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Processes with the Lepton Flavor Violation at Muon Colliders

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Within the framework of the left-right model, the processes of pair production of the W^-- bosons are investigated. These processes going with the lepton flavor violation may be detected at muon colliders both in the regime of a fixed electron target and in the regime of colliding muon beams.

In the second order of the perturbation theory the cross sections of these processes are calculated for the polarized initial particles. It is shown that their cross sections are quite large and are grown with increasing the heavy neutrino mass. The problems connected with detecting these processes are discussed.

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1. Introduction

The standard model (SM) of particle physics has been very successfully forecasting or explaining most experimental results and phenomena. However it is widely believed that the SM is not the ultimate truth. Expectation for departure from SM behavior are based on the following facts: (i) the SM has not found satisfactory explanation of baryon asymmetry of the Universe; (ii) neutrino mass smallness; (iii) the value of the muon anomalous magnetic moment; (iv) a lack of candidates on the role of weakly interacting massive particles which enter into the nonbaryonic cold dark matter.

It is clear that the future ambitious experimental program, both at the upgraded LHC and future linear colliders, which will determine parameters both of the Higgs and of the lepton sectors with higher precision than at present, will play a central role. A particularly interesting possible departure from the SM predictions will be the processes going with the lepton flavor violation (LFV). These processes do not take place even in the minimally extended SM, since lepton flavor symmetry is an exact symmetry of the SM and therefore it predicts vanishing rates for all these LFV processes to all orders in perturbation theory. At present the LFV processes are being searched for very actively in the LHC experiments and, in fact, there are already significant bounds set from the absence of signals in both ATLAS and CMS Collaborations. For example, the current 95% CL limits on the Higgs decays with the LFV are

$$\text{BR}(H \to \mu e) < 3.6\times10^{-4}, \qquad \text{BR}(H \to \tau e) < 0.7\times10^{-2}, \qquad \text{BR}(H \to \mu\tau) < 1.2\times10^{-2}.$$

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Moreover, various B-meson decays have shown significant deviations from the SM predictions, most of which are related to muon final states. The LFV in B-meson decays can be tested by measuring the ratios of the transitions [1]

$$R_K = \frac{\text{BR}(B^+ \to K^+\mu^+\mu^-)}{\text{BR}(B^+ \to K^+e^+e^-)}, \qquad R_K^* = \frac{\text{BR}(B^{*0} \to K^{0*}\mu^+\mu^-)}{\text{BR}(B^0 \to K^{0*} \to +e^+e^-)}.$$

Recently [2] LHCb has updated the measurement on

$$\text{R}_K^{exp} = 0.846^{+0.042+0.13}_{-0.39-0.012}$$

which 3.1σ away from the SM prediction.

The LFV problem is connected with neutrinos as well. In the SM neutrinos are massless particles and the lepton flavor $L_{e,\mu,\tau}$ is a conserved quantity. However, neutrino oscillation experiments have shown that the neutrinos have masses and the neutral lepton flavor $L^n_{e,\mu,\tau}$ is not conserved. Owing to a positive signal in any of the experimental looking for charged lepton flavors (cLFV) processes would automatically imply the existence of physics beyond the SM. Although no such processes have been detected to date, this is a very active field that is being explored by many experiments which have adjusted upper limits to the cLFV processes. Therefore, it is very interesting to investigate the processes going both with the nLFV and with the cLFV, simultaneously. It appears that such processes could be observed at muon colliders (MC).

