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HIGGS → TWO PHOTON DECAY:
QCD radiative correction

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НОВОСИБИРСК

HIGGS → TWO PHOTON DECAY:
QCD radiative correction

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Abstract

QCD radiative correction to Higgs → two photons decay rate is calculated. Below the threshold we found negligible correction, thus supporting results obtained earlier by Djouadi et all [7]. Above the threshold radiative correction appears to be large for both real and imaginary part of $H\gamma\gamma$ vertex. This leads to radiative correction for $\Gamma(H \to \gamma\gamma)$ to be of order 20–100 percents at $m_t = 150$ GeV. Possible applications of our results for Higgs search at Next Linear Colliders (NLC) are briefly discussed.

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1. INTRODUCTION

The problem of Higgs boson hunting remains to be the most important problem of contemporary high-energy physics. Different ideas and suggestions were put forward in this direction.

Recently, the two-photon decay mode of Higgs-boson attracted much attention of both theorists and experimentalists. This interest is based on two different stories:

- firstly, this decay chanel, having obviously small rates ($\mathrm{Br}(H \to \gamma\gamma) \sim$ $\sim O(10^{-3})$ for $m_H \approx 150$ GeV) provides us attractive possibility to discover and study Higgs boson in the intermediate mass range at hadron colliders such as LHC and SSC [1].
- secondly, two photon production of heavy Higgs boson via $\gamma\gamma \to H \to$ $\to X$ $(X = ZZ,\ t\bar{t})$ is quite interesting and promising. One can hope to study the contribution of nonstandard ultraheavy particle to $\Gamma(H \to \gamma\gamma)$, probe different anomalous interactions [2–4] using this very reaction. It was also suggested [5] to use $\gamma\gamma \to H \to t\bar{t}$ to study Yukawa Higgs-top coupling.

The important point for all these discussions is the two-photon width of the Higgs boson, which was calculated to leading order in ref. [6]. In this letter we report the calculation of QCD radiative correction to $H \to \gamma\gamma$ decay channel. This radiative correction seems to be the largest within the Standard Model and one must know its value in order to exploit both two — photon decay and production of Higgs boson.

It must be noted that similar calculation already exists in the literature [7]. However, the authors of ref. [7] restricted themselves to the calculation of QCD radiative correction for Higgs boson lighter then $2m_t$ only.

In our work we tried to improve the situation and have solved the problem for the whole range of Higgs masses.

2. METHOD OF CALCULATION

As it is well-known [6], Higgs – two photon interaction can be described by the effective Lagrangian:

$$\mathcal{L} = \frac{\alpha F}{4\pi}(\sqrt{2}G_F)^{\frac{1}{2}} F_{\mu\nu}F^{\mu\nu}H. \qquad (1)$$

Here α is the fine structure constant, G_F is Fermi coupling constant while $F_{\mu\nu}$ and H stand for photon and Higgs fields respectively. F is Higgs – two photon formfactor, which reads:

$$F = \sum_i N_{c_i} {Q_i}^2 f_i\left(\frac{{m_H}^2}{{m_i}^2}\right). \qquad (2)$$

Here N_{c_i} is a number of colors, Q_i is charge of the particle and summation is performed over all particles which contribute to the loop. ${f_i}^0$ were computed in ref.[5]:

$$f_t^{(0)} = -2\beta_t((1-\beta_t)\cdot x^2 + 1)$$

$$f_W^{(0)} = 2 + 3\beta_W + 3\beta_W\cdot(2-\beta_W)\cdot x^2.$$

Here

$$x = \arctan\left(\frac{1}{\sqrt{\beta_i - 1}}\right) \qquad \beta_i > 1$$

$$x = \frac{1}{2}\left(i\cdot\log\left(\frac{1+\sqrt{1-\beta_i}}{1-\sqrt{1-\beta_i}}\right) + \pi\right) \qquad \beta_i < 1$$

$$\beta_i = \frac{4{m_i}^2}{{m_H}^2}.$$

It is sufficient to consider only top's and W contribution; light quarks interaction with Higgs are negligible.

