Radiative corrections to single Higgs boson production in e^+e^- annihilation

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Abstract

For energies relevant to future linear colliders, $\sqrt{s} \gtrsim 500$ GeV, the WW fusion channel dominates the Higgs boson production cross section $e^+e^- \to \bar{\nu}\nu h^0$. We have calculated the one-loop corrections to this process due to fermion and sfermion loops in the context of the MSSM. As a special case, the contribution of the fermion loops in the SM has also been studied. In general, the correction is negative and sizeable of the order of 10%, the bulk of it being due to fermion loops.

No Higgs boson could be detected so far. The four LEP experiments delivered lower bounds [1] for the Standard Model (SM) Higgs mass, $m_h \gtrsim 114$ GeV and the light CP even Higgs boson mass $m_{h^0} \gtrsim 88.3$ GeV of the Minimal Supersymmetric Standard Model (MSSM). In e^+e^- collisions, for energies $\gtrsim 200$ GeV, the production of a single Higgs boson plus missing energy starts to be dominated by WW fusion [2, 3, 4], that is $e^+e^- \to \bar{\nu}_e\nu_e\, WW \to \bar{\nu}_e\nu_e\, h^0$, whereas the Higgsstrahlung process [5] $e^+e^- \to Zh^0 \to \bar{\nu}\nu\, h^0$ becomes less important. The rates for the ZZ fusion are generally one order of magnitude smaller than those of the WW channel.

At LHC, in $p\,p$ collisions, the gluon-gluon fusion mechanism provides the dominant contribution to Higgs production. Recently, it has been argued that also the channels $WW \to h^0/H^0 \to \tau\bar{\tau}$ and WW, can serve as suitable search channels at LHC even for a Higgs boson mass of $m_h \sim 120$ GeV [6, 7]. It was also shown [9] that the $e\,p$-option at LHC would offer the best opportunity to search for a Higgs boson in the mass range $m_h < 140$ GeV with WW (and ZZ) fusion as the most important Higgs boson production mechanism there. At Tevatron, with $p\,\bar{p}$ collisions at 2 TeV, the WW fusion process plays a less important rôle at least for $m_h \lesssim 180$ GeV [8].

This contribution follows Ref. [10] where the leading one-loop corrections to the WWh^0 vertex in the MSSM were calculated. Because of their Yukawa couplings, the fermion/sfermion loops are taken into account. Then the total cross section in e^+e^- annihilation was worked out for $e^+e^- \to \bar{\nu}_e\nu_e\, WW \to \bar{\nu}_e\nu_e\, h^0$. We also included the Higgsstrahlung process $e^+e^- \to Zh^0 \to \bar{\nu}\nu\, h^0$ and the interference between these two mechanisms. Because the Higgsstrahlung process is much smaller in this range, we have neglected its radiative corrections. We have also discussed the SM case.

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As for energies $\sqrt{s} > 500$ GeV the dominant channel $e^+e^- \to \bar{\nu}\nu h^0$ is by far the WW fusion, taking into account only (s)fermion loops, the renormalization of the five-point function simplifies to the renormalization of the WWh^0 vertex with off-shell W bosons. The renormalization of the other two vertices in the process (e. g. the $e^-\nu_e W^+$ coupling) is absorbed. For the renormalization procedure the on-shell scheme has been adopted.

