

# Heavy neutral MSSM Higgs bosons at the Photon Collider - a comparison of two analyses

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Measurement of the cross section for the process  $\gamma\gamma \rightarrow A/H \rightarrow b\bar{b}$  at the Photon Linear Collider has been considered in two independent analyses [2, 3] for the parameter range corresponding to the so-called "LHC wedge". Significantly different expectations for signal to background ratio were obtained (36 vs. 2). After detailed comparison 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.

In this contribution [1] two analyses [2, 3] are compared which estimate the precision of the cross section measurement for the production of heavy neutral MSSM Higgs bosons in the process  $\gamma\gamma \rightarrow A/H \rightarrow b\bar{b}$ . 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  $\tan\beta = 7$  and  $M_2 = \mu = 200$  GeV.

In the first analysis [2] the NLO corrections to the background process  $\gamma\gamma \rightarrow b\bar{b}$  have been calculated according to Ref. [4]. 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 [5]. The NLO- $\alpha_s$  was normalized to  $\alpha_s(M_Z) = 0.119$  and the scale given by the  $\gamma\gamma$  invariant mass was used. Jets were defined within the Sterman-Weinberg criterion and slim two-jet configurations in the final state were selected: if the radiated gluon energy was larger than 10% of the total  $\gamma\gamma$  invariant energy and if the angles between all 3 partons in the final state were larger than  $20^\circ$ , the event was rejected. The interference between the signal and background processes has been taken into account. The NLO QCD corrections of the interference terms to quark final states including the resummation of the large (non-)Sudakov logarithms were calculated. The description of the  $\gamma\gamma$ -luminosity was based on the LO cross section formula for the Compton process. The beam energy was tuned to obtain maximum luminosity at the value of the pseudoscalar Higgs mass  $M_A$ . The background was reduced with a cut on the polar angle of the bottom quark only,  $|\cos\theta_b| < 0.5$ . Events were collected within the invariant-mass window  $M_A \pm 3$  GeV. The results for the peak cross section are shown in Fig. 1.

The second analysis [3] was based on realistic simulations of the  $\gamma\gamma$ -luminosity for the PLC [6, 7]. One-year run of PLC was assumed with beam energy 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 HDECAY [8]. These results were used

to generate events and to calculate the signal cross section in the resonance approximation with PYTHIA. As the main background to Higgs-boson production the heavy-quark pair production was considered; the event samples were generated using the program by G. Jikia [9] which includes exact one-loop QCD corrections to the lowest order processes  $\gamma\gamma \rightarrow q\bar{q}(g)$  [10], and the non-Sudakov form factor in the double-logarithmic approximation, calculated up to 4 loops [11]. The JADE jet definition with  $y_{cut}^J = 0.01$  is used to define 2- and 3-parton final states. The resummation of Sudakov logarithms due to soft gluon bremsstrahlung is omitted. The LO- $\alpha_s$  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  $\gamma\gamma \rightarrow hadrons$  events (*overlying 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 (simulated with SIMDET) jets were reconstructed using the Durham algorithm with  $y_{cut}^D = 0.02$ . Events with 2 or 3 jets were accepted. To reduce the background a cut on the polar angle for each jet was imposed,  $|\cos\theta_{jet}| < 0.65$ , and the ratio of the total longitudinal momentum to the total measured energy was required to be small,  $|P_z|/E < 0.06$ . Cuts to suppress the influence of overlying events and the  $\gamma\gamma \rightarrow W^+W^-$  background were also applied. A realistic  $b$ -tagging algorithm was used. All cuts were optimized (see [12]). The result of the analysis is shown in Fig. 2 where the distribution of the corrected invariant mass,  $W_{corr}$  (see [13]), after imposing all cuts is presented for the signal and individual background contributions.