As W does not interact with gluons, we need top's contribution only to compute QCD radiative correction. Generic diagramms are shown in Figs. 1 and 2.

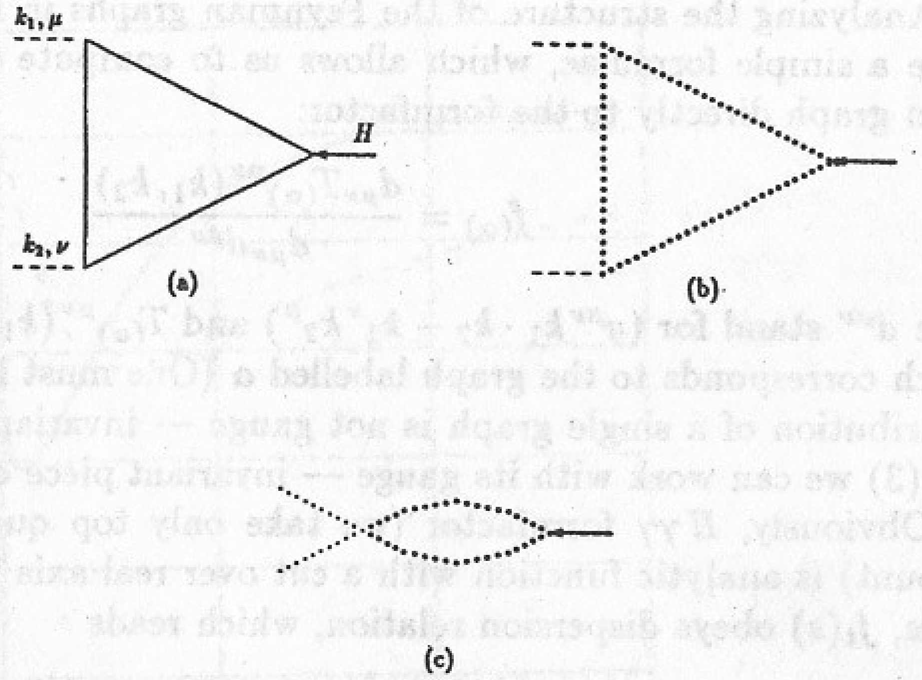

Fig. 1. One-loop Feynman diagrams for $H \to \gamma\gamma$.
W-boson — dotted line, photon-dashed line, top-solid line.

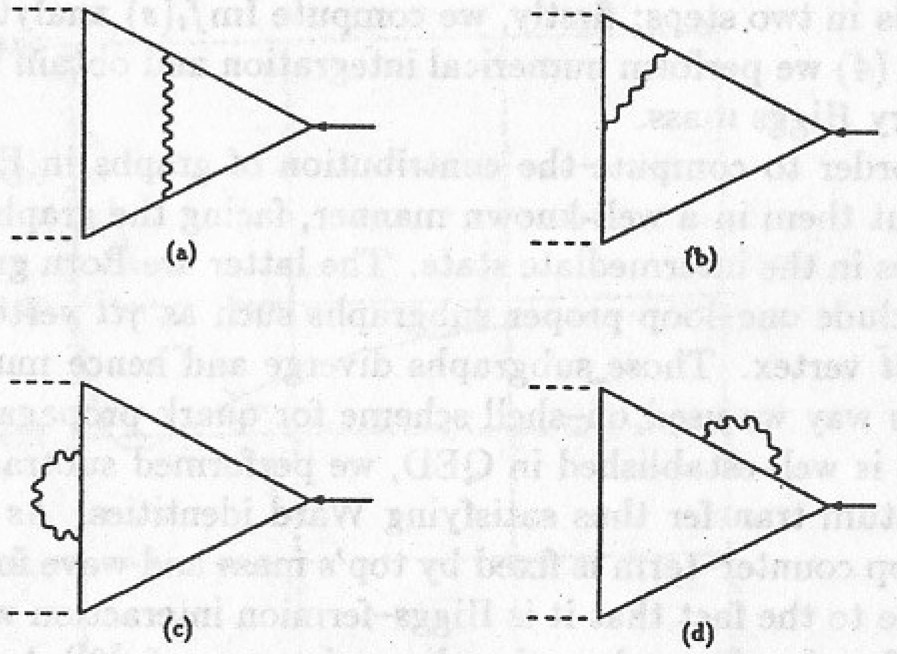

Fig. 2. Two-loop Feynman diagrams for $H \to \gamma\gamma$.
Gluon-wavy line, photon-dashed line, top-solid line.

