International Sakharov Environmental Institute of Belorussian State University

Decays of the Higgs and Z bosons going with lepton flavor violation

O.M.Boyarkin, G.G.Boyarkina, D.S.Vasileuskaya

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- The SM is based on the $SU(3)_c \times SU(2)_L \times U(1)_Y$ gauge group

- **Particles of the SM**

1) matter particles – quarks and leptons

$$\begin{pmatrix} \nu_e \\ e^- \end{pmatrix}, \qquad \begin{pmatrix} u \\ d' \end{pmatrix}^\alpha$$

$$\begin{pmatrix} \nu_\mu \\ \mu^- \end{pmatrix}, \qquad \begin{pmatrix} c \\ s' \end{pmatrix}^\alpha,$$

$$\begin{pmatrix} \nu_\tau \\ \tau^- \end{pmatrix}, \qquad \begin{pmatrix} t \\ b' \end{pmatrix}^\alpha.$$

$\alpha =$ red, green, blue

2) carriers of interactions $g_i, W^+, W^-, Z, \gamma.$

3) Higgs boson H

In the end we have 37 particles

Fundamental particles of the SM

It is convenient to present the fundamental particles of the SM in the three-dimensional coordinate system, in which the operator eigenvalues of the weak isospin projection on the third axis S_3^W are plotted along the z axis while the plane xy is used for the definition of the eigenvalues of the color spin operator $S^{(col)}$.
Two analogous prisms will correspond to the fundamental fermions of the second and third generations.

