On the one - loop amplitude of the $e^+e^- \to t\bar{t}$ process in R_ξ and unitary gauges

L. V. Kalinovskaya

Laboratory of Nuclear Physics,

Joint Instutute for Nuclear Research, Dubna, Russia

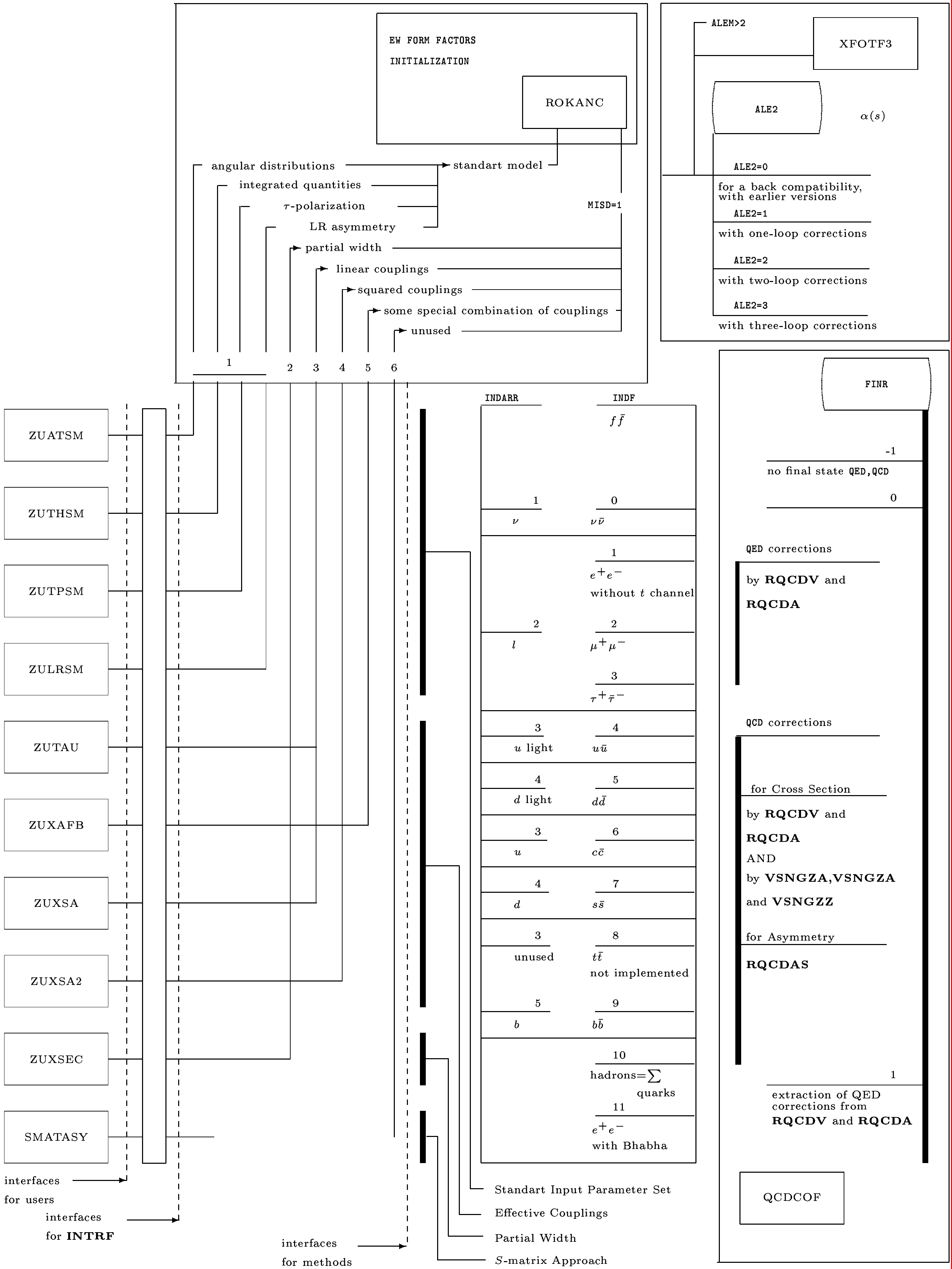
Z F I T T E R

Various interfaces allow fits of different channels with different sets of input parameters.

LEP1	LEP2	LC
$2E_{beam} \sim M_Z$	$2E_{beam} \sim 200\mathrm{GeV}$	$2E_{beam} \geq 2m_t$

For next update of ZFITTER $\to t\bar{t}$ channel

D. Bardin, LK, G. Nanava



Preparations for the ZFITTER interfaces in subroutine EWCOUP

THE ELECTROWEAK PART OF THE AMPLITUDE

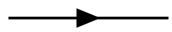
$e^+e^- \longrightarrow t\bar{t}$

- TWO GAUGES $\longrightarrow$ R_ξ AND THE UNITARY
- SYSTEM FOR AUTOMATIC CALCULATION OF FEYNMAN DIAGRAMS

P.S. OMS RENORMALIZATION SCHEME a complete presentation of which was done recently in the book D.Bardin, G.Passarino *The Standart Model in the Making*, Oxford University Press, Oxford, 1999.

Feynman rules for propagators (full collection)

Propagator of a fermion, f


f

$$\frac{-i\not{p}+m_f}{p^2+m_f^2}$$

Vector boson propagators

A

$$\frac{1}{p^2}\left\{\delta_{\mu\nu}+\left(\xi_A^2-1\right)\frac{p_\mu p_\nu}{p^2}\right\}$$

Z

$$\frac{1}{p^2+M_Z^2}\left\{\delta_{\mu\nu}+\left(\xi_Z^2-1\right)\frac{p_\mu p_\nu}{p^2+\xi_Z^2M_Z^2}\right\}$$

$W^\pm$

$$\frac{1}{p^2+M^2}\left\{\delta_{\mu\nu}+\left(\xi^2-1\right)\frac{p_\mu p_\nu}{p^2+\xi^2M^2}\right\}$$

Propagators of unphysical fields


Y^A

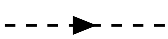
$$\frac{\xi_A}{p^2}$$

ϕ^0

$$\frac{1}{p^2+\xi_Z^2\dfrac{M_Z^2}{c_\theta^2}}$$


Y^Z

$$\frac{\xi_Z}{p^2+\xi_Z^2\dfrac{M_Z^2}{c_\theta^2}}$$


$\phi^\pm$

$$\frac{1}{p^2+\xi^2M^2}$$


$X^\pm$

$$\frac{\xi}{p^2+\xi^2M^2}$$

Propagator of physical scalar field, H-boson

H

$$\frac{1}{p^2+M_H^2}$$

Every propagator should be multiplied by factor $\dfrac{1}{(2\pi)^4 i}$.

