HIGGS BOSON PRODUCTION IN NEUTRINO-ELEKTRON SCATTERING

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In the framework of Standard Model the processes of scalar Higgs boson production in neutrino-electron scattering has been investigated: $\nu_\mu e^- \to H\nu_\mu e^-$, $\nu_\mu e^- \to H\nu_e\mu^-$. The ZZ-fusion and WW-fusion mechanisms are the most important mechanisms for the production of Higgs bosons in neutrino-electron scattering. It is shown that, the process $\nu_\mu e^- \to H\nu_\mu e^-$ is defined by only two helicity amplitudes: F_{LL} and F_{LR} which describe following reactions: $\nu_\mu e_L^- \to H\nu_\mu e_L^-$, $\nu_\mu e_R^- \to H\nu_\mu e_R^-$. The mechanism $WW \to H$ is defined by one helicity amplitude, which describes the process $\nu_\mu e_L^- \to H\nu_e\mu_L^-$. We have calculated the cross sections for the helicity processes and detailed numerical results are presented.

Keywords: Standard Model, Higgs boson, left and right coupling constants, helicity amplitudes, Weinberg's parameter, helicity.
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1. INTRODUCTION.

The Standard Model (SM) to describe the strong and electroweak interactions between quarks and leptons, is based on the gauge symmetry group $SU(3)_C \times SU(2)_L \times U(1)_Y$. A cornerstone of the *SM* is the mechanism of spontaneous electroweak symmetry breaking. An *SU*(2) doublet of complex scalar field is introduced and its neutral component develops a non-zero vacuum expectation value. As a consequence, the electroweak $SU(2)_L \times U(1)_Y$ symmetry is spontaneously broken to the electromagnetic $U_Q(1)$ symmetry. Three of the four degrees of freedom of the doublet scalar field are absorbed by the $W^\pm$ and *Z* weak vector bosons to form their longitudinal polarizations and to acquire masses. The remaining degree of freedom corresponds to a scalar particle, the Higgs boson.

Some experiments are carried out for the discovery of Higgs boson in different experimental labs. Finally in LHC new information are received concerning the existence of Higgs boson with the mass of 125 *GeV* [1-5]. So the channels which give rise to Higgs bosons have got more attentions [6-14].

In this work the neutrino-electron scattering are studied for the sake of production of Higgs boson:

$$\nu_\mu + e^- \to H + \nu_\mu + e^-, \qquad (1)$$

$$\nu_\mu + e^- \to H + \nu_e + \mu^-. \qquad (2)$$

2. THE *ZZ* FUSION MECHANISM

The Feynman diagrams for the Higgs boson production in the ZZ fusion mechanism in the neutrino-electron collisions is shown in the Fig. 1 (the 4-momentum of particles are shown over the diagram).

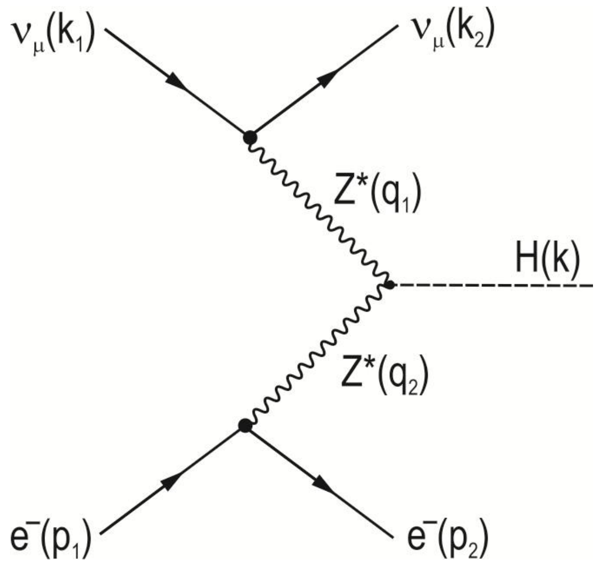

Fig.1. The Feynman diagram for the processes $\nu_\mu e^- \to H\nu_\mu e^-$.