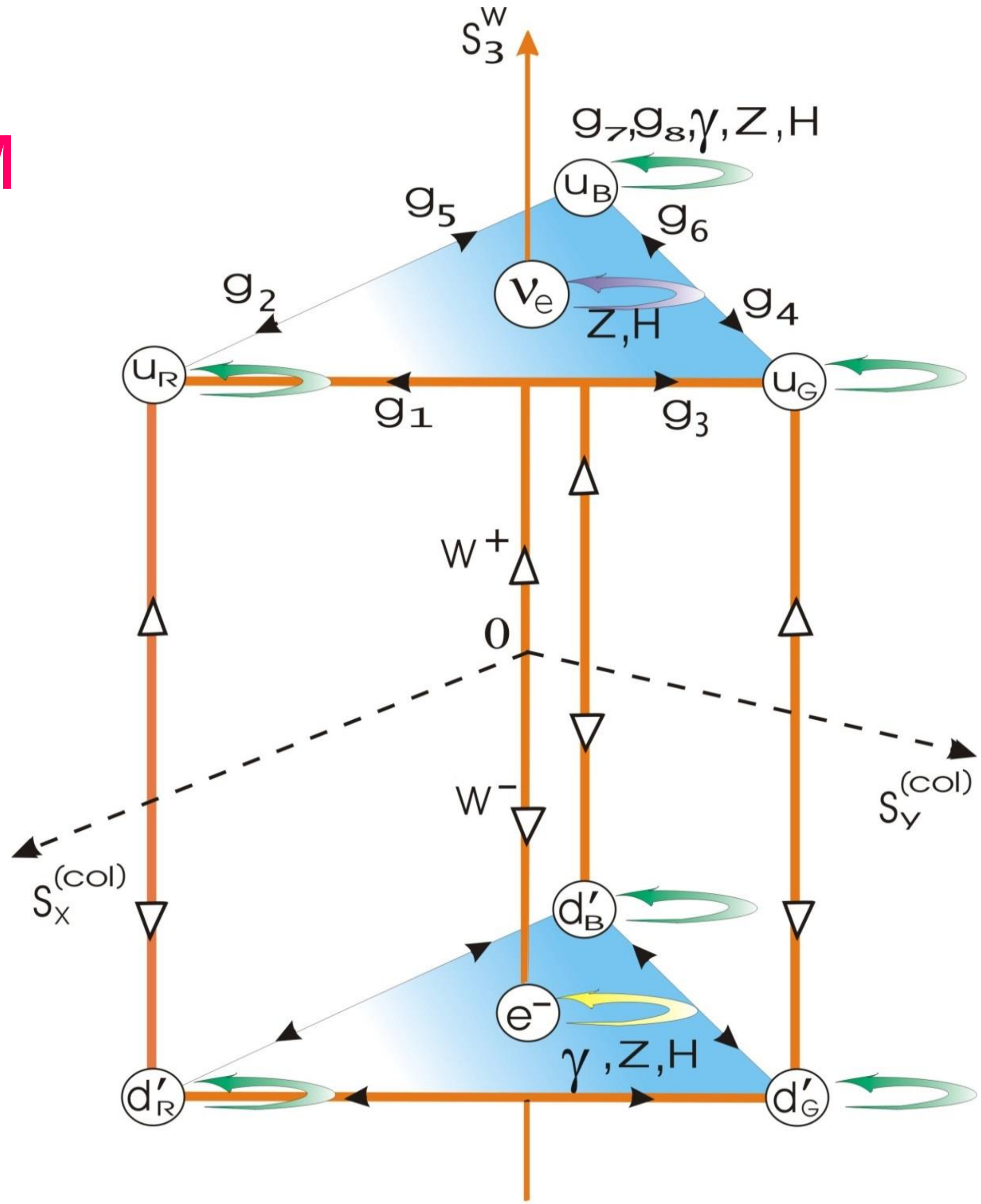

Fig. 44

Experimental data collected within the range of energies available today strongly support the standard model (SM)

However it is widely believed that the SM is not the ultimate truth

Expectations for departure from SM behavior are based on the following facts:

- **The SM has not found satisfactory explanation of baryon asymmetry of the Universe**
- **Neutrino mass smallness**
- **The value of the muon anomalous magnetic moment**
- **A lack of candidates on the role of weakly interacting massive particles which enter into the non-baryonic cold dark matter**

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. Of course, the minimally extended SM may be invoked for description of neutrino oscillation experiments but processes involving violation of charged lepton flavors (CLFV) are extremely suppressed in it because of the small neutrino masses. Therefore, a positive signal in any of the experimental looking for 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.

By now the strongest limits on the CLFV processes have been set in the $\mu \to e$ conversions in heavy nuclei and in the radiative $\mu \to e\gamma$ decay, whose branching ratios have been bounded to be below 7.0×10^{-13} and 4.2×10^{-13} by the SINDRUM II and MEG collaborations, respectively.

The currently running LHC could shed light on the CLFV as well.

Three new CLFV channels of the LFV Higgs boson decays into two leptons of different flavor, $H \to l_k \bar{l}_m$, have already been searched by the CMS and ATLAS experiments. Whilst CMS detected a small but intriguing excess in the $H \to \tau\mu$ channel after run-I, it has not been confirmed yet with run-II data. At present CMS has further enhanced the sensitivities of the LFV Higgs decays with new run-II data, setting the following upper bounds at the 95% CL:

$$\mathrm{BR}(H \to \mu e) < 3.5 \times 10^{-4}$$

$$\mathrm{BR}(H \to \tau e) < 0.61 \times 10^{-2}$$

$$\mathrm{BR}(H \to \tau\mu) < 0.25 \times 10^{-2}$$

The future LHC runs provide an upgrading of sensitivities to $\mathrm{BR}^{\mathrm{exp}}(H \to l_k \bar{l}_m)$ of at least two orders of magnitude with respect to the present sensitivity. In much the same way, at the planned lepton colliders ILC and TLEP, the expectations are of about 1 and 2 million Higgs boson events, respectively, with much lower backgrounds owing to the cleaner environment, which will also allow for a large improvement in LFV Higgs boson decay searches regarding to the current sensitivities.

Other interesting manifestation of the CLFV that the LHC is also searching for are the Z boson decays into two leptons of different flavor $Z \to l_k \bar{l}_m$.
Interestingly enough after the run-I, ATLAS has already reached the previous precision of the LEP experiment. The current LFV Z boson decay branching ratios are found to be

$$\mathrm{BR}(Z \to e^{\pm}\mu^{\mp}) < 1.7 \times 10^{-6}$$

$$\mathrm{BR}(Z \to e^{\pm}\tau^{\mp}) < 9.8 \times 10^{-6}$$

$$\mathrm{BR}(Z \to \mu^{\pm}\tau^{\mp}) < 1.2 \times 10^{-5}$$

At ILC and TLEP the sensitivities to LFV Z decay rates could be improved up to 10^{-9} and 10^{-13}, respectively.

The LFV decays of the Higgs and Z bosons have been studied for a long time in the literature within various SM extensions (see, for example, S.Baek, Phys. Rev. D 93 (2016) 015002; A.Abada et al. JHEP 04 (2015) 051). It is clear that amongst the models predicting the CLFV the models having common mechanism both for NLFV and for CLFV are most attractive. The LRM belongs among such models.

In this work we are going to investigate the CLFV decays of the Higgs and Z bosons from the point view of the LRM.

Why the LRM ?

