Effects of the R-parity violation in the minimal supersymmetric standard model on dilepton pair production at the CERN LHC *

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Abstract

We investigate in detail the effects of the R-parity lepton number violation in the minimal supersymmetric standard model (MSSM) on the parent process $pp \to e^+e^- + X$ at the CERN Large Hadron Collider (LHC). The numerical comparisons between the contributions of the R-parity violating effects to the parent process via the Drell-Yan subprocess and the gluon-gluon fusion are made. We find that the R-violating effects on e^+e^- pair production at the LHC could be significant. The results show that the cross section of the e^+e^- pair productions via gluon-gluon collision at the LHC can be of the order of 10^2 fb, and this subprocess maybe competitive with the production mechanism via the Drell-Yan subprocess. We give also quantitatively the analysis of the effects from both the mass of sneutrino and coupling strength of the R-parity violating interactions.

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I Introduction

The extensions of the standard model (SM) have been intensively studied over the past years[1]. The minimal supersymmetric standard model (MSSM) is one of the most attractive ones among the general extended models of the SM. In the usual MSSM the R-parity is conserved. Here the R-parity is defined as

$$R_p = (-1)^{3B+L+2S}.$$

We can see that the lepton-number or baryon-number violating interactions can induce R-parity violation ($\not{R}_p$) . In the usual supersymmetric (SUSY) extension models, R-parity conservation [2] is imposed due to two reasons. One is to retain the electroweak gauge invariance of the SM. the other is to solve the proton decay problem, since the R-parity violation leads to unacceptable short proton lifetime. But the most general SUSY extension of the SM should contain R-parity violating interactions. Until now have we been lacking in credible theoretical argument and experimental tests for R_p conservation, so we can say that the R_p violation would be equally well motivated in the supersymmetric extension of the SM. Up to now we have experimentally only some upper limits on $\not{R}_p$ parameters. Therefore, it is necessary to continue the work on finding $\not{R}_p$ signal or getting further stringent constraints on the $\not{R}_p$ parameters in future experiments.

Recent experimental and theoretical works have demonstrated that the dilepton production processes in hadron collisions ($p\bar{p} \to l\bar{l} + X$ and $pp \to l\bar{l} + X$ $(l = e, \mu)$), are very important [3], since there is a continuous c.m.s energy distribution of the colliding partons inside protons(and anti-protons) at hadron colliders. These dilepton production channels at hadron colliders can be used to study the parton distribution functions(PDFs) at small x values [4] [5], to determine the W mass [6] [7] [8], and to extract the effective weak mixing angle[9] and the information on the width of the W boson [10] [11],...etc. The most attractive purpose is that at the c.m.s hadron colliding energy region beyond the m_{Z^0}, one can probe the new physics beyond the SM, such as large extra dimensions [12] [13], extra neutral gauge bosons[14], R-parity violation[15] and composite quarks and leptons[16]. Therefore, we can conclude that at the upgrade Fermilab Tevatron Run II with integrate luminosity 2-20$fb^{-1}/year$ at $\sqrt{s} = 2\ TeV$ and the CERN Large Hadron Collider (LHC) with $100 fb^{-1}/year$ at $\sqrt{s} = 14\ TeV$, it would be possible to extract the new physics effects beyond the SM by investigating the dilepton production processes.

The dilepton pairs can be produced via the Drell-Yan subprocess and gluon fusion at hadron colliders. The analysis of the sensitivity to $\not{R}_p$ couplings in measurement on the Drell-Yan production processes $pp \to u_j u_j (d_k d_k) \to l_i^+ l_i^- + X$ at the LHC was studied in Ref.[15]. But we suppose that the process $pp \to gg \to l_i^+ l_i^- + X$ could be important too due to the large gluon luminosity in hadron colliders, although the dilepton pair production via gluon fusion is an one-loop process.