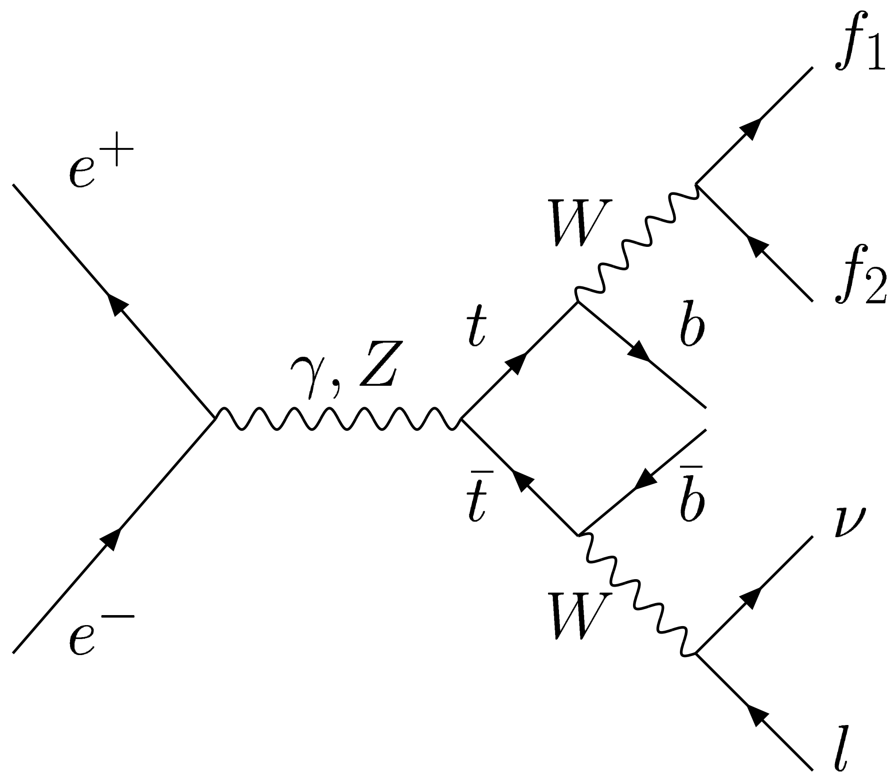
The PURPOSES are:

- Explicitly control gauge invariance in R_ξ, examining cancellation of gauge parameters, and search for gauge invariant subsets of diagrams;

- Possibility to compare with the result in the unitary gauge as a cross-check.

- Create a FORTRAN code for IMPROVED **BORN** APPROXIMATION

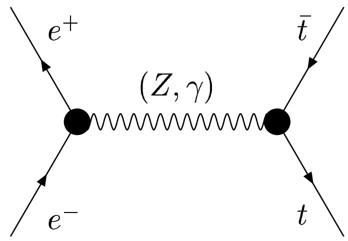
$$|A|^2 = |A_B|^2 + 2Re A_B^* A^{WEAK}$$



f_1
e^+
W
f_2
t
b
γ, Z
$\bar{t}$
$\bar{b}$
ν
W
e^-
l

AMPLITUDES in L, Q, D - BASIS

which naturally arises if the final fermion mass is not ignored.



$$A \sim$$

$$\left[i\gamma_\mu\left(1+\gamma_5\right)F_L^e\left(s\right)+i\gamma_\mu F_Q^e\left(s\right)\right]\otimes$$

$$\left[i\gamma_\mu\left(1+\gamma_5\right)F_L^t\left(s\right)+i\gamma_\mu F_Q^t\left(s\right)+m_t I D_\mu F_D^t\left(s\right)\right]$$

$$D_\mu = \left(p_3 - p_4\right)_\mu$$

Every form factors in R_ξ gauge could be represented as a sum of two terms

$$F^{\xi}_{L,Q,D}(s) = F^{(1)}_{L,Q,D}(s) + F^{add}_{L,Q,D}(s,\xi)$$

First term corresponds to $\xi = 1$ gauge and the second contains all ξ dependence and vanishes for $\xi = 1$ by construction.

CHECKED THE CANCELLATION

of the additional terms and we made this separately

for five subsets of diagrams with virtual

- $\left\{\gamma \longrightarrow \xi_A\right\}$ – QED
- $\left\{Z, \phi^0 \longrightarrow \xi_Z\right\}$ – VERTICES + WF REN

CLUSTER

- $\left\{H, \phi^0 \longrightarrow \xi_Z\right\}$ **cluster**
- $\left\{W, \phi^\pm \longrightarrow \xi\right\}$ **cluster**

+ self-energies and WW box

- ZZ box

Gauge invariant subsets of **QED** diagrams :

QED cluster

$\gamma\gamma$, $Z\gamma$ boxes

QED bremsstrahlung diagrams

———————————————-

Free of infrared divergences.

——————————————————————-

The remaining one-loop diagrams form

WEAK corrections.

The total weak amplitude is a sum

of *dressed* γ and Z exchange amplitudes.

BUILDING BLOCKS

in the order of increasing complexity:

SELF-ENERGIES

VERTICES

WEAK BOXES (WW and ZZ)

————————————————-

Free of ultraviolet divergences.

