Higgs-Higgs Interaction

I. The one-loop amplitude in the Standard Model

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The beginning of the work: V.V. Dvoeglazov, V.I. Kikot' & N.B. Skachkov
JINR Communications E2-90-569, E2-90-570
Dubna, 1990 (Standard Model)

V.V. Dvoeglazov & N.B. Skachkov
JINR Communications E2-91-114, E2-91-115,
E2-91-179, Dubna, 1991 (minimal SUSY model)

The consideration on the basis of the equivalence theorem:

L. Durand, J.M. Johnson & J.L. Lopez, Phys. Rev. Lett., 64, 1215 (1990), Phys. Rev. D45, 3112 (1992)

L. Durand, J.M. Johnson & P.N. Maher, Phys. Rev. D44, 127 (1991)

L. Durand, P.N. Maher & K. Riesselmann, Phys. Rev D48, 1061 (1993), ibid, 1084 (1993)

Renormalization group: W. Marciano & S. Willenbrock, Phys. Rev.
G. Valencia D40, 1725 (1989)

G.E. Vayonakis, Europhys. Lett. 12, 23 (1990)

Tree level: B.W. Lee, C. Quigg & H.B. Thacker, Phys. Rev. Lett., 38, 883 (1977), Phys. Rev. D16, 1519 (1977)

R.N. Cahn & M. Suzuki, Phys. Lett., 134B (1-2) 115 (1984)

Grifols, Anselmino et al.

PREVIOUS WORKS : R.N. Cahn and M. Suzuki, J.A. Grifols, M. Anselmino et al, L. Durand et al.

MOTIVATION: THE HIGGS-HIGGS $2 \to 2$ AMPLITUDES IS NESESSARY IN ORDER TO INVESTIGATE POSSIBLE EXISTENSE OF BOUND STATES. THEY MAY SERVE AS INPUT FOR QUASIPOTENTIAL VERSION OF THE BETHE-SALPETER FORMALISM [Logunov, Tavkhelidze, Nuovo Cimento, 1963 and V. Kadyshevsky, Nucl. Phys., 1968]; TO OBTAIN UNITARY CONSTRAINTS ON THE HIGH-ENERGY SCATTERING OF W, Z, H in the SM.

METHOD :
- UNITARY GAUGE $(\xi \to \infty)$ THAT PERMITS TO AVOID INTRODUCTION OF GHOSTS
- NO APPROXIMATIONS
- DIMENSIONAL REGULARIZATION
- RENORMALIZATION SCHEME ON THE MASS SHELL ANALOGOUS TO THAT PROPOSED BY [A. Sirlin, Phys. Rev. D $\underline{22}$, 971 (1980)]
- INDEPENDENT CONSTANTS ARE : $e_0, M_{W_0}, M_{Z_0}, M_{H_0}, m_{f_0}$
- strengths of Higgs-fermion pseudoscalar interaction depend on the parameters b_i: $\sim (1 + b_i \gamma_5)$

RESULTS:
- THE HIGGS-HIGGS $2 \to 2$ AMPLITUDE, WHICH IS DIFFERENT FROM THAT OBTAINED BY DURAND et al.
- GENERALIZATION TO THE MSSM MODEL.

R.N. Cahn and M. Suzuki, PLB, **134**, 115 (1984)

Bound states $m_H > 1.3$ TeV, the binding energy at $m_H = 2$ TeV is only about 150 GeV

L. Durand, J.M. Johnson and J.L. Lopez, PRL **64**, 1215 (1990) and PRD **45**, 3112 (1992)

ONE-LOOP CORRECTIONS: $(\lambda = M_H^2/2v^2)$

$$M = -a\lambda\left[1 + \frac{\lambda}{(4\pi)^2}\left(1 - \frac{9\pi}{\sqrt{3}} + \eta - \alpha \ln\frac{M_H^2}{-s} - \beta \ln\frac{M_H^2}{-t} - \right.\right.$$
$$\left.\left. - \gamma \ln\frac{M_H^2}{-u}\right)\right],$$ where λ is the coupling constant, $\alpha+\beta+\gamma = 12$, $\left[Z_\phi^{1/2}\right]^4 = 1 + \frac{\lambda}{(4\pi)^2}\eta$ and a is the $2\to 2$ tree-level interaction coefficient for the channel considered

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P.N. Maher, L. Durand, K. Riesselmann, PRD **48**, 1061 (1993), ibid 1084 (1993)

TWO-LOOP CORRECTIONS:

$$M = \mathcal{Z}\, \mathcal{F}_R\, \mathcal{Z}$$, where

$$\mathcal{Z} = \frac{Z_H}{Z_W}$$

$$\mathcal{F}_R = A(s) + A(t) + A(u)$$

$$A_R = -2\lambda + \frac{\lambda^2}{16\pi^2}\left(-16\ln(-s) - 4\ln(-t) - 4\ln(-u) + 2 + 6\sqrt{3}\pi\right) +$$
$$+ \lambda^3/(16\pi^2)^2\left(-192\ln^2(-s) + 176\ln(-s) + 96\sqrt{3}\pi\ln(-s) + \ldots\right.$$

The equivalence theorem

(e.g. J. Cornwall, D. Levin & G. Tiktopoulos
Phys. Rev. D10, 1145 (1974)
B. W. Lee, C. Quigg & H. B. Thacker
Phys. Rev. Lett. 38, 883 (1977); Phys. Rev. D16, 1519 (1977)

The scattering amplitudes for n longitudinally-polarized vector bosons $W_L^\pm$, Z_L and any number of other external particles are related to the corresponding scattering amplitudes for the scalar Goldstone bosons $w^\pm, z$ to which $W_L^\pm$, Z_L reduce for vanishing gauge couplings g, g' by

$$T(W_L^\pm, Z_L, H\ldots) = (iC)^n \, T(w^\pm, z, H\ldots) + O(M_W/\sqrt{s})$$

where the constant C depends on the renormalization scheme.