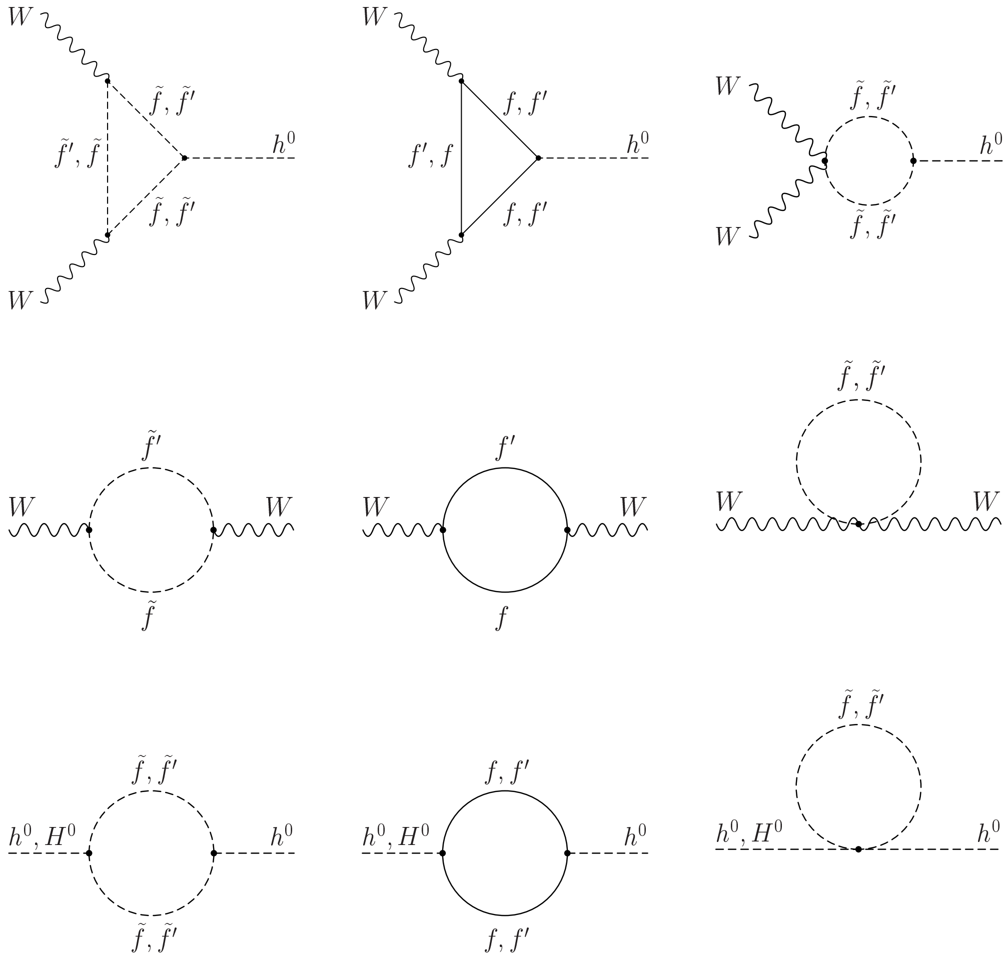

Figure 1: The Feynman graphs that contribute to the vertex correction to the form factors F^{00} and F^{21} and the wave-function correction to F^{00}. f (f') denotes the up (down) type fermion.

The one-loop part of the WWh^0 coupling can be expressed in terms of all possible form factors

$$\left(\Delta g_{WW}^{h^0}\right)^{\mu\nu} = F^{00} g^{\mu\nu} + F^{11} k_1^\mu k_1^\nu + F^{22} k_2^\mu k_2^\nu + F^{12} k_1^\mu k_2^\nu + F^{21} k_2^\mu k_1^\nu + i\, F^\epsilon \epsilon^{\mu\nu\rho\delta} k_{1\rho} k_{2\delta}\,, \quad (1)$$

where $k_{1,2}$ denote the four-momenta of the off-shell W-bosons. The full analytic expressions of the renormalized form factor F^{00} and of F^{21}, which are based on the evaluation of the Feynman graphs given in Fig. 1 with additional counter terms, can be found in Ref. [12].

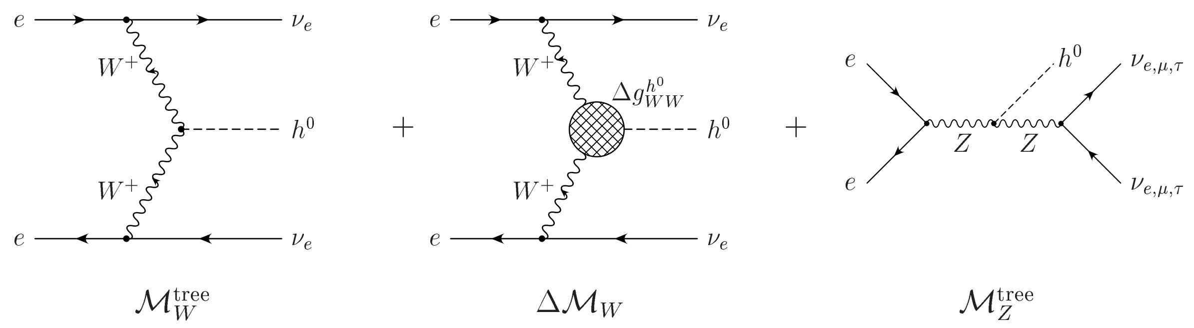

Figure 2: The Feynman graphs for the process $e^+e^- \to \bar{\nu}\nu h^0$ including the one-loop correction $\Delta g^{h^0}_{WW}$. Note that for $|\mathcal{M}^{\rm tree}_Z|^2$ one has to sum over all three neutrino flavors.

