Di-Photon Decay of Higgs in CP-Violating MSSM

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Plan

- Motivation & Introduction
- $H_1 \to \gamma\gamma$
- Summary & Outlook

Motivation & Introduction

- Exploring Electroweak Symmetry Breaking is one of the main objectives of LHC
- Standard Model (SM) Higgs mechanism introduces a doublet scalar field, and predicts one physical Higgs scalar particle (mass is a free parameter)

  Hierarchy problem: Quadratically divergent contribution to Higgs mass corrections.
- Supersymmetry solves hierarchy problem by canceling divergent contributions from particles with that of their super partners.

  Other attractions include: Gauge couplings unification, motivation from string theory, etc.

Motivation & Introduction

- MSSM: has 2 Higgs doublets
  2 neutral scalar particles ($h,\ H$)
  1 neutral pseudo-scalar (A)
  charge Higgs $H^{\pm}$.
- CP Violation:
  Relative phase between the vev's v_1 and v_2 ($\tan\beta \equiv \frac{v_1}{v_2}$)
  — spontaneous CP violation, not possible within MSSM

  Explicitly complex couplings:
  M_1, M_2, M_3 (Gaugino masses);
  μ, $A_{f_i f_j}$ $(i, j = 1, 2, 3)$.
- Some of these phases could be rotated away using the symmetries of the theory.
- Even after that there are far too many couplings, if we consider all of them as independent of each other.

Motivation & Introduction

- Phenomenological studies are restricted to specific scenarios. (e.g., $A_{f_i f_j} \propto \delta_{ij}$)
- EDM restricts the phases to negligibly small values. Avoided by taking the sparticles of first two generations too heavy, and setting $A_{f_1} = A_{f_2} = 0$
- To sum up we have
  $M_1, \ \ M_2$: real (using two $U(1)$ symmetries of the theory.)
  $M_3, \ \ \mu, \ \ A_{f_3}$: complex
- Gluino will not affect our discussion, so phase of M_3 is irrelevant to us.
- What enters in the CP-violating observable quantities is the product of $\mu \ A_f$. Therefore effectively we are left with a single phase parameter.

CP mixed states

- Consequences of CP-violating phases:
  Physical Higgs particles are not CP eigenstates

$$\begin{pmatrix} H_1 \\ H_2 \\ H_3 \end{pmatrix} = O \begin{pmatrix} \phi_1 \\ \phi_2 \\ a \end{pmatrix}$$

- The mass matrix

$$\begin{pmatrix} \mathcal{M}_S^2 & \mathcal{M}_{SP}^2 \\ \mathcal{M}_{PS}^2 & \mathcal{M}_P^2 \end{pmatrix} . \qquad (1)$$

  $\mathcal{M}_S^2$: 2×2 matrix – transition betw. the CP-even states
  $\mathcal{M}_P^2$: gives the mass of the CP-odd state
  $\mathcal{M}_{PS}^2 = (\mathcal{M}_{SP}^2)^T$ (a 1×2 matrix) describes the mixing between the CP-even and CP-odd states.

CP mixed states

- The mixing matrix elements are typically proportional to product of μ and A_f

$$\mathcal{M}^2_{SP} \propto \mathcal{I}m(\mu A_f) \tag{2}$$

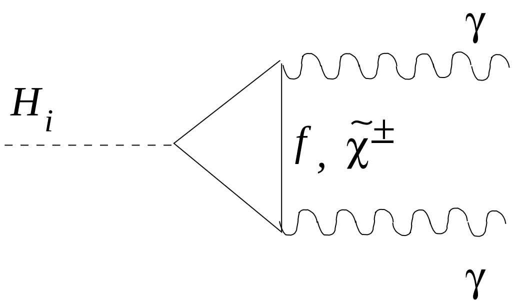
- H_1 decay is sensitive to the CP-violating phase
- In addition, H_i-(s)particle couplings are affected.