If we set the values of the R-parity violating parameters concerned to be near the corresponding upper limits[17], we can see that the major R-parity effects on cross section of subprocess $gg \to l_i^+ l_i^- (l_{i=1,2} = e, \mu)$ come from the loops involving the third generation quarks. Then we would have the conclusion that the cross section of $gg \to l_\alpha^+ l_\alpha^-$ is approximately proportional to $\sum_{i=1}^{2,3} (\lambda'_{i33} \lambda_{i\alpha\alpha})^2$ (i, α are the generation indices of the sneutrino and dilepton, respectively). From the experimental constraints of $\not{R}_p$ parameters[17], we have the upper limitations on the related R-parity violating parameters: $\lambda'_{133} \leq 1.4 \times 10^{-3}\sqrt{m_{\tilde{b}}/100GeV}$, $\lambda'_{333} \leq 0.45$, $\lambda'_{233} \leq 0.15 \times \sqrt{m_{\tilde{b}}/100GeV}$, $\lambda_{311} \leq 0.062 \times \frac{m_{\tilde{e}_R}}{100GeV}$, and $\lambda_{211} \leq 0.049 \times \frac{m_{\tilde{e}_R}}{100GeV}$. Due to $\lambda_{ijk} = -\lambda_{jik}$, we have $\lambda_{ijk} = 0$, $(for\ i = j)$. Since the upper limitation of λ'_{133} is much smaller than those of λ'_{233} and λ'_{333}, the cross section of $gg \to \mu^+\mu^-$ is approximately proportional to $(\lambda'_{333}\lambda_{322})^2$. And the cross section of $gg \to e^+e^-$ is approximately proportional to $(\lambda'_{333}\lambda_{311} + \lambda'_{233}\lambda_{211})^2$. Then we can estimate that the cross section of $gg \to e^+e^-$ may be several times larger than that of $gg \to \mu^+\mu^-$, if the related R-parity violating parameters have the values near the corresponding upper limits.

In this paper we concentrated on finding the effects of R-parity lepton number violating MSSM in the e^+e^- pair production processes via both Drell-Yan and gluon fusion subprocesses at the CERN LHC. In section II we present the relevant model and the calculation of the processes $pp \to e^+e^- + X$. Analytical calculation is presented in section II. Numerical results and discussion are given in section III, where the cross sections in the minimal standard supersymmetric models with and without R-parity violation will be compared. In section IV we give a short summary.

II Relevant Theory and Calculations

In this section we review briefly the MSSM with R-parity lepton number violation. All renormalizable supersymmetric $\not{R}$ interactions can be introduced in the superpotential. The general form of the super potential can be written as [18].

$$\mathcal{W} = \mathcal{W}_{MSSM} + \mathcal{W}_{\not{R}} \tag{2.1}$$

where $\mathcal{W}_{MSSM}$ represents the R-parity conserved term, which can be written as

$$\mathcal{W}_{MSSM} = \mu\epsilon_{ij}H_i^1H_j^2 + \epsilon_{ij}l_IH_i^1\tilde{L}_j^I\tilde{R}^I - u_I(H_1^2C^{JI*}\tilde{Q}_2^J - H_2^2\tilde{Q}_1^J)\tilde{U}^I - d_I(H_1^1\tilde{Q}_2^I - H_2^1C^{IJ}\tilde{Q}_1^J)\tilde{D}^I \tag{2.2}$$

and $\mathcal{W}_{\not{R}}$ represents the term of R-parity violation,

$$W_{\not{R}} = \epsilon_{ij}(\lambda_{IJK}\tilde{L}_i^I\tilde{L}_j^J\tilde{R}^K + \lambda'_{IJK}\tilde{L}_i^I\tilde{Q}_j^J\tilde{D}^K + \epsilon_IH_i^2\tilde{L}_j^I) + \lambda''_{IJK}\tilde{U}^I\tilde{D}^J\tilde{D}^K \tag{2.3}$$

The soft breaking terms can be expressed as

$$\begin{aligned}\mathcal{L}_{soft} \;=\; & -m_{H^1}^2H_i^{1*}H_i^1 - m_{H^2}^2H_i^{2*}H_i^2 - m_{L^I}^2\tilde{L}_i^{I*}\tilde{L}_i^I - m_{R^I}^2\tilde{R}^{I*}\tilde{R}^I - m_{Q^I}^2\tilde{Q}_i^{I*}\tilde{Q}_i^I \\ & -m_{D^I}^2\tilde{D}^{I*}\tilde{D}^I - m_{U^I}^2\tilde{U}^{I*}\tilde{U}^I + (m_1\lambda_B\lambda_B + m_2\lambda_A^i\lambda_A^i + m_3\lambda_G^a\lambda_G^a + h.c.) \\ & +\{B\mu\epsilon_{ij}H_i^1H_j^2 + B_I\epsilon_I\epsilon_{ij}H_i^2\tilde{L}_j^I + \epsilon_{ij}l_{sI}H_i^1\tilde{L}_j^I\tilde{R}^I \\ & +d_{sI}(-H_1^1\tilde{Q}_2^I + C^{IK}H_2^1\tilde{Q}_1^K)\tilde{D}^I + u_{sI}(-C^{KI*}H_1^2\tilde{Q}_2^I + H_2^2\tilde{Q}_1^I)\tilde{U}^I \\ & +\epsilon_{ij}\lambda_{IJK}^S\tilde{L}_i^I\tilde{L}_j^J\tilde{R}^K + \lambda_{IJK}^{S'}(\tilde{L}_i^I\tilde{Q}_2^J\delta^{JK} - \tilde{L}_2^IC^{JK}\tilde{Q}_1^J)\tilde{D}^K + \lambda_{IJK}^{S''}\tilde{U}^I\tilde{D}^J\tilde{D}^K \\ & +h.c.\}\end{aligned} \tag{2.4}$$

