Di-Photon Higgs Decay in SUSY with CP Violation

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Abstract. Physical Higgs particles in the Minimal Supersymmetric Standard Model (MSSM) with explicit CP violation are CP mixed states. The decay of these Higgs particles can be analysed to study the CP properties of the MSSM. In the present work we consider the di-photon channel of the lightest neutral Higgs boson for this purpose. Compared to earlier studies on effects of scalar/pseudo-scalar mixing, our analysis also investigates the effect due to Higgs-sfermion-sfermion couplings along with that of mixing. We find that a light stop may have a strong impact on the width and Branching Ratio (BR) of the decay process $H_1 \to \gamma\gamma$, whereas other light sparticles have only little influence. In some regions of the MSSM parameter space with large CP-violating phase $\phi_\mu \sim 90^\circ$ a light (~ 200 GeV) stop can change the di-photon BR by more than 50% compared to the case with heavy (~ 1 TeV) stop and otherwise same MSSM parameters.

PACS. 14.80.Cp Non-standard-model Higgs bosons – 12.60.Jv Supersymmetric models

1 Introduction

One of the main objectives of the upcoming Large Hadron Collider (LHC) is to investigate ElectroWeak Symmetry Breaking (EWSB). While the Standard (SM) Higgs mechanism predicts one physical scalar particle, many models beyond it have more than one scalar states as well as pseudo-scalar (and charged) ones. In the presence of CP-violation scalar/pseudo-scalar mixing occurs to give the physical Higgs states. Studying CP properties of the Higgs particles thus becomes an important feature in distinguishing different models. Among the new-physics scenarios Supersymmetry (SUSY) is one of the favourites of particle physicists. LHC will investigate various aspects of SUSY with special attention to the Minimal Supersymmetric Standard Model (MSSM). While the phenomenology of the CP-conserved MSSM has been thoroughly studied, many issues of the MSSM with CP violation are yet to be investigated. Many parameters of the MSSM can well be complex and thus explicitly break CP invariance inducing CP violation also in the Higgs sector beyond Born approximation [1]. After elimination of unphysical phases and imposing universality conditions at the unification scale two independent phases remain, the phase ϕ_μ of the higgsino mass term μ and a common phase ϕ_{A_f} of the soft trilinear Yukawa couplings A_f in the sfermion sector [2]. Experimental searches of Electric Dipole Moments (EDMs) of electron and neutron put constraints on the CP phases of any model. In the MSSM with CP violation these constraints can be avoided by taking the sfermions belonging to the first two generations to be very heavy (see [3] for a review).

We consider the di-photon decay mode, $H_1 \to \gamma\gamma$, of the lightest neutral Higgs boson H_1, which involves direct, i.e. leading, effects of the SUSY phases through couplings of the H_1 to SUSY particles in the loops as well as indirect, i.e. sub-leading, effects through the scalar/pseudo-scalar mixing yielding the Higgs mass-eigenstate H_1. In scenarios with heavy SUSY particles, where CP violation enters solely through the scalar/pseudo-scalar mixing, the SUSY CP phases can result in a strong suppression of the BR of the decay $H_1 \to \gamma\gamma$ as well as of the rate of the combined production and decay process $gg \to H_1 \to \gamma\gamma$ [4]. Here, we summarize the results of [5,6] focusing especially on the effects of light SUSY particles in the decay $H_1 \to \gamma\gamma$. The analysis of the full production and decay process at the LHC is postponed to a forthcoming publication [7].

2 The $H_1 \to \gamma\gamma$ decay

As mentioned in the Introduction we consider explicit CP violation (and assume that the Higgs vacuum expectation values are real). Thus, in this particular scenario under study with common phases for the trilinear couplings and separately for the gaugino masses, we are left with two independent phases after symmetry considerations. As intimated, we take these to be ϕ_μ and ϕ_{A_f}. The leading terms in the CP-violating

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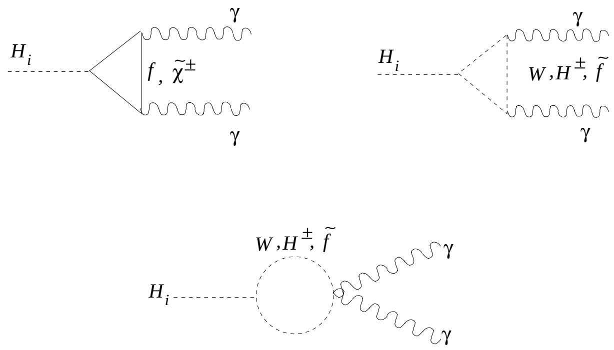

