NLO Electroweak Corrections to Higgs Decay to Two Photons

Stefano Actis

Institut für Theoretische Physik E, RWTH Aachen University,
D-52056 Aachen - Germany

The recent calculation of the next-to-leading order electroweak corrections to the decay of the Standard Model Higgs boson to two photons in the framework of the complex-mass scheme is briefly summarized.

1 Introduction

The production of the Standard Model Higgs boson in photon-photon collisions represents an interesting mechanism for measuring the partial width $\Gamma(H \to \gamma\gamma)$ with a 3% accuracy at an upgrade option of the International Linear Collider (see [2] and references therein). Therefore, the computation of radiative corrections to the leading order (LO) decay width [3] has been an active field of research in the last years.

QCD corrections to the partial width of an intermediate-mass Higgs boson have been computed at next-to-leading order (NLO) in [4] and at next-to-next-to-leading order (NNLO) in [5]. The NLO result has been extended in [6] to the entire Higgs-mass range.

Electroweak NLO corrections have been evaluated in [7] in the large top-mass scenario and in [8] assuming a large Higgs-mass scenario. The two-loop corrections due to light fermions have been derived by the authors of [9], and electroweak effects due to gauge bosons and the top quark have been evaluated through an expansion in the Higgs external momentum in [10].

More recently, all electroweak corrections at NLO have been computed in [11] for a wide range of the Higgs mass, including the region across the $W$-pair production threshold. It has been shown that the divergent behavior of the amplitude at a two-particle normal threshold can be removed introducing the complex-mass scheme of [12], a program carried out in [13]. Note that we have not addressed the issue of re-summing Coulomb singularities, as performed by the authors of [14].

In Section 2 of this note we review the implementation of the complex-mass scheme in the two-loop computation and the effect on the two-particle threshold region. Next, in Section 3 we discuss the numerical impact of the NLO electroweak corrections on the partial width $\Gamma(H \to \gamma\gamma)$.

2 Normal thresholds and complex masses

The $H \to \gamma\gamma$ amplitude shows a divergent behavior around two-particle normal thresholds, related to the presence of square-root and logarithmic singularities in the variable $\beta^2 \equiv 1 - 4M_i^2/M_H^2$, where $M_H$ is the Higgs mass and $M_i$, with $i = W, Z, t$, stands for the mass of the $W$ ($Z$) boson or the top quark.

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Square-root singularities are related to: 1) derivatives of two-point one-loop functions, associated with Higgs wave-function renormalization; 2) derivatives of three-point one-loop integrals, generated by mass renormalization; 3) genuine irreducible two-loop diagrams containing a one-loop self-energy insertion.

Concerning the Higgs wave-function renormalization factor at one loop, it is possible to explicitly prove that the coefficient of the derivative of the two-point one-loop integral involving a top quark contains a positive power of the threshold factor $\beta_t$. Therefore, square-root singularities associated with wave-function renormalization appear only at the $2M_W$ and $2M_Z$ thresholds.

We consider now genuine two-loop diagrams containing a self-energy insertion; they naturally join terms induced by one-loop mass renormalization as shown in Figure 1 where bosonic and fermionic diagrams are illustrated. Fermionic diagrams of Figure 1 and Figure 2 are $\beta_t$-protected at threshold, and do not require any special care. The two-loop irreducible diagram of Figure 1 can be cast in a representation where the divergent part is completely written in terms of the one-loop diagrams of Figure 1. Moreover, it is possible to check explicitly that the $\beta_W^{-1}$ behavior generated by the two-loop diagram exactly cancels the $\beta_W^{-1}$ divergency due to one-loop $W$-mass renormalization performed in the complex-mass scheme.

Therefore, at the amplitude level, square-root singularities are confined to the Higgs-boson wave-function renormalization factor (see also [15]).

As thoroughly discussed in [11, 13], logarithmic singularities are generated by the bosonic diagram of Figure 2 whereas top-quark terms are $\beta_t$-protected at threshold.

A pragmatic gauge-invariant solution to the problem of threshold singularities due to unstable particles for the $H \rightarrow \gamma\gamma$ decay has been introduced and formalized in [14]. In this setup (Minimal Complex-Mass scheme) the amplitude is written as the sum of divergent and finite terms, and the complex-mass scheme of [12] is introduced for all gauge-invariant divergent terms. The Minimal Complex-Mass (MCM) scheme allows for a straightforward removal of unphysical infinities. Real masses of unstable gauge bosons are traded for complex poles in divergent terms, also at the level of the couplings, gauge-parameter invariance and Ward identities are preserved and the amplitude has a decent threshold behavior, as shown in Figure 3 for the NLO electroweak corrections to the $H \rightarrow \gamma\gamma$ decay width ($\delta_{\text{EW,MCM}}$).
However, the MCM scheme does not deal with artificial cusps associated with the crossing of gauge-boson normal thresholds, as shown in Figure 3 for the $WW$ threshold. In order to cure these effects, in [13] we have performed a full implementation of the complex-mass scheme in the two-loop computation. In the complete Complex-Mass (CM) setup, real masses are replaced with complex poles and the real part of the $W$-boson self-energy, stemming from mass renormalization at one loop, is traded for the full expression, including its imaginary part. As shown in Figure 3, the full introduction of the CM scheme leads to a complete smoothing of the corrections ($\delta_{\text{EW,CM}}$) at threshold. A more striking effect is associated with the production of a Higgs boson through gluon-gluon fusion as discussed in [13].

### 3 Results

Numerical results for the percentage NLO electroweak corrections to the partial width $\Gamma(H \rightarrow \gamma\gamma)$ are shown in Figure 4. All light-fermion masses have been set to zero in the collinear-free amplitude and we have defined the $W$- and $Z$-boson complex poles by

$$s_j \equiv \mu_j \left(\mu_j - i \gamma_j\right), \quad \mu_j^2 \equiv M_j^2 - \Gamma_j^2, \quad \gamma_j \equiv \Gamma_j \left[1 - \Gamma_j^2/(2M_j^2)\right],$$

with $j = W, Z$. As input parameters for the numerical evaluation we have used the following values for the masses and the widths of the gauge bosons: $M_W = 80.398\text{ GeV}$, $M_Z = 91.1876\text{ GeV}$, $\Gamma_W = 2.093\text{ GeV}$ and $\Gamma_Z = 2.4952\text{ GeV}$.

Figure 4: NLO percentage corrections to the $H \rightarrow \gamma\gamma$ decay; see text for details.

In Figure 4 we have shown QCD corrections ($\delta_{\text{QCD}}$), electroweak contributions in the MCM and CM setups ($\delta_{\text{EW,MCM}}$ and $\delta_{\text{EW,CM}}$) and the full NLO prediction involving both
electroweak effects in the complex-mass scheme and QCD ones ($\delta_{\text{EW, CM}} + \delta_{\text{QCD}}$). We observe that QCD and electroweak corrections almost compensate below the WW threshold, as shown by \cite{9, 10}, leading to an overall very small correction, well below the expected 3\% accuracy at the planned linear collider operating in the $\gamma\gamma$ option. Above the WW threshold, instead, both corrections are positive and lead to a global 4\% effect for $M_H = 170$ GeV.

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