The Feynman graphs for the one-loop corrected amplitude are drawn in Fig. 2. The tree-level part of the squared amplitude was already calculated in Ref. [4], and the expresions for the one-loop part, $2\,\Re\left[\Delta\mathcal{M}_W\,(\mathcal{M}^{\rm tree}_W)^\dagger\right]$ and $2\,\Re\left[\Delta\mathcal{M}_W\,(\mathcal{M}^{\rm tree}_Z)^\dagger\right]$, can be found in Ref. [10].

For the calculation of the cross section at tree-level, it is possible to perform some of the phase space integrations analytically and the rest of them numerically [3, 4]. However, including the one-loop correction terms, it is impossible to perform any of these integrations analytically [10].

Now let us discuss to the numerical results. The tree-level WWh^0 coupling for values of $\tan\beta > 5$ as preferred by the LEP Higgs boson searches, mimics the SM one. For the calculation of the fermion/sfermion one-loop corrections to the WWh^0 vertex, the contribution of the third family of fermions/sfermions has been taken into account. This contribution turns out to be the dominant one, in comparison with the first two families corrections, due to the large values of the Yukawa couplings h_t and h_b. The effect of the running of the coupling constants g and g' has been taken into account.

For simplicity, for all plots we have used $A_t = A_b = A_\tau = A$, $\{m_{\tilde{U}}, m_{\tilde{D}}, m_{\tilde{L}}, m_{\tilde{E}}\} = \{\frac{9}{10}, \frac{11}{10}, 1, 1\}\, m_{\tilde{Q}}$ and $M_1 = \frac{5}{3}\, M_2\, \tan^2\theta_W$. The choice of a common trilinear coupling and the correlation between the soft sfermion masses are inspired by unification.

In Fig. 3 the parameters $\tan\beta = 10$, $\mu = -100$ GeV, $A = -500$ GeV, $m_{\tilde{Q}} = 300$ GeV, $M_A = 500$ GeV, and $M_2 = 400$ GeV are taken. Note that choosing different sets of parameters, the basic characteristics of these plots remain indifferent. In the left figure the various cross sections as a function of $\sqrt{s}$ for values up to 1 TeV are plotted. The dotted-dashed line represents the contribution from the WW channel at tree-level alone, whereas the dotted line includes the Higgsstrahlung contribution as well. The dashed line comprises in addition the interference between the WW channel and Higgsstrahlung. One can perceive that the size of this interference term is extremely small, and for this reason

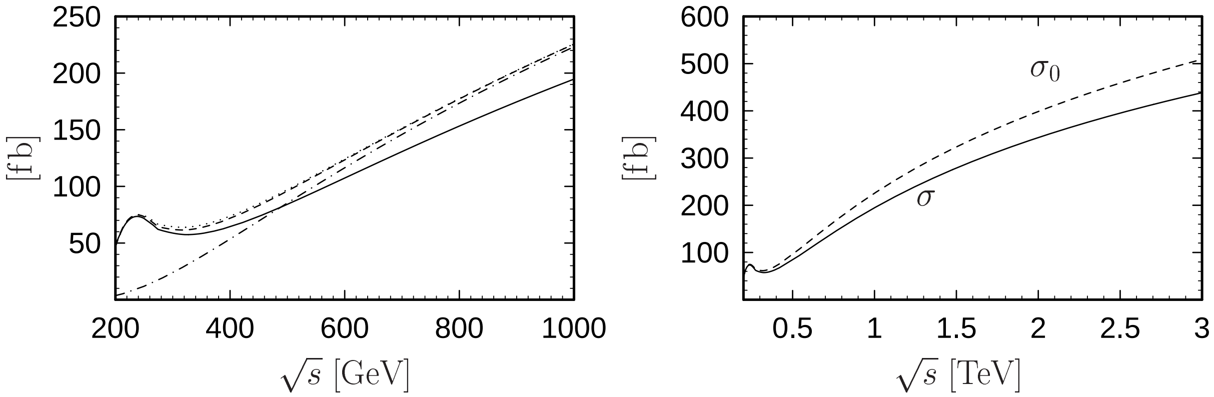

Figure 3: The various cross sections as functions of $\sqrt{s}$ (left). The dotted-dashed line represents the tree-level cross section σ_0^{WW}, the dotted line $\sigma_0^{WW} + \sigma_0^{h-str}$. The dashed line includes also the interference term $\sigma_0^{\text{interf.}}$ and represents the total tree-level cross section. The solid line includes the one-loop correction. The SUSY parameters are: $\tan\beta = 10$, $\mu = -100$ GeV, $A = -500$ GeV, $m_{\tilde{Q}} = 300$ GeV, $M_A = 500$ GeV, and $M_2 = 400$ GeV. For the same set of parameters also the tree-level cross section σ_0 and the one-loop corrected σ are plotted for $\sqrt{s}$ up to 3 TeV (right).