The Lagrangian is (Higgs sector)

$$\mathcal{L} = -\frac{1}{2}(\partial_\mu \chi)^2 - \frac{1}{2} M_\chi^2 \chi^2 - \frac{e M_W}{(1-R)^{1/2}} W_\mu^+ W_\mu^- \chi -$$

$$- \frac{e M_Z}{2R^{1/2}(1-R)^{1/2}} Z_\mu^2 \chi - \frac{e}{2M_W(1-R)^{1/2}} \sum_f m_f \bar{f} f \chi -$$

one can add pseudoscalar interaction

$$- \frac{e^2}{4(1-R)} W_\mu^+ W_\mu^- \chi^2 - \frac{e^2}{8R(1-R)} Z_\mu^2 \chi^2 -$$

$$- \frac{e M_\chi^2}{4M_W(1-R)^{1/2}} \chi^3 - \frac{e^2 M_\chi^2}{32 M_W^2 (1-R)} \chi^4$$

where $R = M_W^2 / M_Z^2$

The coupling constants in the Feynman rules:

$f^{W\chi}$	$-ig M_W$	f^{χ}	$-\frac{ig}{2} \frac{m_i}{M_W}$
$f^{Z\chi}$	$-ig M_Z^2/M_W$	$f^{3\chi}$	$-\frac{3}{2} ig \frac{M_\chi^2}{M_W}$
$f^{2W2\chi}$	$-ig^2/2$	$f^{4\chi}$	$-\frac{3}{4} \frac{ig^2 M_\chi^2}{M_W^2}$
$f^{2Z2\chi}$	$-\frac{ig^2}{2} \frac{M_Z^2}{M_W^2}$		

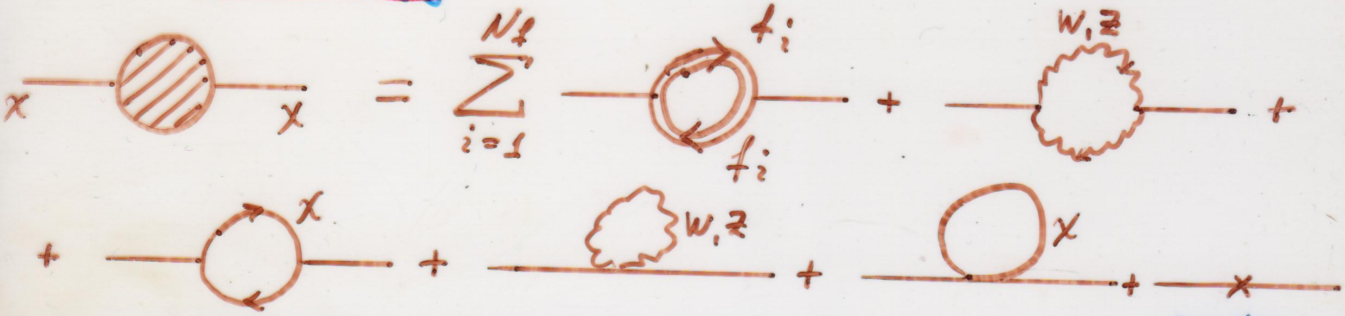
$g = e/\sin\theta_W$

K_{ij} is the Kobayashi – Maskawa matrix

$2P = -\frac{1}{\varepsilon} + \gamma + \ln \frac{M_W^2}{4\pi\mu^2}$, γ is the Euler constant

The diagrams:

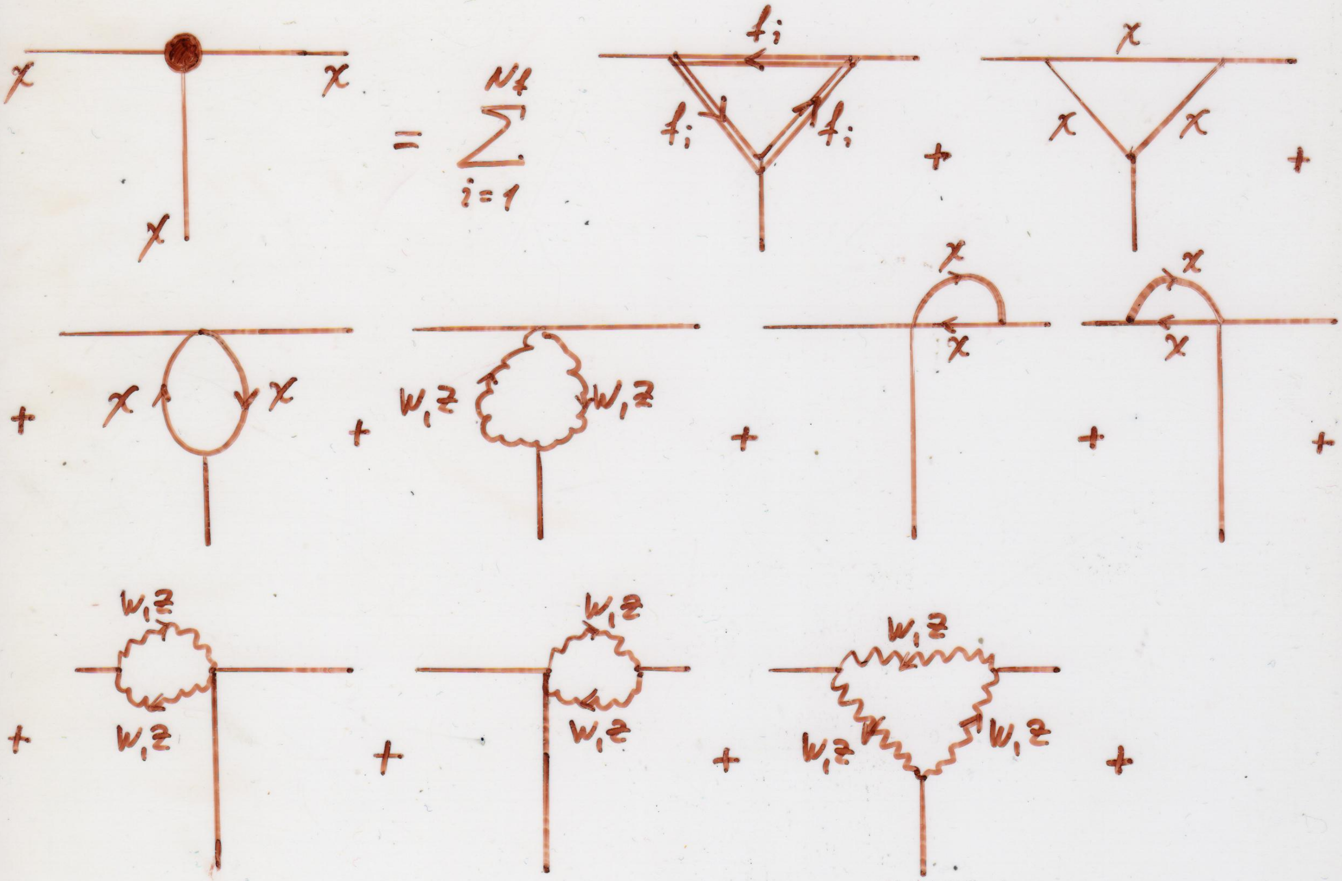
a) self-energy



(tadpoles are contracted in the final expression)