Fig. 1. Diagrams for Higgs decay into $\gamma\gamma$ pairs in the CP-violating MSSM: $f \equiv t,\ b,\ \tau;\ \ \tilde{f} \equiv \tilde{t}_{1,2}, \tilde{b}_{1,2}, \tilde{\tau}_{1,2}$.

scalar/pseudo-scalar mixing in the Higgs sector are proportional to $\mathrm{Im}(\mu A_f)$, hence we assume $\phi_{A_f} = 0$ and analyse the effects of a non-zero ϕ_μ in the following. With the help of the publicly available FORTRAN code CPSUPERH [8], version 2, which calculates the mass spectrum and decay widths of all Higgs bosons along with their couplings to SM and SUSY particles, we analyse the Higgs decay into the di-photon channel in the CP-violating MSSM and compare it with that of the CP-conserving MSSM.

A Higgs boson in the MSSM decays at one-loop level into two photons through loops of fermions, sfermions, $W^\pm$ bosons, charged Higgs bosons and charginos, see Fig. 1. A random parameter space scan over about 100,000 parameter space points to study the general behaviour of the $\mathrm{BR}(H_1 \to \gamma\gamma)$ for non-zero ϕ_μ has revealed that about 50% deviations are possible for M_{H_1} around 104 GeV for $\phi_\mu = 100°$. In the considered mass range of 90–130 GeV an average of 30% deviation is found to occur. Furthermore, this study of the average behaviour with and without a light stop clearly establishes the strong impact of a $\tilde{t}_1$ with a mass around 200 GeV on the deviations of the BR [5]. Fig. 2 illustrates this fact for a particular parameter set except for the stop mass and ϕ_μ, where $BR(H_1 \to \gamma\gamma)$ is plotted against M_{H_1} for different values of ϕ_μ in the two cases of light and heavy stop.

A detailed analysis at the matrix element level was undertaken in [6], which consolidated the above observations. Since the mass of the Higgs particle itself changes by changing ϕ_μ (and keeping all other parameters the same), the difference in the BR read out from Fig. 2 will have to be corrected for this change in M_{H_1}. (For the parameter set considered, the change in M_{H_1} going from CP-conserving MSSM to CP-violating MSSM, by changing the value of ϕ_μ, is within the typical experimental uncertainty expected at LHC.) In Fig. 3 we plot the $\mathrm{BR}(H_1 \to \gamma\gamma)$ for five representative ϕ_μ values between 0° and 180° as a function of M_{H^+} for the two cases $M_{\tilde{U}_3} = 1$ TeV (all SUSY particles heavy) and $M_{\tilde{U}_3} = 250$ GeV (light $\tilde{t}_1$). The respective values of M_{H_1} are indicated separately on the horizontal lines for each ϕ_μ value. The cross over point in the Higgs mass eigenstates at $M_{H^+} \sim 150$ GeV is clearly visible. This corresponds to the sharp rise of