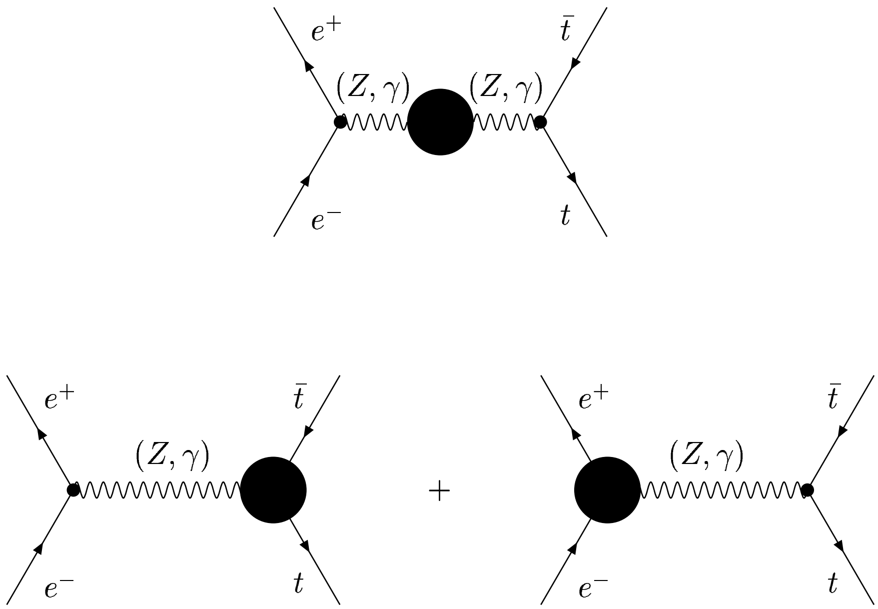


Figure 1: EW dressing of vertices and propagators in the process $e^+ e^- \to (Z,\gamma) \to t\,\bar{t}$.

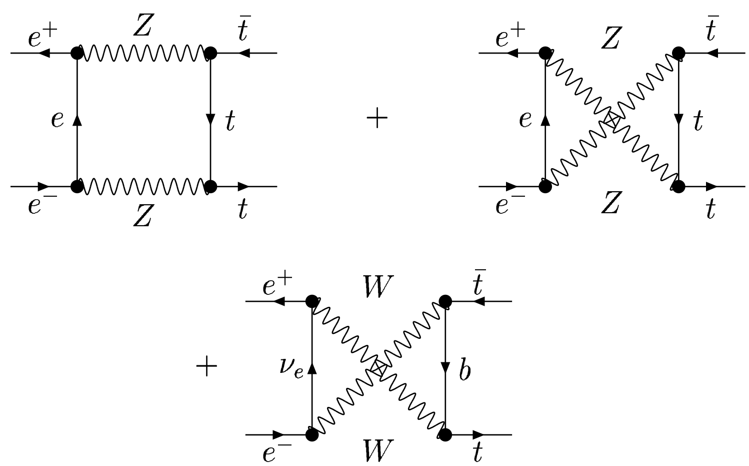


Figure 2: ZZ and WW boxes for the process $e^+ e^- \to t\bar{t}$.

Born-like structure of the WEAK AMPLITUDE in terms of LL, QL, LQ, QQ, LD and QD form factors:

$$
\begin{aligned}
A_\gamma &= i\frac{4\pi Q_e Q_f}{s}\chi_\gamma(s)\alpha(s)\gamma_\mu\otimes\gamma_\mu \\
\mathcal{A}_Z &= i\frac{g^2}{16\pi^2}\,e^2\,4I_e^{(3)}I_t^{(3)}\frac{\chi_Z(s)}{s}
\end{aligned}
$$

$$
\begin{aligned}
&\times\Big\{\gamma_\mu(1+\gamma_5)\otimes\gamma_\mu(1+\gamma_5)F_{LL}(s,t) \\
&-4|Q_e|s_W^2\gamma_\mu\otimes\gamma_\mu(1+\gamma_5)F_{QL}(s,t) \\
&-4|Q_t|s_W^2\gamma_\mu(1+\gamma_5)\otimes\gamma_\mu F_{LQ}(s,t) \\
&+16|Q_eQ_t|s_W^4\gamma_\mu\otimes\gamma_\mu F_{QQ}(s,t) \\
&+\gamma_\mu(1+\gamma_5)\otimes(-im_tD_\mu)\,F_{LD}(s,t) \\
&-4|Q_e|s_W^2\gamma_\mu\otimes(-im_tD_\mu)\,F_{QD}(s,t)\Big\}
\end{aligned}
$$

BOSONIC SELF-ENERGIES

In the R_ξ gauge there are 14 diagrams which contribute to the *total* Z and γ bosonic self-energies and to the Z–γ transition.

With S_{ZZ}, $S_{Z\gamma}$ and $S_{\gamma\gamma}$ standing for the sum of all diagrams, depicted by a grey circle, we define the three corresponding self-energy functions Σ:

$$
\begin{aligned}
S_{ZZ} &= (2\pi)^4 i \frac{g^2}{16\pi^2 c_W^2} \Sigma_{ZZ} \\
S_{Z\gamma} &= (2\pi)^4 i \frac{g^2 s_W}{16\pi^2 c_W} \Sigma_{Z\gamma} \\
S_{\gamma\gamma} &= (2\pi)^4 i \frac{g^2 s_W^2}{16\pi^2} \Sigma_{\gamma\gamma}
\end{aligned}
$$

All **bosonic** self-energies and transitions may be naturally split into *bosonic* and *fermionic* components.