In Eqs.(2.2-4), L^I, Q^I, H^I represents the SU(2) doublets of lepton, quark and Higgs superfields respectively, while R^I, U^I, D^I are the singlets of lepton and quark superfields. The bilinear term $\epsilon_{ij}\epsilon_IH_i^2\tilde{L}_j^I$ can give neutrinos and make the diagonalization of mass matrix more complexity. In the processes considered in this paper, we assumed their effects negligible. In this paper we consider only the lepton number violation, i.e., λ and λ' are assumed to be non-zero while λ'' is fixed to be zero.

The main subprocesses for the parent process $pp \to e^+e^- + X$ are the following three: (1) $u\bar{u} \to e^+e^-$, (2)$d\bar{d} \to e^+e^-$, (3) $gg \to e^+e^-$. The Feynman diagrams of subprocesses (1) and

(2) contributed by R-parity conserving MSSM are plotted in Fig.1(a) and Fig.2(a), respectively. The diagrams of subprocesses (1),(2) involving the R-parity violating interactions are depicted in Fig.1(b) and Fig.2($b-c$), respectively. The Fig.3 shows the Feynman diagrams of subprocess (3) in the R-parity conserving MSSM at the lowest order. The Feynman diagrams of subprocess (3) involving R-parity violating interactions are given in Fig.4. For simplicity we do not give the diagrams which can be obtained by exchanging the initial gluons in Fig.3 and Fig.4.

III Calculation

Firstly we consider the e^+e^- pair production subprocess via photon and Z boson exchanges in quark-antiquark annihilation as

$$q(p_1) + \bar{q}(p_2) \to \gamma, Z \to e^-(k_1) + e^+(k_2), \quad (q = u, d). \tag{3.1}$$

The differential Born cross sections at the parton-level for above subprocesses (1) $u\bar{u} \to e^+e^-$, (2)$d\bar{d} \to e^+e^-$ in the framework of the R-parity conserving MSSM, corresponding to the diagrams Fig.1(a) and Fig.2(a) respectively, are given by

$$d\hat{\sigma}^{(i)}_{MSSM} = dP_{2f} \frac{1}{12} \sum |A^{(i)}_{\gamma}(\hat{s}, \hat{t}, \hat{u}) + A^{(i)}_{Z}(\hat{s}, \hat{t}, \hat{u})|^2, \quad (i = 1, 2) \tag{3.2}$$

where the summation is taken over the spin and color degrees of freedom of the initial and final states, and dP_{2f} denotes the two-particle phase space element. The factor 1/12 results from the average over the spins and the colors of the incoming partons. The $A^{(i)}_{\gamma}$ and $A^{(i)}_{Z}$ represent the amplitudes of the photon and Z boson exchange diagrams at tree level, respectively. The

Mandelstam kinematical variables in the parton center of mass system are defined as

$$\hat{s} = (p_1 + p_2)^2, \quad \hat{t} = (p_1 - k_1)^2, \quad \hat{u} = (p_1 - k_2)^2, \tag{3.3}$$

The expressions of the squared matrix elements for massless external fermions are

$$\begin{aligned}
\sum |\mathcal{A}_\gamma^{(i)}(\hat{s}, \hat{t}, \hat{u})|^2 &= 8\, Q_q^2\, Q_l^2\, (4\pi\alpha)^2\, \frac{(\hat{t}^2 + \hat{u}^2)}{\hat{s}^2} \,, \\
\sum |\mathcal{A}_Z^{(i)}(\hat{s}, \hat{t}, \hat{u})|^2 &= 8\, \frac{|\chi(\hat{s})|^2}{\hat{s}^2}\, \left[(v_q^2 + a_q^2)(v_l^2 + a_l^2)(\hat{t}^2 + \hat{u}^2) - 4 v_q a_q v_l a_l\, (\hat{t}^2 - \hat{u}^2) \right] \,, \\
2 \sum \mathcal{R}e(\mathcal{A}_Z^{(i)} \mathcal{A}_\gamma^{(i)*}) &= 64\pi\alpha\, Q_q\, Q_l\, a_q\, a_l\, \left[v_q v_l (\hat{t}^2 + \hat{u}^2) - a_q a_l (\hat{t}^2 - \hat{u}^2) \right] \frac{\mathcal{R}e\chi(\hat{s})}{\hat{s}^2} \,,
\end{aligned} \tag{3.4}$$

