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Heavy neutral MSSM Higgs bosons at the photon linear collider – a comparison of two analyses

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Abstract. Measurement of the heavy neutral MSSM Higgs bosons H and A production in the process $\gamma\gamma \to A/H \to b\bar{b}$ at the Photon Linear Collider [1,2] has been considered in two independent analyses for the parameter range corresponding to the so-called 'LHC wedge'. Significantly different conclusions were obtained; signal-to-background ratio 36 vs. 2. Here assumptions and results of these two analyses are compared. We have found that differences in the final results are mainly due to different assumptions on $\gamma\gamma$-luminosity spectra, jet definitions and selection cuts.

Keywords. MSSM Higgs bosons; photon linear collider; LHC wedge.

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A photon-collider option of the future e^+e^- linear collider offers a unique possibility to produce neutral Higgs bosons as s-channel resonances. In this contribution two analyses [1,2] are compared which estimate the precision of the cross-section measurement for the production of heavy neutral MSSM Higgs bosons in the process $\gamma\gamma \to A/H \to b\bar{b}$. Both analyses were focused on the so-called 'LHC wedge', i.e. the region of intermediate values of $\tan\beta$, $\tan\beta \approx 4$–10, and masses $M_{A/H}$ above 200 GeV, where the heavy bosons A and H may not be discovered at the LHC and at the first stage of the e^+e^- linear collider. In each of these analyses NLO corrections to signal and background processes were taken into account. As the results of the two approaches seem to differ significantly, we undertook the task of comparing them, focusing on the case of $M_A = 300$ GeV with MSSM parameters $tg\beta = 7$ and $M_2 = \mu = 200$ GeV.

In the first analysis [1] the NLO corrections to the background process $\gamma\gamma \to b\bar{b}$ have been calculated according to ref. [3]. Resummation of large Sudakov and non-Sudakov logarithms due to soft gluon radiation and soft gluon and bottom-quark exchange in the virtual corrections has been taken into account [4]. The NLO-α_s was normalized to $\alpha_s(M_Z) = 0.119$ and the scale given by the $\gamma\gamma$ invariant mass was used. In order to suppress gluon radiation slim two-jet configurations in the final state were selected; jets were defined within the Sterman–Weinberg criterion.

If the radiated gluon energy was larger than 10% of the total $\gamma\gamma$ invariant energy and if, at the same time, the opening angles between all three partons in the final state were larger than 20°, the event was classified as three-jet event and rejected. The interference between the signal and background processes has been taken into account properly. The NLO QCD corrections of the interference terms to quark final states including the resummation of the large (non-)Sudakov logarithms were calculated (for details, see [5]). The description of the $\gamma\gamma$-luminosity was based on the LO cross-section formula for the Compton process. It was assumed that the beam energy is tuned to obtain maximum luminosity at the value of the pseudoscalar Higgs mass M_A. In this analysis the selection of events was applied at the parton level. The background was reduced with a cut in the production angle of the bottom quark only, $|\cos\theta_b| < 0.5$. By collecting $b\bar{b}$ final states with a resolution in the invariant mass $M_A \pm 3$ GeV, the sensitivity to the combined A and H resonance peaks above the background was strongly increased. The result for the peak cross-section is shown in figure 1 as a function of M_A. It can be inferred from the figure that the background is strongly suppressed (signal-to-background ratio ≈ 36 for $M_A = 300$ GeV).