Bosonic self-energies and transitions

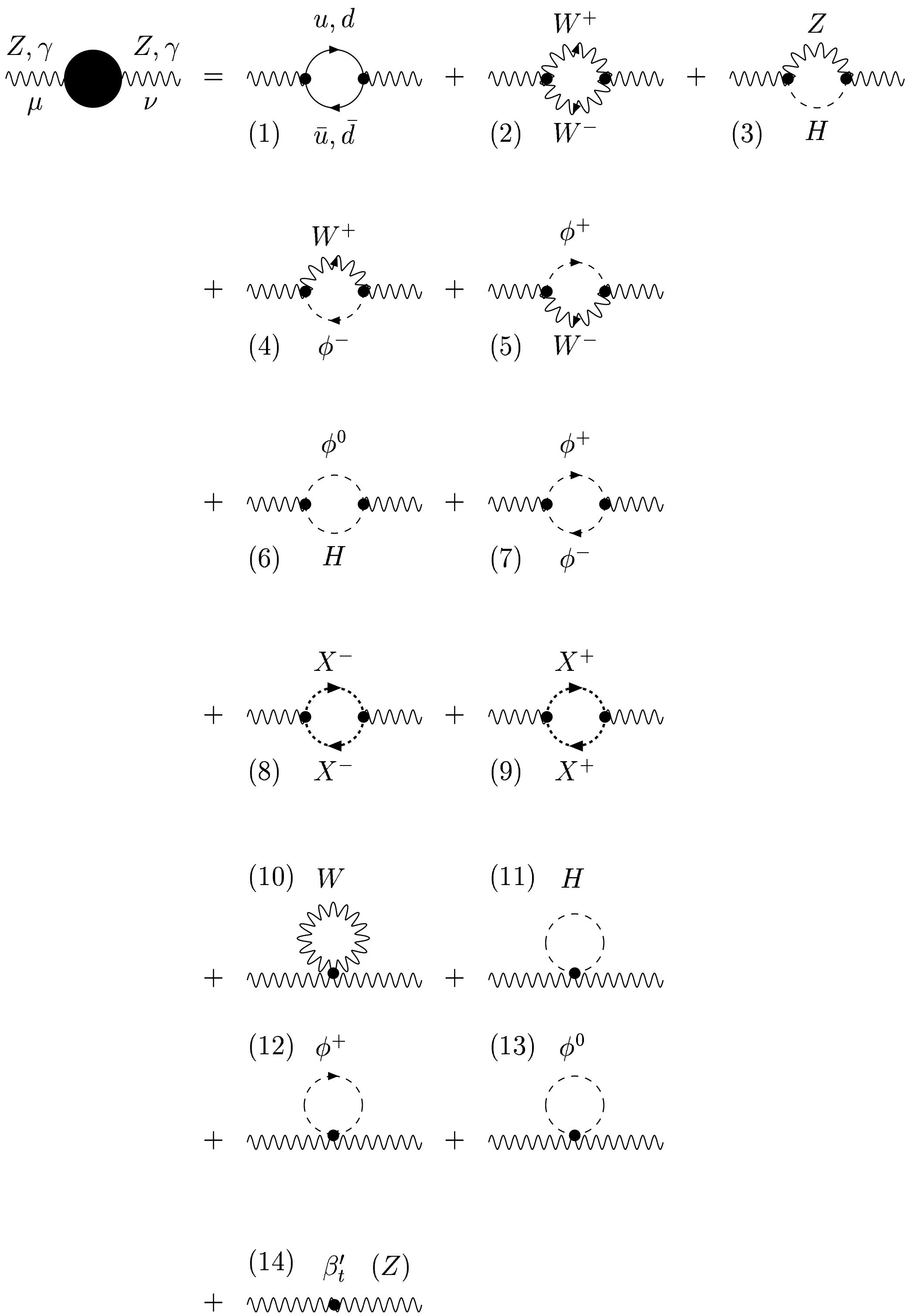


Figure 3: (Z, A)-boson self-energy; $Z - A$ transition

- Bosonic components of Z,γ self-energies and Z–γ transitions, are:

$$\Sigma^{\rm bos}_{ZZ}(s) = M^2_Z\Biggl\{\frac{1}{3}\frac{1}{R_Z}\left(\frac{1}{2}-c^2_W-9c^4_W\right)$$
$$-\frac{3}{2}\left[\left(1+2c^4_W\right)\frac{1}{r_{HZ}}-\frac{1}{2}-c^2_W+\frac{8}{3}c^4_W+\frac{1}{2}r_{HZ}\right]\Biggr\}\frac{1}{\bar{\varepsilon}}+\Sigma^{{\rm bos},F}_{ZZ}(s)$$

$$\Sigma^{{\rm bos},F}_{ZZ}(s) = \frac{M^2_Z}{12}\Biggl\{\left[4c^2_W\left(5-8c^2_W-12c^4_W\right)+\left(1-4c^2_W-36c^4_W\right)\frac{1}{R_Z}\right]$$
$$B^F_0\bigl(-s;M_W,M_W\bigr)$$
$$+\left[\frac{1}{R_Z}+10-2r_{HZ}+\left(r_{HZ}-1\right)^2R_Z\right]B^F_0\bigl(-s;M_H,M_Z\bigr)$$
$$+\left[\frac{18}{r_{HZ}}+1+\left(1-r_{HZ}\right)R_Z\right]L_\mu(M^2_Z)$$
$$+r_{HZ}\Bigl[7-\left(1-r_{HZ}\right)R_Z\Bigr]L_\mu(M^2_H)$$
$$+2c^2_W\left(\frac{18}{r_{HW}}+1+8c^2_W-24c^4_W\right)L_\mu(M^2_W)$$
$$+\frac{4}{3}\left(1-2c^2_W\right)\frac{1}{R_Z}$$
$$-6\left(1+2c^4_W\right)\frac{1}{r_{HZ}}-3(1+2c^2_W)-9r_{HZ}-\left(1-r_{HZ}\right)^2R_Z\Biggr\}$$

Here $L_\mu(M^2)$ denotes the log containing t'Hooft scale μ:

$$L_\mu(M^2)=\ln\frac{M^2}{\mu^2}$$

$$B_0\bigl(-s;M_1,M_2\bigr)=\frac{1}{\bar{\varepsilon}}+B^F_0\bigl(-s;M_1,M_2\bigr)$$

Therefore B^F_0 also depends of the scale μ.

