Extended Analysis of the MSSM Higgs Boson Production at the Photon Collider

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New analysis of the heavy, neutral MSSM Higgs bosons H and A production at the Photon Collider is presented for $M_A = 200$, 250, 300 and 350 GeV in the parameter range corresponding to the so called "LHC wedge" and beyond. The expected precision of the cross section measurement for the process $\gamma\gamma \to A, H \to b\bar{b}$ and the "discovery reach" of the Photon Collider are compared for different MSSM scenarios. The analysis takes into account all relevant theoretical and experimental issues which could affect the measurement. For MSSM Higgs bosons A and H, for $M_A =$ 200–350 GeV and $\tan\beta = 7$, the statistical precision of the cross-section determination is estimated to be 8–34%, after one year of Photon Collider running, for four considered MSSM parameters sets. As heavy neutral Higgs bosons in this scenario may not be discovered at LHC or at the first stage of the e^+e^- collider, an opportunity of being a discovery machine is also studied for the Photon Collider.

1. INTRODUCTION

A photon-collider option of the future e^+e^- linear collider offers unique possibility to produce neutral Higgs bosons as s-channel resonances. In case of the Minimal Supersymmetric extension of the Standard Model (MSSM) production of three neutral Higgs bosons, h, A and H, can be considered. For the light Higgs boson h the statistical precision of the cross section measurement of about 2% is expected, similar to the Standard Model case [1]. In this contribution we estimate the precision of the corresponding measurement in case of the heavy MSSM Higgs bosons. If MSSM parameter values are in the so-called "LHC wedge", *i.e.* region of intermediate values of $\tan\beta$, $\tan\beta \approx$ 4–10, and masses $M_{A,H}$ above 200 GeV, the heavy pseudoscalar and scalar bosons, A and H, may not be discovered at the LHC [2–4] and at the first stage of the e^+e^- linear collider [5]. Therefore we also study the measurement of the cross section $\gamma\gamma \to A, H \to b\bar{b}$ at the Photon Collider to evaluate the discovery potential of this experiment. Possibility of discovering heavy MSSM Higgs bosons at the Photon Collider has already been studied in the past (see *e.g.* [6]). However, many relevant experimental aspects of the measurement are taken into account in this study for the first time. Parameter range considered in this analysis corresponds to a SM-like scenario where the lightest MSSM Higgs boson h has properties similar to the SM Higgs boson, while heavy neutral Higgs bosons are nearly degenerated in mass and have negligible couplings to the gauge bosons W/Z.

2. MSSM SCENARIOS

We consider MSSM scenarios described by parameter sets similar to those used in [7], *i.e.* $\tan\beta = 7$, $\mu = \pm 200$ GeV and $M_2 = 200$ GeV; these two parameter sets we denote as I and III, see Tab. 2. As compared to [7], the values of trilinear couplings are changed (from $A_{\tilde{f}} = 0$ to $A_{\tilde{f}} = 1500$ GeV), so that the mass of the lightest Higgs boson, instead of being around 105 GeV (for $\tan\beta = 4$ and $M_A = 300$ GeV) is above the current lower limit for the SM Higgs boson mass, $M_h > 114.4$ GeV. The intermediate scenario II with $\mu = -150$ GeV was also proposed. For comparison with predictions presented by LHC experiments, the scenario IV used in [4] is also included. The common sfermion mass equal to 1 TeV was assumed in all scenarios. We have checked that all parameter sets imply masses of neutralinos, charginos, sleptons and squarks higher than current experimantal limits.

Symbol	μ [GeV]	M_2 [GeV]	$A_{\tilde{f}}$ [GeV]	$M_{\tilde{f}}$ [GeV]
I	200	200	1500	1000
II	-150	200	1500	1000
III	-200	200	1500	1000
IV	300	200	2450	1000

Table I: MSSM parameter sets used in the described analysis.