the difference between the dotted and dashed lines is rather minute. For $\sqrt{s} \gtrsim 500$ GeV the WW fusion contribution dominates the total cross section for the Higgs production $e^+e^- \to \bar{\nu}\nu h^0$. Actually, for $\sqrt{s} \gtrsim 800$ GeV the total tree-level cross section is due to WW fusion. In the solid line we have taken into account the one-loop correction from the fermion/sfermion loops. The right figure of Fig. 3 shows the tree-level cross section σ_0 (dashed line) and the one-loop corrected cross section σ (solid line) for energies up to 3 TeV. Both figures show that the correction is always negative and in the order of 10%. In Fig. 4 shows the relative correction $\Delta\sigma/\sigma_0$ as a function of $\sqrt{s}$. The solid line corresponds

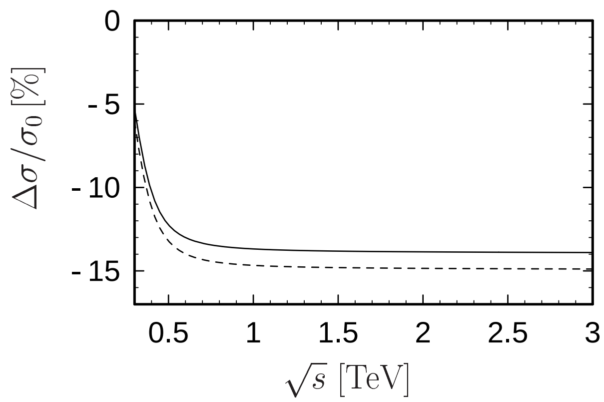

Figure 4: The relative correction $\Delta\sigma/\sigma_0$ as a function of $\sqrt{s}$ ($\Delta\sigma = \sigma - \sigma_0$), where σ_0 is the tree-level and σ the one-loop corrected cross section. The solid and dashed lines correspond to two different choices of the SUSY parameters, as described in the text.

to the set $\tan\beta = 10$, $\mu = -100$ GeV, $A = -500$ GeV, $m_{\tilde{Q}} = 300$ GeV, $M_A = 500$ GeV, and $M_2 = 400$ GeV, whereas for the dashed line $\tan\beta = 40$, $\mu = -300$ GeV and $A = -100$ GeV was taken, keeping the rest of parmeters unchanged. We see that the size of the one-loop correction to the Higgs production cross section becomes practically constant for $\sqrt{s} > 500$ GeV and weighs about -15%, almost independently of the choice of the SUSY parameters. This is due to the fact that the one-loop corrections are dominated by the fermion loops, and therefore the total correction is not very sensitive to the choice of the SUSY parameters.

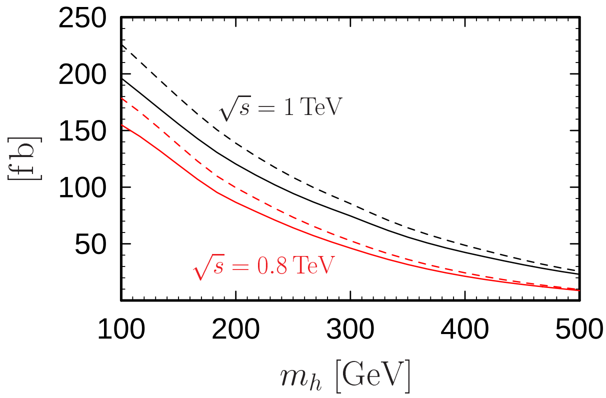

Figure 5: Cross sections for the SM case, for $\sqrt{s} = 0.8$ TeV (red lines) and 1 TeV (black lines). The dashed lines correspond to the tree-level cross section, whereas the solid lines to the one-loop corrected one.