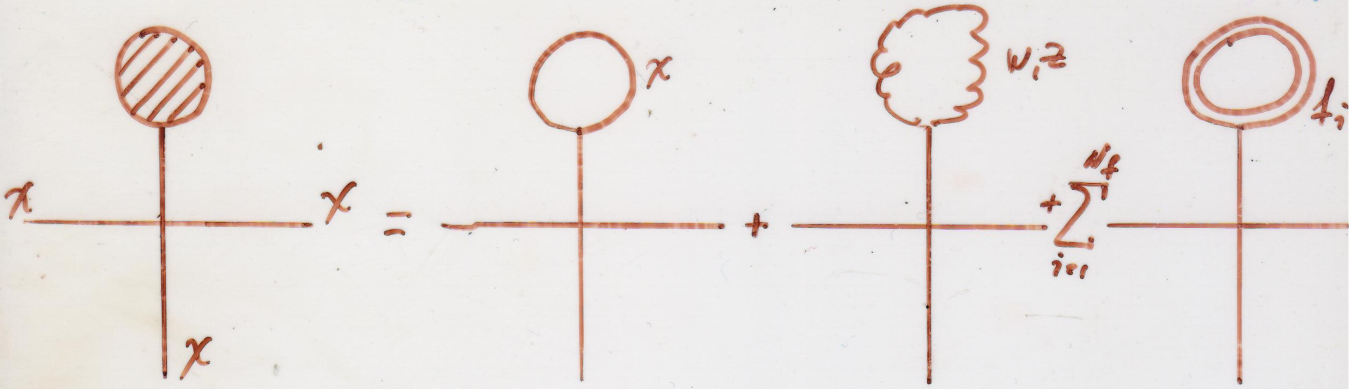
counter term

b) vertex diagrams

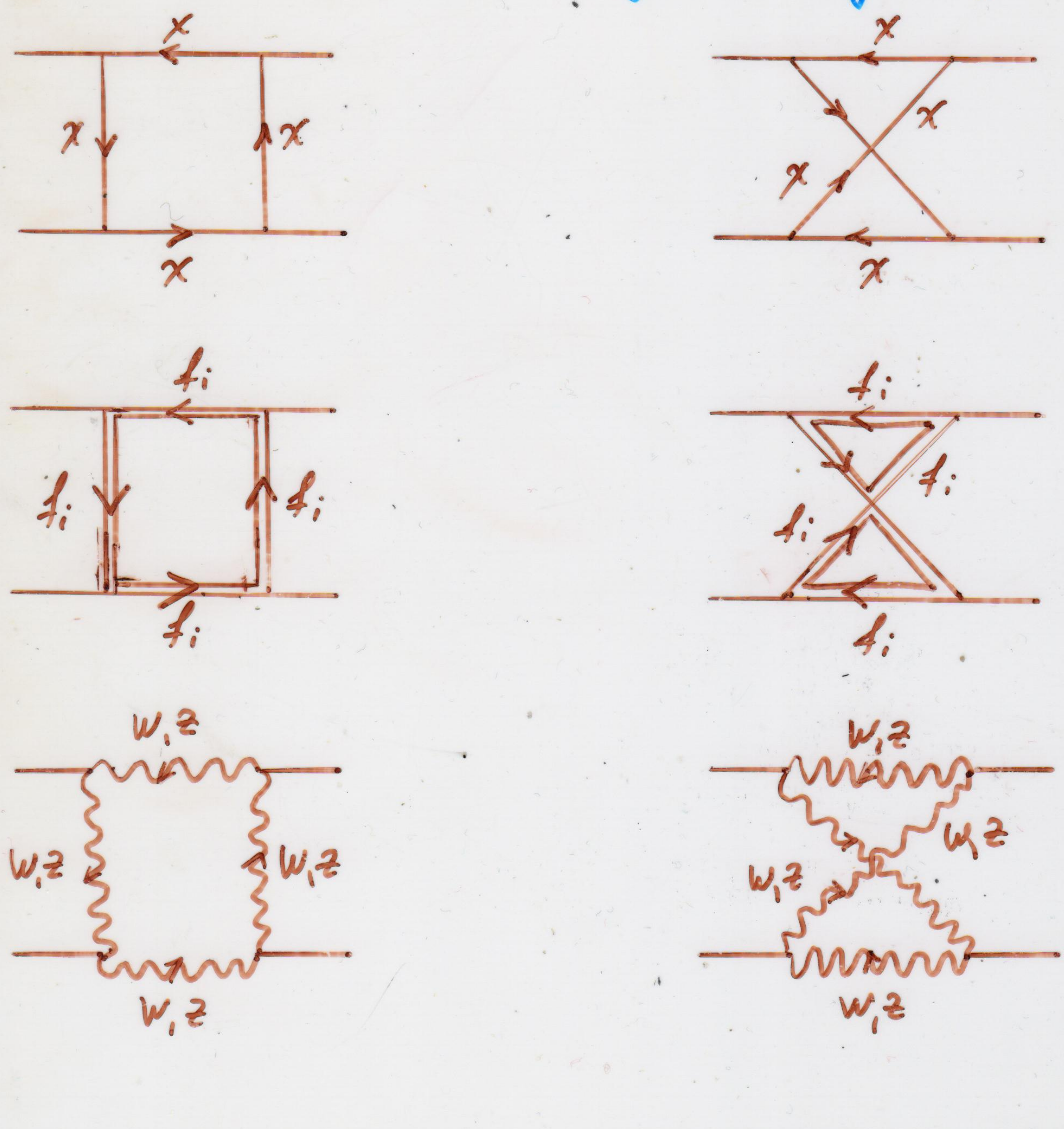


+ tadpoles + Γ (counter term)

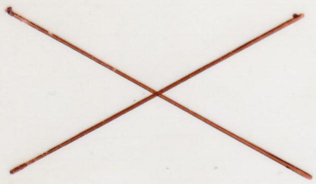
c) tadpoles diagrams (contributed to $\Gamma^{c.t.}$ and $i\mathcal{M}^{c.t.}$)



d) the complete set (including box diagrams)

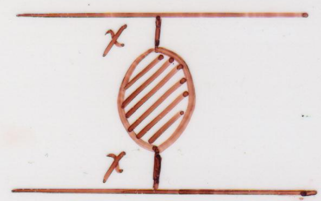


The one-loop amplitudes are $\left(r_W = M_\chi^2/M_W^2,\ r_Z = M_\chi^2/M_Z^2\right)$

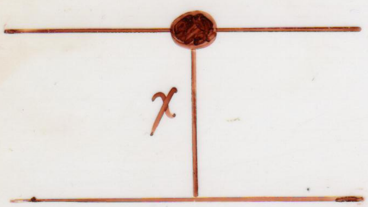


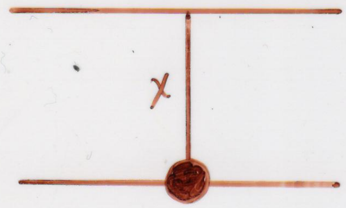
$i\mathcal{M} = -\frac{3ig^2}{4} r_W$

$i\mathcal{M} = \frac{9ig^2}{4} r_W \frac{M_\chi^2}{t+M_\chi^2}$

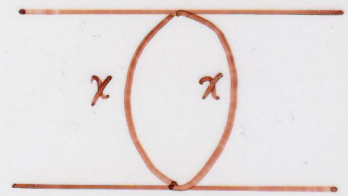


$\frac{9g^2}{4} r_W \frac{M_\chi^2 \Pi^{ren}(t)}{(t+M_\chi^2)^2}$



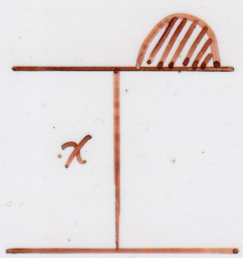


$-\frac{3g}{2} r_W \frac{M_W \Gamma^{ren}(p_{1,2}^2, q_{1,2}^2, t)}{t+M_\chi^2}$

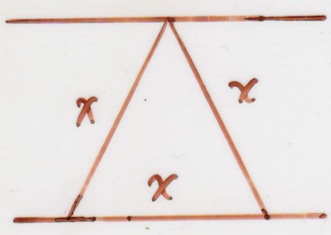


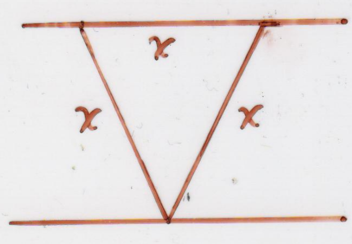
$\frac{9g^4}{16} r_W^2 \Pi^{\chi}(t)$

$\frac{9g^2}{4} r_W \frac{M_\chi^2 \Pi^{ren}(p_{1,2}^2)}{(p_{1,2}^2+M_\chi^2)(t+M_\chi^2)}$

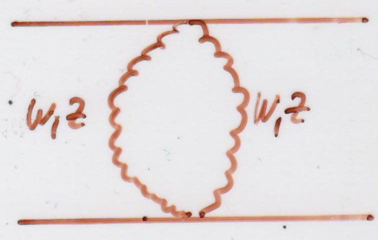


$\frac{9g^2}{4} r_W \frac{M_\chi^2 \Pi^{ren}(q_{1,2}^2)}{(q_{1,2}^2+M_\chi^2)(t+M_\chi^2)}$

