# On Higgs Production in $\gamma\gamma$ Collisions

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**Abstract.** I review recent progress on the Higgs production in $\gamma\gamma$ collisions at the photon mode of the Next Linear Collider (NLC). I mainly focus on two particular topics. The first topic is the Higgs-two photon vertex, which is sensitive to new physics, and can be considered a counter of the number of new heavy particles. I recall the results on QCD and electroweak two loop radiative corrections. The second topic is the heavy quark anti-quark pair production in $\gamma\gamma$ collisions, which is the dominant background process for the Higgs production at $m_H < 150$ GeV. We suggest a procedure for the resummation of double (DL) and single (SL) logarithms in the process $\gamma\gamma \to b\bar{b}$.

## I INTRODUCTION

The neutral scalar Higgs boson [1] is an important ingredient of the Standard Model (SM) and is the only SM elementary particle which has not been detected so far (see for the review [2]). A lower limit on $m_H$, of approximately 113.5 GeV at $95\% c.l.$, has been obtained from direct searches at LEP [3]. Current experiments are concentrating on the possibility of finding a Higgs particle in the intermediate mass region $113.5 < m_H < 150$ GeV. In this region the Higgs particle decays mainly to a $b\bar{b}$ pair.

The *photon mode* of the NLC, namely the collisions of the energetic polarized Compton photons, will be used for the production and studies of the Higgs particle.

In this talk I review recent progress on the Higgs production in $\gamma\gamma$ collisions at the NLC. I will mainly focus on:

1) the Higgs-$\gamma\gamma$ vertex, which is sensitive to new physics, and can be considered the counter of the number of new heavy particles. I review the results of QCD and electroweak radiative corrections performed in [4–8].

2) the heavy quark anti-quark pair production in $\gamma\gamma$ collisions, which is main background of the Higgs production for $m_H < 150$ GeV. The radiative corrections to $\gamma\gamma \to b\bar{b}$ are extremely large [9] and are dominated by large QCD double logarithms (DL) [10]. We have resummed large QCD double logarithms of the form $(\alpha_s \ln^2(s/m^2))^n$ [11,14,7]. We have derived the next-to-leading logarithmic correction to the DL result, which is effectively an resummation of all terms of the form $\alpha_s^n \ln^{2n-1}(s/m^2)$ [11].

# II HIGGS-TWO PHOTON VERTEX

The coupling of the Higgs boson with two photons is absent at tree level in the Standard Model. The first non-zero contribution arises from fermions and W boson loops. Because the Yukawa coupling of the quark is proportional to the quark mass, the contributions of the light quarks as well as charm and bottom quarks are well suppressed in comparison to the top quark loop contribution. Because we intend to use the Higgs-$\gamma\gamma$ coupling as a counter for new undiscovered particles, it should be a very well calibrated tool. One important question is: how large are QCD corrections? The answer is: the QCD corrections are small for Higgs masses $m_H < 2m_t$ [6,4]. This has been shown by the explicit calculations in [6,4]. The only source of QCD corrections at two loop order is the gluon corrections to the top quark loop. For the heavy Higgs masses, $m_H > 2m_t$, the corrections are large (about 40%), although this mass range is ruled out by the electro-weak data. It was observed in [4] that in the limit of large ratio $\frac{m_H}{m_q}$ the form factor gives the QCD double logarithmic asymptotic, $(1-\frac{\rho}{12})$, with $\rho = \frac{C_F\alpha_s(\mu^2)}{2\pi}\ln^2\left(\frac{s}{m^2}\right)$. This limit can be the case of the $b$ loop, its contribution can be large in MSSM. The nature of these new DL has been clarified in [10,7]. It was shown that the logarithms are related to Sudakov form factor entered into the one loop triangle diagram. In the ref. [7], we have resummed these DL explicitly. The result is

$$F = F^{\text{t-loop}}\sum_{n=0}^{\infty}\frac{2\Gamma(n+1)}{\Gamma(2n+3)}\Big(-\rho\Big)^n \rightarrow_{\rho\to\infty} \Big(\frac{2\ln(2\rho)}{\rho}\Big)F^{\text{t-loop}}. \tag{1}$$

First two terms in the series do coincide with the result of direct loop calculations. The scale of the QCD coupling in eq.(1) should be $\mu^2 \approx 9m^2$ [8,12]. The single logarithms in this sum have been resummed in [12], the result is given by the eq.(6).