1. LRM explains smallness neutrino masses (see-saw mechanism);
2. Quantum numbers of the U(1) group is identified with B-L that enables to connect the parity violation with the local B-L symmetry breaking;
3. LRM explains the observed value of the muon anomalous magnetic moment;
4. LRM predicts the values of the neutrino DMM which are close to the experimental bounds;
5. Within LRM one may obtain the upper experimental limit on the branching ratio for radiative muon decay $\mu^{\pm} \rightarrow e^{\pm} + \gamma$;
6. In LRM all the fundamental fermions enter the theory in symmetric way (they form left- and right-handed doublets according to weak isospin)

$$Q_L^a(\frac{1}{2}, 0, \frac{1}{3}) = \begin{pmatrix} u_L^a \\ d_L^a \end{pmatrix}, \qquad Q_R^a(0, \frac{1}{2}, \frac{1}{3}) = \begin{pmatrix} u_R^a \\ d_R^a \end{pmatrix},$$

$$\Psi_L^a(\frac{1}{2}, 0, -1) = \begin{pmatrix} \nu_{aL} \\ l_{aL} \end{pmatrix}, \qquad \Psi_R^a(0, \frac{1}{2}, -1) = \begin{pmatrix} N_{aR} \\ l_{aR} \end{pmatrix},$$

that is, the initial Lagrangian is P -invariant;
7. LRM offers a satisfactory explanation of the neutrino oscillations.

The Higgs sector content is as follows

$$\Phi = \begin{pmatrix} \Phi_1^0 & \Phi_2^+ \\ \Phi_1^- & \Phi_2^0 \end{pmatrix}$$

$$(\tau \cdot \Delta_L) = \begin{pmatrix} \delta_L^+/\sqrt{2} & \delta_L^{++} \\ \delta_L^0 & -\delta_L^+/\sqrt{2} \end{pmatrix}, \qquad (\tau \cdot \Delta_R) = \begin{pmatrix} \delta_R^+/\sqrt{2} & \delta_R^{++} \\ \delta_R^0 & -\delta_R^+/\sqrt{2} \end{pmatrix}$$

The spontaneous symmetry breaking is realized for the following choice of the vacuum expectation values:

$$< \delta_{L,R}^0 >= \frac{v_{L,R}}{\sqrt{2}}, \qquad < \Phi_1^0 >= k_1, \qquad < \Phi_2^0 >= k_2.$$

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

After the SSB we are left with 14 Higgs bosons: four doubly-charged scalars $\Delta^{(\pm\pm)}_{1,2}$, four singly-charged scalars $\tilde{\delta}^{(\pm)}$ and $h^{(\pm)}$, four neutral scalars $S_{1,2,3,4}$, and two neutral pseudo scalars $P_{1,2}$. The S_1 boson is an analog of the SM Higgs boson (H).

The masses of fermions and their interactions with the gauge bosons are controlled by the Yukawa Lagrangian. Its expression for the lepton sector will look like

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

$$+ i f_{ab} [\Psi^T_{aL} C \tau_2 (\tau \cdot \Delta_L) \Psi_{bL} + (L \to R)] + \text{h.c.}\},$$

h_{ab}, h'_{ab} and $f_{ab} = f_{ba}$ are bidoublet and triplet Yukawa couplings(YC’s),respectively.

It is convenient to express the coupling constants of the S_1 boson with the neutrinos in terms of neutrino oscillation parameters. In the two flavor appro-ximation the neutrino mass matrix in the basis $\Psi^T = \left(\nu^T_{aL}, N^T_{aR}, \nu^T_{bL}, N^T_{bR} \right)$ is given by the expression

$$M = \begin{pmatrix} f_{aa} v_L & m^a_D & f_{ab} v_L & M_D \\ m^a_D & f_{aa} v_R & M'_D & f_{ab} v_R \\ f_{ab} v_L & M'_D & f_{bb} v_L & m^b_D \\ M_D & f_{ab} v_R & m^b_D & f_{bb} v_R \end{pmatrix}.$$

$$m^a_D = h_{aa} k_1 + h'_{aa} k_2,$$

$$M_D = h_{ab} k_1 + h'_{ab} k_2, \qquad M'_D = h_{ba} k_1 + h'_{ba} k_2.$$

The transition to the eigenstate neutrino mass basis m_i $(i = 1, 2, 3, 4)$ is carried out by the matrix

$$U = \begin{pmatrix} c_{\varphi_a} c_{\theta_\nu} & s_{\varphi_a} c_{\theta_N} & c_{\varphi_a} s_{\theta_\nu} & s_{\varphi_a} s_{\theta_N} \\ -s_{\varphi_a} c_{\theta_\nu} & c_{\varphi_a} c_{\theta_N} & -s_{\varphi_a} s_{\theta_\nu} & c_{\varphi_a} s_{\theta_N} \\ -c_{\varphi_b} s_{\theta_\nu} & -s_{\varphi_b} s_{\theta_N} & c_{\varphi_b} c_{\theta_\nu} & s_{\varphi_b} c_{\theta_N} \\ s_{\varphi_b} s_{\theta_\nu} & -c_{\varphi_b} s_{\theta_N} & -s_{\varphi_b} c_{\theta_\nu} & c_{\varphi_b} c_{\theta_N} \end{pmatrix},$$

where φ_a and φ_b are the mixing angles between heavy and light neutrinos inside a and b generations, respectively, $\theta_\nu (\theta_N)$ is the mixing angle between the light (heavy) neutrinos belonging to the a and b generations.