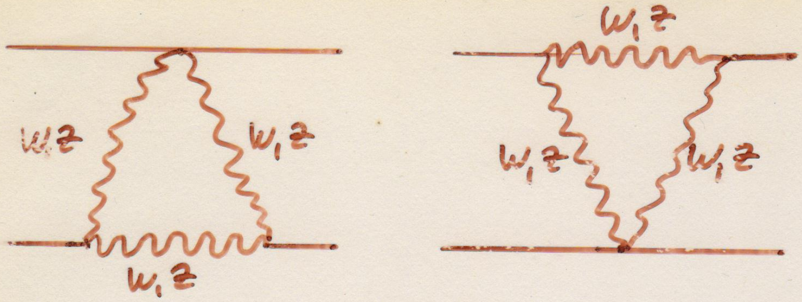




$-\frac{27}{16} g^4 r_W^2 M_\chi^2 \Gamma^{3\chi}(p_{1,2}^2, q_{1,2}^2, t)$



$\frac{g^4}{4} \Pi^{2W}(t) + \frac{g^4}{4R^2} \Pi^{2Z}(t)$



$$+ \, i\mathcal{M}^{c.t.}$$

$$i\mathcal{M} = -\frac{g^4}{2} M_W^2 \, \Gamma^{3W}(p_{1,2}^2, q_{1,2}^2, t) - \frac{g^4}{2R^2} M_Z^2 \, \Gamma^{3Z}(p_{1,2}^2, q_{1,2}^2, t)$$

$$i\mathcal{M} = -\frac{3g^2}{4} r_W \frac{\Pi^{ren}(p_{1,2}^2)}{p_{1,2}^2 + M_X^2} \qquad i\mathcal{M} = -\frac{3g^2}{4} r_W \frac{\Pi^{ren}(q_{1,2}^2)}{q_{1,2}^2 + M_X^2}$$

$$\Pi^{ren}(q^2) = \Pi^X(q^2) - \delta M_X^2 - (Z_X - 1)(q^2 + M_X^2)$$

$$\Gamma^{ren}(p^2, q^2, t) = \Gamma(p^2, q^2, t) + \Gamma^{c.t}, \quad \text{where}$$

$$\Gamma^{c.t.} = -\frac{3}{2} g \frac{M_X^2}{M_W} \left[\frac{3}{2}(Z_X - 1) + \frac{\delta g}{g} + \frac{\delta M_X^2}{M_X^2} - \frac{1}{2} \frac{\delta M_W^2}{M_W^2} \right]$$

$$\frac{\delta g}{g} = Z_A^{-1/2} \left(1 - \frac{\delta R}{1-R}\right)^{-1/2} - 1 \simeq \frac{1}{2}\left[\frac{\delta R}{1-R} - (Z_A - 1)\right]$$

$$\frac{\delta R}{R} = \frac{Z_{\mu W} Z_W^{-1}}{Z_{\mu Z} Z_Z^{-1}} - 1 \simeq \frac{\delta M_W^2}{M_W^2} - \frac{\delta M_Z^2}{M_Z^2}$$

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

needed in the unitary gauge

Method : reduction to the scalar one-loop integrals [t'Hooft, Nucl. Phys. B153, 365 (1979)] similar to [G. Passarino & M. Veltman; Nucl. Phys. B160, 151 (1979)].

a) $$I_0(q^2, M_1^2, M_2^2) = \int_0^1 dx \log \frac{q^2 x(1-x) + M_1^2 x + M_2^2 (1-x)}{M_W^2} =$$

$$= -2 + \log \frac{M_1 M_2}{M_W^2} - \frac{1}{2} \frac{M_1^2 - M_2^2}{q^2} \log \frac{M_1^2}{M_2^2} + \frac{1}{2q^2} L(q^2, M_1^2, M_2^2)$$

where

$$L(q^2, M_1^2, M_2^2) = \left[(q^2 + M_1^2 + M_2^2) - 4M_1^2 M_2^2\right] \int_0^1 \frac{dx}{q^2 x(1-x) + M_1^2 x + M_2^2 (1-x)}$$

$$= \frac{1}{\sqrt{(q^2 + M_1^2 + M_2^2)^2 - 4M_1^2 M_2^2}} \begin{cases} \log \ldots \\ \text{arccot} \ldots \end{cases}$$ depending on the region of q^2 (see Bardin I, p. 440)

$-(m_1 - m_2)^2 \leq q^2 < \infty$, $-\infty < q^2 \leq -(m_1 + m_2)^2$, $-(m_1^2 + m_2^2) \leq q^2 \leq -(m_1 - m_2)^2$, $-(m_1 + m_2)^2 < q^2$

b) $$I_1(q^2, t, p^2, M_1^2, M_2^2, M_3^2) = \int_0^1 dx \int_0^x dy \left[a x^2 + b y^2 + c xy + d x + e y + f\right]^{-1}$$

where $a = -t$, $b = -q^2$, $c = -2(pq - q^2)$

$d = M_2^2 - M_3^2 + t$, $e = M_1^2 - M_2^2 + 2pq - q^2$, $f = M_3^2 - i\varepsilon$

c) $$I_2(q_1^2, q_2^2, p_2^2, p_1^2, s, t, M_1^2, M_2^2, M_3^2, M_4^2) =$$

$$= \int_0^1 dx \int_0^x dy \int_0^y dz \left[a x^2 + b y^2 + g z^2 + c xy + h xz + j yz + d x + e y + k z + f\right]^{-2}$$