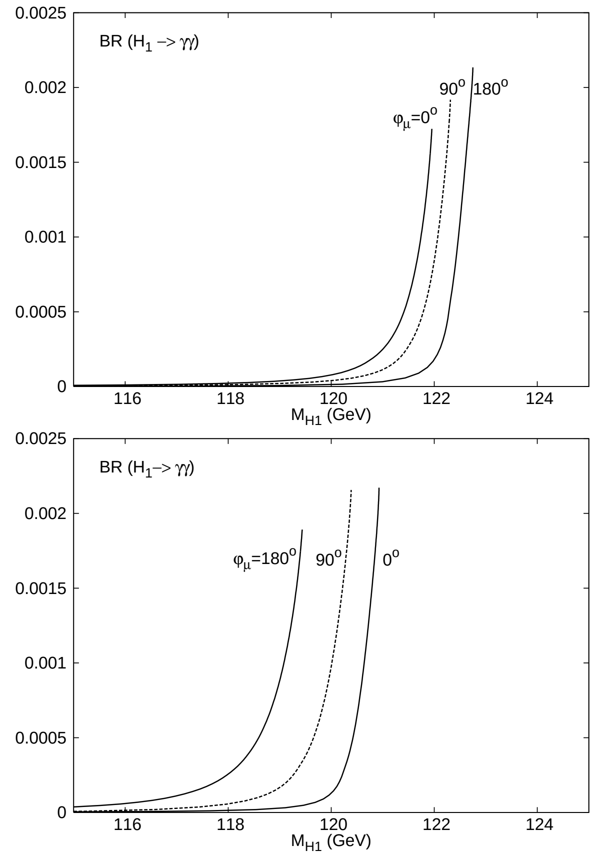

Fig. 2. $\mathrm{BR}(H_1 \to \gamma\gamma)$ plotted against M_{H_1}. Parameters used are: $\tan\beta = 20$, $M_1 = 100$ GeV, $M_2 = M_3 = 1$ TeV, $M_{(\tilde{Q}_3, \tilde{D}_3, \tilde{L}_3, \tilde{E}_3)} = 1$ TeV, $|\mu| = 1$ TeV, $|A_f| = 1.5$ TeV. The upper plot is for $M_{\tilde{U}_3} = 1$ TeV while the lower one is for $M_{\tilde{U}_3} = 250$ GeV (the latter giving a rather light stop, $m_{\tilde{t}_1} = 200$ GeV).

the BR at around $M_{H_1} \sim 120$ GeV in Fig. 2. Below this point the BRs are very small and there is a strong ϕ_μ dependence of M_{H_1}, hence our analysis is not relevant in this parameter region. Above $M_{H^+} \sim 150$ GeV and $M_{H_1} \gtrsim 115$ GeV, the ϕ_μ dependence of M_{H_1} is within the expected experimental uncertainty and the BR is large enough to be important for the LHC Higgs search. In scenarios with heavy SUSY particles (upper plot) the BR increases with increasing ϕ_μ leading to a 50% increase for $\phi_\mu = 90°$ at $M_{H^+} \sim 200$ GeV. This ϕ_μ dependence is caused mainly by the ϕ_μ dependence of the H_1 couplings to $W^\pm$ bosons and t and b quarks, which appear in the loop-induced decay $H_1 \to \gamma\gamma$. When a light $\tilde{t}_1$ is present (lower plot) the additional ϕ_μ dependence in the stop sector causes a considerable change of the ϕ_μ dependence of the BR. In fact, the BR increases again with increasing ϕ_μ up to a maximum for some value of ϕ_μ around 40°, beyond which, however, the BR decreases to about 50% at $\phi_\mu = 180°$.

Our analysis with other relevant sparticles like sbottom and stau being light shows that they do not play any major role in the $H_1 \to \gamma\gamma$ decay, even for $\tan\beta$ values as large as 50. We have also taken care that the changes in the masses of sparticles are not too large (i.e., again within expected experimental er-

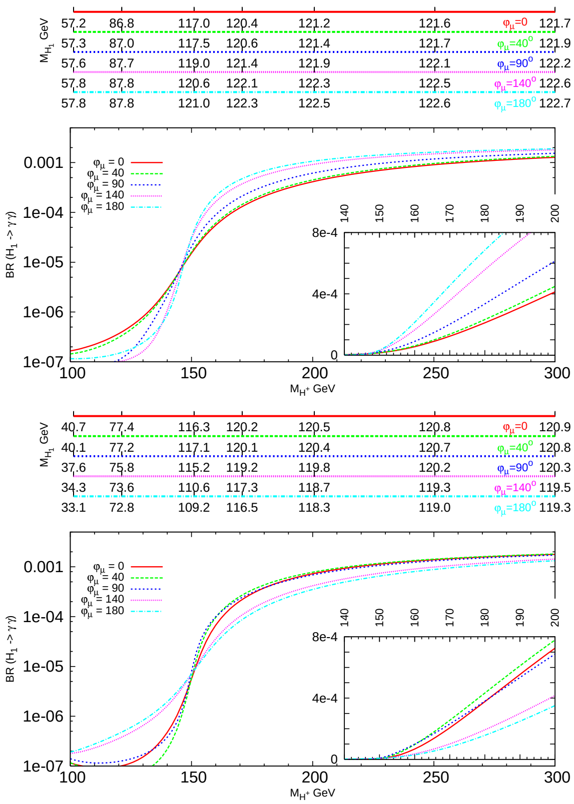

Fig. 3. BR of $H_1 \to \gamma\gamma$ for $|A_f| = 1.5$ TeV, $|\mu| = 1$ TeV and $\tan\beta = 20$. Values of M_{H_1} corresponding to representative points on the M_{H+} axis are indicated on the horizontal lines above separately for the values of ϕ_μ used. The upper plot corresponds to the case with $M_{\tilde{U}_3} = 1$ TeV (no light SUSY particles), while the lower plot corresponds to the case with $M_{\tilde{U}_3} = 250$ GeV (a light stop is present).

rors) when going from $\phi_\mu = 0$ to non-zero values of ϕ_μ while keeping the other parameters constant. Concerning the dependence on other SUSY parameters, we have found that a smaller value of $|A_f|$ considerably changes the ϕ_μ dependence of the BR in scenarios with light a $\tilde{t}_1$ (see lower plot in Fig. 4) whereas a smaller $|\mu|$ value leads generally to a smaller ϕ_μ dependence (Fig. 5).