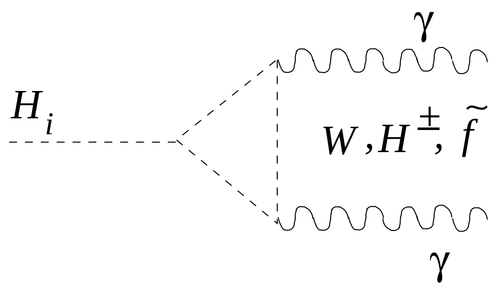
CP mixed states

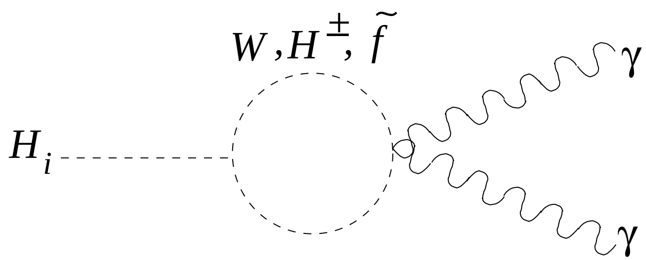
- Programmes available:
  CPsuperH
  `http://www.hep.man.ac.uk/u/jslee/CPsuperH/htm`
  (RG improved effective potential approach.) FeynHiggs
  `http://www.feynhiggs.de`
  (Feynman (Feynman digramatic approach)
  Computes (s)particle masses, couplings, decay widths, branching ratios, etc. for a set of input parameters.
- We have used CPsuperH (no specific reason to prefer this over FeynHiggs)
- CP studies of $H_i \to f\bar{f}$ and H_i productions in the context of LHC available.
- CP-violating observables are constructed making use of the spin information of the decay fermions.

$H_1 \to \gamma\gamma$

- We consider $H_1 \to \gamma\gamma$, which is the important channel for the mass range $100 \lesssim m_{H_1} \lesssim 130$ GeV.