Using the eigenvalues equation for the mass matrix we get the relations connecting the YC's with the masses and mixing angles of the neutrinos

$$m_D^a = c_{\varphi_a} s_{\varphi_a} (-m_1 c^2_{\theta_\nu} - m_3 s^2_{\theta_\nu} + m_2 c^2_{\theta_N} + m_4 s^2_{\theta_N}),$$

$$m_D^b = m_D^a(\varphi_a \to \varphi_b, \theta_{\nu,N} \to \theta_{\nu,N} + \frac{\pi}{2}), \qquad M'_D = M_D(\varphi_a \leftrightarrow \varphi_b),$$

$$M_D = c_{\varphi_a} s_{\varphi_b} c_{\theta_\nu} s_{\theta_\nu} (m_1 - m_3) + s_{\varphi_a} c_{\varphi_b} c_{\theta_N} s_{\theta_N} (m_4 - m_2),$$

$$f_{ab} v_R = s_{\varphi_a} s_{\varphi_b} c_{\theta_\nu} s_{\theta_\nu} (m_3 - m_1) + c_{\varphi_a} c_{\varphi_b} c_{\theta_N} s_{\theta_N} (m_4 - m_2),$$

$$f_{aa} v_R = (s_{\varphi_a} c_{\theta_\nu})^2 m_1 + (c_{\varphi_a} c_{\theta_N})^2 m_2 + (s_{\varphi_a} s_{\theta_\nu})^2 m_3 + (c_{\varphi_a} s_{\theta_N})^2 m_4,$$

$$f_{bb} v_R = (s_{\varphi_b} s_{\theta_\nu})^2 m_1 + (c_{\varphi_b} s_{\theta_b})^2 m_2 + (s_{\varphi_b} c_{\theta_\nu})^2 m_3 + (c_{\varphi_b} c_{\theta_N})^2 m_4,$$

The change $L \to R$ results in the replacement $\varphi_{a,b} \to \varphi_{a,b} + \frac{\pi}{2}$

Calculations give the exact formula for the heavy-light neutrino mixing angle

$$\sin 2\varphi_a = 2\frac{\sqrt{f_{aa}^2 v_R v_L - [f_{aa}(v_R + v_L) - m_{\nu_1} c^2_{\theta_\nu} - m_{\nu_2} s^2_{\theta_\nu}](m_{\nu_1} c^2_{\theta_\nu} + m_{\nu_2} s^2_{\theta_\nu})}}{f_{aa}(v_R + v_L) - 2(m_{\nu_1} c^2_{\theta_\nu} + m_{\nu_2} s^2_{\theta_\nu})}, \quad \sin 2\varphi_b = \sin 2\varphi_a \left(f_{aa} \to f_{bb}, \theta_\nu \to \theta_\nu + \frac{\pi}{2} \right.$$

The heavy-light mixing angles belonging to different generations are practically equal in value

$$\sin 2\varphi_a \simeq \sin 2\varphi_b \simeq 2\frac{\sqrt{v_R v_L}}{v_R + v_L} \equiv \sin 2\varphi.$$

$$v_R \leq 5.7 \ \text{TeV} \qquad v_L \leq 3 \ \text{GeV} \qquad \longrightarrow \qquad (\sin 2\varphi)_{\max} \simeq 4.6 \times 10^{-2}.$$

The Lagrangians we need are as follows

$$L_l = -\frac{1}{\sqrt{2}k_+}\{\sum_a m_a \bar{l}_{aR} l_{aL} S_1 + \sum_{a,b} \overline{N}_{aR} \nu_{bL} [h_{ab} k_1 + h'_{ab} k_2] S_1\} + \text{h.c.}.$$

$$\mathcal{L}_{WWV} = i\rho_{kl}^{(V)} B_{\mu\nu,\lambda\sigma}\Big\{[\partial^\mu W_k^{\lambda *}(x)] W_l^\nu(x) V^\sigma(x) + W_k^{\sigma *}(x)[\partial^\mu W_l^\lambda(x)] V^\nu(x) +$$