Analyzing the structure of the Feynman graphs in Figs. 1 and 2, we can write a simple formulae, which allows us to compute the contribution of a given graph directly to the formfactor:

$$f_{(\alpha)} = \frac{d_{\mu\nu} T_{(\alpha)}{}^{\mu\nu}(k_1, k_2)}{d_{\mu\nu} d^{\mu\nu}}. \tag{3}$$

Here $d^{\mu\nu}$ stand for $(g^{\mu\nu} k_1 \cdot k_2 - k_1{}^{\nu} k_2{}^{\mu})$ and $T_{(\alpha)}{}^{\mu\nu}(k_1, k_2)$ is the amplitude which corresponds to the graph labelled α (One must keep in mind that the contribution of a single graph is not gauge — invariant itself, but applying Eg. (3) we can work with its gauge — invariant piece only.)

Obviously, $H\gamma\gamma$ formfactor (we take only top quark contribution into account) is analytic function with a cut over real axis from $4m_t{}^2$ to infinity. Thus, $f_t(s)$ obeys dispersion relation, which reads

$$f_t(s) = \frac{1}{\pi} \int\limits_{4m_t{}^2}^{\infty} \frac{Im f_t(s')}{s' - s - i\varepsilon} ds'. \tag{4}$$

For our mind, using dispersion relation (Eq. (4)) is the best way to calculate the contribution of graphs in Fig. 2 to the formfactor. Thus, our work proceeds in two steps: firstly, we compute $\mathrm{Im} f_t(s)$ analytically and then, using Eq. (4) we perform numerical integration and obtain the answer valid for arbitrary Higgs mass.

In order to compute the contribution of graphs in Fig. 2 to $\mathrm{Im} f_t(s)$ we must cut them in a well-known manner, facing the graphs with two or three particles in the intermediate state. The latter are Born graphs, while the former include one–loop proper subgraphs such as $\gamma t\bar{t}$ vertex, top's self-energy and $Ht\bar{t}$ vertex. Those subgraphs diverge and hence must be renormalized. On this way we used on–shell scheme for quark propagator renormalization and, as is well-established in QED, we performed subtraction for $\gamma t\bar{t}$ in zero momentum transfer thus satisfying Ward identities. As for $Ht\bar{t}$ vertex, the one–loop counter–term is fixed by top's mass and wave function renormalization due to the fact that it is Higgs–fermion interaction which gives the mass to the fermion (for exhaustive discussion see ref. [8]) Analitical calculations were performerd, by Reduce 33 , on the base of the package, written by us.

3. RESULTS

Following the way, outlined in the previous section, we obtained $f_t(s)$ and $F(s)$ on two-loop level. In order to present our results in the convenient

