The Standard Model Higgs in $\gamma\gamma$ Collisions

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Abstract. For a Higgs boson below the $W^\pm$ threshold, the $\gamma\gamma$ collider option of a future linear e^+e^- machine is compelling. In this case one can measure the "gold-plated" loop induced $\Gamma(H \longrightarrow \gamma\gamma)$ partial width to high precision, testing various extensions of the Standard Model. With recent progress in the expected $\gamma\gamma$ luminosity at TESLA, we find that for a Higgs of 115 GeV a statistical accuracy of the two photon partial width of 1.4 % is possible. The total width depends thus solely on the accuracy of $BR(H \longrightarrow \gamma\gamma)$ and is of $\mathcal{O}(10\%)$.

The two photon Higgs width $\Gamma(H \longrightarrow \gamma\gamma)$, measured at the $\gamma\gamma$ Compton-backscattered option of a future linear $e^\pm$ collider, is a very important physical quantity [1]. In Ref. [2] it was found that the MSSM and SM predictions can differ in the percentile regime for large masses of the pseudoscalar Higgs m_A, depending mainly on the chargino-masses. The SM with two Higgs doublets (2HDM) and all other Higgs particles heavy differs by about 10% [3]. At the PLC one measures the product $\Gamma(H \longrightarrow \gamma\gamma) \times BR(H \longrightarrow b\overline{b})$ and it is assumed that the branching ratio can be measured in the $e^\pm$ mode via $BR(H \longrightarrow b\overline{b}) = \frac{[\sigma(ZH) \times BR(H \longrightarrow b\overline{b})]}{\sigma(ZH)}$ with a 1 % accuracy [4]. It was recently demonstrated in Ref. [5,6] that using conservative assumptions an accuracy of 2% is feasible for the two photon Higgs width at a PLC. There has been considerable progress in the theoretical understanding of the BG to the intermediate mass Higgs boson decay into $b\overline{b}$ recently. The Born cross section for the $J_z = 0$ channel is suppressed by $\frac{m_q^2}{s}$ relative to the $J_z = \pm 2$ which means that by ensuring a high degree of polarization of the incident photons one can *simultaneously* enhance the signal and suppress the background. QCD radiative corrections can remove this suppression, however, and large bremsstrahlung and double logarithmic corrections need to be taken into account. In Ref. [7] the exact one loop corrections to $\gamma\gamma \longrightarrow q\overline{q}$ were calculated and the largest virtual correction was contained in novel non-Sudakov double logarithms. For some choices of the invariant mass cutoff y_{cut} even a negative cross section was obtained in this approximation. The authors of Ref. [8] elucidated the physical nature of the novel double logarithms and performed a two loop calculation in the