The second analysis [2] was based on realistic simulations of the $\gamma\gamma$-luminosity spectra for the PLC at the TESLA collider [6,7]. One-year run of PLC was assumed with the center-of-mass energy of the colliding electron beams optimized for the production of the pseudoscalar Higgs bosons. The distribution of the primary vertex and the beam crossing angle were taken into account. The total widths and branching ratios of the Higgs bosons and the H mass were calculated with the program HDECAY [8], taking into account decays to and loops of supersymmetric particles [9]. These results were used to calculate the signal cross-section in the resonance approximation. The events were generated with the PYTHIA program [10]. As the main background to Higgs-boson production heavy-quark pair production was considered; the event samples were generated using the program by Jikia [11] which includes exact one-loop QCD corrections to the lowest order processes $\gamma\gamma \to q\bar{q}(g)$ [12], and the non-Sudakov form factor in the double-logarithmic approximation, calculated up to 4 loops [13]. The JADE jet definition with a parameter $y^J_{\rm cut} = 0.01$ is used to define 2- and 3-parton final states. The resummation of Sudakov logarithms due to soft gluon bremsstrahlung is omitted. In the calculation the LO-α_s normalized to $\alpha_s(M_Z) = 0.119$ was used at the scale given by the average of the squared transverse masses of the quark and anti-quark. Other background processes were also studied. As about two $\gamma\gamma \to$ hadrons events (so-called overlaying events) are expected per bunch crossing, they were generated with PYTHIA, and have been overlaid on signal and background events according to the Poisson distribution. On the detector level [14] jets were reconstructed using the Durham algorithm with $y^D_{\rm cut} = 0.02$. Two or three jet events were accepted. To reduce the heavy-quark production background a cut on the polar angle for each jet was imposed: $|\cos\theta_{\rm jet}| < 0.65$. Since the Higgs bosons are produced almost at rest, the ratio of the total longitudinal momentum calculated from all jets in the event, P_z, to the total measured energy, E, was required to be small: $|P_z|/E < 0.06$. Additional cuts to suppress the influence of overlaying events and the $\gamma\gamma \to W^+W^-$ background were also applied. A realistic b-tagging algorithm was used. All cuts were optimized. A more detailed description of event generation, simulation and selection cuts can be found in [16,17]. The result of the analysis is shown in figure 2 where the distribution of the corrected invariant mass, $W_{\rm corr}$ (correction for escaping neutrinos; see [18]), after imposing all selection cuts is presented for the signal and individual background contributions. From the number of signal and background events in the optimized $W_{\rm corr}$-window the expected statistical precision of the cross-section measurement for $M_A = 300$ GeV is equal to 11%.

The results of both analyses differ significantly. In the first analysis the background contribution is negligible: the signal-to-background ratio $S/B \approx 36$ in the invariant mass window 297–303 GeV. For comparison in the second analysis $S/B \approx 2$ was obtained in the corrected invariant mass window 295–305 GeV if only the process $\gamma\gamma \to b\bar{b}$ is taken into account as the background. In order to understand the sources of those differences the cross-sections for the background process $\gamma\gamma \to b\bar{b}$ and signal process $\gamma\gamma \to A/H \to b\bar{b}$ were recalculated within both approaches with the same cuts and the same $\gamma\gamma$-luminosity spectrum.

The following conclusions emerged after investigation of the two calculations of the heavy quark background. With the polar angle cut imposed only on the quark b the 3-jet part is larger than the 2-jet part by more than an order of magnitude. However, if the cut on the anti-quark angle is added, the 2- and 3-jet cross-sections differ only by a factor 2 to 3. Thus, requiring only 2-jet events is less essential if the angular cut is applied for both quarks. This corresponds to the common cut on the jet polar angle which is usually applied on the detector level. The 2-jet cross-sections obtained in the two approaches agree within a factor of 2. Moreover, the full resummation of Sudakov and non-Sudakov logarithms does not modify the 2-jet numbers too much compared to the 4-loop expansion of the non-Sudakov logarithms. If the JADE algorithm is applied in both analyses then the obtained cross-sections agree within 15%. These residual differences can be mainly attributed to the different scale choices of the strong coupling α_s.

Next, the analogous comparison for the signal process was performed for $M_A =$ 300 GeV. The same MSSM parameter set was used, i.e. $\tan\beta = 7$, $\mu = 200$ GeV, $M_2 = 200$ GeV, trilinear couplings equal to 1500 GeV, and common sfermion mass equal to 1 TeV were assumed. A top quark mass of 174 GeV has been adopted. Decays to supersymmetric particles and loops with them were taken into account. Small contributions from the decays $A/H \to gg^* \to gb\bar{b}$ were not added to the branching ratio BR$(A/H \to b\bar{b})$. With JADE jet definitions the results of both approaches agree within 5% for the total cross-section, and within 30% for the 2- and 3-jet classes separately. The differences in the separation of 2- and 3-jet classes mainly originate from the different approaches used in the two analyses. The second analysis used the resonance approximation and generated gluon radiation by parton showers, while the first analysis used a full NLO calculation for the signal process including soft gluon resummation for the 2-jet part.