with

$$v_f = \frac{1}{2 s_w c_w} (I_f^3 - 2 s_w^2 Q_f), \qquad a_f = \frac{I_f^3}{2 s_w c_w} \,, \qquad \chi(\hat{s}) = \frac{4\pi\alpha\hat{s}}{(\hat{s} - m_Z^2 + i\hat{s}\Gamma_Z/m_Z^2)} \,, \tag{3.5}$$

where $f = q, l$.

In the MSSM with the R-parity lepton number violation, the tree level differential cross sections for subprocess (1) and (2) can be expressed as

$$d\hat{\sigma}_{\not{R}}^{(i)}(\hat{s}, \hat{t}, \hat{u}) = dP_{2f} \frac{1}{12} \sum |A_\gamma^{(i)}(\hat{s}, \hat{t}, \hat{u}) + A_Z^{(i)}(\hat{s}, \hat{t}, \hat{u}) + A_{\not{R}}^{(i)}(\hat{s}, \hat{t}, \hat{u})|^2 \quad (i = 1, 2), \tag{3.6}$$

The R-parity violation amplitudes $A_{\not{R}}^{(1)}$ and $A_{\not{R}}^{(2)}$, which correspond to the subprocess (1) $u\bar{u} \to e^+ e^-$ and (2) $d\bar{d} \to e^+ e^-$ respectively, can be expressed as:

$$A_{\not{R}}^{(1)}(\hat{s}, \hat{t}, \hat{u}) = A_{\tilde{d}}^{(1)}(\hat{s}, \hat{t}, \hat{u}), \quad A_{\not{R}}^{(2)}(\hat{s}, \hat{t}, \hat{u}) = A_{\tilde{u}}^{(2)}(\hat{s}, \hat{t}, \hat{u}) + A_{\tilde{\nu}}^{(2)}(\hat{s}, \hat{t}, \hat{u}) \tag{3.7}$$

where $A_{\tilde{d}}^{(1)}$, $A_{\tilde{u}}^{(2)}$ and $A_{\tilde{\nu}}^{(2)}$ are just the contributions from the diagrams Fig.1(b), Fig.2(b) and Fig.2(c), respectively. By using the relevant Feynmann rules, we can easily write down the expressions:

$$
\begin{array}{rcl}
A^{(1)}_{\tilde{d}}(\hat{s},\hat{t},\hat{u}) & = & (\lambda'_{11j})^2[\bar{v}(p_2)Z^{2i}_{D_j}P_R v(k_1)]\frac{i}{\hat{t}-m^2_{\tilde{d}_{j\,i}}}[\bar{u}(k_2)Z^{2i}_{D_j}P_L u(p_1)] \\
A^{(2)}_{\tilde{u}}(\hat{s},\hat{t},\hat{u}) & = & -(\lambda'_{1j1})^2[\bar{u}(k_1)Z^{1i}_{U_j}P_R u(p_1)]\frac{i}{\hat{u}-m^2_{\tilde{u}_{j\,i}}}[\bar{v}(p_2)Z^{1i}_{U_j}P_L v(k_2)] \\
A^{(2)}_{\tilde{\nu}}(\hat{s},\hat{t},\hat{u}) & = & -(\lambda'_{j11})(\lambda_{j11})[\bar{v}(p_2)P_L u(p_1)]\frac{i}{\hat{s}-m^2_{\tilde{\nu_j}}+im_{\tilde{\nu_j}}\Gamma_{\tilde{\nu_j}}}[\bar{u}(k_1)P_R v(k_2)] \\
 & & -(\lambda'_{j11})(\lambda_{j11})[\bar{v}(p_2)P_R u(p_1)]\frac{i}{\hat{s}-m^2_{\tilde{\nu_j}}+im_{\tilde{\nu_j}}\Gamma_{\tilde{\nu_j}}}[\bar{u}(k_1)P_L v(k_2)]
\end{array}
\tag{3.8}
$$

where $Z^{ij}_{D_k}$ and $Z^{ij}_{U_k}$ represent the elements of the matrices used to diagonalize the down-type squark and up-type squark mass matrices, respectively.