The design of a future $\mu^+\mu^-$-collider with multi-TeV energy has recently been proposed, showing outstanding possibilities to discover and test different aspects of high energy physics. Among these, very interesting prospects have been highlighted for the discovery of Weakly Interacting Massive particles (WIMPs) and for new heavy neutral bosons [3],[4], [**?**]. It is well known that the creation of e^-e^+ colliders with multi-TeV energy is restricted by two factors: (i) increasing losses by synchrotron radiation; (ii) drastic increase in the material costs as two linear accelerators will be required to avoid considerable synchrotron radiation in the storage rings. In its tern, the bremsstrahlung of muons is negligible. They may be accelerated and stored in the rings, whose radius is considerably less as opposed to hadron colliders with comparable energies. Unlike hadron colliders, where the background appears at the point of particles interaction and comes from the accelerator as well, the background of the MC may be found in the detectors only. Also, the MC exhibits high monochromaticity. The roof-mean-square deviation R from the Gaussian energy distribution in the beam falls within the interval from 0.04% to 0.08%. Owing to cooling of the muon beam, R may be decreased down to 0.01%. Thus, the energy resolution of the beam in the MC is much higher than that in e^-e^+ colliders. Another advantage of the MC is its fast rearrangement for operation in the $\mu^-\mu^-$- or $\mu^+\mu^+$ -mode. Since the construction of the MC includes special storage rings to provide optimization of the luminosity for some energy, the MC is an ideal instrument for investigation of resonances with an extremely small decay width (e.g., the Higgs boson of the SM).

The aim of our work is to investigate the possibilities of the MCs in detecting the LFV processes. In the next section we give the brief summary of the LRM. In Sections 3, constraining the second order of the perturbation theory we consider the pair production of the W^- gage bosons and analyze the results obtained. Section 4 includes our conclusion.

2. Brief description of the LRM

In the LRM quarks and leptons enter into the left- and right-handed doublets (for detail, see, Ref.[6])

$$\left.\begin{array}{ll} Q^a_L(\frac{1}{2},0,\frac{1}{3})=\begin{pmatrix} u^a_L \\ d^a_L\end{pmatrix}, & Q^a_R(0,\frac{1}{2},\frac{1}{3})=\begin{pmatrix} u^a_R \\ d^a_R\end{pmatrix}, \\ \Psi^a_L(\frac{1}{2},0,-1)=\begin{pmatrix} \nu_{aL} \\ l_{\alpha L}\end{pmatrix}, & \Psi^a_R(0,\frac{1}{2},-1)=\begin{pmatrix} N_{aR} \\ l_{aR}\end{pmatrix}, \end{array}\right\} \qquad (1)$$

where $a=1,2,3$, in brackets the values of S_L^W, S_R^W and $B-L$ are given, S_L^W (S_R^W) is the weak left (right) isospin while B and L are the baryon and lepton numbers. Note that introducing the heavy neutrinos N_{aR} leads to the existence of the see-saw relation which, in its turn, gives explanation of the ν_l-neutrino mass smallness. The Higgs sector structure of the LRM determines the neutrino nature. The mandatory element of the Higgs sector is the bi-doublet $\Phi(1/2,1/2,0)$

$$\Phi=\begin{pmatrix} \Phi_1^0 & \Phi_2^+ \\ \Phi_1^- & \Phi_2^0\end{pmatrix}. \qquad (2)$$

Its nonequal vacuum expectation values (VEV's) of the electrically neutral components bring into existence the masses of quarks and leptons. For the neutrino to be a Majorana particle, the Higgs sector must include two triplets $\Delta_L(1,0,2)$, $\Delta_R(0,1,2)$

$$(\boldsymbol{\tau}\cdot\boldsymbol{\Delta}_L)=\begin{pmatrix} \delta_L^+/\sqrt{2} & \delta_L^{++} \\ \delta_L^0 & -\delta_L^+/\sqrt{2}\end{pmatrix}, \qquad (\boldsymbol{\tau}\cdot\boldsymbol{\Delta}_R)=\begin{pmatrix} \delta_R^+/\sqrt{2} & \delta_R^{++} \\ \delta_R^0 & -\delta_R^+/\sqrt{2}\end{pmatrix}. \qquad (3)$$

If the Higgs sector consists of two doublets $\chi_L(1/2,0,1)$, $\chi_R(0,1/2,1)$ and one bidoublet $\Phi(1/2,1/2,0)$, then the neutrino represents a Dirac particle. In what follows we shall consider the LRM version with Majorana neutrinos.