In Fig. 5 we have plotted the cross section as a function of m_h for the SM case, for $\sqrt{s} = 0.8$ TeV (red lines) and 1 TeV (black lines). The dashed lines correspond to the tree-level cross section for $e^+e^- \to \bar{\nu}\nu h^0$, whereas the solid lines contains the one-loop correction stemming from the fermion loops. In addition, the couplings have been adjusted to the SM corresponding couplings. The plot exhibits the expected dependence of the cross section on m_h. What must be noticed is that especially for small Higgs boson masses $\lesssim 200$ GeV, the size of the fermion loops correction becomes important for the correct determination of the Higgs boson mass.

Finally, Fig. 6 exhibits the percentage of the sfermion loops to the total one-loop correction as a function of $\tan\beta$ (left) and μ (right), for two different values of μ and $\tan\beta$, respectively, as shown in the figure. In the left (right) figure $A = -100$ GeV ($A = -400$ GeV). Further we have $m_{\tilde{Q}} = 300$ GeV, $M_A = 500$ GeV, and $M_2 = 400$ GeV, and $\sqrt{s}$ has been fixed to 1 TeV. The grey area in the right figure is excluded due to the chargino mass bound. One can see that the maximum value of order 10% can be achieved for large values of μ and $\tan\beta$. There, due to the significant mixing in the stop and sbottom sector, the contribution of stops and sbottoms in the loops is enhanced. Even

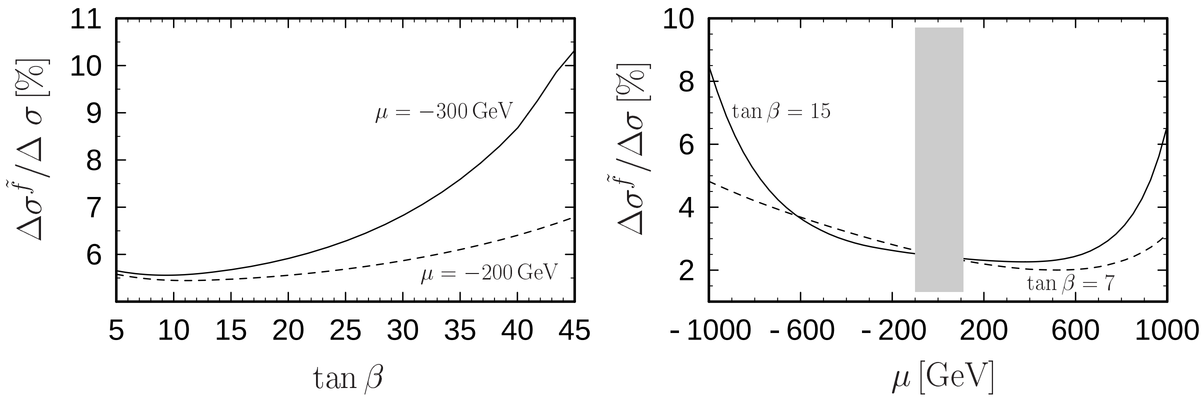

Figure 6: The percentage of the sfermions to the total one-loop correction as a function of $\tan\beta$ (left) and μ (right). The rest of the SUSY parameters have been fixed as described in the text. Here $\sqrt{s} = 1$ TeV. The grey area in the right figure is excluded due to the chargino mass bound.

for such a parameter set the dominant correction, at least 90% of the total correction, is due to the fermion loops.

An effective approximation of the one-loop corrections to the WWh^0 vertex can be found in [11], but it does not fully account for the whole effect.

In conclusion, we have calculated the fermion/sfermion loops corrections to the single Higgs boson production $e^+e^- \to \bar{\nu}\nu h^0$ in the context of the MSSM and SM. They are supposed to be the dominant radiative corrections. For energies relevant to the future linear colliders, $\sqrt{s} \gtrsim 500$ GeV, the WW fusion channel dominates the cross section. In general, the correction due to fermion/sfermion loops is negative and yields a correction to the cross section of the order of -10%. The bulk of this correction stems from the fermion loops, and usually turns to be more than 90% of the total correction. For the case of maximal mixing in the sfermion mass matrices, the contribution of the sfermion loops is enhanced, but nevertheless weighs less than 10% of the total one-loop correction. As the correction is dominated by fermion loops and is rather independent of $\sqrt{s}$ for $\sqrt{s} > 500$ GeV, we think that it can be approximated by a factor correction to the tree-level cross section. Such an approximation would be most useful for including initial state radiation (ISR) and beamstrahlung in an efficient way.

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