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QCD corrections to the HZγ coupling ☆

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The Z decay into Higgs plus photon Z→Hγ (for $m_H < m_Z$) and the rare Higgs decay mode H→Zγ (for $m_H > m_Z$) are mediated by loops and can thus provide information on new particle spectra. To exploit this potential, the predictions of the standard model must be determined accurately. Besides W loops, the HZγ vertex is built up by heavy quark loops in the standard model. We present the QCD corrections to these processes which turn out to be of order α_s/π, and thus are well under control.

1. Introduction

Even though the Z decay into Higgs plus photon [1,2]

$$Z \to H\gamma \tag{1}$$

is predicted to occur with a branching ratio at a level of $O(10^{-6})$ in the Higgs mass range $50 \leqslant m_H \leqslant 80$ GeV, it deserves attention as a possible telescope for new particles [3] (see for example ref. [4]). The HZγ vertex is built up by loops so that its strength can be sensitive to scales far beyond the Higgs mass. The dominant contribution in the standard model is due to the W gauge boson loops but additional important contributions are provided by the (heavy) top quark loops, fig. 1a. To utilize this process as a telescope, the radiative corrections to the width $\Gamma(Z\to H\gamma)$ must be proven to be under control. In this letter we present the QCD gluon corrections to the top quark loop, fig. 1b. Being a fraction of α_s/π in the amplitude for the relevant Higgs mass range, they are found to be small enough not to blind the telescope. This result is in contrast to the two-gluon decay channel of the Higgs boson in which the lowest order top quark loop is substantially modified by radiative corrections [5].

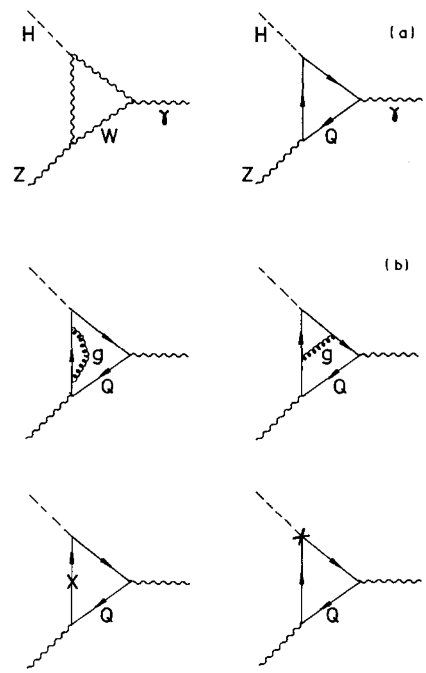

Fig. 1. Generic diagrams building up the HZγ coupling, (a) lowest order W and quark loops; (b) QCD corrections to the quark loops (gluonic diagrams and counter terms).

Similar conclusions can be drawn, mutatis mutandis, for the rare Higgs decay mode [2]

$$H \to Z\gamma . \tag{2}$$

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In the Higgs mass range between 120 and 150 GeV, the branching ratio for this decay mode is a fraction of a percent [6]. Outside this bracket the branching ratio falls quickly to very small values. [Note that in the intermediate mass range the branching ratio BR($H\to Z\gamma$) is larger than the branching ratio for two-photon decays BR($H\to\gamma\gamma$) which however are much easier to isolate experimentally.]

For $m_t \geqslant 91$ GeV [7] the Higgs mass of less than 150 GeV in the intermediate range falls below the $t\bar{t}$ threshold and the W^+W^- threshold. As a result, the top as well as the W component of the $HZ\gamma$ vertex are real.

2. The process $Z\to H\gamma$

Since there is no $HZ\gamma$ coupling in the basic lagrangian of the standard model, the decay $Z\to H\gamma$ is mediated by W loops and fermion loops. Denoting the W contribution by A_W and the fermionic amplitude by A_f, the decay rate is determined by [1,2]

$$\Gamma(Z\to H\gamma)=\frac{G_F\alpha^2 M_Z^3}{192\sqrt{2}\pi^3}\left(1-\frac{M_H^2}{M_Z^2}\right)^3 |A_W+A_f|^2 . \tag{3}$$

As the light fermion contributions are negligible, only the W boson and the top quark effectively contribute to this partial width in the standard model with three generations. The amplitudes A_W and A_f can be expressed as

$$A_W=\cot\theta_w\{4(3-\tan^2\theta_w)I_2(\tau_W,\lambda_W) + [(1+2\tau_W)\tan^2\theta_w-(5+2\tau_W)]I_1(\tau_W,\lambda_W)\} , \tag{4}$$

$$A_f=\sum_f N_c \frac{2Q_f(I_f^{3L}-2Q_f\sin^2\theta_w)}{\sin\theta_w\cos\theta_w} \times[I_1(\tau_f,\lambda_f)-I_2(\tau_f,\lambda_f)] , \tag{5}$$

where θ_w is the electroweak mixing angle, Q_f the charge of the fermion, I_f^{3L} the third weak isospin component and N_c the number of colors. The arguments τ_i and λ_i are defined as the mass ratios