The masses of fermions and their interactions with the gauge boson are controlled by the Yukawa Lagrangian. Its expression for the lepton sector is as follows

$$\mathcal{L}_Y=-\sum_{a,b}\{h_{ab}\overline{\Psi}_{aL}\Phi\Psi_{bR}+h'_{ab}\overline{\Psi}_{aL}\tilde{\Phi}\Psi_{b,R}+$$

$$+if_{ab}[\Psi^T_{aL}C\tau_2(\boldsymbol{\tau}\cdot\boldsymbol{\Delta}_L)\Psi_{bL}+(L\to R)]+\text{h.c.}\}, \qquad (4)$$

where C is a charge conjugation matrix, $\tilde{\Phi}=\tau_2\Phi^*\tau_2$, $a,b=e,\mu,\tau$, h_{ab}, h'_{ab} and $f_{ab}=f_{ba}$ are bidoublet and triplet Yukawa couplings (YC's), respectively.

The spontaneous symmetry breaking (SSB) according to the chain

$$SU(2)_L\times SU(2)_R\times U(1)_{B-L}\to SU(2)_L\times U(1)_Y\to U(1)_Q$$

is realized for the following choice of the vacuum expectation values (VEV's):

$$<\delta^0_{L,R}>=\frac{v_{L,R}}{\sqrt{2}}, \qquad <\Phi^0_1>=k_1, \qquad <\Phi^0_2>=k_2. \qquad (5)$$

To achieve agreement with experimental data, it is necessary to ensure fulfillment of the conditions

$$v_L<<\max(k_1,k_2)<<v_R. \qquad (6)$$

After the SSB we are left with 14 physical Higgs bosons: four doubly charged scalars $\Delta^{(\pm\pm)}_{1,2}$, four singly charged scalars $h^{(\pm)}$ and $\tilde{\delta}^{(\pm)}$, four neutral scalars S_i ($i=1,2,3,4$) and two neutral pseudoscalars $P_{1,2}$.

In the gauge boson sector we have two charged gauge bosons (W and W') and two neutral gauge bosons (Z and Z').

3. Pair production of the W^--bosons

r In the neutrino sector the problem associated with the neutrino nature exists. Until now the question remains open as to whether the neutrino is the Majorana or Dirac particle. One of the key experiments that may confirm the Majorana nature of the neutrino will be the observation of the neutrinoless double-β decay ($0\nu 2\beta$). However, one can establish the neutrino nature in collider experiments too. In the case of the Majorana neutrino the processes of a inverse neutrinoless double-β decay

$$e^- + e^- \to W^- + W^- \tag{7}$$

which is connected (by time reversal symmetry) to ($0\nu 2\beta$) and an inverse neutrinoless double-μ decay

$$\mu^- + \mu^- \to W^- + W^- \tag{8}$$

prove to be allowed. The process (8) will be observed at the MC in the regime of the colliding beams. Let us calculate the cross section of the reaction (8) being restricted by the second order of the perturbation theory. In doing so, we shall assume that only the mixing angles between the neutrinos of one and the same generation are nonzero. The corresponding Feynman diagrams are presented in Fig. 1. We shall consider the initial