Vacuum polarization $\Pi^{\rm bos}_{Z\gamma}(s)$ and $\Pi^{\rm bos}_{\gamma\gamma}(s)$:

$$\Sigma^{\rm bos}_{Z\gamma}(s) = -s\Pi^{\rm bos}_{Z\gamma}(s)$$

$$\Sigma^{\rm bos}_{\gamma\gamma}(s) = -s\Pi^{\rm bos}_{\gamma\gamma}(s)$$

Bosonic self-energies and bosonic counter-terms.

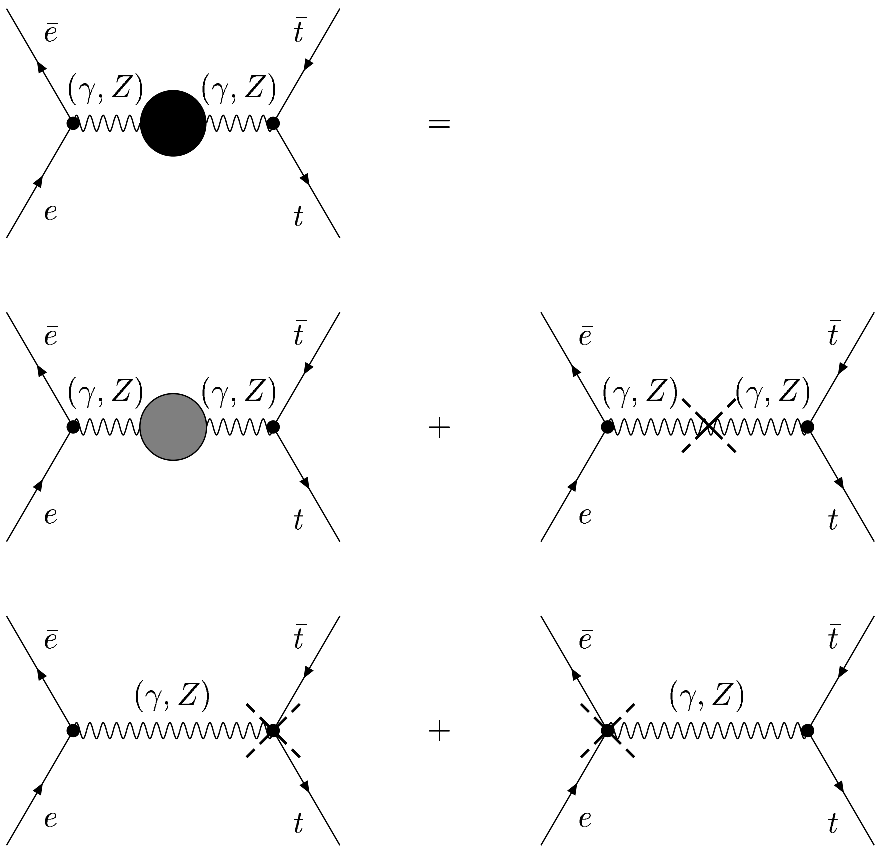


Figure 4: *Bosonic self-energies and bosonic counter-terms for* $e\bar{e} \to (Z,\gamma) \to f\bar{f}$

$$
\begin{aligned}
F^{ct}_{LL}(s) &= \mathcal{D}_Z(s) - s_W^2 \Pi_{\gamma\gamma}(0) \\
&+ \frac{c_W^2 - s_W^2}{s_W^2}\left(\Delta\rho + \Delta\bar{\rho}^{\rm bos}\right)
\end{aligned}
$$

$$
\begin{aligned}
F^{ct}_{QL(LQ)}(s) &= \mathcal{D}_Z(s) - \Big(\Pi_{Z\gamma}(s) + \bar{\Pi}^{\rm bos}_{Z\gamma}(s)\Big) \\
&- s_W^2 \Pi_{\gamma\gamma}(0) - \left(\Delta\rho + \Delta\bar{\rho}^{\rm bos}\right)
\end{aligned}
$$

$$
\begin{aligned}
F^{ct,\rm bos}_{QQ}(s) &= \mathcal{D}^{\rm bos}_Z(s) - 2\Big(\Pi^{\rm bos}_{Z\gamma}(s) + \bar{\Pi}^{\rm bos}_{Z\gamma}(s)\Big) \\
&+ c_W^2\left(1 - R_Z\right)\left[\Pi^{\rm bos}_{\gamma\gamma}(s) - \Pi^{\rm bos}_{\gamma\gamma}(0)\right] \\
&- s_W^2 \Pi^{\rm bos}_{\gamma\gamma}(0) - \frac{1}{s_W^2}\left(\Delta\rho^{\rm bos} + \Delta\bar{\rho}^{\rm bos}\right)
\end{aligned}
$$

$$
\begin{aligned}
F^{ct,\rm fer}_{QQ}(s) &= \mathcal{D}^{\rm fer}_Z(s) - 2\Pi^{\rm fer}_{Z\gamma}(s) \\
&- s_W^2 \Pi^{\rm fer}_{\gamma\gamma}(0) - \frac{1}{s_W^2}\Delta\rho^{\rm fer}
\end{aligned}
$$

The term $c_W^2\left(1 - R_Z\right)\left[\Pi^{\rm fer}_{\gamma\gamma}(s) - \Pi^{\rm fer}_{Z\gamma}(s)\right]$ is extracted from $F^{ct,\rm fer}_{QQ}(s)$ and shifted to A^{OLA}_{γ}.