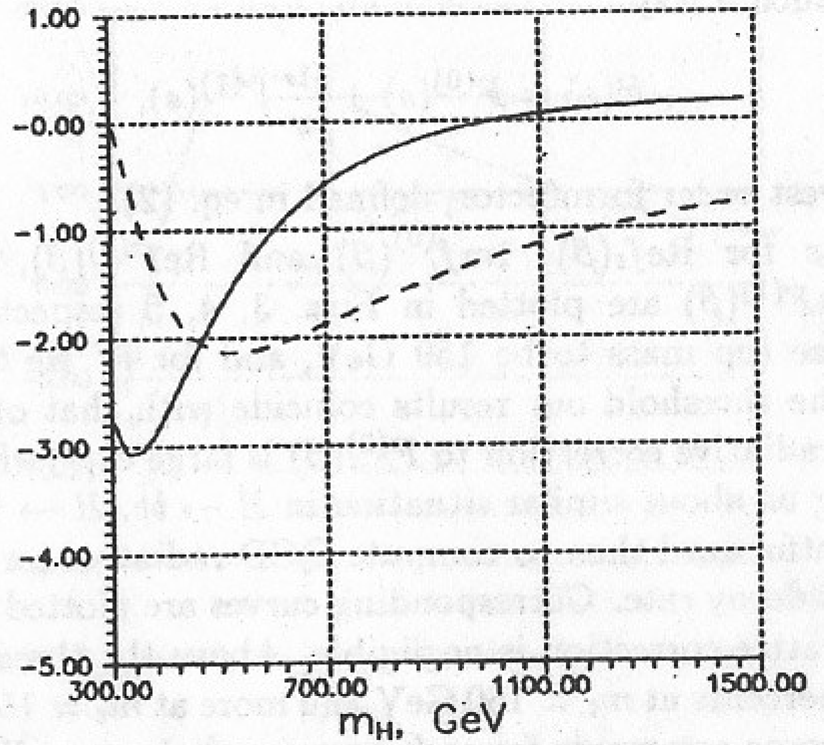

Fig. 3. Solid — Re $f_{(t)}^{(0)}(m_H)$ $m_t = 150$ GeV
Dashed — Im $f_{(t)}^{(0)}(m_H)$.

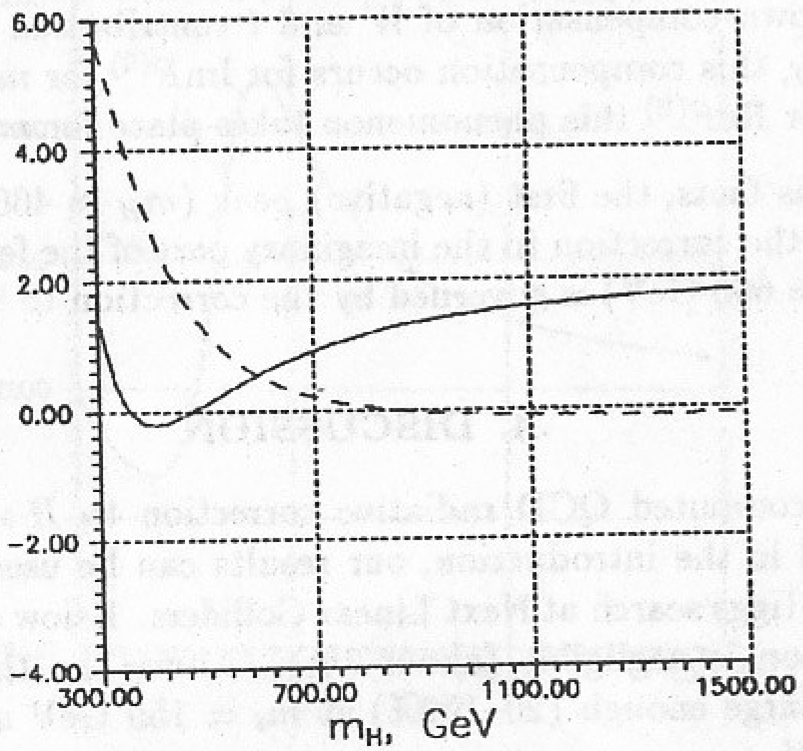

Fig. 4. Solid — Re $F^{(0)}(m_H)$ $m_t = 150$ GeV
Dashed — Im $F^{(0)}(m_H)$.

form, we will need some notations. Let us write two-loop QCD corrected formfactor in such a way

$$F(s) = F^{(0)}(s) + \frac{\alpha_s}{\pi} F^{(1)}(s), \tag{5}$$

$F^{(0)}$ is the lowest order formfactor, defined in eq. (2).

