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# HIGGS-HIGGS INTERACTION UP TO HIGHER ORDERS OF PERTURBATION THEORY IN THE STANDARD MODEL

## II. Box Diagrams and One-Loop Amplitude

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## I. Introduction

In the present paper we continue our calculation of the amplitude of Higgs–Higgs interaction with taking account of one-loop corrections started in /1/. The method of calculation of the diagrams of two-Higgs interaction in the framework of the Standard Model (SM) is analogous to that proposed by Passarino and Veltman /2/. The Feynman integrals are reduced to scalar form factors $B_0(q^2, M_1^2, M_2^2)$, $C_0(q^2, (p-q)^2, p^2, M_1^2, M_2^2, M_3^2)$ and $D_0(q_1^2, p_2^2, q_2^2, p_1^2, s, t, M_1^2, M_2^2, M_3^2, M_4^2)$ that are connected with the scalar one-loop integrals of t'Hooft and Veltman /3/. The renormalization program used here is described in our previous paper, i.e. it uses the parameters recommended by the Trieste conference /4/ $(e, M_W, M_Z, M_X, m_f)$, and performs on the mass shell of incoming and outgoing particles /5/. The application of the unitary gauge allows us to avoid the ghost states (see /6/), but forces us to introduce the counter terms $i\mathcal{M}^{c.t.}$ for that amplitude. The used notation would allow us to perform easily the generalization of the obtained results to other models.

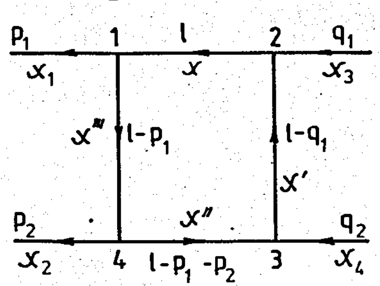
The resulting amplitude is assumed to be used for consideration of the problem of possible existence of the Higgsonium, the bound state of two Higgs bosons /7/.

The plan of the paper is as follows. In Sect.2 the "box" diagrams are calculated (we still do not fix the value of the constants $f^X$, $f^{WX}$, $f^{ZX}$, $f^{3X}$. In Sect.3 we present the results for the remaining diagrams with the renormalized blocks for vertex and self-energy parts from our previous paper /1/.

The counterterm for the renormalization of the total Higgs–Higgs amplitude is found. The Summary contains the discussion of possible applications.

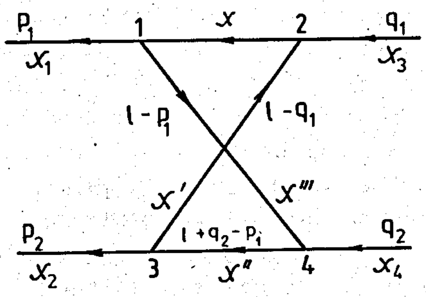
2. Box diagrams

1.



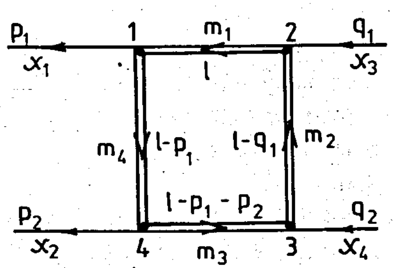

$$iM(p_1^2,p_2^2,q_1^2,q_2^2,s,t) = \frac{i f_1^{3X} f_2^{3X} f_3^{3X} f_4^{3X}}{16\pi^2}\, I_2(q_1^2, q_2^2, p_2^2, p_1^2, s, t, M_X^2, M_{X'}^2, M_{X''}^2, M_{X'''}^2). \qquad (2.1)$$

2.




$$iM(p_1^2,p_2^2,q_1^2,q_2^2,s,t) = \frac{i f_1^{3X} f_2^{3X} f_3^{3X} f_4^{3X}}{16\pi^2}\, I_2(q_1^2, p_2^2, q_2^2, p_1^2, u, t, M_X^2, M_{X'}^2, M_{X''}^2, M_{X'''}^2). \qquad (2.2)$$

3.




and a similar diagram with the opposite lepton ourrent dire otion.

$$iM(p_1^2,p_2^2,q_1^2,q_2^2,s,t) = -\frac{i f_1^X f_2^X f_3^X f_4^X}{4\pi^2}\Big\{-2B_5 P - \frac{1}{2}B_5$$



$$-\frac{1}{2}B_5 I_0(s,m_1^2,m_3^2) - \frac{1}{2}B_5 I_0(t,m_2^2,m_4^2) +$$

$$+\frac{1}{2}\Big[B_5(q_1q_2 - m_2^2) - B_6 m_1 m_2 - B_7 m_1 m_3 - B_9 m_2 m_3\Big]$$

$$\times I_1(q_1^2, q_2^2, s, m_1^2, m_2^2, m_3^2) + \frac{1}{2}\Big[-B_5(q_1p_1 +$$

$$+ m_1^2) - B_6 m_1 m_2 - B_8 m_1 m_4 - B_{10} m_2 m_4\Big] I_1(q_1^2,$$

$$t, p_1^2, m_1^2, m_2^2, m_4^2) + \frac{1}{2}\Big[B_5(p_1p_2 - m_4^2) - B_7 m_1 m_3$$

