left(g_A^{PP}\right)^2\alpha^2\alpha_s^2}{256\pi\sin^4\theta_W}\frac{M_P^2}{M_W^4}\beta\left|\sum_{q=u,d}\pm g_A^q\left(1+2\lambda_q I_q\right)\right|^2, \tag{18}$$

where the summations run over all generations. The loop integrals involved in the evaluation of the elementary cross section can be expressed in terms of the function $I_i\left(\lambda_i\right)\equiv I_i$ which is defined through

$$I_i=\int_0^1\frac{dx}{x}\ln\left[1-\frac{(1-x)\,x}{\lambda_i}\right]= \left\{\begin{array}{ll} -2\left[\sin^{-1}\left(\frac{1}{2\sqrt{\lambda_i}}\right)\right]^2, & \lambda_i>1/4,\\ \frac{1}{2}\ln^2\left(R\right)+i\pi\ln\left(R\right)-\pi^2/2, & \lambda_i<1/4\end{array}\right., \tag{19}$$

with $R = \left(1+\sqrt{1-4\lambda_i}\right)/\left(1-\sqrt{1-4\lambda_i}\right)$ and $\lambda_i = m_i^2/\hat{s}$. Here, $i=q$ stands for the particle (quark) running in the loop.

The diagram with a Z' in the s channel does not exhibit the resonance for $\hat{s}=M_{Z'}^2$, since the on shell production of a massive spin-one particle on shell from two massless spin-one particle is forbidden (Yang's theorem) [19]. Furthermore, the effective coupling of the gluons to the Z' is proportional to $\partial_\mu Z'^\mu$, where Z'^μ is the vector boson. On the other hand the Z' amplitude is proportional to $\partial_\mu J_P^\mu$, where J_P^μ is the neutral current associated with the heavy lepton P. Therefore, this diagram is proportional to M_P, as can be seen from the above expressions. It is interesting to notice that C conservation forbids the coupling of the gluons to γ. Moreover taking into account a heavy-lepton, must be considered the large $-\lambda_i$ limit, where the contributions involving the Z' are proportional to the mass split of the quark doublet due to the presence of T_3^q. The total cross section for the process $pp\to gg\to P^-P^+$ is related to the subprocess $gg\to P^-P^+$ total cross section $\hat{\sigma}$ through

$$\sigma=\int_{\tau_{min}}^{1}\int_{\ln\sqrt{\tau_{min}}}^{-\ln\sqrt{\tau_{min}}} d\tau dy G\left(\sqrt{\tau}e^{y},Q^2\right)\times G\left(\sqrt{\tau}e^{-y},Q^2\right)\hat{\sigma}\left(\tau,s\right), \tag{20}$$

where $G\left(x,Q^2\right)$ is the gluon structure function.

IV. RESULTS AND CONCLUSIONS

The process for the heavy-lepton production in hadronic colliders was well studied in the literature and was shown that the dominant contribution are the well known Drell-Yan process (Fig. 1a) and gluon-gluon fusion (Fig. 1b) [5,12,20].

Lepton pairs/year	$P^+P^-\left(\gamma+Z^0+Z'^0\right)$
Total of events for Drell-Yan process	1.2×10^6
Total of events for gluon-gluon fusion	10^5

TABLE I. Annual production of heavy-leptons as for the Drell-Yan mechanism and as for the gluon-gluon fusion.

We present the cross section for the process $pp \to qq \to P^-P^+$, involving the Drell-Yan (Fig. 1a) mechanism and the gluon-gluon fusion (Fig. 1b), both to produce the heavy leptons. Considering that the expected integrated luminosity for the LHC will be of order of 10^5/pb/yr we present our results for heavy lepton pairs produced by year in the Table I. We compare the production for the both process considered above, where we take for the charged heavy-lepton a mass equal to 300 GeV and for the boson Z' a mass equal to 1 TeV. In Fig. 4 we show the different cross sections for the masses of boson Z' for Drell-Yan process.