$$+ W_k^{\nu *}(x) W_l^\sigma(x)[\partial^\mu V^\lambda(x)]\Big\},$$

where $k, l = 1, 2$, $V = Z_1, Z_2$, $\rho_{ll}^{(Z_1)} = \cos^2\left(\xi + \frac{\pi}{2}\delta_{l2}\right) g_L M_{11} + \sin^2\left(\xi + \frac{\pi}{2}\delta_{l2}\right) g_R M_{12}$,

$$\rho_{kl}^{(Z_1)} = \rho_{lk}^{(Z_1)} = \frac{1}{2}\sin 2\xi (g_L M_{11} - g_R M_{12}), \qquad B^{\mu\nu,\lambda\sigma} = g^{\mu\nu} g^{\lambda\sigma} - g^{\mu\sigma} g^{\nu\lambda},$$

$$M = \begin{pmatrix} \cos\phi & \sin\phi \\ -\sin\phi & \cos\phi \end{pmatrix} \begin{pmatrix} e(g'^{-2} + g_R^{-2})^{1/2} & -e g_L^{-1} g_R^{-1} (g'^{-2} + g_R^{-2})^{-1/2} \\ 0 & g'^{-1}(g'^{-2} + g_R^{-2})^{-1/2} \end{pmatrix},$$

$$\rho_{ll}^{(Z_2)}, \rho_{kl}^{(Z_2)} \quad \longrightarrow \quad g_L M_{11} \to g_R M_{22}, \quad g_L M_{12} \to g_R M_{21}, \quad \xi \to \xi + \frac{\pi}{2}.$$

$$L_l^{CC} = \frac{g_L}{2\sqrt{2}} \sum_l [\bar{l}(x)\gamma^\mu (1 - \gamma_5) \nu_{lL}(x) W_{L\mu}(x) + \bar{l}(x)\gamma^\mu (1 + \gamma_5) N_{lR}(x) W_{R\mu}(x)],$$

$$W_1 = W_L \cos\xi + W_R \sin\xi, \qquad W_2 = -W_L \sin\xi + W_R \cos\xi,$$

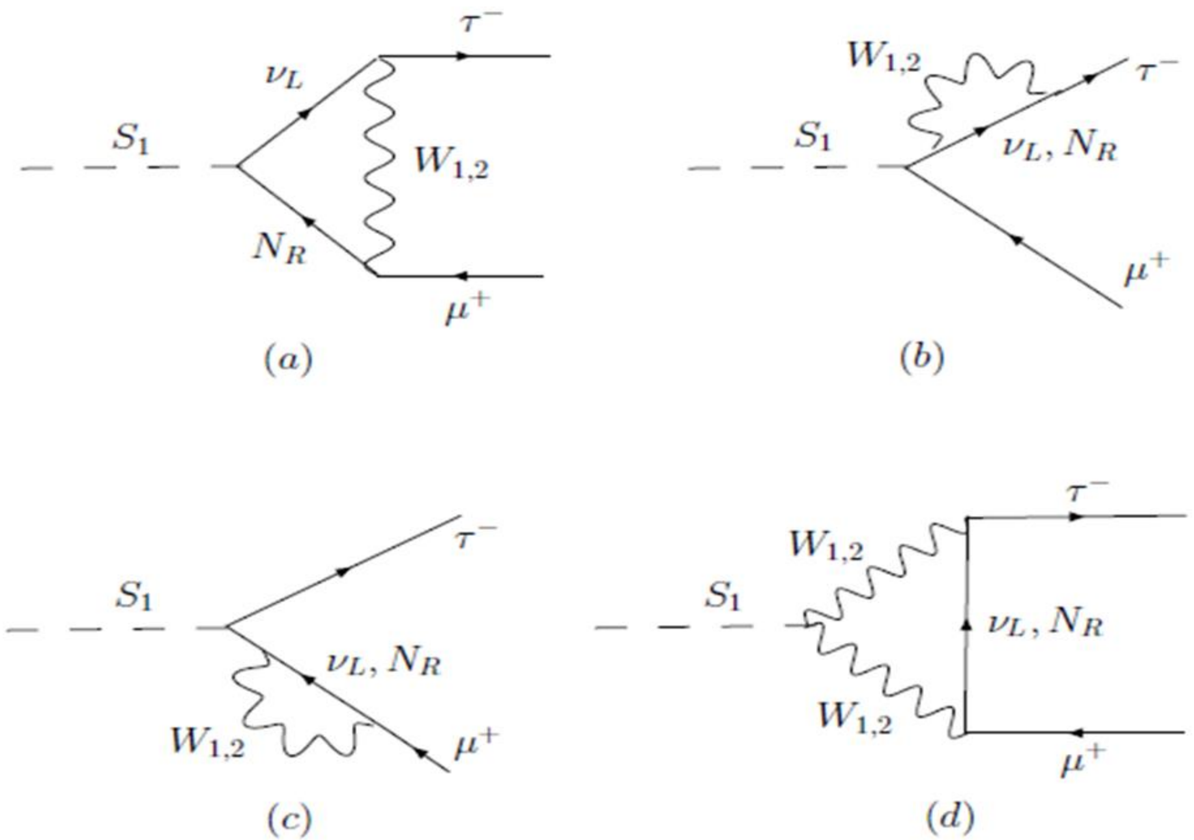

Figure 1: The Feynman diagrams contributing to the decay $S_1 \to \mu^+ + \tau^-$.