$$- B_8 m_1 m_4 - B_{11} m_3 m_4\Big] I_1(s, p_2^2, p_1^2, m_1^2, m_3^2,$$

$$m_4^2) + \frac{1}{2}\Big[B_5(k_2p_2 - m_3^2) - B_9 m_2 m_3 - B_{10} m_2 m_4 -$$

$$- B_{11} m_3 m_4\Big] I_1(q_2^2, p_2^2, t, m_2^2, m_3^2, m_4^2) + \frac{1}{2}\times$$

$$\times\Big[B_5\Big(\frac{(q_1^2+m_1^2+m_2^2)(p_2^2+m_3^2+m_4^2)}{2} - \frac{(s+m_1^2+m_3^2)(t+m_2^2-m_4^2)}{2}$$

$$+ \frac{(p_1^2+m_1^2+m_4^2)(q_2^2+m_2^2+m_3^2)}{2}\Big) + B_6 m_1 m_2 (p_2^2+m_3^2+m_4^2) +$$

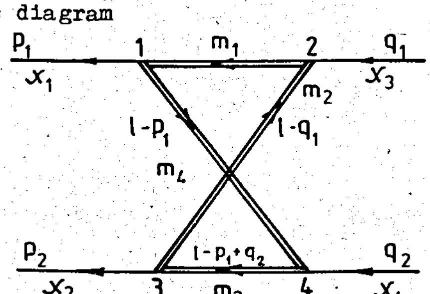
$$+ B_7 m_1 m_3 (t+m_2^2+m_4^2) + B_8 m_1 m_4 (q_2^2+m_2^2+m_3^2) +$$

$$+B_9 m_2 m_3 (p_1^2+m_1^2+m_4^2) + B_{10} m_2 m_4 (s+m_1^2+m_3^2) + B_{11} \times m_3 m_4 (q_1^2+m_1^2+m_2^2) + 2B_{12} m_1 m_2 m_3 m_4 \Big] I_2 (q_1^2, q_2^2, p_2^2, p_1^2, s, t, m_1^2, m_2^2, m_3^2, m_4^2), \qquad (2.3)$$

where

$$\begin{aligned}
B_5 &= 1 - b_1 b_2 + b_1 b_3 - b_1 b_4 - b_2 b_3 + b_2 b_4 - b_3 b_4 + b_1 b_2 b_3 b_4, \\
B_6 &= 1 + b_1 b_2 + b_1 b_3 - b_1 b_4 + b_2 b_3 - b_2 b_4 - b_3 b_4 - b_1 b_2 b_3 b_4, \\
B_7 &= 1 + b_1 b_2 - b_1 b_3 - b_1 b_4 - b_2 b_3 - b_2 b_4 + b_3 b_4 + b_1 b_2 b_3 b_4, \\
B_8 &= 1 + b_1 b_2 - b_1 b_3 + b_1 b_4 - b_2 b_3 + b_2 b_4 - b_3 b_4 - b_1 b_2 b_3 b_4, \qquad (2.4) \\
B_9 &= 1 - b_1 b_2 - b_1 b_3 - b_1 b_4 + b_2 b_3 + b_2 b_4 + b_3 b_4 - b_1 b_2 b_3 b_4, \\
B_{10} &= 1 - b_1 b_2 - b_1 b_3 + b_1 b_4 + b_2 b_3 - b_2 b_4 - b_3 b_4 + b_1 b_2 b_3 b_4, \\
B_{11} &= 1 - b_1 b_2 + b_1 b_3 + b_1 b_4 - b_2 b_3 - b_2 b_4 + b_3 b_4 - b_1 b_2 b_3 b_4, \\
B_{12} &= 1 + b_1 b_2 + b_1 b_3 + b_1 b_4 + b_2 b_3 + b_2 b_4 + b_3 b_4 + b_1 b_2 b_3 b_4 .
\end{aligned}$$

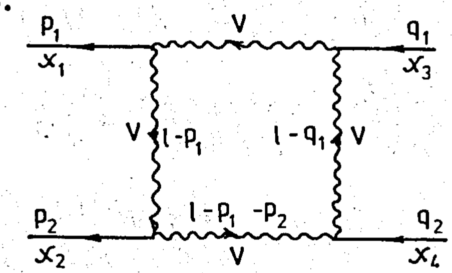
The diagram

4. 


and an analogous diagram with the opposite lepton current direction



are described by the above expression but with the substitution $p_2 \Longleftrightarrow -q_2$.