with

$a = -p_2^2$ $\quad$ $d = M_3^2 - M_4^2 + p_2^2$ $\quad$ $g = -q_1^2$

$b = -q_2^2$ $\quad$ $e = M_2^2 - M_3^2 + q^2 - 2p_2 q_2$ $\quad$ $h = 2p_2 q_1$

$c = 2p_2 q_2$ $\quad$ $f = M_4^2 - i\varepsilon$ $\quad$ $j = -2q_1 q_2$

$k = M_1^2 - M_2^2 + q_1^2 + 2q_1 q_2 - 2q_1 p_2$

$$A(m^2) = \int d^n q \frac{1}{q^2+m^2+i\varepsilon} = \frac{i\pi^{n/2}}{(m^2)^{1-n/2}} \Gamma\left(1-\frac{1}{2}n\right)$$

$$B(\kappa, m_1, m_2) = \int d^n q \frac{1}{(q^2+m_1^2-i\varepsilon)((q+\kappa)^2+m_2^2-i\varepsilon)}$$

$$= \Delta - i\pi^2 \int_0^1 dx \ln\left(-\kappa^2 x^2 + x(\kappa^2+m_2^2-m_1^2)+m_1^2-i\varepsilon\right)$$

(Δ is related with $\mathcal{P}$ in our notation)

$$C(p_1,p_2,m_1,m_2,m_3) = \int d^n q \frac{1}{(q^2+m_1^2)((q+p_1)^2+m_2^2)((q+p_1+p_2)^2+m_3^2)}$$

$$\sim i\pi^2 \int_0^1 dx \int_0^x dy \left[ax^2+by^2+cxy+dx+ey+f\right]^{-1}$$

$$D(p_1,p_2,p_3,p_4,m_1,m_2,m_3,m_4) =$$

$$= \int d^n q \frac{1}{(q^2+m_1^2)((q+p_1)^2+m_2^2)((q+p_1+p_2)^2+m_3^2)((q+p_1+p_2+p_3)^2+m_4^2)}$$

$$\sim i\pi^2 \int_0^1 dx \int_0^x dy \int_0^y dz \left[ax^2+by^2+gz^2+cxy+hxz+jyz+dx+ey+kz+f\right]^{-2}$$

Formulas in terms of Spence functions are given.

$$Sp(x) = -\int_0^x \frac{\ln(1-t)}{t}\, dt$$

a) It is not possible to use the Stuart's computer program [R. Stuart, Comp. Phys. Comm., 48, 367 (1988); R. Stuart & A. Gognova, ibid, 56, 337 (1990)] since preparation of the initial data (for the process $HH \to HH$) consumes much more time than the calculations by hand.

6) It is convenient to use a reduction of the numerator to the structures entering in the denumerator (under the calculation of the diagrams with the tremendous number of the terms).

c) Pauli metric:

V $\quad \dfrac{-i}{(2\pi)^4} \dfrac{\delta_{\alpha\beta} + k_\alpha k_\beta / M^2}{k^2 + M_V^2}$ $\qquad$ A $\quad \dfrac{-i}{(2\pi)^4} \dfrac{\delta_{\alpha\beta}}{k^2}$

f $\quad \dfrac{-1}{(2\pi)^4} \dfrac{\hat{k} + im}{k^2 + m^2}$ $\qquad$ χ $\quad \dfrac{-i}{(2\pi)^4} \dfrac{1}{k^2 + M_\chi^2}$

d) The traces of γ-matrices in a d-dimensional space are

$$Tr\, \gamma_\alpha = Tr\, \gamma_5 = Tr\, \gamma_\alpha \gamma_\beta \gamma_5 = 0$$

$$Tr\, \gamma_\alpha \gamma_\beta = f(d)\, \delta_{\alpha\beta}$$

$$Tr\, \gamma_\alpha \gamma_\beta \gamma_\rho \gamma_\sigma = f(d)\, d_{\alpha\beta\rho\sigma}$$

$$Tr\, \gamma_\alpha \gamma_\beta \gamma_\rho \gamma_\sigma \gamma_5 = f(d)\, \varepsilon_{\alpha\beta\rho\sigma}$$

where

$$d_{\alpha\beta\rho\sigma} = \delta_{\alpha\beta}\delta_{\rho\sigma} - \delta_{\alpha\rho}\delta_{\beta\sigma} + \delta_{\alpha\sigma}\delta_{\beta\rho}$$

In the trace calculations we use

$$f(d) = 2\omega = 4 - 2\varepsilon = d,$$

d is the dimension of space in the dimensional regularization.

Renormalization scheme.

A. Sirlin, Phys. Rev. D22 (4), 971 (1980)

D. Yu. Bardin, P. Ch. Christova & O. M. Fedorenko, Nucl. Phys. B 175, 435 (1980), ibid, 197, 1 (1982)

D. Yu. Bardin, Lectures for young scientists, No. 46, Dubna, 1988 (in Russian)

The features: a) unitary gauge (all we have in the theory are the physical states)

$$R_\xi : \; i\Delta_{\mu\nu}(k) = \frac{-i}{k^2 - M^2 + i\varepsilon}\left[g_{\mu\nu} - (1-\xi)\frac{k_\mu k_\nu}{k^2 - \xi M^2}\right]$$

$$U: \; \xi \to \infty \quad i\Delta_{\mu\nu}(k) = \frac{-i\left(g_{\mu\nu} - k_\mu k_\nu / M^2\right)}{k^2 - M^2 + i\varepsilon}$$

Thanks to t'Hooft [Nucl. Phys B33, 173 (1971), ibid B35, 167 (1971)]

b) independent parameters ($N_f + 4$)

e, M_W, M_Z, M_H and m_f (masses of fermions)