As we know the lagrangians for interaction of fermions with Z^0-boson and Z^0-boson with Higgs boson can be written as follow [15]:

$$L_{\nu_\mu\nu_\mu Z} = \frac{e}{2\sin\theta_w.\cos\theta_w}\frac{1}{2}\bar{\nu}_\mu\gamma_\mu(1+\gamma_5)\nu_\mu \cdot Z_\mu, \qquad (3)$$

$$L_{eeZ} = \frac{e}{2\sin\theta_w.\cos\theta_w}\bar{e}\gamma_\mu[g_L(1+\gamma_5)+g_R(1-\gamma_5)]e\cdot Z_\mu, \qquad (4)$$

$$L_{ZZH} = \frac{e}{\sin\theta_w.\cos\theta_w}M_Z Z_\mu Z_\rho g_{\mu\rho}H(k). \qquad (5)$$

Here

$$g_L = -\frac{1}{2}+\sin^2\theta_w, \qquad g_R = \sin^2\theta_w \qquad (6)$$

– are the left and right couplings constants handed

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electrons with Z^0-boson, $x_W = \sin^2\theta_W -$ is the Weinberg's parameter ($\theta_W -$ is the Weinberg's angle), $M_Z -$ is the mass of Z^0-boson.

According to the lagrangians given in (3)-(5) for the $\nu_\mu + e^- \to H + \nu_\mu + e^-$ we can write the following transition amplitude:

$$M(\nu_\mu e^- \to H\nu_\mu e^-) = \left(\frac{e}{2\sin\theta_W \cos\theta_W}\right)^3 M_Z D_{\mu\rho}(q_1) D_{\rho\nu}(q_2)\bar{u}(k_2)\gamma_\mu(1+\gamma_5)u(k_1)\times$$

$$\times\bar{u}(p_2, \lambda_2)\gamma_\nu[g_L(1+\gamma_5)+g_R(1-\gamma_5)]u(p_1,\lambda_1) \qquad (7)$$

Here

$$D_{\mu\rho}(q_1) = \left(-g_{\mu\rho} + \frac{q_{1\mu}q_{1\rho}}{M_Z^2}\right)\cdot\frac{1}{q_1^2 - M_Z^2} \qquad (8)$$

– is the propagator of Z^0-boson, $q_1 = k_1 - k_2$, $q_2 = p_1 - p_2$, λ_1 and λ_2 are the helicities initial and final electrons.

The neutrino and electron weak currents are conserved:

$$(k_1 - k_2)_\mu \bar{u}(k_2)\gamma_\mu(1+\gamma_5)u(k_1) = 0$$

$$(p_1 - p_2)_\nu \bar{u}(p_2, \lambda_2)\gamma_\nu[g_L(1+\gamma_5)+g_R(1-\gamma_5)]u(p_1,\lambda_1) = 0.$$

This will make the amplitude (7) to take a simpler form:

$$M(\nu_\mu e^- \to H\nu_\mu e^-) = \left(\frac{e}{2\sin\theta_W \cos\theta_W}\right)^3 M_Z D_1\, D_2[\bar{u}(k_2)\gamma_\mu(1+\gamma_5)u(k_1)\times$$

$$\times[\bar{u}(p_2, \lambda_2)\gamma_\mu[g_L(1+\gamma_5)+g_R(1-\gamma_5)]u(p_1,\lambda_1). \qquad (9)$$

Here

$$D_1 = (q_1^2 - M_Z^2)^{-1}, \qquad D_2 = (q_2^2 - M_Z^2)^{-2}. \qquad (10)$$

As we know the helicity is conserved at high energies. The conservation of helicity implay that initial electron and final electron at the same vertex to have the same helicities: $e^-_{L(R)} \to e^-_{L(R)}$. Here $e^-_L(e^-_R)$ – is the electron with left (right) helicity. So two helicity amplitudes will correspond to the processes $\nu_\mu + e^- \to H + \nu_\mu + e^-$: F_{LL} and F_{LR} (first and second indices indicate the initial and final helicities of neutrino and electron). These helicity amplitudes describe the following reactions:

$$\nu_\mu + e^-_L \to H + \nu_\mu + e^-_L, \quad \nu_\mu + e^-_R \to H + \nu_\mu + e^-_R$$

and in the framework of SM they are given by expressions

$$F_{LL} = D_1 D_2 g_L, \qquad F_{LR} = D_1 D_2 g_R. \qquad (11)$$

Let's first calculate the square of amplitude for the spirality process $\nu_\mu + e^-_L \to H + \nu_\mu + e^-_L$:

$$|M_{LL}|^2=\left(\frac{e^2}{4x_w(1-x_w)}\right)^3\cdot M_Z^2\cdot F_{LL}^2\cdot T_{\mu\nu}^{(1)}\cdot T_{\mu\nu}^{(2)}. \tag{12}$$