5. 


and a similar diagram with the opposite vector boson current direction

$$i\mathcal{M}(p_1^2, p_2^2, q_1^2, q_2^2, s, t) = \frac{i f_1^{\rho V\chi} f_2^{\rho V\chi} f_3^{\rho V\chi} f_4^{\rho V\chi}}{16\pi^2} \Big\{ \Big[ \frac{1}{4} \frac{1}{M_V^6} \Big( \frac{9}{2} \times (s+t) - \frac{17}{3}(p_1^2+p_2^2+q_1^2+q_2^2) + \frac{(p_1^2-p_2^2)(q_1^2-q_2^2)}{6s} + \frac{(q_1^2-p_1^2)(q_2^2-p_2^2)}{6t} \Big) - \frac{1}{8}\frac{1}{M_V^8} \Big( p_1^4+p_2^4+q_1^4+q_2^4 + 2(p_1^2 q_1^2 + p_2^2 q_2^2) + \frac{7}{3}(p_1^2 p_2^2 + p_1^2 q_2^2 + p_2^2 q_1^2 + q_1^2 q_2^2) + \frac{1}{3}(s+t)(p_1^2+p_2^2+q_1^2+q_2^2) - \frac{1}{3}(s^2+st+t^2) \Big) \Big] P + \frac{1}{4} \frac{p_1^2+p_2^2+q_1^2+q_2^2}{M_V^6} + \frac{1}{16}\frac{1}{M_V^8} \Big[ \frac{(s+t)^2 - (s+t)(p_1^2+p_2^2+q_1^2+q_2^2) + 2st}{18} + \frac{(p_1^2-p_2^2)(q_1^2-q_2^2) + (q_1^2-p_1^2)(q_2^2-p_2^2)}{18} \Big] + \Big[ 3 + \frac{1}{2}\frac{1}{M_V^2}(p_1^2+p_2^2+q_1^2+q_2^2) + \frac{1}{4}\frac{1}{M_V^4}\Big( p_1^4+p_2^4+q_1^4+q_2^4+s^2+t^2-(s+t) \times (p_1^2+p_2^2+q_1^2+q_2^2) + p_1^2 q_2^2 + p_2^2 q_1^2 \Big) + \frac{1}{8}\frac{1}{M_V^6}\Big( p_1^2 p_2^2 (q_1^2+q_2^2) +$$

$$+q_1^2q_2^2(p_1^2+p_2^2)-s(p_1^2p_2^2+q_1^2q_2^2)-t(p_1^2q_1^2+p_2^2q_2^2)\Big)+\frac{1}{16}\frac{1}{M_V^8}\times$$

$$\times p_1^2p_2^2q_1^2q_2^2\Big]I_2(q_1^2,q_2^2,p_2^2,p_1^2,s,t,M_V^2,M_V^2,M_V^2,M_V^2)+$$

$$+\Big[\frac{1}{4}\frac{1}{M_V^4}(-p_2^2+2s-F_1)+\frac{1}{8}\frac{1}{M_V^6}\Big(t(q_1^2+q_2^2)+sp_2^2-2q_1^2q_2^2-$$

$$-p_1^2q_2^2-p_2^2q_1^2+sF_1\Big)+\frac{1}{16}\frac{1}{M_V^8}(-p_2^2q_1^2q_2^2-q_1^2q_2^2F_1)\Big]I_1(q_1^2,$$

$$q_2^2,s,M_V^2,M_V^2,M_V^2)+\Big[\frac{1}{4}\frac{1}{M_V^4}(-q_2^2+2s-F_2)+$$

$$+\frac{1}{8}\frac{1}{M_V^6}\Big(t(p_1^2+p_2^2)+sq_2^2-2p_1^2p_2^2-p_1^2q_2^2-p_2^2q_1^2+sF_2\Big)+\frac{1}{16}\times$$

$$\times\frac{1}{M_V^8}(-p_1^2p_2^2q_2^2-p_1^2p_2^2F_2)\Big]I_1(p_1^2,p_2^2,s,M_V^2,M_V^2,$$

$$M_V^2)+\Big[\frac{1}{4}\frac{1}{M_V^4}(-q_2^2+2t-F_3)+\frac{1}{8}\frac{1}{M_V^6}\Big(s(p_1^2+q_1^2)+$$

$$+tq_2^2-2p_1^2q_1^2-p_1^2q_2^2-p_2^2q_1^2+tF_3\Big)+\frac{1}{16}\frac{1}{M_V^8}\Big(-p_1^2q_1^2q_2^2-$$

$$-p_1^2q_1^2F_3\Big)\Big]I_1(q_1^2,p_1^2,t,M_V^2,M_V^2,M_V^2)+\Big[\frac{1}{4}\frac{1}{M_V^4}\times$$

$$\times(-p_1^2+2t-F_4)+\frac{1}{8}\frac{1}{M_V^6}\Big(s(p_2^2+q_2^2)+tp_1^2-2p_2^2q_2^2-p_1^2q_2^2-$$

$$-p_2^2q_1^2+tF_4\Big)+\frac{1}{16}\frac{1}{M_V^8}(-p_1^2p_2^2q_2^2-p_2^2q_2^2F_4)\Big]I_1(q_2^2,$$



$$p_2^2,t,M_V^2,M_V^2,M_V^2)-\Big[-\frac{1}{4}\frac{1}{M_V^4}(F_5+F_6)+\frac{1}{8}\frac{1}{M_V^6}\times$$

$$\times(-p_2^2+2q_1^2-t-p_2q_1+sF_5+tF_6)+\frac{1}{16}\frac{1}{M_V^8}\Big(q_1^4-q_1^2(p_2q_1)+$$

$$+p_2^2q_1^2+p_1^2q_1^2-q_1^2q_2^2F_5-p_1^2q_1^2F_6\Big)\Big]I_0(q_1^2,M_V^2,M_V^2)-\Big[-\frac{1}{4}\frac{1}{M_V^4}\times$$