The formulae are

$$f_{0L} = \sqrt{Z_{fL}}\, f_L \qquad m_{f_0} = \left[\left(Z_{fL}^{1/2}\right)^+\right]^{-1} Z_{m_f} \left[Z_{fR}^{1/2}\right]^{-1}$$

$$f_{0R} = \sqrt{Z_{fR}}\, f_R \qquad e_0 = Z_e Z_A^{-1/2} e$$

$$W_0 = \sqrt{Z_W}\, W \qquad M_{W_0}^2 = Z_{M_W} Z_W^{-1} M_W^2$$

$$\chi_0 = \sqrt{Z_\chi}\, \chi \qquad M_{\chi_0}^2 = Z_{M_\chi} Z_\chi^{-1} M_\chi^2$$

$$\begin{pmatrix} Z_0 \\ A_0 \end{pmatrix} = \begin{pmatrix} \sqrt{Z_Z} & 0 \\ \sqrt{Z_M} & \sqrt{Z_A} \end{pmatrix} \begin{pmatrix} Z \\ A \end{pmatrix} \qquad M_{Z_0}^2 = Z_{M_Z} Z_Z^{-1} M_Z^2$$

WHY DO WE NEED RENORMALIZATION IN THE EW THEORY?

THE REASONS ARE THE SAME AS IN QED. QED SHOULD TAKE THE PARAMETERS e and m from the experiment. e is taken from, e.g. the scattering formula (electron in the Coulomb field). But, the higher orders of the contributions to the cross section are divergent....

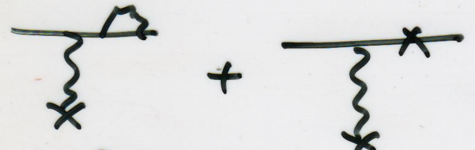
change the mass. One should cancel these diagram contributions. So, we need to reject the interpretation that m and e are taken from experiment. They are BARE mass and charge.

$$\psi_0 = Z_\psi^{1/2}\,\psi$$ (scale transformation) $\rightarrow$ NEW LAGRANGIAN

$Z_i = 1 \Rightarrow$ OLD LAGRANGIAN

THE CONDITION OF THE UNVARIABILITY of PHYSICAL CONSTANTS GIVES US Z_i

$$\mathcal{L}(Z_i) = \mathcal{L}(Z_i) - \mathcal{L}(1) + \mathcal{L}(1) = \mathcal{L}_{c.t.}(Z_i) + \mathcal{L}(1)$$



$= 0$ NONRENORMALIZING COND. OF EXTERNAL LINES (LINES ON THE MASS SHELL)

Z_ψ and Z_m

$= 0 \rightarrow Z_A$

$= 0 \rightarrow Z_e$ (or from γe-scattering) if the external lines are on the mass shell

This is the renormalization scheme on mass shell!

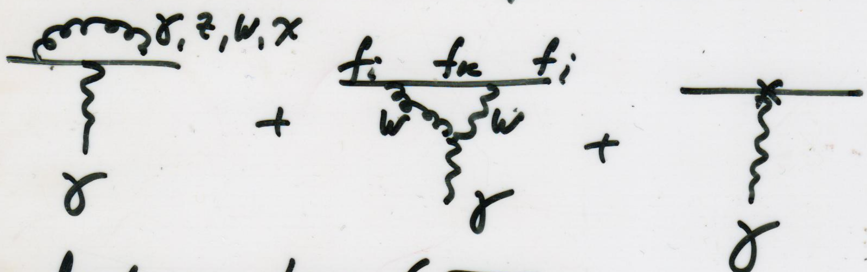
The number of ren. constants is equal to the number of independent fields + unknown apriori constants (Z_A, Z_ψ, Z_m, Z_e). In the EW theory the number of fields and constants is $N_{fields} + N_{ferm} + 4$

$Z_{\psi_{iR}}, Z_{\psi_{iL}}, Z_A, Z_Z, Z_\mu, Z_W, Z_\chi, Z_{m_f}, Z_{M_W}, Z_{M_Z}, Z_{M_\chi}, Z_e$.

In the U-gauge it is simpler to renormalize on the mass shell (any particle can be in in- out-states, so

$= 0$ for all!

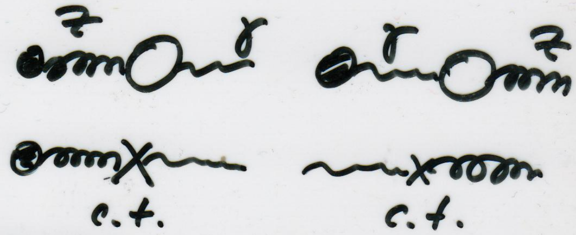
But Z_e should be defined from:



$= 0$

In fact we have $(\sqrt{Z_f})_{ij}$.

$(Z\gamma)$-mixing $\Rightarrow$ $Z_\mu = Z_{Z\gamma}$



Depending constants can be expressed on using their definitions

$$R_0 = R\,\frac{Z_{M_W} Z_W^{-1}}{Z_{M_Z} Z_Z^{-1}}$$

$$\delta R = R_0 - R$$

$$g_0 = \frac{e_0}{\sqrt{1-R_0}} = \frac{e Z_A^{-1/2}}{(1-R)^{1/2}}\left(1 - \frac{\delta R}{1-R}\right)^{-1/2} \text{etc}$$