Here $T_{\mu\nu}^{(1)}$ and $T_{\mu\nu}^{(2)}$ are the tensors of neutrino and electron:

$$T_{\mu\nu}^{(1)}=Sp[u(k_2)\bar{u}(k_2)\gamma_\mu(1+\gamma_5)u(k_1)\bar{u}(k_1)\gamma_\nu(1+\gamma_5)]=$$

$$=8[k_{1\mu}k_{2\nu}+k_{2\mu}k_{1\nu}-(k_1.k_2)g_{\mu\nu}-i\varepsilon_{\mu\nu\rho\sigma}k_{1\rho}k_{2\sigma}], \tag{10}$$

$$T_{\mu\nu}^{(2)}=Sp[u(p_2,\lambda_2)\bar{u}(p_2,\lambda_2)\gamma_\mu(1+\gamma_5)u(p_1,\lambda_1)\bar{u}(p_1,\lambda_1)\gamma_\nu(1+\gamma_5)]=$$

$$=2(1-\lambda_1)(1-\lambda_2)[p_{1\mu}p_{2\nu}+p_{2\mu}p_{1\nu}-(p_1.p_2)g_{\mu\nu}-i\varepsilon_{\mu\nu\alpha\beta}p_{1\alpha}p_{2\beta}]\cdot \tag{11}$$

The product of two tensors $T_{\mu\nu}^{(1)}$ and $T_{\mu\nu}^{(2)}$ is a simple expression:

$$T_{\mu\nu}^{(1)}\cdot T_{\mu\nu}^{(2)}=2^6(1-\lambda_1)(1-\lambda_2)(p_1\cdot k_1)(p_2\cdot k_2). \tag{12}$$

So, the square amplitude of the process $\nu_\mu+e_L^-\to H+\nu_\mu+e_L^-$ will be equal to:

$$|M_{LL}|^2=\left(\frac{e^2}{x_w(1-x_w)}\right)^3 M_Z^2.F_{LL}^2\cdot(1-\lambda_1)(1-\lambda_2)(p_1\cdot k_1)(p_2\cdot k_2) \tag{13}$$

Analogically we can calculate the square of amplitude for the spirality process $\nu_\mu+e_R^-\to H+\nu_\mu+e_R^-$:

$$|M_{LR}|^2=\left(\frac{e^2}{x_w(1-x_w)}\right)^3 M_Z^2.F_{LR}^2\cdot(1+\lambda_1)(1+\lambda_2)(p_1\cdot k_2)(p_2\cdot k_1). \tag{14}$$

In the center of mass frame the cross section for the helicity processes $\nu_\mu+e_L^-\to H+\nu_\mu+e_L^-$ is equal to:

$$\sigma_{LL}=\int\frac{|M_{LR}|^2}{16s(2\pi)^5}\delta(p_1+k_1-p_2-k_2-k)\frac{d\vec{p}_2}{E_2}\frac{d\vec{k}_2}{\omega_2}\frac{d\vec{k}}{E_H}. \tag{15}$$

Here $\sqrt{s}$ is the total energy of neutrino and electron in the center of mass system.