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. These parameters were used during generation of events with the PYTHIA program [9]. For the studied range of parameter values the heavy neutral Higgs bosons, A and H, are nearly mass degenerate. The mass difference $M_H - M_A$ decreases with increasing $\tan\beta$ and M_A and is similar for all considered parameter sets. For $M_A = 200$ GeV the mass difference decreases from $M_H - M_A \approx 12$ GeV for $\tan\beta = 3$ to 0.7 GeV for $\tan\beta = 15$, whereas for $M_A = 350$ GeV the corresponding values are 6 GeV and 0.3 GeV, respectively. The mass difference is larger or comparable to the total widths of A and H which vary between 50 MeV and 4 GeV. However, in most cases it is smaller than the invariant mass resolution, which is of the order of 10 GeV. Therefore, it is only possible to measure the total cross section for A and H production. In the considered parameter range the branching ratios relevant for this study change between 3% and 90% for $\mathrm{BR}(A/H \to b\bar{b})$, and from $2 \cdot 10^{-7}$ to $9 \cdot 10^{-5}$ for $\mathrm{BR}(A/H \to \gamma\gamma)$. As processes $\gamma\gamma \to H \to b\bar{b}$ and $\gamma\gamma \to A \to b\bar{b}$ do not interfere, the total $\gamma\gamma \to A, H \to b\bar{b}$ production rate is equal to the sum of both contributions. Described Monte Carlo simulation of the heavy MSSM Higgs boson production at the Photon Collider was performed for scenario I and parameter value $\tan\beta = 7$, and the obtained results were rescaled to other scenarios and the parameter range $\tan\beta = 3 - 20$.

3. ANALYSIS

This analysis is based on the realistic simulations of the $\gamma\gamma$-luminosity spectra for the Photon Collider at TESLA [10, 11]. It is assumed that the centre-of-mass energy of colliding electron beams, $\sqrt{s_{ee}}$, is optimized for the production of a Higgs bosons with a given mass. Presented results are obtained for a total integrated luminosity expected after one year of the Photon Collider running. The distribution of the primary vertex and the beams crossing angle are taken into account.

As the main background to the Higgs-bosons production the heavy-quark pair production was considered; the event samples were generated using the program by G. Jikia [12] based on the NLO QCD results. Other background processes, which were neglected in the earlier analyses, were also studied: $\gamma\gamma \to W^+W^-$, $\gamma\gamma \to \tau^+\tau^-$, and light-quark pair production $\gamma\gamma \to q\bar{q}$.

Due to the large cross section and huge $\gamma\gamma$-luminosity at low $W_{\gamma\gamma}$, about two $\gamma\gamma \to$ *hadrons* events (so-called overlaying events) are expected per bunch crossing. To evaluate their impact on the reconstruction of other events produced in the same bunch crossing, we generated $\gamma\gamma \to$ *hadrons* events with PYTHIA, and overlaid them on signal and background events according to the Poisson distribution.

The detector performance was simulated by the program SIMDET [13]. Jets were reconstructed using the Durham algorithm. The low-angle tracks and clusters were not taken into account to minimize the influence of $\gamma\gamma \to$ *hadrons* overlaying events. Two or three jet events were accepted. To reduce heavy-quark production background the lower cut on the polar angle for each jet and the upper cut on the total longitudinal momentum of the event were imposed. Additional cuts to suppress $\gamma\gamma \to W^+W^-$ background were also applied. For realistic b-tagging the ZVTOP-B-HADRON-TAGGER package was used [14–16]. The criteria of event selection were optimized separately for each considered Higgs-boson mass. More detailed description of event generation, simulation and selection cuts can be found in [1] and [17].

4. RESULTS

The result of the analysis for $M_A = 300$ GeV is shown in Fig. 1. Distribution of the corrected invariant mass, $W_{corr} \equiv \sqrt{W_{rec}^2 + 2P_T(E + P_T)}$ (see [18]), expected after one year of Photon Collider running, after imposing all selection cuts is presented for signal and all background contributions. From the number of signal and background events in the optimized W_{corr}-window the expected statistical precision of the cross-section measurement is 11%.

We estimated statistical precision for $\gamma\gamma \to A, H \to b\bar{b}$ cross section measurement for all considered parameter sets. Results obtained for $\tan\beta = 7$ are compared in Fig. 2. The most precise measurement is expected for parameter sets II and III — precision is about 10% and hardly depends on M_A. The worst measurement is expected for scenario IV, *i.e.* the one considered by the CMS collaboration [4].