$\Delta\bar{\rho}^{\rm bos}$ and $\bar{\Pi}^{\rm bos}_{Z\gamma}(s)$ stand for shifts of bosonic self-energies. *G. Passarino*, 1991.

$$
\begin{aligned}
\Delta\bar{\rho}^{\rm bos} &= 4 s_W^2\left[\frac{1}{\bar{\epsilon}} - L_\mu\left(M_W\right)\right] \\
\bar{\Pi}^{\rm bos}_{Z\gamma}(s) &= -2R_W\left[\frac{1}{\bar{\epsilon}} - L_\mu\left(M_W\right)\right]
\end{aligned}
$$

A useful ratio

$$
\mathcal{D}_Z(s) = \frac{1}{c_W^2}\frac{\Sigma_{ZZ}(s) - \Sigma_{ZZ}\left(M_Z^2\right)}{M_Z^2 - s}
$$

FORM FACTORS of Z CLUSTER

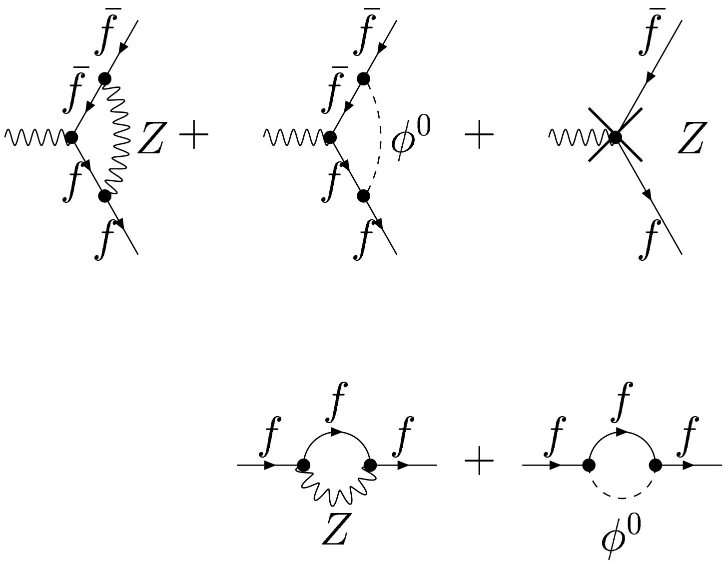


Figure 5: Z cluster

Separating out pole contributions $1/\bar{\epsilon}$, we define finite quantities. We note, that if a form factor $F_A^{ij}(s)$ has a pole, than the corresponding finite part $\mathcal{F}_A^{ij}(s)$ is μ-dependent.

$$F_L^{\gamma Z}(s) = \mathcal{F}_L^{\gamma Z}(s)$$

$$F_Q^{\gamma Z}(s) = \mathcal{F}_Q^{\gamma Z}(s)$$

$$F_D^{\gamma Z}(s) = \mathcal{F}_D^{\gamma Z}(s)$$

$$F_L^{zZ}(s) = -\frac{1}{4} r_{tW} \frac{1}{\bar{\varepsilon}} + \mathcal{F}_L^{zZ}(s)$$

$$F_Q^{zZ}(s) = -\frac{1}{16} \frac{1}{|Q_t| \, s_W^2} r_{tW} \frac{1}{\bar{\varepsilon}} + \mathcal{F}_Q^{zZ}(s)$$

$$F_D^{zZ}(s) = \mathcal{F}_D^{zZ}(s)$$

$$
\begin{aligned}
\mathcal{F}_L^{\gamma Z}(s) = \frac{2}{c_W^2} Q_t v_t a_t \Biggl\{ & 2\left(2+\frac{1}{R_Z}\right) \\
& \times M_Z^2 C_0\bigl(-m_t^2, -m_t^2, -s; m_t, M_Z, m_t\bigr) \\
& -3 B_0^F\bigl(-s; m_t, m_t\bigr) \\
& +2 B_0^F\bigl(-m_t^2; m_t, M_Z\bigr) - L_\mu(m_t^2) \\
& +\frac{1}{r_{tZ}}\Bigl[B_0^F\bigl(-m_t^2; m_t, M_Z\bigr) + L_\mu(M_Z^2) - 1\Bigr] \\
& -2\left(1+4r_{tZ}\right)\frac{M_Z^2}{4m_t^2-s} L_{ab}\left(0, m_t, M_Z\right) \Biggr\}
\end{aligned}
$$

FORM FACTORS of W CLUSTER

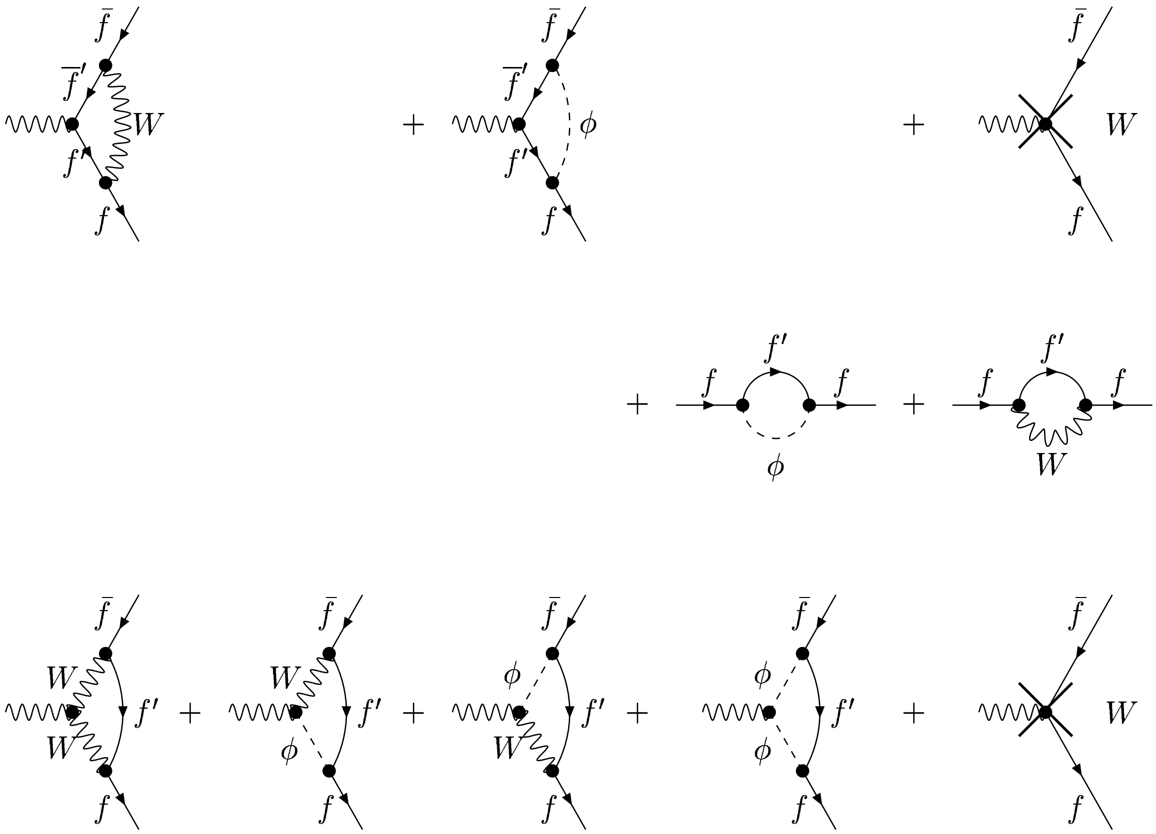


Figure 6: W cluster.