Finally, we have compared the results for the invariant-mass window 297–303 GeV taking into account the assumed $\gamma\gamma$-luminosity spectra with the same normalization. Our first conclusion is that if the JADE jet definition were used in both analyses, the difference in the signal-to-background ratio between our analyses would be mainly due to the different contributions of $J_z = 0$ and $|J_z| = 2$ parts to the $\gamma\gamma$-luminosity. The $J_z = 0$ luminosity component of the realistic luminosity distribution used in the second analysis amounts only to 94% of the same

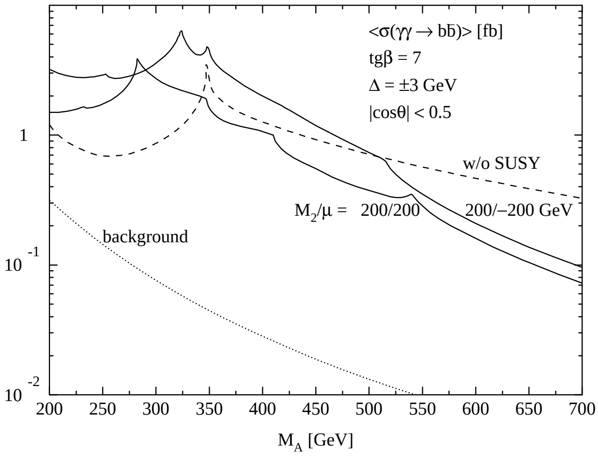

Figure 1. Average cross-sections in the invariant mass window ± 3 GeV for resonant heavy Higgs boson H, A production in $\gamma\gamma$ collisions as a function of the pseudoscalar Higgs mass M_A with final decays into $b\bar{b}$ pairs, and the corresponding background cross-section. The maximum of the photon luminosity has been tuned to M_A. The MSSM parameters have been chosen as $tg\beta = 7, M_2 = \pm\mu = 200$ GeV; the limit of vanishing SUSY-particle contributions is shown for comparison (from ref. [1]).

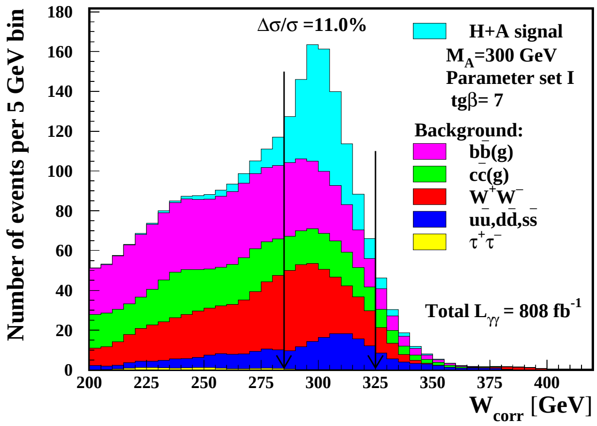

Figure 2. Distributions of the corrected invariant mass, W_{corr}, for signal and all considered background contributions, with overlaying events included. The best precision of 11% for $\gamma\gamma \to A/H \to b\bar{b}$ cross-section measurement is achieved in the W_{corr} window between 285 and 325 GeV (from ref. [2]).

component of the ideal spectrum used in the first analysis. What is more important is, in the realistic spectrum about 5.5 times more of the $|J_z| = 2$ component is taken into account relative to the same component in the ideal spectrum. If the JADE algorithm with $y^J_{\mathrm{cut}} = 0.01$ is used, the signal-to-background ratio is around 12 in case of the first approach with angular cuts $|\cos\theta_{b/\bar{b}}| < 0.5$ applied for each quark and if 2- and 3-jet events are taken into account. In the second approach the ratio is around 6. However, if a correction accounting for the differences in the luminosity spectra is applied, the rescaled result of the second analysis is around 10, thus only 17% less than in the first analysis.

Our second observation is that the use of the Sterman–Weinberg jet definition leads to much higher rates of 2-jet events for the signal than for the background. This results in nearly two times higher signal-to-background ratios in comparison to the results obtained with the JADE jet definition if only 2-jet events are taken into account.

The measurement of the process $\gamma\gamma \to A/H \to b\bar{b}$ at the PLC is very promising, even for the realistic $\gamma\gamma$-luminosity spectrum, which is less advantageous than the ideal one. Use of the clustering algorithm based on the Sterman–Weinberg jet definition would lead to much higher signal-to-background ratios, if only 2-jet events were taken into account.

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