Following Ref. [12] and recalling that the transverse momenta of the scattered particles are small, one may write the four momenta as

$$k_1=\left(\frac{\sqrt{s}}{2},\frac{\sqrt{s}}{2},\vec{0}\right),\quad p_1=\left(\frac{\sqrt{s}}{2},-\frac{\sqrt{s}}{2},\vec{0}\right),$$

$$k_2=\left(x_1\frac{\sqrt{s}}{2}+\frac{p_{T1}^2}{x_1\sqrt{s}},\quad x_1\frac{\sqrt{s}}{2},\ \vec{p}_{T1}\right), \tag{16}$$

$$p_2=\left(x_2\frac{\sqrt{\hat{s}}}{2}+\frac{p_{T2}^2}{x_2\sqrt{\hat{s}}},\quad -x_2\frac{\sqrt{s}}{2},\ \vec{p}_{T2}\right).$$

Neglect terms of the order of $p_{T1}^2/s << 1,\ p_{T2}^2/s << 1$ in the amplitude squared then immediently obtains for the invariants:

$$(p_1 \cdot k_1)(p_2 \cdot k_2) = (p_1 \cdot k_2)(p_2 \cdot k_1) \approx x_1 x_2 \frac{s^2}{4},$$

$$q_1^2 = (k_1 - k_2)^2 = -2(k_1 \cdot k_2) = -\frac{p_{T1}^2}{x_1},$$

$$q_2^2 = (p_1 - p_2)^2 = -2(p_1 \cdot p_2) = -\frac{p_{T2}^2}{x_2}.$$

Then an amplitude squared for the helicity processes that is simply given by:

$$|M_{LL}|^2 = \left(\frac{e^2}{x_w(1-x_w)}\right)^3 \cdot M_Z^2 \cdot \frac{g_L^2 (x_1 x_2)^3 \cdot s^2}{(p_{T1}^2 + x_1 M_Z^2)^2 (p_{T2}^2 + x_2 M_Z^2)^2},$$

$$|M_{LR}|^2 = \left(\frac{e^2}{x_w(1-x_w)}\right)^3 \cdot M_Z^2 \frac{g_R^2 (x_1 x_2)^3 \cdot s^2}{(p_{T1}^2 + x_1 M_Z^2)^2 (p_{T2}^2 + x_2 M_Z^2)^2}. \quad (17)$$

The three-body phase space also simplifies to

$$d\Phi = \frac{d\vec{p}_2}{E_2} \cdot \frac{d\vec{k}_2}{\omega_2} \cdot \frac{d\vec{k}}{E_H} \delta(p_1 + k_1 - p_2 - k_2 - k) = \frac{dx_1}{x_1} \cdot \frac{dx_2}{x_2} d^2\vec{p}_{T1} d^2\vec{p}_{T2} \cdot \frac{2}{\hat{s}} \delta((1-x_1)(1-x_2) - r_H) \quad (18)$$

Here $r_H = M_H^2 / s$ and M_H – is the mass of Higgs boson.

The integration on the transverse momenta can there fore be easily done

$$\int \frac{d^2\vec{p}_{Ti}}{(p_{Ti}^2 + x_i M_Z^2)^2} \approx \pi \int_0^\infty \frac{dp^2}{(p^2 + x_i M_Z^2)} = \frac{\pi}{x_i M_Z^2} \quad (i = 1, 2),$$

with the help of the delta function the integration on x_1 and x_2 are straightforward. One finally obtains for the total helicity cross sections

$$\sigma_{LL} = \frac{1}{4} \cdot \left(\frac{\alpha}{x_w(1-x_w)}\right)^3 \frac{g_L^2}{M_Z^2} f(r_H),$$

$$\sigma_{LR} = \frac{1}{4} \cdot \left(\frac{\alpha}{x_w(1-x_w)}\right)^3 \frac{g_R^2}{M_Z^2} f(r_H), \quad (19)$$

here

$$f(r_H) = (1 + r_H) \ln \frac{1}{r_H} + 2(r_H - 1). \quad (20)$$

The cross section of the process $\nu_\mu + e^- \to H + \nu_\mu + e^-$ given as follow for the unpolarized electrons

$$\sigma(\nu_\mu e^- \to H\nu_\mu e^-) = \frac{1}{8}\left(\frac{\alpha}{x_w(1-x_w)}\right)^3 \frac{g_L^2 + g_R^2}{M_Z^2} f(r_H). \quad (21)$$

3. **THE W^+W^- FUSION MECHANISM**

The process $\nu_\mu + e^- \to H + \nu_e + \mu^-$ will be due to the W^+W^--fusion process. The Feynman diagram for these process is shown in Fig. 2.