Next, once we understand that QCD corrections are small for the H-$\gamma\gamma$ vertex, we may ask: how large are electro-weak corrections? The explicit calculation of EW corrections does not exist up to now. It is an extremely complicated problem. The only thing that we know is the leading term in the limit of the heavy Higgs masses, $O(G_F m_H^2)$. This result can be taken as an estimation of the whole EW correction. The calculations of the $O(G_F m_H^2)$ term has been performed in [5]. It was suggested to use *the equivalence theorem*, which states that at large Higgs masses the EW part of the Standard Model is described by the following $U(1)$ gauged sigma model:

$$L = L_0 - \frac{m_H^2}{4v^2}(\pi^2+H^2)^2 - \frac{m_H^2}{v}(\pi^2+H^2)H, \tag{2}$$

here $H, m_H, v$ are the Higgs field, the mass and the vacuum expectation value, $\pi = (w^+, z, w^-)$ is the triplet of the Goldstone bosons, and $L_0 = (D_\mu w)(D^\mu w)^* + \frac{1}{2}\partial_\mu z\partial^\mu z + \frac{1}{2}\partial_\mu H\partial^\mu H - \frac{1}{2}m_H H^2 - \frac{1}{2}F^2$ The result for the Higgs-two photon coupling at two loops reads (the details on the calculations can be found in [5])

$$F = F^{1-loop}\Big(1 - 3.027\Big(\frac{m_H}{4\pi v}\Big)^2\Big). \tag{3}$$

The correction is very small, less than one percent at $m_H < 150$ GeV.

## III HEAVY QUARK PRODUCTION AND DL

In the intermediate mass range, the main production process of the Higgs boson is $\gamma\gamma \to H \to b\bar{b}$. Here we would like to consider main background process $\gamma\gamma \to b\bar{b}$, which gets large QCD corrections and can spoil measurements of Higgs properties.

The Born order cross section for the $J_z = 0$ channel of $\gamma\gamma \to b\bar{b}$ is suppressed by $\frac{m_b^2}{s}$ in comparison with $J_z = \pm 2$ [13,9]. By using the polarization of initial photons we can suppress the background process. However, the perturbative QCD correction to $\gamma\gamma \to b\bar{b}$ in $J_z = 0$ channel contains large double logarithms of the form $\rho = \alpha_s \ln^2(\frac{m_b^2}{s})$ at $|s|, |t|, |u| \gg m^2$. They give contributions to the cross section of the same order as Born contribution. This shows the importance of accounting for large logarithmic (DL/SL) terms explicitly in all higher orders. The presence of the large correction was noticed by Jikia in [9]. The double logarithmic nature and the origin of these corrections were studied in the pivotal paper in this subject [10] by Fadin, Khoze and Martin. The authors studied the process with one and two loop accuracy. They demonstrated that the key fact which is relevant for DL analysis is the "triangle topology" of the box diagram. In more details: only the box diagram gives DL, moreover, the only momenta configurations which are important are those in which one of the propagator is much harder than others. As a bottom line, we get four effective triangle diagrams from the box diagram. Only these effective diagrams can give DL at higher orders as well.