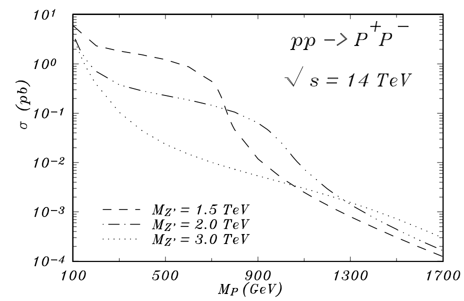


FIG. 4. Total cross section for the process $pp \to qq \to P^-P^+$ as a function of M_P at $\sqrt{s} = 14$ TeV, involving the heavy exotic leptons: for the mass of the boson Z' equal to 1.5 TeV (dashed line), for the mass of the boson Z' equal to 2 TeV (dot dot dashed line) and for the mass of the boson Z' equal to 3 TeV (dotted line).

We see that the Drell-Yan production are suppressed for $2M_P > M_{Z'}$ where the Z' later must produce the heavy leptons pairs.

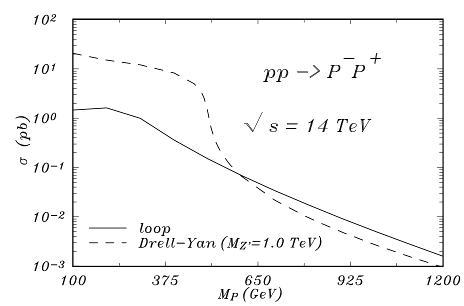


FIG. 5. Total cross section for the process $pp \to qq \to P^-P^+$ as a function of M_P at $\sqrt{s} = 14$ TeV, for the both process (the Drell-Yan and the gluon-gluon fusion): production of heavy leptons through the gluon-gluon fusion (solid line)and production of heavy leptons through the Drell-Yan process (dashed line).

In Fig. 5 we compare the cross section for Drell-Yan production $pp \to qq \to PP$, with the gluon-gluon production $pp \to gg \to PP$, where we take for the mass of the heavy-leptons $M_P = 300$ GeV and for the extra neutral gauge boson $M_{Z'} = 1$ TeV. We see that the Drell-Yan production are always closed to one order of magnitude higher than the gluon-gluon fusion up to masses of 500 GeV. Fig. 6 shows the rapidity distribution $d\sigma/dy$ at $y = 0$ as a function of M_P for Drell-Yan production of P^-P^+. These results are for $M_{Z'} = 1.5$ TeV, 2.0 TeV and 3.0 TeV. Here is also observed that the Drell-Yan production is rapidly suppressed for $2M_P > M_{Z'}$.

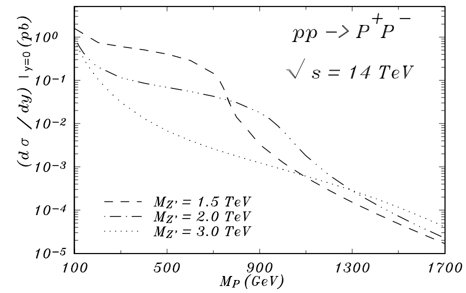


FIG. 6. Distribution of rapidity at $y = 0$ for the process $pp \to qq \to P^-P^+$ as a function of M_P at $\sqrt{s} = 14$ TeV involving the heavy exotic leptons: for the mass of the boson Z' equal to 1.5 TeV (dashed line), for the mass of the boson Z' equal to 2 TeV (dot dot dashed line) and for the mass of the boson Z' equal to 3 TeV (dotted line).

In Fig. 7 we compare the cross section for Drell-Yan production with the gluon-gluon production and with the production cross section for $pp \to W^-W^+$. As before, we take for the mass of the heavy-leptons $M_P = 300$ GeV.

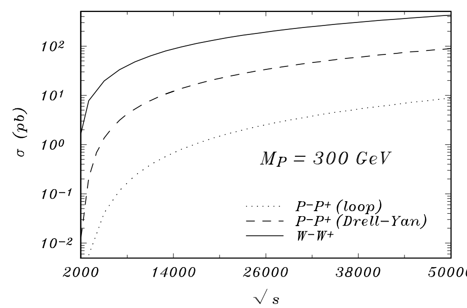


FIG. 7. Total cross section versus the total c. m. energy $\sqrt{s}$ for the following processes: $pp \to gg \to P^-P^+$ for the heavy-leptons (P) coupled to Z'_μ (dotted line), $pp \to qq \to P^-P^+$ for the heavy-leptons (P) coupled to Z'_μ (dashed line) and $pp \to W^-W^+$ (solid line).

We see from these results that the production of W^-W^+ is larger. Here must done a careful analysis of the Monte Carlo simulations to try to separate the signal from the background.

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