Our results for Re$f_t(\beta)$, Im$f_t^{(0)}(\beta)$ and Re$F^{(0)}(\beta)$, Im$F^{(0)}(\beta)$ and Re$F^{(1)}(\beta)$, Im$F^{(1)}(\beta)$ are plotted in Figs. 3, 4, 5 respectively. We used the value of the top mass to be 150 GeV, and for W we took 80.26 GeV. Thus, below the threshold our results coincide with that of ref. [7]. Above the threshold radiative correction to $F^{(0)}(\beta)$ is large everywhere (≈30–40%), thus reminding us about similar situation in $H \to b\bar{b}$, $H \to V\gamma$ studies.

It is straightforward then to compute QCD radiative correction to Higgs → two photons decay rate. Corresponding curves are plotted in Fig. 6. Below threshold, radiative correction is negligible. Above the threshold its value is about 20–100 percents at $m_t = 150$ GeV and more at $m_t = 150-200$ GeV. We want to make some comments for such enormously large radiative correction. This large radiative correction arises for next two reasons:

1. large QCD radiative corrections to purely top's contribution to formfactor;

2. well-known compensation of W and t contribution to the formfactor. Roughly, this compensation occurs for Im$F^{(0)}$ for m_H above 600 GeV, while for Re$F^{(0)}$ this phenomenon takes place for m_H below 600 GeV.

Due to this facts, the first (negative) peak ($m_H \approx 460$ GeV) in Fig. 6 is controlled by the correction to the imaginary part of the formfactor while the second ($m_H \approx 660$ GeV) is governed by the correction to the real part of the formfactor.

4. DISCUSSION

We have computed QCD radiative correction to $H \to \gamma\gamma$ decay rate. As mentioned in the introduction, our results can be used for studying the possibility of Higgs search at Next Linear Colliders. Below two tops threshold QCD correction is negligible (about 1%). Above the threshold, radiative correction is large enough (20–100%) at $m_t = 150$ GeV and more at $m_t = 150 - 200$ GeV.

For example, for $\gamma\gamma \to H \to ZZ$ [2], the total cross section is proportional to $\Gamma(H \to \gamma\gamma)$. Thus $\Delta\sigma(\gamma\gamma \to H \to ZZ)$ is equal to $\Delta\Gamma(H \to \gamma\gamma)$. (Here

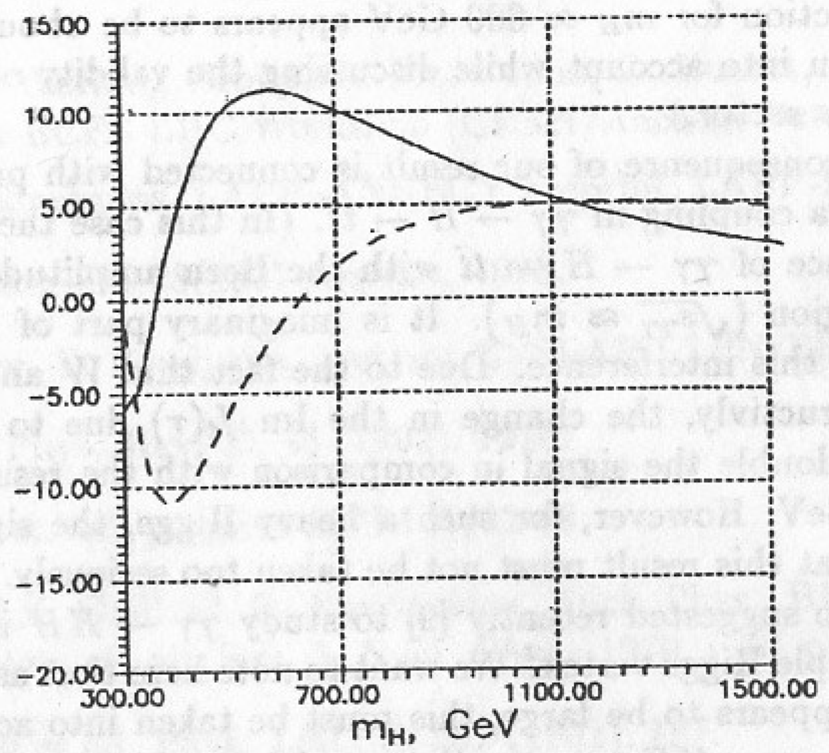

Fig. 5. Solid — Re $F^{(1)}(m_H)$ $m_t = 150$ GeV
Dashed — Im $F^{(1)}(m_H)$.