For all considered values of M_A the dependence of the measurement precision on $\tan\beta$ was studied; the results for $M_A = 200$ and 350 GeV are shown in Fig. 3. The precision weakly depends on $\tan\beta$ if parameter sets II or III are considered. We also observed that for greater M_A values better precision of the cross section determination can be achieved. In case of parameter sets I or IV the precise measurement will not be possible for low $\tan\beta$ values, $\tan\beta \lesssim 5$.

After discovery or a 'hint' of the resonant-like excess of events at LHC or ILC the Photon Collider can be used to confirm the observation and to measure the cross section for production of the new state. Thus, for all considered values of M_A we studied the significance of signal measurement as a function of $\tan\beta$, for $\tan\beta = 3$–20. Results obtained for different parameter sets for $M_A = 200$, 350 GeV are compared in Fig. 4. The estimated lower limit of the discovery region of LHC experiments (as presented by CMS collaboration [4]) is indicated by arrows. For all parameter sets the expected statistics of signal events for $M_A = 200$–350 GeV will be sufficient to cover most of the considered MSSM parameters space. We can conclude that for $M_A \gtrsim 300$ GeV the Photon Collider should be able to discover Higgs bosons for much lower values of $\tan\beta$ than experiments at the LHC.

5. SUMMARY

In the presented analysis the production of heavy MSSM Higgs bosons A and H at the Photon Collider, in the process $\gamma\gamma \to A, H \to b\bar{b}$, was studied taking into account all relevant experimental and theoretical aspects. The considered MSSM parameter range corresponds to the so-called "LHC wedge", where identification of A and H may not be possible at LHC and e^+e^- collider.

Our analysis shows that, for $M_A \sim 300$ GeV, the cross section for the MSSM Higgs-bosons production $\sigma(\gamma\gamma \to A, H \to b\bar{b})$ can be measured with a statistical precision of about 11% already after one year of Photon Collider running at nominal luminosity. For other considered values of M_A it turns out to be lower – from 16% to 21%. Although this result is less optimistic than the earlier estimate [7], still the photon–photon collider gives opportunity of a precision measurement of $\sigma(\gamma\gamma \to A, H \to b\bar{b})$, assuming that we know the mass of the Higgs boson(s).

A discovery of MSSM Higgs-bosons requires energy scanning or a run with a broad luminosity spectrum, perhaps followed by the run with a peaked one. We estimate the significance expected for the Higgs production measurement for four different parameter sets and for $\tan\beta = 3$–20. The discovery reach of the Photon Collider is compared with the estimated reach of the CMS experiment. For the optimum energy and polarizations choice the photon–photon collisions allow for the discovery of the Higgs bosons even for $\tan\beta$ values lower than the expected reach of the LHC experiments. Thus, at least partially, the Photon Collider will cover the so-called "LHC wedge". For low $\tan\beta$ values the measurement could probably profit from use of additional channels: decays of A and H to charginos and neutralinos, and in case of H also decays to hh.