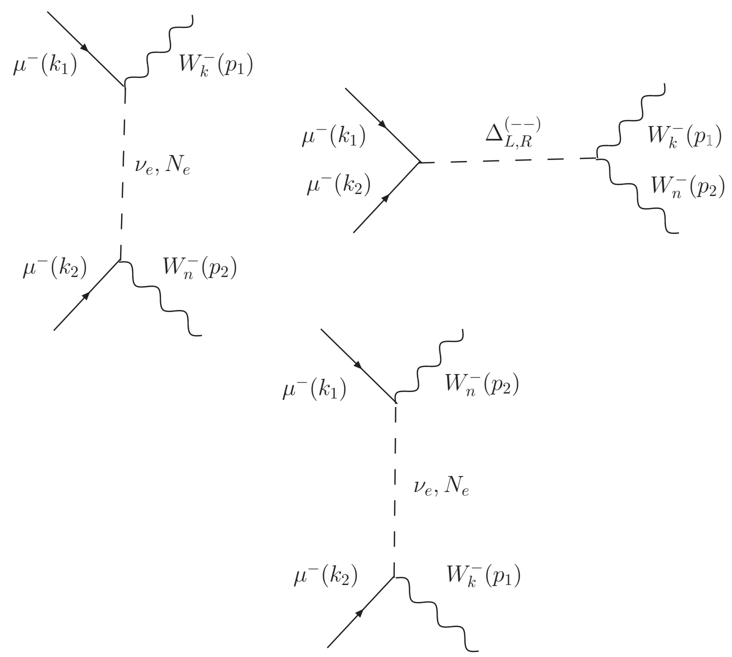

Figure 1: The Feynman diagrams connected with the reaction $\mu^-\mu^- \to W_k^- W_n^-$, (k,n=1,2).

particles to be polarized and the final particles to be unpolarized. Then, the differential cross section of the process

$$\mu_L^- + \mu_R^- \to W_k^- + W_n^- \tag{9}$$

takes the form

$$\frac{d\sigma_{LR}^{(k,n)}}{dt} = \frac{(g_L g_R m_{W_n}^2 \sin 2\alpha)^2}{512\pi s^2}\left[\left(\frac{b_R^{(n)} b_L^{(k)}}{t - m_{N_\mu}^2}\right)^2 B_3^{(kn)}(s,t,u) + \left(\frac{b_R^{(k)} b_L^{(n)}}{u - m_{N_\mu}^2}\right)^2 B_3^{(kn)}(s,u,t) + \right.$$
$$\left. + \frac{b_L^{(k)} b_L^{(n)} b_R^{(k)} b_R^{(n)}}{(t - m_{N_\mu}^2)(u - m_{N_\mu}^2)} B_4^{(kn)}(s,t,u)\right], \tag{10}$$

where

$$B_1^{(kn)}(s,t,u) = \frac{\beta^2 s(m_{W_n}^2 + m_{W_k}^2)}{2m_{W_n}^2 m_{W_k}^2} + F\left[\left(\frac{s - m_{W_n}^2 - m_{W_k}^2}{4m_{W_n}m_{W_k}}\right)^2 + \frac{1}{2}\right], \tag{11}$$

$$B_2^{(kn)}(s,u,t) = \frac{m_{W_n}^2 + m_{W_k}^2}{m_{W_n}^2 m_{W_k}^2}\left[s - m_{W_n}^2 - m_{W_k}^2 + \frac{2m_{W_n}^2 m_{W_k}^2}{t}\right] - $$
$$-\frac{Fs}{8m_{W_n}^2 m_{W_k}^2}\left[u + t + \frac{4m_{W_n}^2 m_{W_k}^2}{t}\right], \tag{12}$$

$$B_3^{(kn)}(s,t,u) = F\left[\left(\frac{s}{4m_{W_n}^2 m_{W_k}^2}\right)^2 + \frac{s^2}{4t^2}\right] + \frac{s(m_{W_n}^2 + m_{W_k}^2)}{2m_{W_n}^2 m_{W_k}^2}. \tag{13}$$

$$\beta = \left[\left(1 - \frac{m_{W_n}^2 + m_{W_k}^2}{s}\right)^2 - \frac{4m_{W_n}^2 m_{W_k}^2}{s^2}\right]^{1/2}, \qquad F = \frac{4(ut - m_{W_n}^2 m_{W_k}^2)}{s^2}, \tag{14}$$