$$\times(1+F_7+F_8)+\frac{1}{8}\frac{1}{M_V^6}(2p_1^2-q_2^2-p_1q_2+sF_7+tF_8)+\frac{1}{16}\frac{1}{M_V^8}\times$$

$$\times(p_1^4-p_1^2(p_1q_2)+p_1^2q_2^2-p_1^2p_2^2F_7-p_1^2q_1^2F_8)\Big]I_0(p_1^2,M_V^2,M_V^2)-$$

$$-\Big[-\frac{1}{4}\frac{1}{M_V^4}(F_9+F_{10})+\frac{1}{8}\frac{1}{M_V^6}\Big(-p_1^2+2q_2^2-p_1q_2^2-s+sF_9+$$

$$+tF_{10}\Big)+\frac{1}{16}\frac{1}{M_V^8}\Big(q_2^4+q_2^2(p_1q_2)+p_1^2q_2^2+q_1^2q_2^2-q_1^2q_2^2F_9-$$

$$-q_2^2p_2^2F_{10}\Big)\Big]I_0(q_2^2,M_V^2,M_V^2)-\Big[-\frac{1}{4}\frac{1}{M_V^4}(-1+F_{11}+F_{12})+$$

$$+\frac{1}{8}\frac{1}{M_V^6}(2p_2^2-q_1^2-s-t+sF_{11}+tF_{12})+\frac{1}{16}\frac{1}{M_V^8}\Big(p_2^4-$$

$$-p_2^2(p_2q_1)+p_1^2p_2^2+p_2^2q_1^2+p_2^2q_2^2-p_1^2p_2^2F_{11}-p_2^2q_2^2F_{12}\Big)\Big]\times$$

$$\times I_0(p_2^2,M_V^2,M_V^2)-\Big[-\frac{1}{4}\frac{1}{M_V^4}(F_{13}+F_{14})+\frac{1}{8}\frac{1}{M_V^6}\Big(\frac{5}{6}(p_1^2+$$

$$+p_2^2+q_1^2+q_2^2)+\frac{1}{6}s-\frac{5}{3}t+\frac{(p_1^2-p_2^2)(q_1^2-q_2^2)}{6s}+sF_{13}+$$

$$+sF_{14}\Big)+\frac{1}{16}\frac{1}{M_V^8}\Big(\frac{p_1^2q_2^2+p_2^2q_1^2}{6}+\frac{p_1^2q_1^2+p_2^2q_2^2}{3}+\frac{s^2}{3}+$$

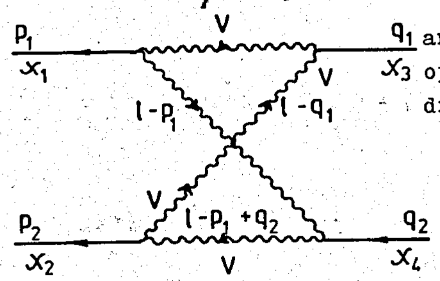
$$+\frac{s(p_1^2+p_2^2+q_1^2+q_2^2)}{6}-p_1^2p_2^2F_{14}-q_1^2q_2^2F_{13}\Big)\Big]I_c(s,M_V^2,M_V^2)-$$

$$-\Big[-\frac{1}{4}\frac{1}{M_V^4}(F_{15}+F_{16})+\frac{1}{8}\frac{1}{M_V^6}\Big(\frac{5}{6}(p_1^2+p_2^2+q_1^2+q_2^2)-\frac{5}{6}t-$$

$$-\frac{5}{3}s+\frac{(q_1^2-p_1^2)(q_2^2-p_2^2)}{6t}+tF_{15}+tF_{16}\Big)+\frac{1}{16}\frac{1}{M_V^8}\Big(p_1^2q_1^2+$$

$$+\frac{p_1^2p_2^2+q_1^2q_2^2}{3}+\frac{p_1^2q_2^2+p_2^2q_1^2}{6}+\frac{t^2}{3}+\frac{st}{6}+\frac{t(p_1^2+p_2^2+q_1^2+q_2^2)}{6}$$

$$-p_1^2q_1^2F_{15}-p_2^2q_2^2F_{16}\Big)\Big]I_c(t,M_V^2,M_V^2)\Big\}. \qquad (2.5)$$

6. 

and an analogous diagram with the opposite vector boson current direction

are obtained from the above expression but with the substitution $p_2 \Longleftrightarrow -q_2$.

Here

$$F_1=p_1q_1-4\frac{(p_1q_2)(q_1q_2)q_1^2-(p_1q_1)(q_1q_2)q_2^2-(p_1q_1)(q_1q_2)^2+(p_1q_2)q_1^2q_2^2}{q_1^4+q_2^4+s^2-2q_1^2q_2^2-2q_1^2s-2q_2^2s}, \qquad (2.6)$$

$$F_2=p_1q_1-4\frac{(p_2q_1)(p_1p_2)p_1^2-(p_1q_1)(p_1p_2)p_2^2-(p_1q_1)(p_1p_2)^2+(p_2q_1)p_1^2p_2^2}{p_1^4+p_2^4+s^2-2p_1^2p_2^2-2p_1^2s-2p_2^2s}, \qquad (2.7)$$