For the sake of simplicity we shall consider the individual contributions of each diagram to the total width of the decay. Let us start with kind of the diagrams one of them shown in Fig.1a. There are eight diagrams depending on what neutrinos are produced in the virtual state. For example, when in the virtual state the $\nu_\tau \overline{N}_\tau$ pair comes into being the corresponding matrix element takes the form

$$M_1^{(a)} = \frac{g_L^2 m_D^\tau \cos\alpha \sin 2\theta_N \sin\xi}{32k_+\sqrt{2}} \sqrt{\frac{m_\tau m_\mu}{2m_{S_1} E_\tau E_\mu}} \bar{u}(p_1)\gamma_\lambda(1-\gamma_5)\{\int_\Omega \frac{\hat{p}-\hat{k}+m_{\nu_i}}{(p-k)^2 - m_{\nu_i}^2} \times$$

$$\times(1+\gamma_5)[\frac{\hat{k}+m_{N_2}}{k^2 - m_{N_2}^2} - \frac{\hat{k}+m_{N_1}}{k^2 - m_{N_1}^2}]\gamma_\sigma(1+\gamma_5) \frac{g^{\lambda\sigma} - (k-p_2)^\lambda (k-p_2)^\sigma / m_{W_1}^2}{(k-p_2)^2 - m_{W_1}^2} d^4k\} v(p_2),$$

Taking into account connection between the Yukawa couplings and neutrino oscillation parameters, we find that the matrix element corresponding to all eight diagrams is given by the expression

$$M^{(a)} = \sum_{i=1}^{8} M_i^{(a)} = \frac{g_L^2 \cos\alpha \sin 2\varphi \sin 2\theta_N \sin\xi}{16k_+\sqrt{2}} \sqrt{\frac{m_\tau m_\mu}{2m_{S_1} E_\tau E_\mu}} \bar{u}(p_1)\gamma_\lambda(1-\gamma_5)\{\int_\Omega \frac{\hat{p}-\hat{k}+m_{\nu_i}}{(p-k)^2 - m_{\nu_i}^2} \times$$

$$\times(1+\gamma_5)[\frac{m_{N_2}(\hat{k}+m_{N_2})}{k^2 - m_{N_2}^2} - \frac{m_{N_1}(\hat{k}+m_{N_1})}{k^2 - m_{N_1}^2}]\gamma_\sigma(1+\gamma_5) \frac{g^{\lambda\sigma} - (k-p_2)^\lambda (k-p_2)^\sigma / m_{W_1}^2}{(k-p_2)^2 - m_{W_1}^2} d^4k\} v(p_2).$$

Using the procedure of dimensional regularization, we get

$$\Gamma(S_1 \to \bar{\nu}_L^* N_R^* W_1^* \to \mu^+\tau^-) = \frac{\pi^3 (g_L^2 \cos\alpha \sin 2\varphi \sin 2\theta_N \sin\xi)^2}{16 m_{S_1}^3} \{4m_\tau m_\mu (\Delta L)(\Delta R) +$$

$$+(m_{S_1}^2 - m_\tau^2 - m_\mu^2)[(\Delta L)^2 + (\Delta R)^2]\} \sqrt{(m_{S_1}^2 - m_\mu^2 - m_\tau^2)^2 - 4m_\mu^2 m_\tau^2},$$

Could the obtained expressions for $\mathrm{BR}(S_1 \to \tau^- \mu^+)$ reproduce the experimental bound on the branching ratio of the decay $S_1 \to \tau^- \mu^+$?

First and foremost we note that the width of this decay does not equal to zero only provided the heavy neutrino masses are hierarchical while the heavy-heavy and heavy-light neutrino mixing angles do not equal to zero. For example, we may get the results

$$\mathrm{BR}(S_1 \to \tau^- \mu^+) \simeq \begin{cases} 0.24 \times 10^{-4}, & \text{when} \quad \sin\varphi = 2.3 \times 10^{-2}, \\ 0.45 \times 10^{-6}, & \text{when} \quad \sin\varphi = 3.2 \times 10^{-3}. \end{cases}.$$

We see that the theoretical expression for the branching ratio of the decay $S_1 \to \tau^- \mu^+$ proves to be, at its best, on two orders of magnitude less than the upper experimental bound.