$$\tau_i=\frac{m_H^2}{4m_i^2} , \quad \lambda_i=\frac{m_Z^2}{4m_i^2} .$$

The loop integrals can be cast into the form

$$I_1(\tau,\lambda)=-\frac{1}{2(\tau-\lambda)}+\frac{1}{2(\tau-\lambda)^2}[f(\tau)-f(\lambda)] +\frac{\lambda}{(\tau-\lambda)^2}[g(\tau)-g(\lambda)] ,$$

$$I_2(\tau,\lambda)=\frac{1}{2(\tau-\lambda)}[f(\tau)-f(\lambda)] ,$$

where

$$f(\tau)=\arcsin^2(\sqrt{\tau}) ,$$
$$g(\tau)=\sqrt{\tau^{-1}-1}\arcsin(\sqrt{\tau})$$

for $\tau<1$. The W and top amplitudes interfere destructively.

A generic subset of the twelve two-loop diagrams plus the corresponding counter terms for the gluonic QCD corrections to the top quark loops are depicted in fig. 1b. The calculation of these diagrams is a straightforward extension of the related $H\gamma\gamma$ coupling which has been discussed in a preceding letter [8]. Note in particular that, as a consequence of C conjugation, only the vectorial Z coupling to quarks enters the amplitude. We have chosen the on-shell renormalization scheme which is very convenient for diagrams involving heavy quarks. In this scheme the residue of the quark propagator at the pole mass is normalized to unity. The electromagnetic vertex is renormalized at zero-momentum transfer so that the Ward identity renders the corresponding counter term equal to the counter term of the wave function. The Z vector coupling is renormalized analogously. Since the Yukawa–Higgs coupling is set by the fermion mass, the counter term for the Higgs–quark vertex is fixed by the counter terms of the mass and of the wave function [8,9].

The numerical evaluation of the five-dimensional Feynman parameter integrals has been performed by means of the integration routine VEGAS. For the Higgs mass range we are interested in, no singularities are encountered and the integrals converge fast. The stability of the results has been checked by evaluating test functions numerically and analytically which have a shape similar to the loop integrals. In the (artificial) limit where Higgs and quark masses are chosen much larger than the Z mass, but the ratio m_H/m_f is kept fixed, the results of the related two-

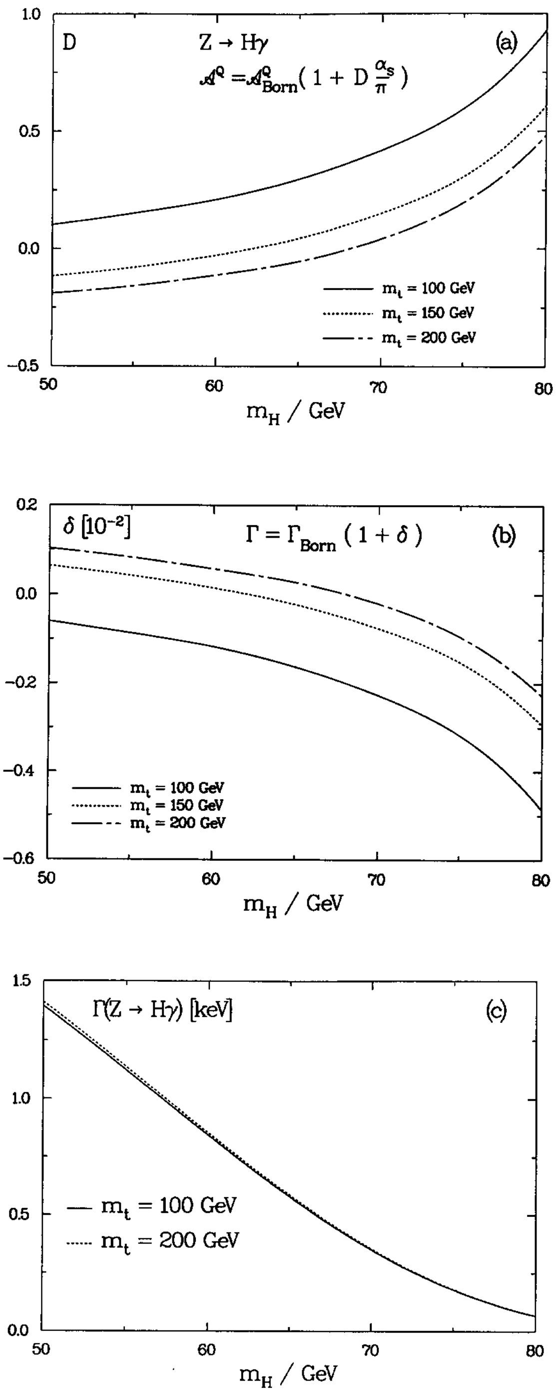

Fig. 2. The Z→Hγ decay in the standard model, (a) coefficient of the QCD corrections to the top quark amplitude; (b) relative magnitude of the QCD correction to the partial width; (c) partial width $\Gamma(Z \to H\gamma)$ for two (extreme) top mass values.