$$B_4^{(kn)}(s,t,u) = s(m_{W_k}^2 + m_{W_n}^2)\left(\frac{2}{ut} - \frac{1}{m_{W_k}^2 m_{W_n}^2}\right) - \frac{F}{8}\frac{s^2}{m_{W_k}^2 m_{W_n}^2}, \tag{15}$$

$$\left.\begin{aligned} a_\pm^{kn} &= \tfrac{1}{4}\left\{1 + (-1)^{k+n} \mp \left[(-1)^k + (-1)^n\right]\cos 2\xi \pm \left[1 - (-1)^{k+n}\right]\sin 2\xi\right\}, \\ b_\pm &= \tfrac{1}{4}\left\{1 + (-1)^{k+n}\cos^2 2\xi \mp \left[(-1)^k + (-1)^n\right]\cos 2\xi\right\}, \end{aligned}\right\} \tag{16}$$

$$m_{N_1} = m_{N_\mu}, \qquad d_{N_\mu} = (t - m_{N_\mu}^2)^{-1}, \qquad d_{Z_j} = (s - m_{Z_j}^2 + i\Gamma_{Z_j} m_{Z_j})^{-1},$$

Corresponding calculations for the process

$$\mu_L^- + \mu_L^- \to W_n^- + W_k^- \tag{17}$$

gives the differential cross section in the view

$$\frac{d\sigma_{LL}^{(kn)}}{dt} = \frac{(g_L^2 m_{N_\mu} b_L^{(k)} b_L^{(n)} \sin^2\alpha)^2}{512\pi s^2}\left\{\left[3s - \frac{Fs^2(s - 2m_{W_n}^2 - 2m_{W_k}^2)}{4m_{W_n}^2 m_{W_k}^2} - \frac{st(s - m_{W_n}^2 - m_{W_k}^2)}{m_{W_n}^2 m_{W_k}^2}\right]\times\right.$$
$$\times\frac{1}{(t - m_{N_\mu}^2)^2} + \frac{4s}{(s - m_{\Delta_L}^2)^2 + \Gamma_{\Delta_L}^2 m_{\Delta_L}^2}\left[8 + \frac{(s - m_{W_n}^2 - m_{W_k}^2)^2}{m_{W_n}^2 m_{W_k}^2} + \frac{s - m_{\Delta_L}^2}{t - m_{N_\mu}^2}\right.$$
$$\left.\left.\times\left(8 + \frac{2t(m_{W_n}^2 + m_{W_k}^2 - s)}{m_{W_n}^2 m_{W_k}^2}\right)\right] + (u \leftrightarrow t) + \left[2s + \frac{Fs^2(s - 2m_{W_n}^2 - 2m_{W_k}^2)}{2m_{W_n}^2 m_{W_k}^2}\right]\frac{1}{(t - m_{N_\mu}^2)(u - m_{N_\mu}^2)}\right\}, \tag{18}$$

where Γ_{Δ_L} is the decay width of the $\Delta_L^{(--)}$ boson. Considering only the prominent decay mode of $\Delta_{L,R}^{(--)}$ into $\tau^-\tau^-$, we obtain

$$\Gamma_{\Delta_{L,R}} = \frac{m_{N_\mu}^2}{16\pi v_{L,R}^2} m_{\Delta_{L,R}} \left(\frac{m_\tau}{m_{\Delta_{L,R}}}\right)^2 \sqrt{1 - \frac{4m_\tau^2}{m_{\Delta_{L,R}}^2}},$$

where m_τ is the τ-lepton mass. The differential cross section of the reaction

$$\mu_R^- + \mu_R^- \to W_k^- + W_n^- \tag{19}$$

follows from (18) by the substitution

$$g_L \to g_R, \qquad b_L^{(k)} \to b_R^{(k)}, \qquad \alpha \to \alpha + \frac{\pi}{2}, \qquad m_{\Delta_L} \to m_{\Delta_R}. \tag{20}$$