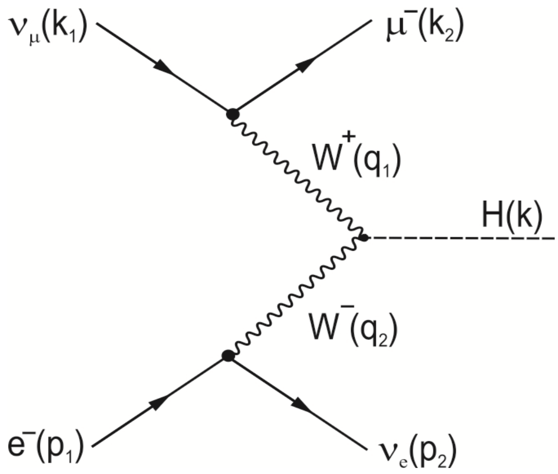

Fig. 2. The Feynman diagram for the processes $\nu_\mu e^- \to H\nu_e\mu^-$.

In the charge weak neutral current involves only left-handed electrons (muons), so that the process $\nu_\mu + e^- \to H + \nu_e + \mu^-$ is defined by one helicity amplitude

$$M(\nu_\mu e_L^- \to H\nu_e\mu_L^-) = \left(\frac{g}{2\sqrt{2}}\right)^2 g\, M_W \cdot D_3 \cdot D_4 \times$$

$$\times[\bar{u}(k_2,\lambda_2)\gamma_\mu(1+\gamma_5)u(k_1)][\bar{u}(p_2)\gamma_\mu(1+\gamma_5)u(p_1,\lambda_1)]. \quad (22)$$

here

$$D_3 = (q_1^2 - M_W^2)^{-1}, \quad D_4 = (q_2^2 - M_W^2)^{-1}, \quad (23)$$

M_W is the mass of W-boson, $g = e/\sin\theta_W$ is the coupling constant of the $SU_L(2)$ group.

The square of amplitude (22) is equal to

$$\left|M(\nu_\mu e_L^- \to H\nu_e\mu_L^-)\right|^2 = 4\left(\frac{e^2}{x_W}\right)^3 M_W^2\, D_3^2 D_4^2 (p_1 \cdot k_1)(p_2 \cdot k_2) =$$

$$= \left(\frac{e^2}{x_W}\right)^3 M_W^2 \cdot \frac{(x_1x_2)^3 \cdot s^2}{(p_{T1}^2 + x_1M_W^2)^2(p_{T2}^2 + x_2M_W^2)^2}. \quad (24)$$

The total cross section for the process $\nu_\mu + e_L^- \to H + \nu_e + \mu_L^-$ can be written in the form

$$\sigma(\nu_\mu e_L^- \to H\nu_e \mu_L^-) = \frac{1}{4}\left(\frac{\alpha}{x_W}\right)^3 \cdot \frac{1}{M_W^2} f(r_H) \qquad (25)$$

In the case for the unpolarized particles the total cross section given by expression:

$$\sigma(\nu_\mu e^- \to H\nu_e \mu^-) = \frac{1}{8}\left(\frac{\alpha}{x_W}\right)^3 \cdot \frac{1}{M_W^2} f(r_H)\,. \qquad (26)$$

4. CONCLUSION

The total cross sections we obtained for the processes $\nu_\mu e^- \to H\nu_\mu e^-$, $\nu_\mu e^- \to H\nu_e \mu^-$. The total cross section for $\nu_\mu e^- \to H\nu_\mu e^-$ and $\nu_\mu e^- \to H\nu_e \mu^-$ are displayed in Fig. 3 and 4 as a function of the energy in the center of mass system for $M_H = 125 GeV$, $M_Z = 91{,}1875$ GeV, $M_W = 80{,}425 GeV$ and $x_w = 0{,}232$. One can see that the total production cross sections for the ZZ fusion mechanism is smaller than the cross section for W^+W^- fusion.