$$F_3=-p_1p_2+4\frac{(p_1p_2)(p_1q_1)q_1^2+(p_1q_1)(p_2q_1)p_2^2-(p_1p_2)(p_1q_1)^2-(p_2q_1)p_1^2q_1^2}{p_1^4+q_1^4+t^2-2p_1^2q_1^2-2p_1^2t-2q_1^2t}, \qquad (2.8)$$



$$F_4=-q_1q_2+4\frac{(p_2q_1)(p_2q_2)q_2^2+(q_1q_2)(p_2q_2)p_2^2-(q_1q_2)(p_2q_2)^2-(p_2q_1)p_2^2q_2^2}{p_2^4+q_2^4+t^2-2p_2^2q_2^2-2p_2^2t-2q_2^2t}, \qquad (2.9)$$

$$F_5=\frac{(p_1q_1)(q_1q_2)-(p_1q_2)q_1^2}{q_1^4+q_2^4+s-2q_1^2q_2^2-2q_1^2s-2q_2^2s}, \qquad (2.10)$$

$$F_6=\frac{(p_1q_1)(p_2q_1)-(p_1p_2)q_1^2}{p_1^4+q_1^4+t^2-2p_1^2q_1^2-2p_1^2t-2q_1^2t}, \qquad (2.11)$$

$$F_7=\frac{(p_1q_1)(p_1p_2)-(p_2q_1)p_1^2}{p_1^4+p_2^4+s^2-2p_1^2p_2^2-2p_1^2s-2p_2^2s}, \qquad (2.12)$$

$$F_8=\frac{(p_1p_2)(p_1q_1)-(p_2q_1)p_1^2}{p_1^4+q_1^4+t^2-2p_1^2q_1^2-2p_1^2t-2q_1^2t}, \qquad (2.13)$$

$$F_9=-\frac{(p_1q_2)(q_1q_2)-(p_1q_1)q_2^2}{q_1^4+q_2^4+s^2-2q_1^2q_2^2-2q_1^2s-2q_2^2s}, \qquad (2.14)$$

$$F_{10}=\frac{(p_2q_2)(q_1q_2)-(p_2q_1)q_2^2}{p_2^4+q_2^4+t^2-2p_2^2q_2^2-2p_2^2t-2q_2^2t}, \qquad (2.15)$$

$$F_{11}=-\frac{(p_1p_2)(p_2q_1)-(p_1q_1)p_2^2}{p_1^4+p_2^4+s^2-2p_1^2p_2^2-2p_1^2s-2p_2^2s}, \qquad (2.16)$$

$$F_{12}=\frac{(p_2q_1)(p_2q_2)-(q_1q_2)p_2^2}{p_2^4+q_2^4+t^2-2p_2^2q_2^2-2p_2^2t-2q_2^2t}, \qquad (2.17)$$

$$F_{13}=\frac{(p_1q_2)(q_1q_2)-(p_1q_1)(q_1q_2)-(p_1q_1)q_2^2+(p_1q_2)q_1^2}{q_1^4+q_2^4+s^2-2q_1^2q_2^2-2q_1^2s-2q_2^2s}, \qquad (2.18)$$

$$F_{14} \doteq \frac{(p_1p_2)(p_2q_1)-(p_1p_2)(p_1q_1)+(p_2q_1)p_1^2-(p_1q_1)p_2^2}{p_1^4+p_2^4+s^2-2p_1^2p_2^2-2p_1^2s-2p_2^2s}, \quad (2.19)$$

$$F_{15} = -\frac{(p_1p_2)(p_1q_1)+(p_1q_1)(p_2q_1)-(p_2q_1)p_1^2-(p_1p_2)q_1^2}{p_1^4+q_1^4+t^2-2p_1^2q_1^2-2p_1^2t-2q_1^2t}, \quad (2.20)$$

$$F_{16} = -\frac{(p_2q_1)(p_2q_2)+(p_2q_2)(q_1q_2)-(p_2q_1)q_2^2-(q_1q_2)p_2^2}{p_2^4+q_2^4+t^2-2p_2^2q_2^2-2p_2^2t-2q_2^2t} \quad (2.21)$$

and

$$p_1p_2 = \frac{1}{2}\left(s-p_1^2-p_2^2\right), \quad p_1q_2=\frac{1}{2}\left(s+t-p_2^2-q_1^2\right),$$

$$q_1q_2 = \frac{1}{2}\left(s-q_1^2-q_2^2\right), \quad p_2q_1=\frac{1}{2}\left(s+t-p_1^2-q_2^2\right),$$

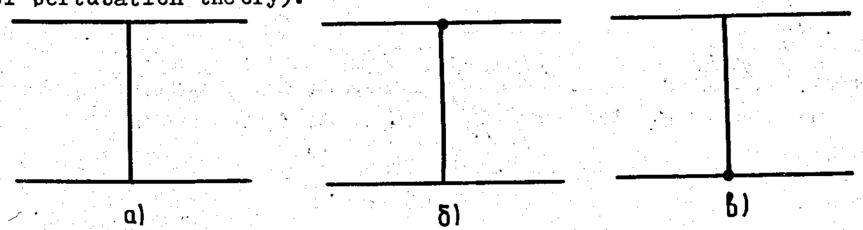
$$p_1q_1 = -\frac{1}{2}\left(t-p_1^2-q_1^2\right),$$

$$p_2q_2 = -\frac{1}{2}\left(t-p_2^2-q_2^2\right)$$

$s, t, u$ are the Mandelstam variables.
$I_0, I_1, I_2$ are the scalar one-loop integrals calculated in /3/.