Now we turn to the calculation of the gluon fusion subprocess. We denote this subprocess (3) as

$$
g(p_1,\alpha,\mu)+g(p_2,\beta,\nu)\to e^-(k_1)+e^+(k_2), \tag{3.9}
$$

where α,β are the color indices of initial gluinos, respectively. In the MSSM with R-conserving the differential cross section can be expressed as

$$
d\hat{\sigma}_{MSSM}=dP_{2f}\,\frac{1}{256}\sum|A^{(3)}_a(\hat{s},\hat{t},\hat{u})+A^{(3)}_b(\hat{s},\hat{t},\hat{u})+A^{(3)}_c(\hat{s},\hat{t},\hat{u})+A^{(3)}_d(\hat{s},\hat{t},\hat{u})+A^{(3)}_e(\hat{s},\hat{t},\hat{u})|^2\ , \tag{3.10}
$$

where the sum is again taken over the spin and color degrees of freedom of the initial gluons and final states, and dP_{2f} denotes the two-particle phase space element. And $A^{(3)}_i$ represent the amplitudes of diagrams in Fig.3(i) (i=a,b,c,d,e). As we can see from Fig.3, all the diagrams are Z^0/γ exchanging s-channels. Therefore all these contributions can be neglected. This is the consequence of Furry theorem. The Furry theorem forbids the production of the spin-one components of the Z^0 and γ, and the contribution from the spin-zero component of the Z^0 vector boson coupling with a pair of leptons is negligibly small. So we have the amplitudes corresponding to Fig.3(a-e) approaching to zero and the cross section σ_{MSSM} part with the R-parity conserving interactions (shown in Fig.3) are vanished.

In the case of the R-parity lepton number violation, the differential cross section of subprocess (3) can be written as

$$
\begin{aligned}
d\hat{\sigma}^{(3)}_{\not R} &= dP_{2f}\,\frac{1}{256}\sum|A^{(3)}_a(\hat{s},\hat{t},\hat{u})+\cdots+A^{(3)}_e(\hat{s},\hat{t},\hat{u})+A^{(4)}_a(\hat{s},\hat{t},\hat{u})+\cdots+A^{(4)}_i(\hat{s},\hat{t},\hat{u})|^2 \\
&= dP_{2f}\,\frac{1}{256}\sum|A^{(4)}_a(\hat{s},\hat{t},\hat{u})+\cdots+A^{(4)}_i(\hat{s},\hat{t},\hat{u})|^2
\end{aligned}
\tag{3.11}
$$

which has a nonzero result. The total cross section of process $pp\to e^+e^-+X$ with the lower cut value of the e^+e^--pair invariant mass $m^{cut}_{e^+e^-}$ can be written as:

$$
\begin{aligned}
&\sigma_{ij}(m_{(e^+e^-)}\geq m^{cut}_{(e^+e^-)})=\int^1_{(m^{cut}_{(e^+e^-)})^2/s}d\tau\frac{d\mathcal{L}_{ij}}{d\tau}\hat{\sigma}_{ij}(\hat{s}=\tau s), \\
&\frac{d\mathcal{L}_{ij}}{d\tau}=\frac{1}{1+\delta_{ij}}\int^1_\tau\frac{dx_1}{x_1}\left\{\left[f(i,x_1,Q^2)f(j,\frac{\tau}{x_1},Q^2)\right]+\left[f(j,x_1,Q^2)f(i,\frac{\tau}{x_1},Q^2)\right]\right\}
\end{aligned}
\tag{3.12}
$$

where $\sqrt{s}$ and $\sqrt{\hat{s}}$ are the pp collision and subprocess c.m.s. energies respectively, and $d\mathcal{L}_{ij}/d\tau$ is the luminosity of incoming partons. Here, i,j represent the partons $u,d,\bar{u},\bar{d},g$, $\tau=x_1\ x_2$. The definitions of x_1 and x_2 can be seen from Ref.[19], we adopt the CTEQ5 parton distribution function [20]. In $f(i,x,Q^2)$, factorization scale Q is taken to be $\sqrt{\hat{s}}$. Then we can obtain the cross section for the parent process of $pp\to ij\to e^+e^-+X$ with the dilepton invariant mass $m_{(e^+e^-)}$ being larger than $m^{cut}_{(e^+e^-)}$:

$$
\begin{aligned}
&\sigma_{ij}(m_{(e^+e^-)}\geq m^{cut}_{(e^+e^-)})=\int^{\sqrt{s}}_{m^{cut}_{(e^+e^-)}}d\sqrt{\hat{s}}\hat{\sigma}_{ij}(\hat{s})H_{ij}(\hat{s}), \\
&H_{ij}(\hat{s})=\frac{1}{1+\delta_{ij}}\int^1_{\frac{\hat{s}}{s}}\frac{2dx_1\sqrt{\hat{s}}}{x_1 s}\left\{\left[f(i,x_1,Q^2)f(j,\frac{\hat{s}}{x_1 s},Q^2)\right]+\left[f(j,x_1,Q^2)f(i,\frac{\hat{s}}{x_1 s},Q^2)\right]\right\}
\end{aligned}
\tag{3.13}
$$

where $\sigma^{(i)}$ $(i=1,2,3)$ represent the cross sections of processes: (1) $pp\to u\bar{u}\to e^+e^-+X$, (2) $pp\to d\bar{d}\to e^+e^-+X$, and (3) $pp\to gg\to e^+e^-+X$, respectively. Then the total cross sections of the e^+e^- pair production with its invariant mass larger than $m^{cut}_{(e^+e^-)}$ in the R-violating and

R-conserving supersymmetric models can be written as :

$$\begin{aligned}
\sigma_{\not R}(m_{e^+e^-} \geq m^{cut}_{(e^+e^-)}) &= \sigma^{(1)}_{\not R}((m_{(e^+e^-)} \geq m^{cut}_{(e^+e^-)}) + \sigma^{(2)}_{\not R}(m_{(e^+e^-)} \geq m^{cut}_{(e^+e^-)}) \\
&+ \sigma^{(3)}_{\not R}(m_{(e^+e^-)} \geq m^{cut}_{(e^+e^-)}) \\
\sigma_{MSSM}(m_{(e^+e^-)} \geq m^{cut}_{(e^+e^-)}) &= \sigma^{(1)}_{MSSM}(m_{(e^+e^-)} \geq m^{cut}_{(e^+e^-)}) + \sigma^{(2)}_{MSSM}(m_{(e^+e^-)} \geq m^{cut}_{(e^+e^-)}) \\
&+ \sigma^{(3)}_{\not R}(m_{(e^+e^-)} \geq m^{cut}_{(e^+e^-)}) \\
&= \sigma^{(1)}_{MSSM}(m_{(e^+e^-)} \geq m^{cut}_{(e^+e^-)}) + \sigma^{(2)}_{MSSM}(m_{(e^+e^-)} \geq m^{cut}_{(e^+e^-)})
\end{aligned} \tag{3.14}$$

where we used $\sigma^{(3)}_{MSSM} \approx 0$, which was mentioned above. For presentation of the $\not R$ effect of the process $pp \to e^+e^- + X$, we define $\not R$ parameter η as:

$$\eta = \frac{\sigma_{\not R}(m_{(e^+e^-)} \geq 200GeV) - \sigma_{MSSM}(m_{(e^+e^-)} \geq 200GeV)}{\sigma_{MSSM}(m_{(e^+e^-)} \geq 200GeV)}. \tag{3.15}$$

IV Numerical result and discussion

In the numerical calculation we set the input SM parameters to be : $m_u = 5MeV$, $m_d = 5MeV$, $m_c = 1.2GeV$, $m_s = 120MeV$, $m_t = 170GeV$, $m_b = 4.2GeV$, $m_Z = 91.187GeV$, $\Gamma_Z = 2.49GeV$. In this work, we do numerical calculation in the minimal supergravity (mSUGRA) scenario[21]. In this scenario, only five sypersymmetric parameters should be given which are named $M_{1/2}$, M_0, A_0, sign of μ and $\tan\beta$, where $M_{1/2}$, M_0 and A_0 are the universal gaugino mass, scalar mass at GUT scale and the trilinear soft breaking parameter in the superpotential respectively. As we know that the effects of the R-parity violating couplings on the renormalization group equations(RGE's) are the crucial ingredient of mSUGRA-type models, and the complete 2-loop RGE's of the superpotential parameters for the supersymmetric standard model including the full set of R-parity violating couplings are given in Ref.[22]. But in our numerical presentation to get the low energy scenario from the mSUGRA [21], we ignored those effects in the RGE's for simplicity and use the program ISAJET 7.44. In this program the RGE's [23] are run from the weak scale m_Z up to the GUT scale, taking all thresholds into account and using two loop RGE's only for the gauge couplings and the one-loop RGE's for the other supersymmetric parameters. The GUT scale boundary conditions are imposed and the RGE's are run back to m_Z, again taking threshold into account. The R-parity violating parameters chosen above satisfy the constraints given by Ref.[17].