The total cross section of the reaction (19) is obtained from (18) after multiplication by $\beta s/2$ and substitution

$$\left.\begin{array}{c} \dfrac{B_3^{(kn)}(s,t,u)}{(t-m_{N_\mu}^2)^2} \\ \dfrac{B_3^{(kn)}(s,u,t)}{(u-m_{N_\mu}^2)^2} \end{array}\right\} \to D_3^{(kn)}(s), \tag{21}$$

$$\frac{B_4^{(kn)}(s,t,u)}{(t-m_{N_\mu}^2)(u-m_{N_\mu}^2)} \to D_4^{(kn)}(s), \tag{22}$$

where

$$D_3^{(kn)}(s) = \frac{1}{m_{W_n}^2 m_{W_k}^2}\left[1 + \frac{(m_{W_n}^2 + m_{W_k}^2 - s - 2m_{N_\mu}^2)\ln L}{2\beta s}\right] +$$
$$+\frac{1}{m_{N_\mu}^4}\left\{\frac{[4m_{W_n}^2 m_{W_k}^2 - 2m_{N_\mu}^2(m_{W_n}^2 + m_{W_k}^2 - s)](\ln L - \ln L_\nu)}{\beta s m_{N_\mu}^2} - 4\right\} + \frac{s(m_{W_n}^2 + m_{W_k}^2)C_\nu}{m_{W_n}^2 m_{W_k}^2}, \tag{23}$$

$$D_4^{(kn}(s) = -\frac{2[2s(m_{W_n}^2 + m_{W_k}^2) - C_\nu^{-1}]\ln L}{\beta s m_{W_n}^2 m_{W_k}^2 (m_{W_n}^2 + m_{W_k}^2 - s - 2m_{N_\mu}^2)} - \frac{1}{m_{W_n}^2 m_{W_k}^2} -$$
$$-\frac{8(m_{W_n}^2 + m_{W_k}^2)}{\beta m_{N_\mu}^2 (m_{N_\mu}^2 - m_{W_n}^2 - m_{W_k}^2 + s)}\left[\frac{\ln L}{m_{W_n}^2 + m_{W_k}^2 - s - 2m_{N_\mu}^2} - \frac{\ln L_\nu}{m_{W_n}^2 + m_{W_k}^2 - s}\right]. \tag{24}$$

For the total cross section of (17) we find the expression

$$\sigma_{LL}^{(kn)} = \beta \frac{(g_L^2 m_{N_\mu} b_L^{(k)} b_L^{(n)} \sin^2\alpha)^2}{256\pi s}\left\{\frac{s - 4(m_{W_n}^2 + m_{W_k}^2)}{m_{W_n}^2 m_{W_k}^2} + sC_\nu\left(3 + \frac{m_{N_\mu}^4 + m_{W_n}^2 m_{W_k}^2}{m_{W_n}^2 m_{W_k}^2}\right) +\right.$$
$$+\frac{\ln L}{\beta s}\left[\frac{2sm_{N_\mu}^2 + 2(m_{W_n}^2 + m_{W_k}^2 - s - 2m_{N_\mu}^2)(m_{W_n}^2 + m_{W_k}^2)}{m_{W_n}^2 m_{W_k}^2} +\right.$$
$$\left.+\frac{2}{m_{W_n}^2 + m_{W_k}^2 - s - 2m_{N_\mu}^2}\left(s - \frac{s - 2m_{W_n}^2 - 2m_{W_k}^2}{C_\nu m_{W_n}^2 m_{W_k}^2}\right)\right] +$$
$$+\frac{1}{(s - m_{\Delta_L}^2)^2 + \Gamma_{\Delta_L}^2 m_{\Delta_L}^2}\left[16s + \frac{2s(s - m_{W_n}^2 - m_{W_k}^2)^2}{m_{W_n}^2 m_{W_k}^2} + 16(s - m_{\Delta_L}^2)\left(\frac{\ln L}{\beta} +\right.\right.$$
$$\left.\left.\left.+\frac{s(m_{W_n}^2 + m_{W_k}^2 - s)}{4m_{W_n}^2 m_{W_k}^2}(1 + \frac{m_{N_\mu}^2 \ln L}{\beta s})\right)\right]\right\}. \tag{25}$$

Having done the replacement (20) in the expression (18), we get the total cross section of the reaction (19).