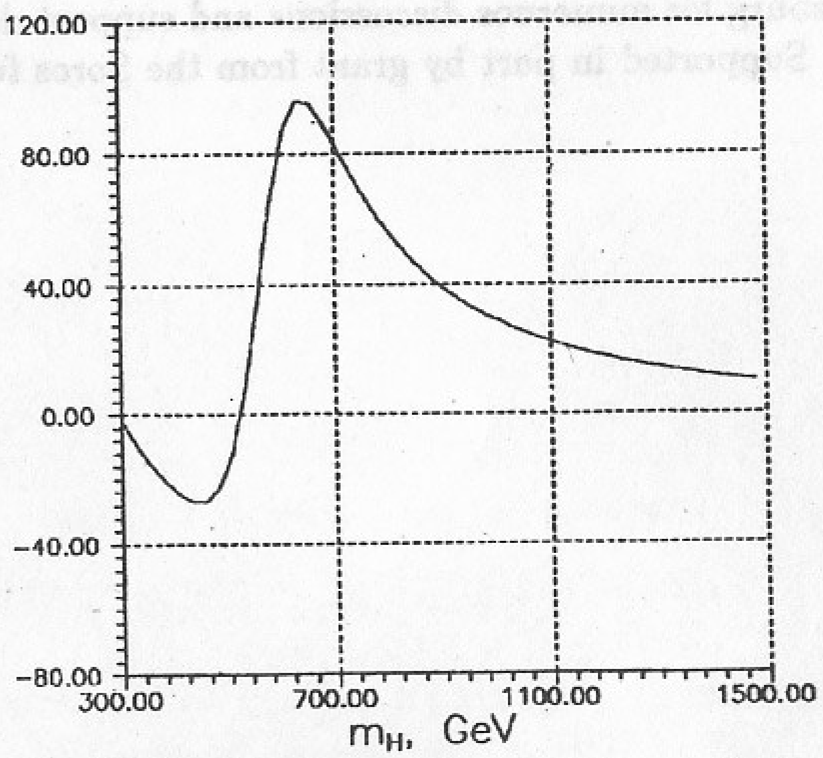

Fig. 6. Radiative correction to Higgs → two photon wigth, %.
$m_t = 150$ GeV

by Δ we mean relative radiative correction of the corresponding quantity). As this correction for $m_H \approx 600$ GeV appears to be about 100%, this fact must be taken into account while discussing the validity of this channel for probing Higgs sector.

Another consequence of our result is connected with proposed study [5] of the Yukawa coupling in $\gamma\gamma \to H \to t\bar{t}$. (In this case the effect arise from the interference of $\gamma\gamma \to H \to t\bar{t}$ with the Born amplitude $\gamma\gamma \to t\bar{t}$ in the resonance region ($\sqrt{s_{\gamma\gamma}} \approx m_H$). It is imaginary part of $H\gamma\gamma$ vertex that contribute to this interference. Due to the fact that W and t contributions interfere distructivly, the change in the Im $f_t(\tau)$ due to QCD correction will roughly double the signal in comparison with the results of ref. [5] for $m_H \geq 700$ GeV. However, for such a heavy Higgs, the signal is so hardly observable that this result must not be taken too seriously.

It was also suggested recently [9] to study $\gamma\gamma \to HH$ in order to probe anomalous triple Higgs vertex. We want to note here that as QCD correction to $\gamma\gamma \to H$ appears to be large, this must be taken into account for proper discussion of $\gamma\gamma \to HH$ cross-section sensitivity for triple Higgs anomalous coupling. It seems, that spoiling interference of W and top contribution will inspire better manifestation of possible anomalies.

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