$$F_L^{\gamma W}(s) = 2\frac{1}{\bar{\varepsilon}} + \mathcal{F}_L^{\gamma W}(s)$$

$$F_Q^{\gamma W}(s) = \mathcal{F}_Q^{\gamma W}(s)$$

$$F_D^{\gamma W}(s) = \mathcal{F}_D^{\gamma W}(s)$$

$$F_L^{zW}(s) = 2c_W^2\frac{1}{\bar{\varepsilon}} + \mathcal{F}_L^{zW}(s)$$

$$F_Q^{zW}(s) = \mathcal{F}_Q^{zW}(s)$$

$$F_D^{zW}(s) = \mathcal{F}_D^{zW}(s)$$

$$\mathcal{F}_L^{\gamma W}(s) = Q_b \Bigg[\left(4 + 2r_{tW} + r_{tW}^2 + \frac{2}{R_W} \right) M_W^2$$

$$C_0\big(- m_t^2, -m_t^2, -s; 0, M_W, 0\big)$$

$$- \left(3 + \frac{1}{2} r_{tW} \right) B_0^F \big(- s; 0, 0\big)$$

$$+\frac{1}{2}(5 + r_{tW}) B_0^F \big(- m_t^2; 0, M_W\big) - \frac{1}{2} L_\mu(M_W^2)$$

$$+\frac{1}{r_{tW}} \Big[B_0^F \big(- m_t^2; 0, M_W\big) + L_\mu(M_W^2) - 1 \Big]$$

$$- \left(2 + 9r_{tW} + 3r_{tW}^2\right) \frac{M_W^2}{4m_t^2 - s} L_{ab}\left(m_t, 0, M_W\right) \Bigg]$$

$$+\frac{1}{2}(6 - r_{tW}) B_0^F \big(- s; M_W, M_W\big)$$

$$-\frac{1}{2}(3 - r_{tW}) B_0^F \big(- m_t^2; 0, M_W\big) - \frac{1}{2} L_\mu(M_W^2)$$

$$+\frac{1}{r_{tW}} \left[B_0^F \big(- m_t^2; 0, M_W\big) + L_\mu(M_W^2) - 1 \right]$$

$$+\frac{3}{2} - \frac{1}{2} r_{tW} - \left[4 - \left(2 + 13r_{tW} + r_t^2\right) \frac{M_W^2}{4m_t^2 - s} \right]$$

$$L_{na}\left(m_t, 0, M_W\right).$$

FORM FACTORS of H CLUSTER

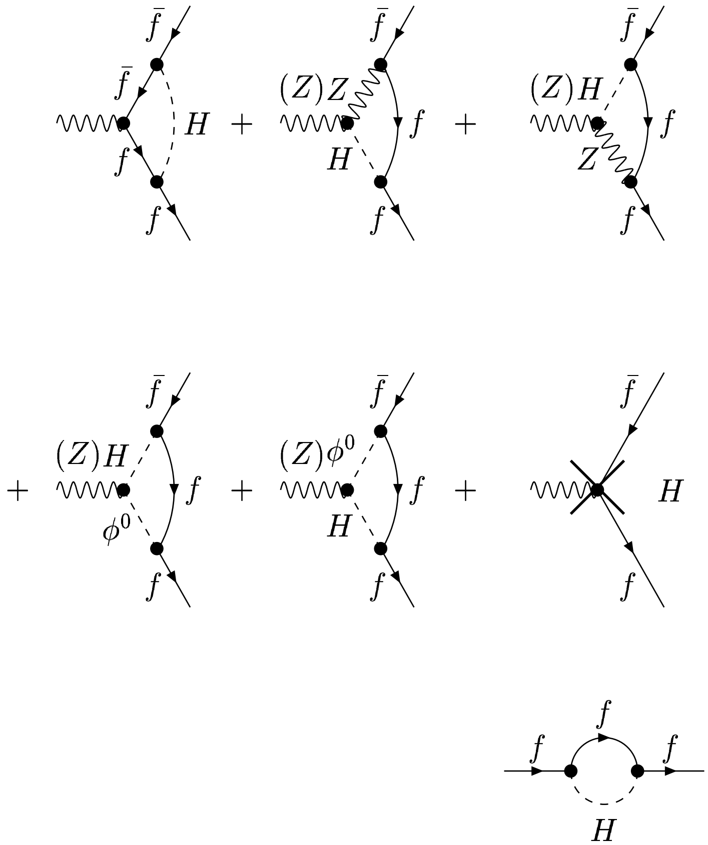


Figure 7: H - cluster

$$F_Q^{\gamma H}(s) = \mathcal{F}_Q^{\gamma H}(s)$$

$$F_D^{\gamma H}(s) = \mathcal{F}_D^{\gamma H}(s)$$

$$F_L^{zH}(s) = \frac{1}{4} r_{tW} \frac{1}{\bar{\varepsilon}} + \mathcal{F}_L^{zH}(s)$$

$$F_Q^{zH}(s) = \frac{1}{16} \frac{1}{|Q_t|} r_{tW} \frac{1}{s_W^2} \frac{1}{\bar{\varepsilon}} + \mathcal{F}_Q^{zH}(s)$$

$$F_D^{zH}(s) = \mathcal{F}_D^{zH}(s)$$

Where we introduce symbols

$$R_W = \frac{M_W^2}{s} \quad R_Z = \frac{M_Z^2}{s}$$

$$r_{tZ} = \frac{m_t^2}{M_Z^2} \quad r_{tW} = \frac{m_t^2}{M_W^2}$$

$$r_{tH} = \frac{m_t^2}{M_H^2} \quad r_{HZ} = \frac{M_H^2}{M_Z^2} \quad r_{HW} = \frac{M_H^2}{M_W^2}$$

