QCD CORRECTIONS TO HIGGS BOSON PRODUCTION

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ABSTRACT

We discuss the $\mathcal{O}(\alpha_s)$ QCD radiative corrections to Higgs boson production in the limit in which the top quark is much heavier than the Higgs boson. The subleading corrections, of $\mathcal{O}(\alpha_s M_H^2/M_{\text{top}}^2)$, are presented for the decay $H \rightarrow \gamma\gamma$ and shown to be small.

1. Introduction

The search for the Higgs boson of the minimal standard model is one of the fundamental missions of future high energy colliders such as the SSC and the LHC. Over much of the interesting Higgs mass range, the dominant production mechanism is gluon fusion. If the Higgs boson is lighter than 160 GeV ($2M_W$), then it will decay predominantly to $b\bar{b}$ pairs. Due to the large QCD backgrounds to the $b\bar{b}$ decay mode, it will probably be necessary to search for the Higgs boson in this mass region through its rare decay modes, of which the decay $H \rightarrow \gamma\gamma$ has been discussed the most. The rates into modes such as $\gamma\gamma$ are small and hence knowledge of the QCD radiative corrections is essential for assessing the viability of the signal.

2. Gluon Fusion

The basic production mechanism is gluon fusion through a triangle diagram. The rate for this reaction is sensitive predominantly to the heavy quarks and has been known for some time.\textsuperscript{1} It is also sensitive to new generations of heavy colored fermions, to the colored scalars of supersymmetric models and to any other new particles which couple to gluons and scalars. Because the Higgs-fermion coupling of the standard model is proportional to the fermion mass, a heavy fermion does not decouple when its mass is much heavier than the Higgs boson mass and so this decay provides a window for observing the consequences of new heavy particles. In the limit in which $M_{\text{top}} \gg M_H$, the rate can be found from the effective Lagrangian,\textsuperscript{2}

$$\mathcal{L} = \frac{\beta_F}{g_s(1 + \delta)} \frac{H}{2v} G^{\alpha\mu\nu} G_{\alpha\mu\nu},$$

where $\beta_F$ contains only the contribution of heavy fermions to the QCD beta function. The factor of $(1 + \delta) = 1 + 2\alpha_s/\pi$ results from the renormalization of the $Ht\bar{t}$ coupling. For $M_H < 2M_{\text{top}}$, the $M_{\text{top}} \rightarrow \infty$ limit is a reasonable approximation to the rate.

\textsuperscript{1}Invited talk given at the November, 1992 DPF Meeting
The radiative corrections to the process $gg \rightarrow HX$ can be performed in a straightforward manner using the effective Lagrangian of Eq. (1) and the results are given in Ref. 3. Numerically, they are well approximated by

$$\sigma(gg \rightarrow H) \sim \sigma_0(gg \rightarrow H) \left[ 1 + \frac{\alpha_s}{\pi} \left( \pi^2 + \frac{11}{2} \right) \right]$$

(2)

For $\alpha_s = 0.2$ this gives an enhancement factor of 1.7. The results are of course also sensitive to the choice of renormalization scale and structure functions.

However we are not really interested in the region where $M_H << M_{top}$, but in the region where they have similar values. This is the so-called “intermediate mass” Higgs boson. It is thus of interest to compute the next contribution to the series, the terms of $O(\alpha_s M_H^2 / M_{top}^2)$ to assess the accuracy of the approximation. These terms cannot be computed using the effective Lagrangian, but rather require a direct evaluation of the relevant two loop graphs. We begin by computing the two-loop graphs contributing to the amplitude for $H \rightarrow \gamma \gamma$, which form a subset of those required for the computation of $gg \rightarrow H$.

3. $H \rightarrow \gamma \gamma$

We utilize the techniques of Hoogeveen for evaluating two-loop graphs involving heavy fermions. This technique has also been successfully used to compute the 2- loop contribution to the $\rho$ parameter from a heavy top quark. Each graph gives a result of the form

$$A_i^{\mu \nu} = \left( a_i g^{\mu \nu} k_1 \cdot k_2 + b_i k_1^\mu k_2^\nu + c_i k_1^\mu k_2^\nu \right) ,$$

(3)

where $k_1^\mu$ and $k_2^\nu$ are the external gluon momenta. Gauge invariance requires that

$$\sum_i a_i = - \sum_i b_i ,$$

(4)

where the sum runs over all the diagrams (the $c_i$ terms do not contribute for on-shell photons). This serves as a check of our result.