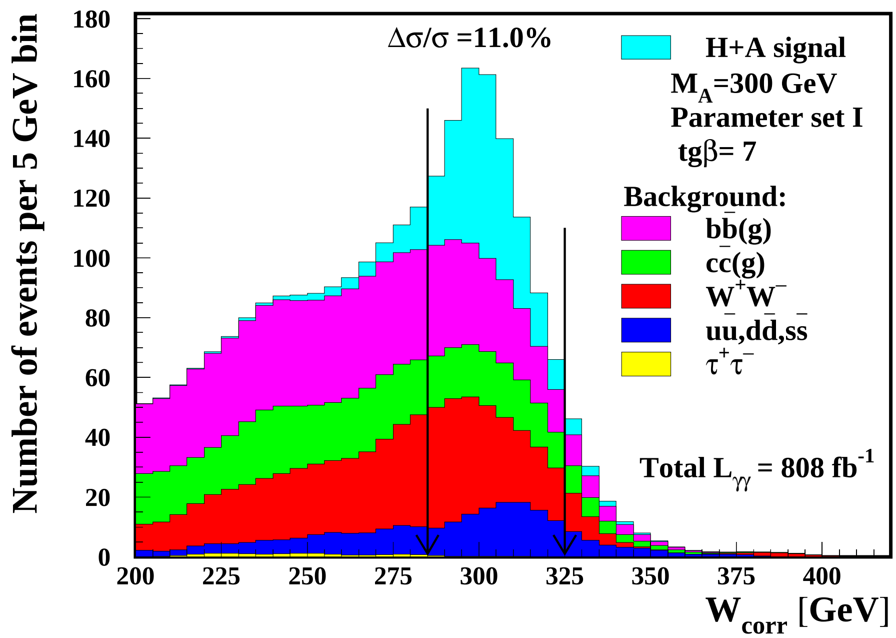

Figure 1: Distributions of the corrected invariant mass, W_{corr}, for signal and all considered background contributions, with overlaying events included. The best precision of 11% for $\gamma\gamma \to A, H \to b\bar{b}$ cross section measurement is achieved in the W_{corr} window between 285 and 325 GeV.

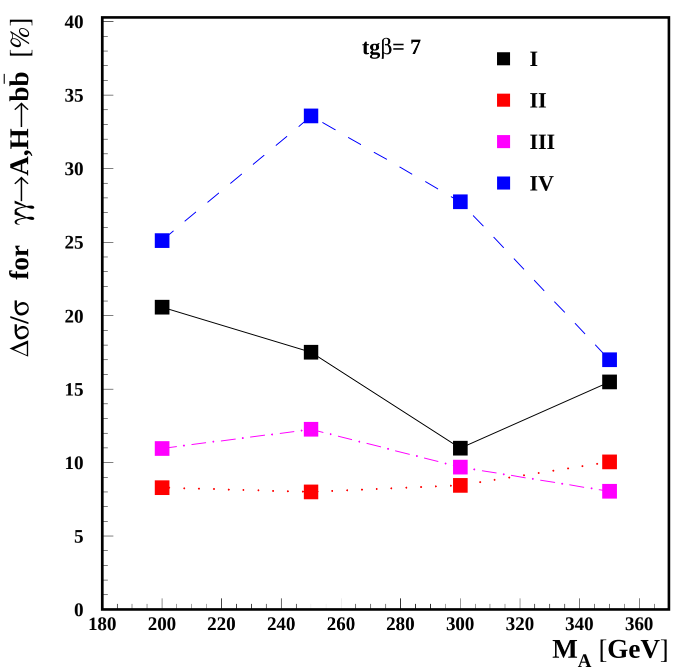

Figure 2: Precisions of $\sigma(\gamma\gamma \to A, H \to b\bar{b})$ measurement are shown for MSSM parameter sets I-IV, for M_A = 200–350 GeV and $\tan\beta = 7$. The lines are drawn to guide the eye.