$$\frac{\sigma(ZZ \to H)}{\sigma(WW \to H)} \sim 0{,}2\,.$$

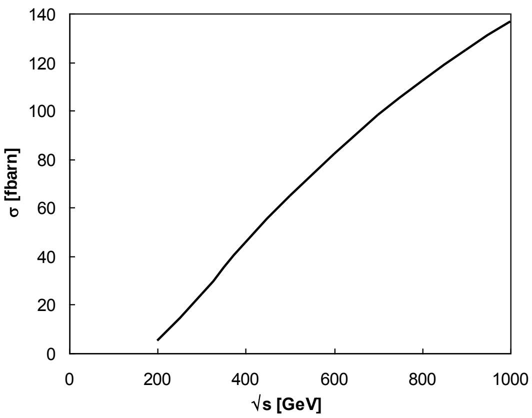

Fig.3. The cross section $\sigma(\nu_\mu e^- \to H\nu_\mu e^-)$ energy dependence for the $M_H = 125 GeV$.

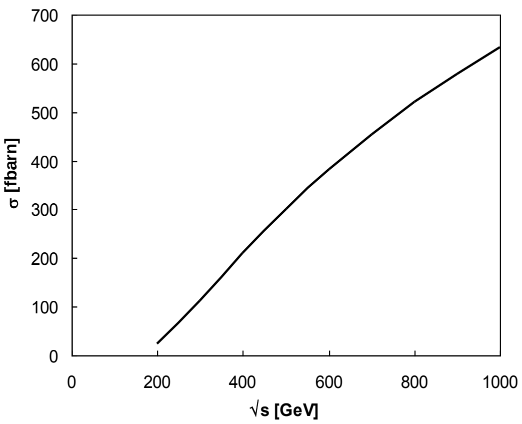

Fig. 4. The cross section $\sigma(\nu_\mu e^- \to H\nu_e \mu^-)$ energy dependence for the $M_H = 125 GeV$.

The cross sections $\sigma(\nu_\mu e^- \to H\nu_\mu e^-)$ and $\sigma(\nu_\mu e^- \to H\nu_e \mu^-)$ are shown in Fig. 5 and 6 as a function M_H for the energy $\sqrt{s} = 500\, GeV$. By increasing the Higgs boson mass the cross section will be decreased.

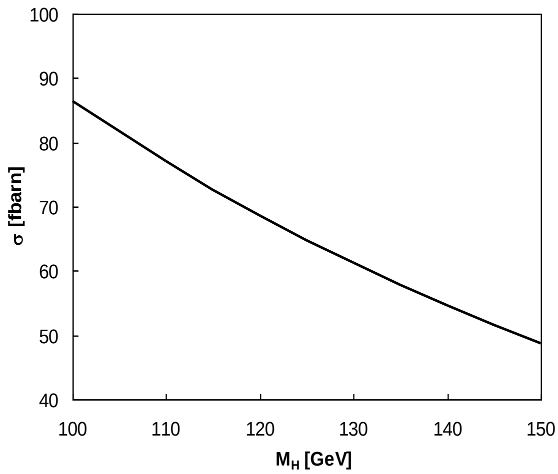

Fig. 5. The cross section $\sigma(\nu_\mu e^- \to H\nu_\mu e^-)$ as a function of M_H .

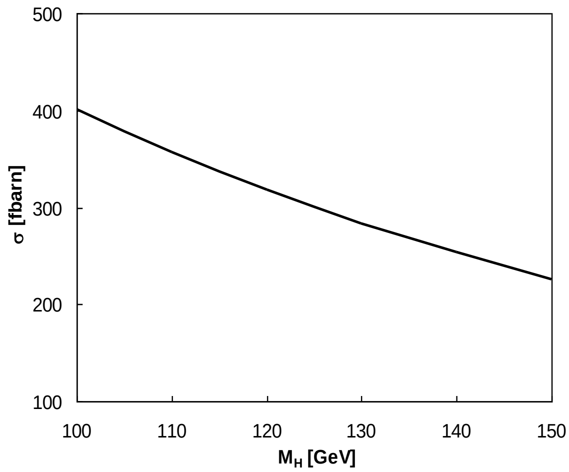

Fig. 6. The cross section $\sigma(\nu_\mu e^- \to H\nu_e \mu^-)$ as a function of M_H .

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