We take the mSUGRA input parameters as: $M_{1/2} = 150GeV;$, $A_0 = 300GeV$, $\tan\beta = 4$, $\mu > 0$, $m_t = 170GeV$. The numerical values of M_0 will be running in a definite range. The ratio of $\tilde{\nu}$ decay width to its mass is taken as $\Gamma_{\tilde{\nu}}/m_{\tilde{\nu}} = 0.07$. Ref.[17] presents the experimental constraints for the coupling parameters in R-parity violating interactions. According to these upper limitations, we take the relevant R-violating coupling parameters $\lambda^{'}_{ijk}$ having the values as

$$\lambda^{'}_{111} = 0.01,$$

$$\lambda^{'}_{ijk} = 0.04, \quad (when\ two\ of\ i, j, k = 1),$$

$$\lambda^{'}_{ijk} = 0.39, \quad (when\ two\ or\ three\ of\ i, j, k = 3).$$

And all of the others λ'_{ijk} which we will use in calculation are chosen to be 0.25. For the related coupling parameters λ_{ijk}, we know that the first two indices of parameters λ_{ijk} are antisymmetric, then the λ_{ijk} should be zero when $i = j$. The others concerned $\not{R}$ coupling parameters λ_{211} and λ_{311} are taken to be -0.18.

The cross section of the subprocess $d\bar{d} \to e^+e^-$, $\hat{\sigma}^{(2)}$ as a function of $\sqrt{\hat{s}}$ is given in Fig.5. We can see there is a peck around the vicinity of the $m_{\tilde{\nu}}$ on the curve for the $\not{R}$-MSSM. Since the energy of this subprocess $\sqrt{\hat{s}}$ from incoming protons has a continuous spectrum, it can be estimated that the total cross section and the $\not{R}$ effects of $pp \to e^+e^- + X$ will be greatly enhanced at hadron colliders. The cross section of subprocess $gg \to e^+e^-$ in $\not{R}$-MSSM as a function of the c.m.s. energy of colliding gluons is depicted in Fig.6. Again we can see the resonance enhancement from $\tilde{\nu}$ exchanging s-channel at the energy position around $m_{\tilde{\nu}}$. Because of the much larger luminosity of gluons in the parton distribution function of proton compared with that of quarks and anti-quarks, the subprocess $gg \to e^+e^-$ would contribute to the total cross section of $pp \to e^+e^- + X$ at the LHC to some extent. Fig.7 gives the total cross section of the process $pp \to e^+e^- + X$ as the function of the lower cut value of the e^+e^- pair invariant mass $m^{cut}_{(e^+e^-)}$. From this figure, we can see that the $\not{R}$ effect on the production rate of e^+e^- pair is rather large, and gluon fusion subprocess plays a significant role. Now we use the parameter η, which is defined in Eq.(3.15), to represent the effect of $\not{R}$ of parent process $pp \to e^+e^- + X$, and we further denote the $\not{R}$ effect parameters η_i $(i = 1, 2, 3)$, which correspond to the parent processes in which the $\not{R}$ effect is contributed by the Drell-Yan mechanism, gluon fusion and both subprocesses, respectively. In Fig.8, we depicted the R-violating effect η as a function of universal scalar mass at GUT scale M_0, which is related to the mass of supersymmetric neutrino $\tilde{\nu}$. From Fig.8 we know that effect of R-parity lepton number violating on e^+e^--pair production at the LHC is rather large, especially in the M_0 range when $M_0 < 300\ GeV$. The effect parameter of R-parity violation η_3, which describes the $\not{R}$ effect for process $pp \to e^+e^- + X$, may be over the value of 70%. We can see also from Fig.8 that the most part of the R-parity violating effect is contributed by the Drell-Yan subprocess, but the part contributed by gluon fusion subprocess $gg \to e^+e^-$ is also significant. Fig.9 shows the ratio of the R-parity violating effects contributed by gluon fusion and Drell-Yan subprocesses, as a function of universal scalar mass at GUT scale(M_0). We can see that the smaller the scalar mass M_0 is, the more contributions to $\not{R}$ effects via subprocess $gg \to e^+e^-$ are. When $M_0 \sim 200\ GeV$, the contribution to $\not{R}$ effects from gluon fusion can reach approximately 25% of that from Drell-Yan subprocess. Fig.10 shows the dependence of the ratio of the $\not{R}$ effects via gluon fusion and Drell-Yan mechanism subprocesses on the value of $\lambda'_{233}(= \lambda'_{333})$. It demonstrates that the ratio η_2/η_1 is strongly related to the R-parity violating parameters $\lambda'_{233}(\lambda'_{333})$. The larger λ'_{233} and λ'_{333} are, the more important the contribution to the $\not{R}$ effect via subprocess $gg \to e^+e^-$ is. From Fig.8, Fig.9 and Fig.10, we can conclude that although the gluon fusion subprocess $gg \to e^+e^-$ has no tree-level Feynman diagram, its contribution to $\not{R}$ effect is also significant comparing to that via Drell-Yan subprocess in some parameter space of the MSSM with R-parity violating. The reason are in two fields: Firstly, it is due to the large gluon luminosity in hadron collider. Secondly, in the loop-order Feynman diagrams for gluon fusion subprocess, there exist the R-parity lepton number violation interactions involving the third generation particles. While the experimental upper limitations of these coupling strengths[17] are much larger than those, their interacting particles involving only the members of the first two generations.