Now we discuss the asymptotic behavior of the cross sections obtained above. From the expressions (21), (22), and (25) we can see that their partial contributions violate the unitary limit. To be definite, in the case of LR electron beam they increase as a linear function of s, while for LL or RR electron beams those tend to constant values when

$s \to \infty$. However, in all cases the total cross section resulting from the sum of those contributions have a right asymptotic behavior

$$\sigma \sim s^{-1} \ln s. \tag{26}$$

It is caused by the cancelation among the partial contributions. We should stress that the reasons leading to (26) are quite different for LR and LL (or RR) polarized electron beams. In the former case the $\Delta^{(--)}$ contribution to the cross section is absent and the cancelation is connected with the spin behavior of the virtual neutrino. If the neutrino flips the helicity between the acts of emission and absorbtion then the amplitudes coming from ν_e and N_e exchanges are proportional to the neutrino masses. Since we neglected m_{ν_e} only the N_e exchange term will contribute. On the contrary, when the neutrino does not flip its helicity (this case is realized for LR electron beams) we have two nonvanishing terms. They are caused by ν_e and N_e exchanges and have opposite signs. As the calculations show, disregarding the contribution of the light neutrino would then lead to a cross section proportional to s.

As it follows from the expression for the cross section of the reaction $\mu^- + \mu^- \to W_k^- + W_n^-$ this reaction could be a good tool for the definition of such LRM parameters as m_{N_μ}, g_R, α, and ξ. Thus, for example, the values of $\sigma^{(kn)}$ strongly depend on m_{N_μ}. Let us set the following values for the LRM parameters:

$$m_{W_2} = 715 \text{ GeV}, \qquad m_{Z_2} = 800 \text{ GeV}, \qquad \phi = 9.6 \times 10^{-3}, \qquad \xi = 3.1 \times 10^{-2},$$

$$m_{\Delta_L} = 100 \text{ GeV}, \qquad m_{\Delta_R} = 110 \text{ GeV}, \qquad \alpha = 10^{-2}.$$

Then, at $m_{N_\mu} = 100$ GeV and $g_L = g_R$ in the energy region up to 200 GeV we have $\sigma_L^{(11)} \approx 8\sigma_R^{(11)} \approx 8 \times 10^{-2}$ fb whereas $\sigma_{LR}^{(11)}$ is about few $\times 10^{-3}$ fb. When increasing m_{N_μ} the contribution from $\sigma_{LR}^{(11)}$ becomes dominant. At $m_{N_\mu} = 1$ TeV and $\sqrt{s} = 200$ GeV we have

$$\sigma_R^{(11)} \approx 3.3 \cdot 10^{-3} \text{ pb}, \qquad \sigma_L^{(11)} \approx 2.6 \cdot 10^{-2} \text{ pb}, \qquad \sigma_{LR}^{(11)} \approx 5 \cdot 10^{-2} \text{ pb}.$$

It should be noted here that at the sufficiently great m_{N_μ} ($m_{N_\mu} > 5$ TeV) the cross section of the reaction $\mu^- + \mu^- \to W_1^- + W_1^-$ could reach the values that are compatible and even greater than the cross section of the reaction

$$e^- + e^+ \to W_1^- + W_1^+.$$

It might be well to point out that in the case

$$m_{\Delta_{L,R}} < (m_{W_n} + m_{W_k})$$

the cross section of the inverse neutrinoless β-decay weakly depends on a supposed value of $m_{\Delta_{L,R}}$. When violating this inequality, we shall have the s-channel resonance ($\Delta_{L,R}$-resonance) giving the increase of the total cross section for $e_L^- e_L^-$ and $e_R^- e_R^-$ beams. Note, in particular, that the signature of doubly charged Higgs bosons would strongly support the idea of a left-right approach.