Auxiliary functions

$$L_{ab}(M_1, M_2, M_3) =$$
$$\left(1 + \frac{M_1^2}{M_3^2}\right) M_3^2 C_0\big(0, 0, -s; M_3, M_2, M_3\big)$$
$$-B_0^F\big(-s; M_3, M_3\big) + B_0^F\big(-m_t^2; M_2, M_3\big)$$

$$L_{na}(M_1, M_2, M_3) =$$
$$\left(1 - \frac{M_1^2}{M_3^2}\right) M_3^2 C_0\big(0, 0, -s; M_3, M_2, M_3\big)$$
$$+B_0^F\big(-s; M_3, M_3\big) - B_0^F\big(-m_t^2; M_2, M_3\big)$$

$$L_{Hi}(M_1, M_2, M_3) =$$
$$\left[\frac{1}{2}\left(1 + \frac{M_2^2}{M_3^2}\right) - 2\frac{M_1^2}{M_3^2}\right] M_3^2 C_0\big(0, 0, -s; M_2, M_1, M_3\big)$$
$$+B_0^F\big(-s; M_3, M_2\big) - \frac{1}{2}B_0^F\big(-m_t^2; M_1, M_2\big)$$
$$-\frac{1}{2}B_0^F\big(-m_t^2; M_3, M_1\big)$$

SCALAR FORM FACTORS

$$
\begin{aligned}
F_{LL}(s,t) &= \mathcal{F}_L^{zee}(s) + \mathcal{F}_L^{ztt}(s) \\
&+ \mathcal{F}_{LL}^{ct}(s) + c_W^2 (R_Z - 1)\, s\mathcal{B}_{LL}^{WW}(s,t) \\
F_{QL}(s,t) &= \mathcal{F}_Q^{zee}(s) + \mathcal{F}_L^{ztt}(s) \\
&+ c_W^2 (R_Z - 1)\, \mathcal{F}_L^{\gamma tt}(s) + \mathcal{F}_{QL}^{ct}(s) \\
F_{LQ}(s,t) &= \mathcal{F}_L^{zee}(s) + \mathcal{F}_Q^{ztt}(s) \\
&+ c_W^2 (R_Z - 1)\, \mathcal{F}_L^{\gamma ee}(s) + \mathcal{F}_{LQ}^{ct}(s) \\
F_{QQ}(s,t) &= \mathcal{F}_Q^{zee}(s) + \mathcal{F}_Q^{ztt}(s) \\
&- \frac{c_W^2}{s_W^2} (R_Z - 1) \left[\mathcal{F}_Q^{\gamma ee}(s) + \mathcal{F}_Q^{\gamma tt}(s)\right] \\
&+ \mathcal{F}_{QQ}^{ct}(s) \\
F_{LD}(s,t) &= \mathcal{F}_D^{ztt}(s) \\
F_{QD}(s,t) &= \mathcal{F}_D^{ztt}(s) + c_W^2 (R_Z - 1)\, \mathcal{F}_D^{\gamma tt}(s)
\end{aligned}
$$

where

$$
\mathcal{F}_Q^{ztt}(s) = \mathcal{F}_Q^{zZ}(s) + \mathcal{F}_Q^{zW}(s) + \mathcal{F}_Q^{zH}(s)
$$

Table 1: EWFF for the process $e^+e^- \to u\bar{u}$. `eett - ZFITTER` comparison.

Without ZZ boxes				
Quantity		$E_{\rm cm}$		
		100	200	300
F_{LL}	$M_W/10$	$12.94466 - i1.84787$	$9.34003 - i9.42491$	$9.03775 - i11.56005$
	M_W	$12.94466 - i1.84787$	$9.34003 - i9.42491$	$9.03774 - i11.56005$
	$10M_W$	$12.94466 - i1.84787$	$9.34003 - i9.42491$	$9.03775 - i11.56005$
ZFITTER		$12.94468 - i1.84786$	$9.34065 - i9.42467$	$9.03903 - i11.55958$
F_{QL}	$M_W/10$	$29.34721 + i3.67329$	$30.33892 + i3.34535$	$31.64554 + i2.75261$
	M_W	$29.34721 + i3.67329$	$30.33891 + i3.34535$	$31.64553 + i2.75261$
	$10M_W$	$29.34721 + i3.67329$	$30.33892 + i3.34535$	$31.64554 + i2.75261$
ZFITTER		$29.34720 + i3.67330$	$30.33889 + i3.34535$	$31.64552 + i2.75259$
F_{LQ}	$M_W/10$	$29.13302 + i3.26972$	$30.03854 + i1.54158$	$31.68636 - i0.22635$
	M_W	$29.13302 + i3.26972$	$30.03854 + i1.54158$	$31.68636 - i0.22635$
	$10M_W$	$29.13302 + i3.26972$	$30.03854 + i1.54158$	$31.68636 - i0.22635$
ZFITTER		$29.13304 + i3.26973$	$30.03855 + i1.54163$	$31.68635 - i0.22634$
F_{QQ}	$M_W/10$	$44.90390 + i8.85688$	$43.80287 + i10.02412$	$44.21224 + i10.83899$
	M_W	$44.90389 + i8.85688$	$43.80285 + i10.02412$	$44.21222 + i10.83899$
	$10M_W$	$44.90390 + i8.85688$	$43.80286 + i10.02412$	$44.21223 + i10.83899$
ZFITTER		$44.90392 + i8.85688$	$43.80285 + i10.02411$	$44.21224 + i10.83894$