### 3. The one-loop amplitudes

Box diagrams from Sect. 2 ( $f^{3X} = -3igM_X^2/2M_W$, $f^X = -igm_i/2M_W$, $f^{WX} = -igM_W$, $f^{ZX} = -igM_Z^2/M_W$ - see the previous paper /1/ ) and the diagrams shown in fig.1 contribute to the Higgs-Higgs amplitude (up to the 4th order of pertubation theory).





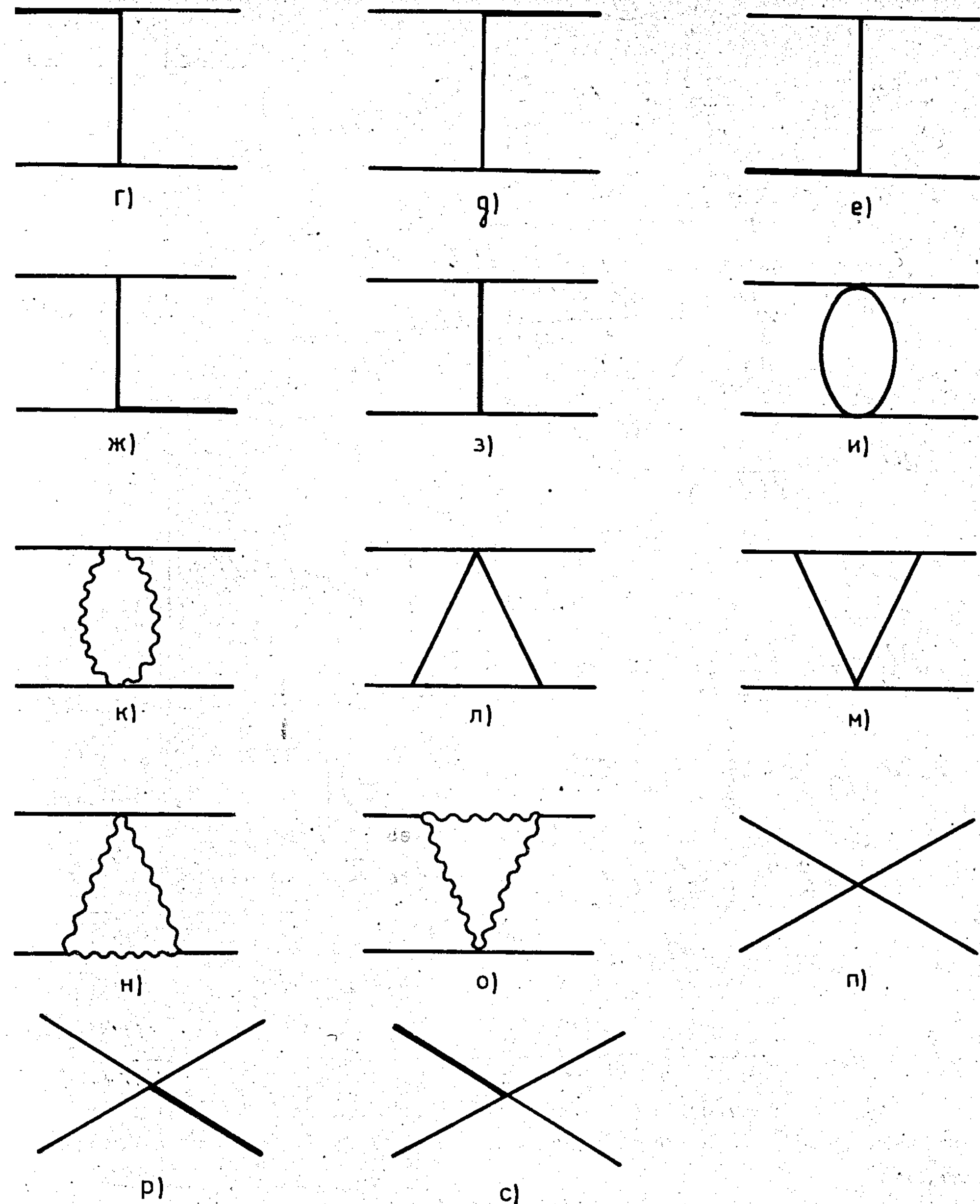




Fig.1. The diagrams describing the interaction of two Higgs particle (s-channel), a solid line corresponds to the renormalized propagator and a black circle corresponds to the renormalized vertex.