The results of both analyses differ significantly. In the first analysis the background contribution is negligible: the signal to background ratio is  $S/B \approx 36$  in the invariant mass window 297-303 GeV. In the second analysis  $S/B \approx 2$  was obtained in the window 295-305 GeV if only the process  $\gamma\gamma \rightarrow b\bar{b}$  is taken into account as the background. In order to understand the sources of those differences the cross sections for the background process  $\gamma\gamma \rightarrow b\bar{b}$  and signal process  $\gamma\gamma \rightarrow A/H \rightarrow b\bar{b}$  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-jet and 3-jet cross sections differ only by a factor 2-3. 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%.

The 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. Decays to supersymmetric particles and loops with them were taken into account. With JADE jet definitions the results of both approaches agree within 5% for the total cross section, and within 30% for the 2-jet and 3-jet classes separately. The differences in the separation of 2-jet and 3-jet classes originate mainly from the different approaches used in the two analyses. The second analysis used the resonance approximation and generated gluon radiation by parton show-

ers, 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 component of the ideal spectrum used in the first analysis. What is more important, 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  $y_{cut}^J = 0.01$  is used, the signal to background ratio is around 12 in case of the first approach with angular cuts  $|\cos \theta_{b/\bar{b}}| < 0.5$  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 Serman-Weinberg jet definition leads to much higher rates of 2-jet events for the signal than for the background. This results in nearly 2 times higher signal to background ratios in comparison to results obtained with the JADE jet definition if only 2-jet events are taken into account.

The measurement of the process  $\gamma\gamma \rightarrow A/H \rightarrow b\bar{b}$  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 Serman-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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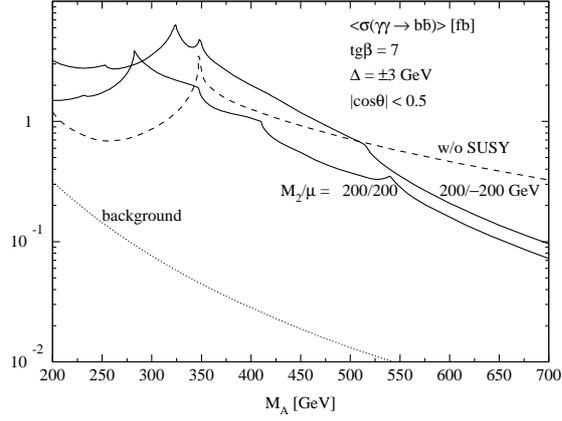


Figure 1: Average cross sections in the invariant mass window  $\pm 3$  GeV for resonant heavy Higgs boson  $H, A$  production in  $\gamma\gamma$  collisions as a function of the pseudoscalar Higgs mass  $M_A$  with final decays into  $b\bar{b}$  pairs, and the corresponding background cross section. From Ref. [2].

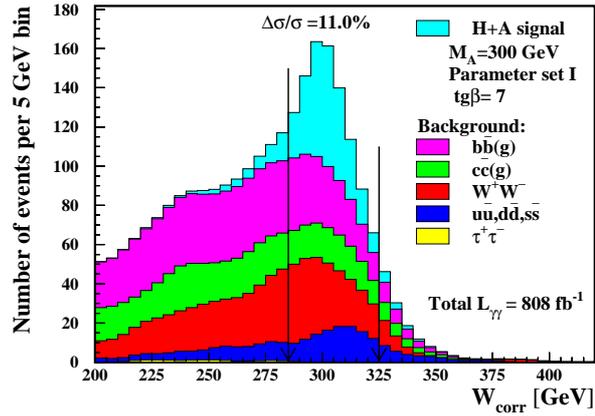


Figure 2: Distributions of the corrected invariant mass,  $W_{corr}$ , for signal and all considered background contributions, with overlaying events included. The best precision of 11% for  $\gamma\gamma \rightarrow A/H \rightarrow b\bar{b}$  cross section measurement is achieved in the  $W_{corr}$  window between 285 and 325 GeV. From Ref. [3].