On the other hand, it should be remembered that in our case $\mathrm{BR}(S_1 \to \tau^- \mu^+)_{exp}$ is nothing more than the experiment precision limit, rather than the measured value of the branching ratio. Therefore, the experimental programs with higher precision than at present are required to get more detail information about the decay $S_1 \to \tau^- \mu^+$

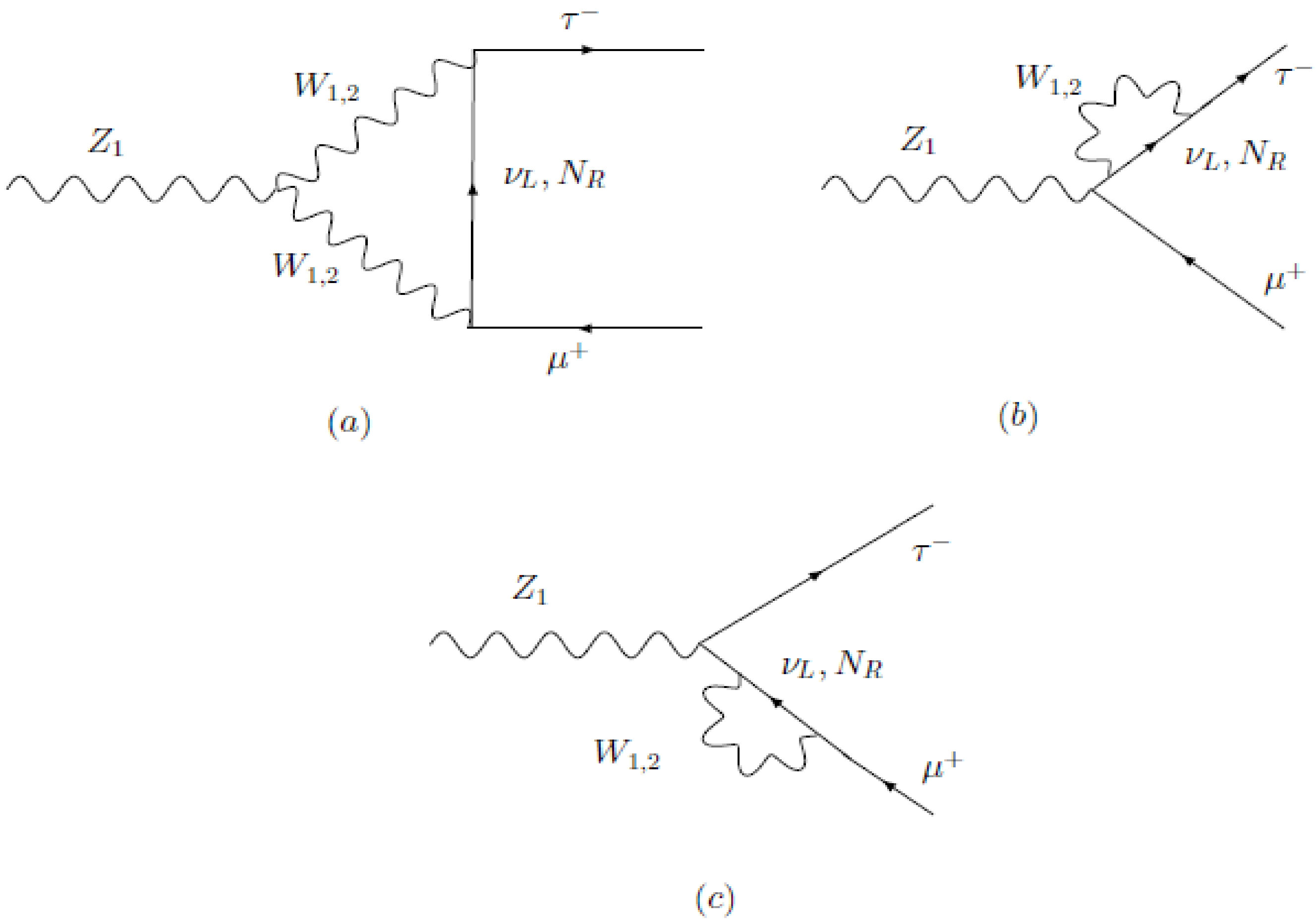

Figure 1: The Feynman diagrams contributing to the decay $Z_1 \to \mu^+ + \tau^-$.