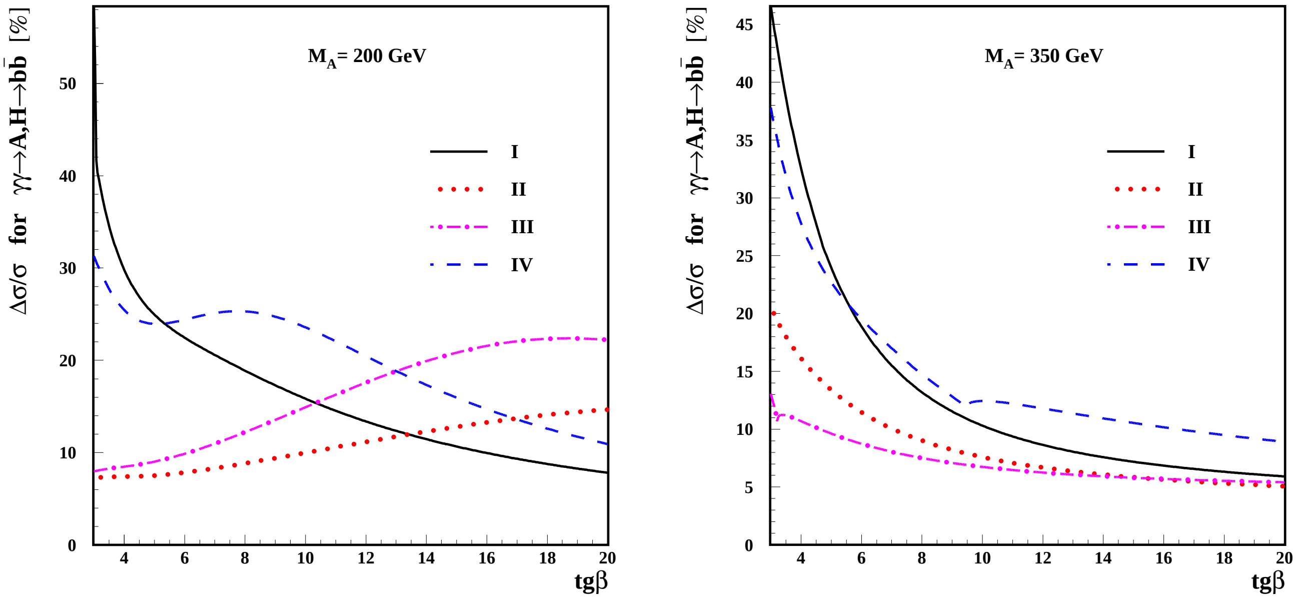

Figure 3: Precisions of $\sigma(\gamma\gamma \to A, H \to b\bar{b})$ measurement are shown for $M_A = 200$, 350 GeV, for MSSM parameter sets *I*-*IV* with $\tan\beta = 3$–20.

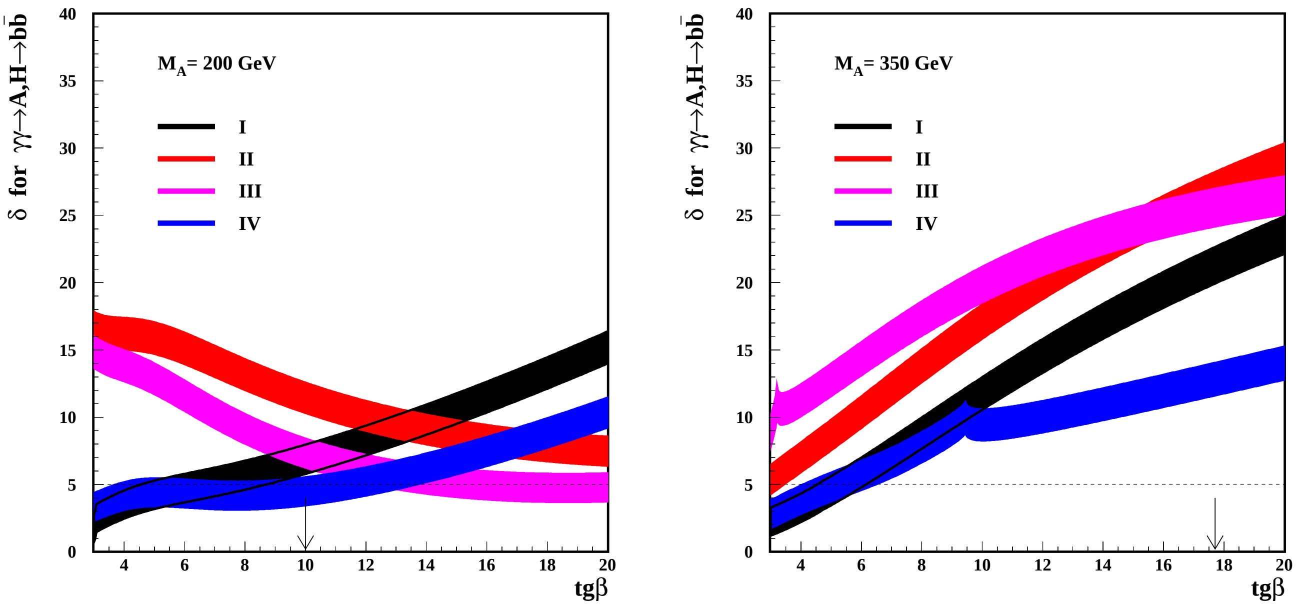

Figure 4: Statistical significances of $\sigma(\gamma\gamma \to A, H \to b\bar{b})$ measurement are shown for $M_A = 200$, 350 GeV, for MSSM parameter sets *I*-*IV* with $\tan\beta = 3$–20. The band widths indicate the level of possible statistical fluctuations of the actual measurement.

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