Recently, large logarithm resummation have been considered by two groups. First, DL resummation and RG improvement have been addressed in the excellent set of the papers by Melles, Stirling and Khoze [14–17] (also see references therein). Second, DL/SL resummation with next-to-leading-log (NLL) accuracy as well the origin and nature of the cancellations of many diagrams at high orders have been studied by us [11,12]. The authors of [14] stated that the double logarithms have "non-Sudakov" origin. We think that the DL in present problem are closely related to Sudakov DL. Our approach is based on two facts. First, only triangle topologies of the one loop box diagram give DL at higher loops. Second, the only origin of the double logarithms is the off-shell Sudakov form factor [18]

$$S(p_1,p_2) = \mathrm{Exp}\Big(-\frac{C_F\alpha_s(\nu^2)}{2\pi}\ln(\frac{s}{|p_1|^2})\ln(\frac{s}{|p_2|^2})\Big), \quad \text{with } m^2 \ll |p_1|^2, |p_2|^2 \ll s. \tag{4}$$

This has to be included in all triangle topologies (fig.1) of the one-loop box diagram. But more importantly, we have proved that the rest of the high loop diagrams (other than those accounted for in eq.(4)) will either cancel in the subgroups of the diagrams or develop standard on-shell Sudakov exponent due to final $b\bar{b}$ lines. We refer reader to [11] for details. The result for the amplitude is the sum of three triangle topologies (A,B,$C_1 = C_2$ in fig.1): $F = F_A + F_B + 2F_C$. The topology A gives a standard on-shell Sudakov form factor. The result for the B topology reads

$$F_B^{DL} = F_B^{\text{1-loop}} \sum_{n=0}^{\infty} \frac{2\Gamma(n+1)}{\Gamma(2n+3)}\Big(-\rho_B\Big)^n = {}_2F_2(1,1;2,\frac{3}{2},-\frac{\rho_B}{4})F_B^{\text{1-loop}}, \tag{5}$$

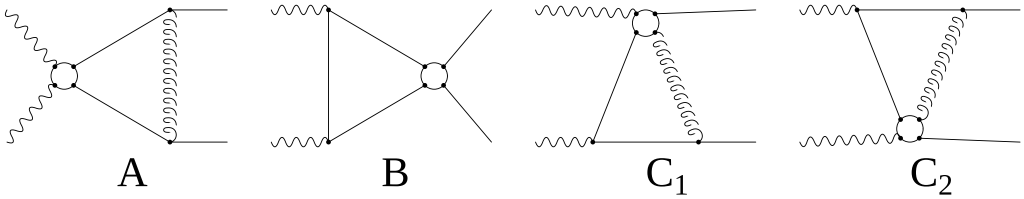

**FIGURE 1.** The triangle topologies of the one loop box diagram.

with $\rho_B = \frac{C_F \alpha_s(\mu^2)}{2\pi} L^2, L = \ln\left(\frac{m^2}{s}\right)$. The topology C differs from B only in color structure. The answers for B and C topologies in the DL approximation are related by simple substitution: $C_F \to C_A/2$. It is possible to develop this approach to achieve next-to-leading-logarithmic accuracy [11]. The final result for the next-to-leading-logarithmic form factor for the topology B (extra to (5)) reads [11]

$$F_B^{NLL} = \frac{1}{L} F_B^{1-loop} \sum_{n=0}^{\infty} \frac{\Gamma(n+1)}{\Gamma(2n+2)} (-\rho_B)^n \Big(3 - \frac{\rho_B \beta_0}{C_F} \frac{n}{2n+2} \Big(\frac{n+1}{2n+3} + \frac{\ln(s/\mu^2)}{L}\Big)\Big), \quad (6)$$

with $\beta_0 = 11 - \frac{2n_f}{3}$. The relative size of SL corrections in comparison to the DL contributions is estimated as $\frac{1}{L}$, which is of order 30%. The normalization point in (4) is $\nu^2 = \frac{|p_1^2 p_2^2|}{s}$, which corresponds to $\mu^2 \approx 9m^2$ in (5,6) [11,16]. More details on the topology C with NLL accuracy can be found in [11], and on numerics in [11,17].

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