V Summary

We studied the effects of the R-parity lepton number violation in the minimal supersymmetric standard model (MSSM) on the parent process $pp \to e^+e^- + X$ at the CERN Large Hadron Collider (LHC). The contribution from the one-loop induced gluon fusion subprocess $gg \to e^+e^-$, may contribute to R-parity violating effect significantly in comparing with that via Drell-Yan subprocess. So in studying the effect of R-parity lepton number violation on e^+e^--pair production process, we should figure out the contributions both from Drell-Yan subprocess $q\bar{q} \to e^+e^-$ and gluon fusion subprocess $gg \to e^+e^-$. Our calculation shows that the R-parity lepton number violating effect from gluon fusion subprocess can reaches 30% of the corresponding part via Drell-Yan subprocess. We find also that the dependences of R-violating effect on the sneutrino mass and the coupling strength of the R-parity violating interactions are obvious.

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Figure Captions

Fig.1 The relevant Feynman diagrams for the subprocess $u\bar{u} \to e^+e^-$ in the MSSM at the tree-level: (a) for the Feynman diagrams for R-parity conserved MSSM part; (b) for the Feynman diagrams for R-parity violation MSSM part.

Fig.2 The relevant Feynman diagrams for the subprocess $d\bar{d} \to e^+e^-$ in the MSSM at the tree-level: (a) for the Feynman diagrams for R-parity conserved MSSM part; (b) and (c) are for the Feynman diagrams for R-parity violation MSSM part.

Fig.3 The relevant Feynman diagrams for the subprocess $gg \to e^+e^-$ for the R-parity conserved MSSM part in the MSSM at the lowest level.

Fig.4 The relevant Feynman diagrams for the subprocess $gg \to e^+e^-$ for the R-parity violation MSSM part in the MSSM at the lowest level.

Fig.5 The cross section of subprocess $d\bar{d} \to e^+e^-$ at the LHC as the function of $\sqrt{\hat{s}}$, with the colliding proton-proton energy $\sqrt{s} = 14TeV$ and $M_0 = 250\ GeV$. The full line is for R-conserving MSSM, the dashed line for R-violating MSSM.

Fig.6 The cross section of subprocess $gg \to e^-e^+$ at the LHC as the function of $\sqrt{\hat{s}}$, with the colliding energy $\sqrt{s} = 14TeV$ and $M_0 = 250GeV$.

Fig.7 The cross section of process $pp \to e^+e^- + X$ at the LHC as the function of $m^{cut}_{e^+e^-}$, with the colliding energy $\sqrt{s} = 14TeV$ and $M_0 = 250GeV$. The full-line is for the R-conserving MSSM. The dashed-line is for the R-violating MSSM, where only $\not R$ effect via $q\bar{q} \to e^+e^-$ is taken into account. The dotted-dashed-line is for the R-violating MSSM, where the effects via both Drell-Yan and gluon fusion subprocesses are taken into account.

fig.9 R-parity violating effect parameters $\eta_i (i = 1, 2, 3)$ as the functions of M_0 . The full-line is for η_1 (for case 1: only $\not R$ effect via $q\bar{q} \to e^+e^-$ is taken into account). The dotted-dashed-line for η_2 (for case 2: only $\not R$ effect via $q\bar{q} \to e^+e^-$ is taken into account). The dashed-line for η_3 (for case 3: the effects via both Drell-Yan and gluon fusion subprocesses are taken into account).

Fig.9 The ratio (η_2/η_1) of the R-violating parameters as a function of M_0 , which shows the importance of the contributions from subprocesses $q\bar{q} \to e^+e^-$ and $gg \to e^+e^-$.

Fig.10 The ratio (η_2/η_1) as a function of the R-violating parameters $\lambda'_{233}(\lambda'_{333})$(where we take $\lambda'_{233} = \lambda'_{333}$) with $M_0 = 250GeV$.