Now we should pay some attention to the question of detecting the processes:

$$\mu^- \mu^- \to W_k^- W_n^- \to l_i^- l_j^- + \text{neutrinos}, \tag{27}$$

$$\mu^- \mu^- \to W_k^- W_n^- \to l_i^- + \text{jet} + \text{neutrinos}, \tag{28}$$

where i and j are the fermion flavors. The most clean signature is the case $i, j = e, \mu$ plus missing momentum carried away by neutrinos. In order to eliminate the major background coming from the RCs to elastic $e^- e^-$ scattering we should demand $i \neq j$ or the sizable $p_\perp$ of outgoing leptons. The cut on $p_\perp$ helps to reduce the QED background caused by radiative pair production

$$\mu^-\mu^- \to e^-e^-\mu^-\mu^+\tau^-\tau^+. \tag{29}$$

Other relevant background processes are

$$\mu^-\mu^- \to e^-e^-Z_k \longrightarrow e^-e^-l_i^-l_i^+, \tag{30}$$

$$\mu^-\mu^- \to e^-e^-Z_k \to e^-e^-\nu_l\overline{\nu_l}, \tag{31}$$

$$\mu^-\mu^- \to e^-e^-W_k^-W_n^+ \to e^-e^-l_i^-l_j^+\nu_i\overline{\nu_j}. \tag{32}$$

The main difference between the final states of the reactions (27),(28), and (29)–(32) is that in the former case they consist of like-sign leptons pair only. Therefore, it is easy to distinguish the W^-W^- signal from these backgrounds by means of the charged final-state leptons identification. We also have the background caused by multihadronic events

$$e^-e^- \longrightarrow e^-e^-W_k^-W_n^+q_i\overline{q_i}. \tag{33}$$

For this reaction there is no possibility to observe the high $p_\perp$ of the final like-sign leptons. Hence, we conclude that the cut on $p_\perp$ and the charged lepton identification of the outgoing leptons will be very useful in order to reduce backgrounds for the $W_k^-W_n^-$ signal.

At the MC the W^-W^- production is also possible in the regime of the fixed electron target

$$\mu^- + e^- \to W_k^- + W_n^-. \tag{34}$$

The expression for the cross section of this reaction could be obtained from $\sigma_{\mu^-\mu^-\to W^-W^-}$ by the corresponding replacement (see, for example, Ref. [7]).

4. Conclusions

Within the framework of the left-right model, the processes of pair production of the W^--bosons have been investigated. These processes go with the lepton flavor violation and could be observed at the projected muon colliders both in the regime of a fixed electron target

$$e^- + \mu^- \to W_k^- + W_n^- \tag{35}$$

and in the regime of colliding muon beams

$$\mu^- + \mu^- \to W_k^- + W_n^-. \tag{36}$$

In the second order of the perturbation theory the cross sections of the processes (35) and (36) have been calculated for the polarized initial particles. In our calculation we assume that in the neutrino sector the one-flavor approximation takes place.

It was shown that the cross sections of these processes are quite large and are increased with increasing mass of the heavy neutrino. For example, at a collider energy of 200 GeV and a heavy neutrino mass of about 1 TeV, the cross section of process (36) reaches values of 0.05 pb. In so doing the main contribution to the cross section comes from oppositely polarized initial particles.

The questions of detecting the processes (35) and (36) have been considered. It was demonstrated that the W^-W^- signal could be easy distinguished from backgrounds by means of the charged final-state leptons identification.

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