$$i\mathcal{M}_{а)} = \frac{9ig^2}{4} r_W \frac{M_\chi^2}{t+M_\chi^2}\,, \qquad (3.1)$$

$$i\mathcal{M}_{б,в)} = -\frac{3g}{2} r_W \frac{M_W \Gamma^{Ren.}(p_{1,2}^2, q_{1,2}^2, t)}{t+M_\chi^2}\,, \qquad (3.2)$$

$$i\mathcal{M}_{г,е)} = \frac{9g^2}{4} r_W \frac{M_\chi^2 \Pi^{Ren.}(p_{1,2}^2)}{(p_{1,2}^2+M_\chi^2)(t+M_\chi^2)}\,, \qquad (3.3)$$

$$i\mathcal{M}_{д,ж)} = \frac{9g^2}{4} r_W \frac{M_\chi^2 \Pi^{Ren.}(q_{1,2}^2)}{(q_{1,2}^2+M_\chi^2)(t+M_\chi^2)}\,, \qquad (3.4)$$

$$i\mathcal{M}_{з)} = \frac{9g^2}{4} r_W \frac{M_\chi^2 \Pi^{Ren}(t)}{(t+M_\chi^2)^2}\,, \qquad (3.5)$$

$$i\mathcal{M}_{и)} = \frac{9g^4}{16} r_W^2 \Pi^{(3)}(t)\,, \qquad (3.6)$$

$$i\mathcal{M}_{к)} = \frac{g^4}{4} \Pi^{(5)}(t)\Big|_{M_V^2=M_W^2} + \frac{g^4}{4}\frac{1}{R^2} \Pi^{(5)}(t)\Big|_{M_V^2=M_Z^2}\,, \qquad (3.7)$$

$$i\mathcal{M}_{л,м)} = -\frac{27g^4}{16} r_W^2 M_\chi^2 \Gamma^{(1)}(p_{1,2}^2, q_{1,2}^2, t)\,, \qquad (3.8)$$

$$i\mathcal{M}_{н,о)} = -\frac{g^4}{2} M_W^2 \Gamma^{(3)}(p_{1,2}^2, q_{1,2}^2, t)\Big|_{M_V^2=M_W^2} - \frac{g^4}{2}\frac{1}{R^2} M_Z^2 \times$$

$$\times \Gamma^{(3)}(p_{1,2}^2, q_{1,2}^2, t)\Big|_{M_V^2=M_Z^2}\,, \qquad (3.9)$$

$$i\mathcal{M}_{п)} = -\frac{3ig^2}{4} r_W\,, \qquad (3.10)$$

$$i\mathcal{M}_{р)} = -\frac{3g^2}{4} r_W \frac{\Pi^{Ren.}(q_2^2)}{(q_2^2+M_\chi^2)}\,, \quad i\mathcal{M}_{с)} = -\frac{3g^2}{4} r_W \frac{\Pi^{Ren}(p_1^2)}{(p_1^2+M_\chi^2)} \qquad (3.11)$$

In the framework of a renormalization scheme /6/ (using the unitary gauge) the appropriate counterterm for $4\chi$ - interaction reads:

$$i\mathcal{M}^{c.t.} = -\frac{3}{4} g^2 \frac{M_\chi^2}{M_W^2}\left[2(Z_\chi - 1) + 2\frac{\delta g}{g} + \frac{\delta M_\chi^2}{M_\chi^2} - \frac{\delta M_W^2}{M_W^2}\right]. \qquad (3.12)$$

After substitution of the renormalization constants from /1,6/ we have



$$i\mathcal{M}^{c.t.}(p_1^2, p_2^2, q_1^2, q_2^2, s, t) = \frac{ig^4}{16\pi^2}\frac{3}{4} r_W \Big\{\Big[-\frac{3}{4} r_W - 9 r_W^{-1} -$$

$$-\frac{9}{2}\frac{1}{R} r_Z^{-1} + 6\frac{1}{M_W^2 M_\chi^2} Tr\, m_i^4\Big] P + \frac{52}{3} - \frac{56}{3} R - 8R^2 -$$

$$-\frac{19}{12}\frac{1}{R} - \frac{1}{12}\frac{1}{R^2} + \frac{31}{8} r_W - \frac{1}{2} r_W^2 + \frac{1}{2} r_W r_Z + \frac{21}{2} r_W^{-1} +$$

$$+\frac{21}{4}\frac{1}{R} r_Z^{-1} + \left(-\frac{3}{8} r_W + \frac{3}{4}\frac{1}{R} + \frac{9}{4}\frac{1}{R} r_Z^{-1}\right) \ln R + \frac{1}{1-R} \times$$

$$\times\Big(-\frac{47}{6} + \frac{14}{3}\frac{1}{R} - \frac{1}{2}\frac{1}{R^2} - \frac{1}{24}\frac{1}{R^3} + \frac{3}{4} r_Z - \frac{1}{4} r_Z^2 +$$

$$+\frac{1}{24} r_Z^3\Big) \ln R + \Big(-\frac{3}{4} - \frac{1}{4} r_W + \frac{1}{4} r_Z + \frac{1}{24} r_W^2 - \frac{1}{24} r_W r_Z -$$

$$-\frac{1}{24} r_Z^2\Big) r_W \ln r_W - \frac{20}{9}(1-R) Tr\, Q_i^2 + \frac{1}{2}\frac{1}{M_W^2}\frac{R}{1-R} \times$$

$$\times\left(-\frac{1}{12} - \frac{4}{9} R + \frac{17}{3} R^2 + 4R^4\right) L(-M_Z^2, M_W^2, M_W^2) + \frac{1}{2}\frac{1}{M_W^2} \times$$