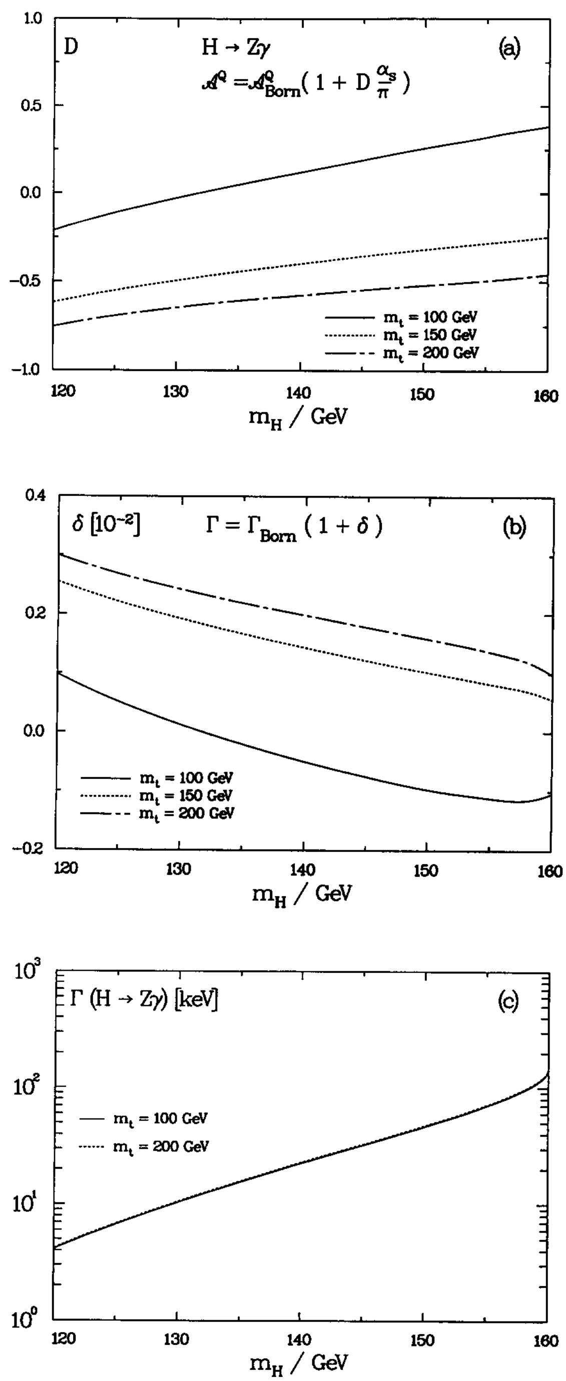

Fig. 3. The H→Zγ decay in the standard model, (a) coefficient of the QCD corrections to the top quark amplitude; (b) relative magnitude of the QCD correction to the partial width; (c) partial width $\Gamma(H \to Z\gamma)$ for two (extreme) top mass values.

photon decay [8] are recovered within the numerical accuracy of $\sim 1\%$.

The QCD corrected amplitude, to be inserted in eq. (3), is given in terms of the lowest-order one-loop amplitude in eq. (5) (renamed $A_Q^{\rm Born}$ for Q=f) by

$$A_Q = A_Q^{\rm Born}\left(1 + D(\tau_Q)\,\frac{\alpha_s}{\pi}\right). \qquad (6)$$

The coefficient D is displayed in fig. 2a. It varies from -0.2 to $+1$ in the mass ranges of interest for the Higgs boson and the top quark. The overall corrections to the partial width $\Gamma(Z \to H\gamma)$ is positive for D negative and vice versa, but it remains below 0.5% as shown in fig. 2b. The final result for the partial width is summarized in fig. 2c.

3. The decay $H \to Z\gamma$

The discussion of this process for Higgs masses between 120 and 150 GeV follows closely the pattern of the preceding section. With the width written as

$$\Gamma(H \to Z\gamma) = \frac{G_F \alpha^2 M_H^3}{16\sqrt{2}\pi^3}\left(1 - \frac{M_Z^2}{M_H^2}\right)^3 |A_W + A_f|^2, \qquad (7)$$

the amplitudes for the W and the top quark loops are the same as in eqs. (4) and (5). The QCD correction to the top quark loops may be parametrized again as in eq. (6). The values of the coefficient D in the intermediate Higgs mass range we are analyzing, are displayed in fig. 3a. They vary between ~ -1 and $\sim +0.5$. This translates into an overall correction of less than 0.3% to the partial decay width, presented in detail in figs. 3b, 3c.

4. Summary

We have demonstrated that QCD corrections to the decays $Z \to H\gamma$ and $H \to Z\gamma$ are well under control. This is a first step of an extensive and complicated programme that includes two-loop electroweak corrections in future studies. From the present investigation one may nevertheless cautiously conclude that deviations from the predictions of the standard model for these widths in excess of a few α_W/π ($\sim$ a few percent) would signal novel mass scales of phenomena beyond the standard model.

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