Word identities: QED, $Z_\psi = Z_e$; EW, $Z_e = 1$ follows authomatically

$$\Pi^{Ren}(q^2) = \Pi^X(q^2) - \delta M_X^2 - (Z_X - 1)(q^2 + M_X^2) =$$

$$= \frac{ig^2}{16\pi^2} M_X^2 \Big\{ \Big[-\frac{3}{4} \frac{q^4}{M_W^2 M_X^2} - \frac{3}{4} r_W - \frac{3}{2} \frac{q^2}{M_W^2} \Big] P +$$

$$+ \frac{3}{4} \frac{q^4}{M_W^2 M_X^2} + \frac{1}{8} \frac{q^4}{M_W^2 M_X^2} \ln R + \frac{q^2}{M_X^2} \Big(1 + \frac{1}{2R} - 3 r_W^{-1}$$

$$- \frac{3}{2} \frac{1}{R} r_Z^{-1} \Big) + \frac{1}{4} \frac{q^2}{M_W^2} \ln R + \frac{1}{8} r_W \ln R + 1 + \frac{1}{2R} -$$

$$- \frac{3}{4} r_W - 3 r_W^{-1} - \frac{3}{2} \frac{1}{R} r_Z^{-1} - \Big(\frac{q^2}{M_X^2} + 1 \Big) \frac{1}{2M_W^2} \mathrm{Tr}\, m_i^2$$

$$+ \Big(\frac{q^2}{M_X^2} + 1 \Big) \frac{2}{M_W^2 M_X^2} \mathrm{Tr}\, m_i^4 - \Big(\frac{1}{8} \frac{q^2}{M_W^2} + \frac{1}{2} + \frac{3}{2} \frac{M_W^2}{q^2} \Big) \frac{1}{M_X^2}$$

$$L(q^2, M_W^2, M_W^2) - \Big(\frac{1}{16} \frac{q^2}{M_Z^2} + \frac{1}{4} + \frac{3}{4} \frac{M_Z^2}{q^2} \Big) \frac{1}{R} \frac{1}{M_X^2} L(q^2, M_Z^2, M$$

$$- \frac{9}{16} \frac{1}{q^2} r_W L(q^2, M_X^2, M_X^2) + \frac{1}{4} \frac{1}{M_X^2 M_W^2} \mathrm{Tr}\, m_i^2 L(q^2, m_i^2, m_i$$

$$+ \frac{1}{M_W^2 M_X^2} \frac{1}{q^2} \mathrm{Tr}\, m_i^4 L(q^2, m_i^2, m_i^2) + \Big(- \frac{q^2}{4M_X^2} + \frac{q^2}{4M_W^2} +$$

$$+ \frac{3q^2}{M_X^2 r_W (r_W - 4)} + \frac{1}{4} + \frac{1}{8} r_W - \frac{3}{2} r_W^{-1} + \frac{3}{r_W (r_W - 4)} \Big) \frac{1}{M_X^2}$$

$$L(-M_X^2, M_W^2, M_W^2) + \Big(- \frac{q^2}{8M_X^2} + \frac{q^2}{8M_Z^2} + \frac{3q^2}{M_X^2 r_Z (r_Z - 4)} + \frac{1}{8} + \frac{1}{16} r_Z$$

$$- \frac{3}{4} r_Z^{-1} + \frac{3}{2 r_Z (r_Z - 4)} \Big) \frac{1}{R} \frac{1}{M_X^2} L(-M_X^2, M_Z^2, M_Z^2) -$$

$$- \Big(\frac{3q^2}{8M_W^2} + \frac{15}{16} r_W \Big) \frac{1}{M_X^2} L(-M_X^2, M_X^2, M_X^2) + \frac{q^2}{4 M_W^2 M_X^4}$$

$$\mathrm{Tr}\, m_i^2 L(-M_X^2, m_i^2, m_i^2) + \frac{1}{2} \Big(3 + \frac{q^2}{M_X^2} \Big) \frac{1}{M_W^2 M_X^4} \mathrm{Tr}\, m_i^4 \times$$

$$\times L(-M_X^2, m_i^2, m_i^2) \Big\}$$

RESULTS and CONCLUSIONS

- We calculated the Higgs-Higgs amplitude with taking into account one-loop radiative corrections
- Due to introduction of some additional parameters like a_i, b_i for fermion interaction one can easily to generalize the calculated results to other generalizations of the SM (calculations have been also produced in the MSSM model).
- The results do not coincide in full with the Durand et al results. We do not yet know, why?
    - error in calculations (we are sure in our results) some misprint have recently been corrected;
    - ghosts, gauge? Recently several authors claimed that some electrodynamical calculations may depend on the 4-potential and, hence, the gauge; [Rohrlich → 4-energy-momentum in CED]
    - renormalization scheme or the equivalence theorem;
    - coherent states? → non-perturbative calculus?

In future we still are going to investigate the origin of our disagreement in detail.

The counter terms:

$$\Pi^{c.t} = -\left[\delta M_X^2 + (Z_X - 1)(q^2 + M_X^2)\right]$$, self-energy

$$\Gamma^{c.t} = -\frac{3gM_X^2}{2M_W^2}\left[\frac{3}{2}(Z_X - 1) + \frac{\delta g}{g} + \frac{\delta M_X^2}{M_X^2} - \frac{\delta M_W^2}{2M_W^2}\right]$$, vertex

where

$$\frac{\delta g}{g} = Z_A^{-1/2}\left(1 - \frac{\delta R}{1-R}\right)^{-1/2} - 1 \simeq \frac{1}{2}\left[\frac{\delta R}{1-R} - (Z_A - 1)\right]$$

$$\frac{\delta R}{R} = \frac{Z_{M_W} Z_W^{-1}}{Z_{M_Z} Z_Z^{-1}} - 1 \simeq \frac{\delta M_W^2}{M_W^2} - \frac{\delta M_Z^2}{M_Z^2}$$

one-loop

and

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

(it is necessary in the unitary gauge!)