$$\times\frac{R}{1-R}\left(-1 + \frac{1}{3} r_Z - \frac{1}{12} r_Z^2\right) L(-M_Z^2, M_Z^2, M_\chi^2) + \frac{1}{2}\frac{1}{M_W^2} \times$$

$$\times\frac{1}{1-R}\left(\frac{25}{3} - \frac{22}{3} R - 8R^2 - \frac{7}{6}\frac{1}{R} - \frac{1}{12}\frac{1}{R^2}\right) L(-M_W^2,$$

$$M_W^2, M_Z^2) + \frac{1}{2}\frac{1}{M_W^2}\frac{1}{1-R}\Big(-1 + 2R + \frac{1}{3} r_W - \frac{2}{3} r_Z + \frac{1}{6} \times$$

$$\times r_W r_Z - \frac{1}{12} r_W^2\Big) L(-M_W^2, M_W^2, M_\chi^2) + \frac{1}{M_W^2}\Big(-\frac{3}{8} + \frac{3}{2} r_W^{-2} -$$

$$-6\frac{1}{r_W^2(r_W-4)}\Big)L(-M_\chi^2,M_W^2,M_W^2)+\frac{1}{M_W^2}\Big(-\frac{3}{16}+\frac{3}{4}r_Z^{-2}-$$

$$-3\frac{1}{r_Z^2(r_Z-4)}\Big)L(-M_\chi^2,M_Z^2,M_Z^2)+\frac{21}{16}\frac{1}{M_W^2}L(-M_\chi^2,M_\chi^2,M_\chi^2)+$$

$$+\frac{1}{M_W^2}Tr\Big[\frac{1}{3}m_i^2+\Big(\frac{8}{3}|Q_i|-\frac{16}{3}Q_i^2\Big)Rm_i^2+\frac{16}{3}Q_i^2R^2m_i^2\Big]+$$

$$+\frac{1}{M_W^4}Tr\Big[\frac{1}{6}m_i^4-\frac{1}{6}\frac{R}{1-R}m_i^4-\frac{15}{2}r_W^{-1}m_i^4\Big]+\frac{1}{M_W^2}Tr\Big[\frac{1}{6}\times$$

$$\times\frac{1}{1-R}M_W^2-\frac{2}{3}|Q_i|M_W^2+\frac{1}{2}\Big(1-\frac{R}{1-R}\Big)m_i^2+3\frac{1}{M_\chi^2}m_i^4\Big]\ln\frac{m_i^2}{M_W^2}+$$

$$+\frac{1}{M_W^2}Tr\Big[-\frac{1}{12}\frac{R}{1-R}+\Big(\frac{1}{3}|Q_i|-\frac{2}{3}Q_i^2\Big)R+\frac{2}{3}Q_i^2R^2+$$

$$-\frac{1}{12}\frac{R}{1-R}\frac{m_i^2}{M_Z^2}+\Big(\frac{4}{3}|Q_i|-\frac{8}{3}Q_i^2\Big)R\frac{m_i^2}{M_Z^2}+\frac{8}{3}Q_i^2R^2\times$$

$$\times\frac{m_i^2}{M_Z^2}\Big]L(-M_Z^2,m_i^2,m_i^2)-\frac{1}{M_W^2}Tr\Big[\frac{1}{4}\frac{m_i^2}{M_\chi^2}+2\frac{m_i^4}{M_\chi^4}\Big]\times$$

$$\times L(-M_\chi^2,m_i^2,m_i^2)+\Big(\frac{R}{1-R}-1\Big)\sum_{i,j}^{1/2N_f}\Big[\frac{1}{3}\frac{m_i^2m_j^2}{M_W^4}-$$

$$-\Big(\frac{1}{3}-\frac{m_i^2+m_j^2}{2M_W^2}\Big)\ln\frac{m_im_j}{M_W^2}+\frac{1}{12}\frac{(m_i^2-m_j^2)^3}{M_W^6}\ln\frac{m_i^2}{m_j^2}+ \qquad (3.13)$$

$$+\Big(\frac{1}{6}\frac{1}{M_W^2}-\frac{m_i^2+m_j^2}{12M_W^4}-\frac{(m_i^2-m_j^2)^2}{12M_W^6}\Big)L(-M_W^2,m_i^2,m_j^2)\Big]K_{ij}K_{ij}^+\Big\}.$$



## 4. Summary

We have computed the Higgs-Higgs amplitude in the fourth order of perturbation theory (that is, with taking account of the one-loop corrections) in the Standard model.

It is interesting in several aspects. First, in the eighties the anomalous $e^+e^-\gamma$ events seen at SPS were interpreted as the manifestation of the bound state of two Higgs scalars or weak bosons /8/. Also, let us mention the idea about the possibility that gauge vector bosons could originate from a strong interacting scalar sector of the electroweak theory /9/. Secondly, the obtained amplitude would be useful for the consideration of the problem of the unitarity violation (e.g. /I0/ ). And finally, it would be interesting to obtain a useful information about the behaviour of the Higgs coupling constants at mass scale $M$ .

Then, let us notice that the Kobayashi - Maskawa matrix elements appeared in the renormalized amplitude as a result of use of the $\delta M_W^2/M_W^2$ and $Z_W-1$ counterterms.

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