The denominators arising from the heavy-quark propagators can be expanded in powers of the external momentum. For example,

$$\frac{1}{(q - k_1)^2 - M_{top}^2} = \frac{1}{q^2 - M_{top}^2} \left( 1 + \frac{2q \cdot k_1}{q^2 - M_{top}^2} + ... \right) .$$

(5)

To obtain the terms of $O(M_H^2 / M_{top}^2)$ each denominator must be expanded up to terms containing two powers of $k_1$ and two powers of $k_2$. After contracting the amplitudes with various combinations of $g^{\mu \nu}$ and the external momenta and expanding the denominators as in Eq. (5) all the contributions have the form

$$\int \frac{d^np}{(2\pi)^n} \int \frac{d^nq}{(2\pi)^n} \frac{(p \cdot q, p \cdot k_i, q \cdot k_i, \text{etc})}{(q^2 - M_{top}^2)^k (p^2 - M_{top}^2)^l (p-q)^2} .$$

(6)
Using the symmetries of the numerators the relevant integrals can be reduced to products of one-loop integrals plus integrals of symmetric form

\[ B_{k,l} = \int \frac{d^n p}{(2\pi)^n} \int \frac{d^n q}{(2\pi)^n} \frac{1}{(q^2 - M_{\text{top}}^2)^k (p^2 - M_{\text{top}}^2)^l (p - q)^2} \cdot \quad (7) \]

Integrals of this form are tabulated as a power series in \(1/M_{\text{top}}^2\) in Ref 4. and we can directly apply them here. Our final result for the fermion contribution to \(H \rightarrow \gamma\gamma\) is then

\[ A^{\mu\nu}_F = A_F \left( g^{\mu\nu} k_1 \cdot k_2 - k_1^\mu k_2^\nu \right) \]

with

\[ A_F = - \left( \frac{2\alpha}{\pi v} \sum_i Q_i^2 \right) \left\{ 1 + \frac{7}{120} \frac{M_H^2}{M_{\text{top}}^2} - \frac{\alpha_s}{\pi} \left( 1 - \frac{61}{270} \frac{M_H^2}{M_{\text{top}}^2} \right) \right\} \cdot \quad (8) \]

It is important to note that the QCD corrections are not just a rescaling of the lowest order result, but rather have a different dependence on \(M_H/M_{\text{top}}\).

The effect of the radiative corrections is shown in Fig. 1 for \(M_{\text{top}} = 200 \text{ GeV}\) (solid line) and also for a degenerate doublet of \(SU(2)\) quarks with \(M = 400 \text{ GeV}\) (dotted line). This figure includes both top and \(W\) loops as can be clearly seen by the threshold at \(2M_W\). The QCD corrections are well under control and are always less than 4%. Of course, in the standard model, the fermion loop contributions are dwarfed by the \(W\) boson loops which accounts for the insensitivity of the rate to the QCD corrections. In extensions of the standard model, however, this is not necessarily the case. In supersymmetric models, for example, it is straightforward to select parameters for which the fermion loop contribution is significantly enhanced relative to the \(W\) boson loops.

4. Conclusions

We have computed the \(O(\alpha_s M_H^2/M_{\text{top}}^2)\) contributions to the decay \(H \rightarrow \gamma\gamma\) and have found them to be small. These corrections form a subset of those required for the \(O(\alpha_s M_H^2/M_{\text{top}}^2)\) computation of the rate for \(gg \rightarrow gH\). This calculation is in progress.

5. Acknowledgements

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6. References

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**Figure Caption**

Fig. 1. Ratio of the $\mathcal{O}(\alpha_s M_H^2/M_{top}^2)$ result for the decay width for $H \to \gamma\gamma$ to the lowest order $M_{top} \to \infty$ limit.