Let us show how the dependence on the mixings angles of heavy neutrinos appears in the matrix element of the reaction

$$Z \to \tau^+ + \mu^-$$

Matrix element includes the term $\nu^{s}_{\tau L}(x)\overline{\nu}^{s}_{\mu L}(y)$ which gives .

$$\nu^s_{\tau L}(x)\overline{\nu}^s_{\mu L}(y) = \Big\{ -\cos\varphi_\tau \sin\theta_\nu \nu_1(x) - \sin\varphi_\tau \sin\theta_N N_1(x) + \cos\varphi_\tau \cos\theta_\nu \nu_2(x) +$$

$$+ \sin\varphi_\tau \cos\theta_N N_2(x)\Big\}^s \Big\{ \cos\varphi_\mu \cos\theta_\nu \overline{\nu}_1(y) + \sin\varphi_\mu \cos\theta_N \overline{N}_1(y) + \cos\varphi_\mu \sin\theta_\nu \overline{\nu}_2(y$$

$$+ \sin\varphi_\mu \sin\theta_N \overline{N}_2(y)\Big\}^s \simeq \sin^2\varphi \sin\theta_N \cos\theta_N [N_2^s(x)\overline{N}_2^s(y) - N_1^s(x)\overline{N}_1^s(y)], \qquad \textbf{(A)}$$

where convolution of the operators is symbolized by s and in the momentum representation the heavy neutrino propagator has the form

$$\frac{\hat{p} + m_{N_i}}{p^2 - m^2_{N_i}}$$

$$M^{(a)} = \frac{g_L^3 c_W \sin 2\theta_{\mu\tau} \sin^2\varphi}{8} \sqrt{\frac{m_\tau m_\mu}{2m_{Z_1} E_\tau E_\mu}}\, \overline{u}(p_1)\gamma^m(1-\gamma_5) \int_\Omega \Big\{ \Big[\frac{\hat{k} - \hat{p}_2 + m_{N_2}}{(k-p_2)^2 - m^2_{N_2}} -$$

$$- \frac{\hat{k} - \hat{p}_2 + m_{N_1}}{(k-p_2)^2 - m^2_{N_1}} \Big] \gamma^n (1-\gamma_5) v(p_2) \Big[g_{\sigma\lambda} \Lambda_{m\nu}(k-p) \Lambda_{n\beta}(k) k_\mu -$$

$$- g_{\nu\lambda} \Lambda_{n\sigma}(k) \Lambda_{m\beta}(k-p)(k-p)_\mu - g_{\beta\lambda} \Lambda_{m\sigma}(k-p) \Lambda_{n\nu}(k) p_\mu \Big] B^{\mu\nu,\beta\sigma} Z^\lambda(p) \Big\} d^4k,$$

where

$$\Lambda_{\mu\nu}(k) = \frac{g_{\mu\nu} - k_\mu k_\nu / m^2_{W_1}}{k^2 - m^2_{W_1}},$$

Calculations lead to the result

$$\Gamma(Z_1 \to W_1^{-*} W_1^{+*} \nu_L^* \to \tau^- \mu^+) \simeq \frac{g_L^6 c_W^2 \pi^3 \sin\varphi^4 \sin^2 2\theta_{\mu\tau} m_{Z_1}}{64 m_{Z_1}^3} f_{A,A}(m_{N_1}, m_{N_2}),$$

Setting

$$\theta = \frac{\pi}{4}, \qquad \varphi = 2.3 \times 10^{-2},$$

we get

$$\mathrm{BR}(Z_1 \to \tau\mu) \simeq \begin{cases} 0.5 \times 10^{-7}, & \text{when} \quad m_{N_1} = 100 \text{ GeV}, \ m_{N_2} = 150 \text{ GeV}, \\ 0.3 \times 10^{-6}, & \text{when} \quad m_{N_1} = 100 \text{ GeV}, \ m_{N_2} = 200 \text{ GeV}, \\ 0.4 \times 10^{-7}, & \text{when} \quad m_{N_1} = 150 \text{ GeV}, \ m_{N_2} = 200 \text{ GeV}. \end{cases} \qquad \text{(I)}$$

From (I) follows that, at its best, the theoretical expression for the branching ratio of the decay $Z_1 \to \tau^- + \mu^-$ appears to be on two orders of magnitude less than the upper experimental bound produced by CMS and ATLAS.

Conclusions

1. Within the LRM the decays

$$S_1 \to \tau^- + \mu^- \quad , \qquad\qquad Z_1 \to \tau^- + \mu^- \qquad (1)$$

have been investigated. The theoretical values of these decay widths prove to be on two orders of magnitude less than the upper experimental bounds obtained at ATLAS and CMS.

2. It is shown that observation of the decays (1) **gives information on the following parameters of the LRM neutrino sector: (i) heavy-heavy neutrino mixing; (ii) heavy-light neutrino mixing; (iii) heavy neutrino masses**

So that is how things are