3 Summary

We have analysed the BR of the di-photon decay of the lightest Higgs boson in the CP-violating MSSM with a complex μ parameter. The presence of a light scalar top is found to influence the ϕ_μ dependence of the BR considerably while other sparticles have only negligible effect. In general, the BR may be increased or decreased for a non-zero ϕ_μ depending on the SUSY parameter point. In scenarios where the relevant SUSY spectrum is already established by the LHC and consistent with both the CP-conserving and CP-violating scenario, our analyses of $H_1 \to \gamma\gamma$ will be able to distinguish between these two cases.

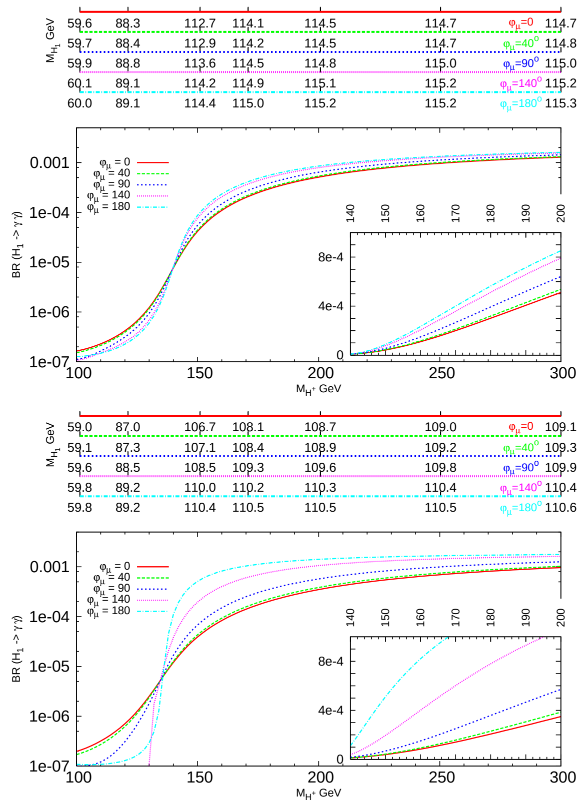

Fig. 4. The same as Fig. 3 but with $|A_f| = 0.5$ TeV, $|\mu| = 1$ TeV and $\tan\beta = 20$.

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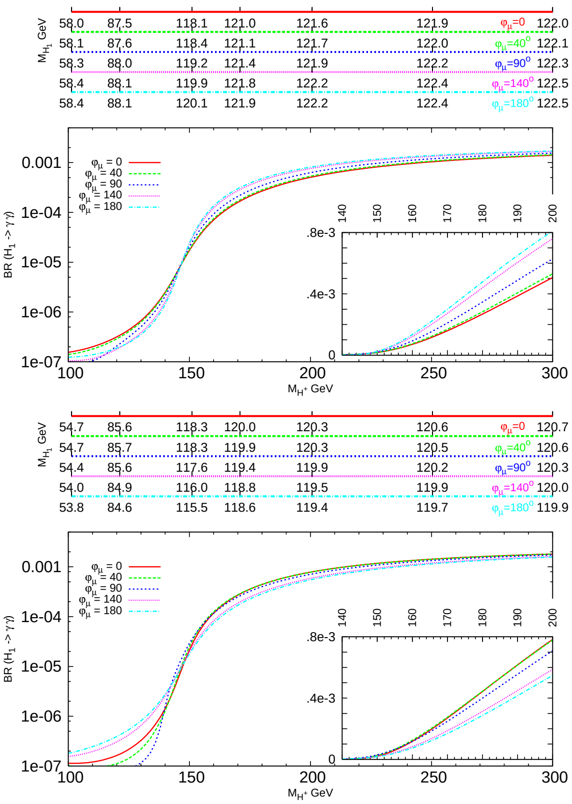

Fig. 5. The same as Fig. 3 but with $|A_f| = 1.5$ TeV, $|\mu| = 0.5$ TeV and $\tan\beta = 20$.