DL-approximation. The results restored positivity to the physical cross section. In Ref. [9], three loop DL-results were presented which revealed a factorization of Sudakov and non-Sudakov DL's and led to the all orders resummation of all DL in form of a confluent hypergeometric function ${}_2F_2$. The general form of the expression is $\sigma_{DL} = \sigma_{Born}(1 + \mathcal{F}_{DL}) \exp(\mathcal{F}_{Sud})$. In Ref. [10] it was demonstrated that at least four loops on the cross section level are required to achieve a converged DL result. At this point the scale of the QCD-coupling is still unrestrained and differs by more than a factor of two in-between the physical scales of the problem, m_q and m_H. This uncertainty was removed in Ref. [11] by introducing a running coupling $\alpha_s(\mathbf{l}_\perp^2)$ into each loop integration, where $l_\perp$ denotes the perpendicular Sudakov loop momentum. The effect of the RG-improvement lead to $\sigma_{DL}^{RG} = \sigma_{Born}(1 + \mathcal{F}_{DL}^{RG}) \exp(\mathcal{F}_{Sud}^{RG})$. The effective scale, defined simply as the one used in the DL-approximation which gives a result close to the RG-improved values, depends on the energy detector resolution ϵ, however in general is rather much closer to m_q than m_H [11]. On the signal side, the relevant radiative corrections have long been known up to NNL order in the SM [12,13] and are summarized including the MSSM predictions in Ref. [14]. For our purposes the one loop corrections to the two photon Higgs width are sufficient as the QCD corrections are small in the SM. The important point to make here and also the novel feature in this analysis is that the branching ratio BR ($H \longrightarrow b\overline{b}$) is corrected by the same RG-improved resummed QCD Sudakov form as the continuum heavy quark background [5]. This is necessary in order to employ the same two jet definition for the final state. Since we use the renormalization group improved massive Sudakov form factor $\mathcal{F}_{Sud}^{RG}$ of Ref. [11], we prefer the Sterman-Weinberg jet definition [15]. This is also necessitated by the fact that for three jet-topologies new DL corrections would enter which are not included in the background resummation of Ref. [9]. We also use an all orders resummed running quark mass evaluated at the Higgs mass for $\Gamma(H \longrightarrow b\overline{b})$. For the total Higgs width, we include the partial Higgs to $b\overline{b}, c\overline{c}, \tau^+\tau^-, WW^*, ZZ^*$ and gg decay widths with all relevant radiative corrections. We begin with a few generic remarks concerning the uncertainties in our predictions. The signal process $\gamma\gamma \longrightarrow H \longrightarrow b\overline{b}$ is well understood and NNL calculations are available. The theoretical error is thus negligible [14]. There are two contributions to the background process $\gamma\gamma \longrightarrow q\overline{q}$ which we neglect in this paper. Firstly, the so-called resolved photon contribution was found to be a small effect, e.g. [7], especially since we want to reconstruct the Higgs mass from the final two-jet measurements and impose angular cuts in the forward region. In addition the good charm suppression also helps to suppress the resolved photon effects as they give the largest contribution. The second contribution we do not consider here results from the final state configuration where a soft quark is propagating down the beam pipe and the gluon and remaining quark form two hard back-to back-jets [16]. We neglect this contribution here due to the expected excellent double b-tagging efficiency and the strong restrictions on the allowed acollinearity discussed below. A good measure of the remaining theoretical uncertainty in the continuum background is given by scanning it below and above the Higgs resonance. For precision extractions of $\Gamma(H \longrightarrow \gamma\gamma)$ the exact functional form for resonant energies is still required, though. In terms of possible systematic errors, the most obvious effect comes from the theoretical uncertainty in the bottom mass determination. Recent QCD-sum rule analyses, however, reach below the 2% level for $\overline{m}_b(\overline{m}_b) = 4.17 \pm 0.05$ [17] including the effect of a massive charm [18]. For quantitative estimates of expected systematic experimental errors it is clearly too early to speculate at this point. The philosophy adopted henceforth is that we assume that they can be neglected at the 1% level and concentrate purely on the statistical error. We focus here not on specific predictions for cross sections, but instead on the expected statistical accuracy of the intermediate mass Higgs signal at a PLC. As detailed in Refs. [1], due to the narrow Higgs width, the signal event rate is proportional to $N_S \sim \frac{dL_{\gamma\gamma}}{dw}\Big|_{m_H}$, while the BG is proportional to $L_{\gamma\gamma}$. To quantify this, we take the *updated* design parameters of the proposed TESLA linear collider [19,20], which correspond to an integrated peak $\gamma\gamma$-luminosity, of 40 fb^{-1} for the low energy running of the Compton collider. This corresponds to an integrated geometrical luminosity $L_{e^\pm}$ of 400 fb^{-1} and a conversion coefficient $k^2 = 0.4$ and a 10^7 sec. run at TESLA. The polarizations of the incident electron beams and the laser photons are chosen such that the product of the helicities $\lambda_e\lambda_\gamma = -1$. This ensures high monochromaticity and polarization of the photon beams [19,20]. Within this scenario a typical resolution of the Higgs mass is about 10 GeV, so that for comparison with the background process $BG \equiv \gamma\gamma \longrightarrow q\overline{q}$ one can use [1] $\frac{L_{\gamma\gamma}}{10\ \mathrm{GeV}} = \frac{dL_{\gamma\gamma}}{dw}\Big|_{m_H}$ with $\frac{dL_{\gamma\gamma}}{dw}\Big|_{m_H}$ =1.7 fb^{-1}/GeV. The number of background events is then given by $N_{BG} = L_{\gamma\gamma}\sigma_{BG}$. In Ref. [5] it was demonstrated that in order to achieve a large enough data sample, a central thrust angle cut $|\cos\theta| < 0.7$ is advantageous and is adopted here. We also assume a (realistic) 70% double b-tagging efficiency. For the charm rejection rate it seems possible to assume improvement from a better single point resolution, thinner detector modules and moving the vertex detectors closer to the beam-line [21]. With these results in hand we keep $|\cos\theta| < 0.7$ fixed and furthermore assume the $\overline{c}c$ misidentification rate of 1% [5]. We vary the cone angle δ between narrow (10^o), medium (20^o) and large (30^o) cone sizes for both $\epsilon = 0.1$ and $\epsilon = 0.05$. The analysis in Ref. [5] using not the updated machine parameters demonstrated that for a Higgs boson with $m_H < 130$ GeV, the statistical precision can be below the 2% level after collecting one year of data. The good charm misidentification rate is important for $\sqrt{N_{tot}}/N_S$. The level of accuracy was confirmed in Ref. [22] with an independent MC-simulation. The previous analyses, however, did not take into account the new luminosity assumptions. These lead to an improvement for the statistical significance of a factor $\frac{1}{\sqrt{3.3}} \approx 0.55$. Together with the expected uncertainty of 1% from the e^+e^- mode determination of BR($H \longrightarrow \overline{b}b$) [21], we conclude that a measurement of the partial width $\Gamma(H \longrightarrow \gamma\gamma)$ of 1.4% precision level[1] is feasible for a Higgs of 115 GeV from a purely statistical point of view. In the entire MSSM mass range the precision

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1) We assume four years of running to determine BR($H \longrightarrow \overline{b}b$) at 1%, uncorrelated error progression and negligible systematic errors.

below the 2% level is achievable. This level of accuracy could significantly enhance the kinematical reach of the MSSM parameter space in the large pseudoscalar mass limit or the 2HDM and thus open up a window for physics beyond the Standard Model. For the total Higgs width, the expected precision is dominated by the branching ratio BR($H \longrightarrow \gamma\gamma$), which can be determined at the 10 % level [23]. In summary, using realistic and optimized machine and detector design parameters, we conclude that the Compton collider option at a future linear collider can considerably extend our ability to discriminate between the SM and MSSM or 2HDM scenarios.

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