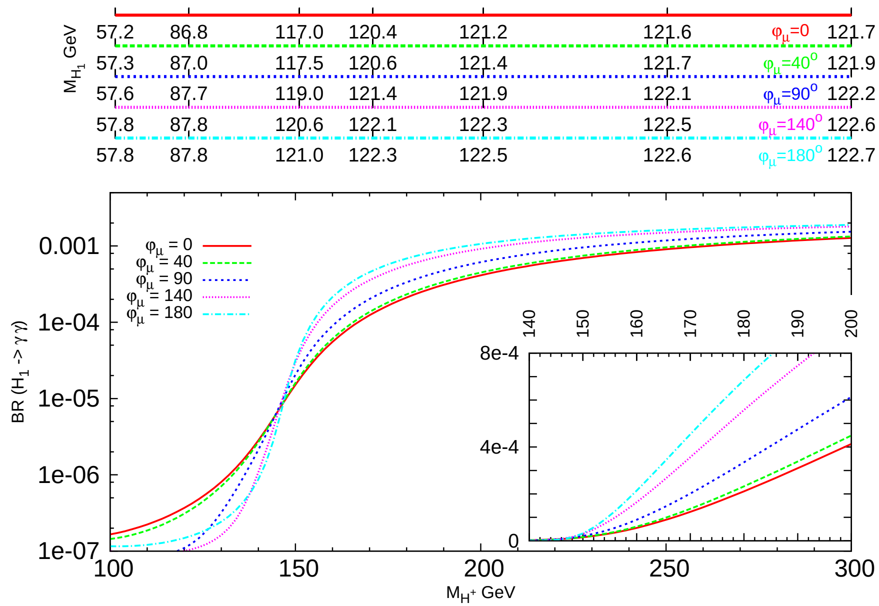


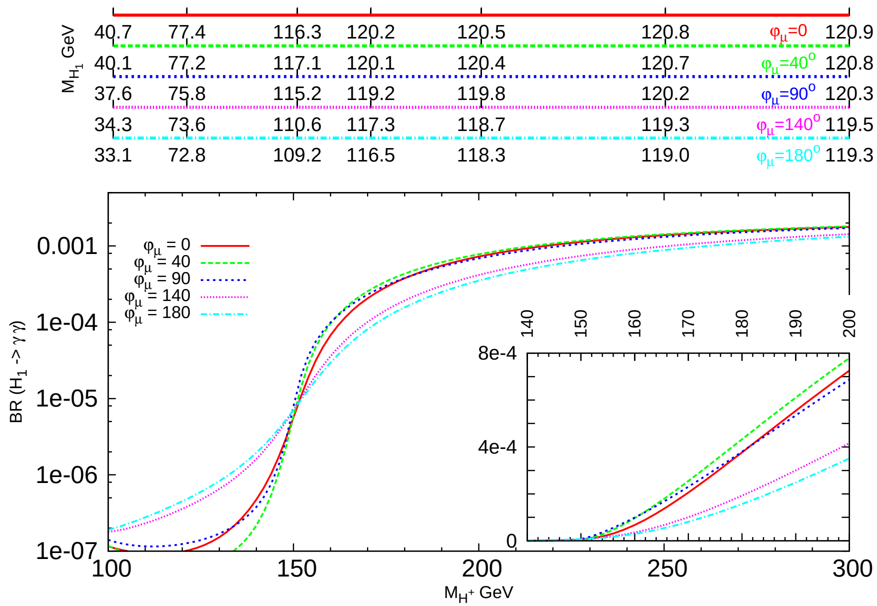
$H_1 \to \gamma\gamma$

- Choi, Hagiwara, Lee (2001) studied $H_1 \to \gamma\gamma$, restricted to the parameter space with no light (sparticles). CP violation enters entirely through scalar – pseudo-scalar mixing.
- They found BR suppressions of $10^2 - 10^3$
- $gg \to H_i$ studies: Choi, Lee (1999); Moretti, Dedes (1999)

$H_1 \to \gamma\gamma$

- Our investigation:
  Light $\tilde{t}_1$ does have an effect. We compare this with the no-light sparticle case.

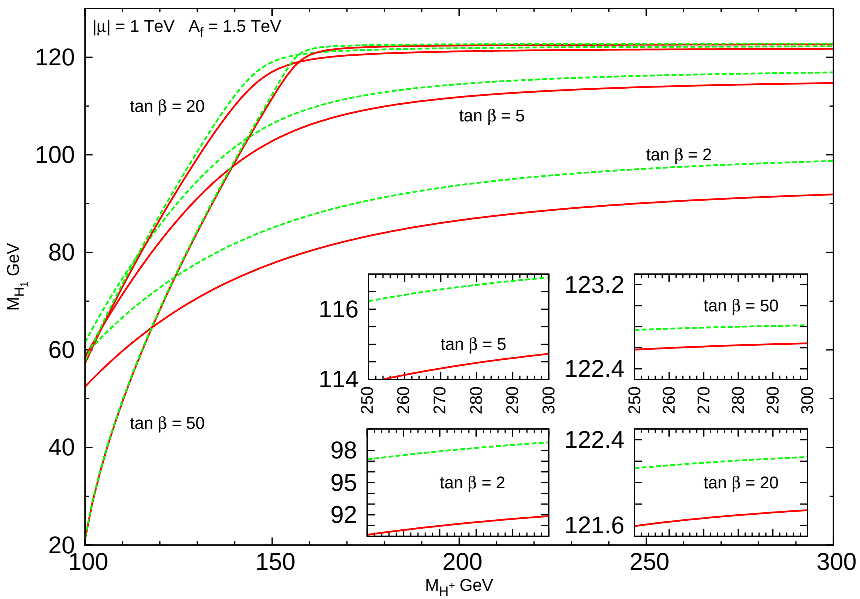


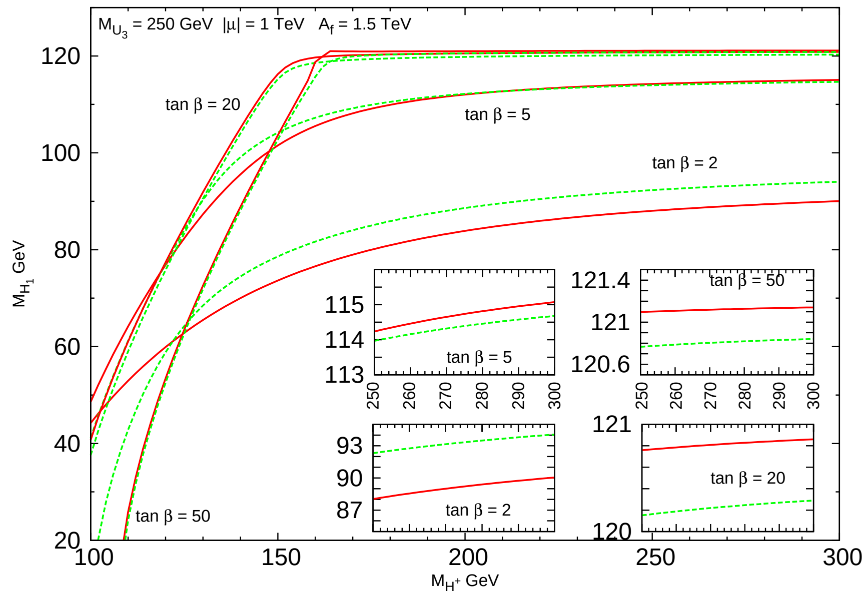


no light sparticle light $\tilde{t}_1$

$H_1 \to \gamma\gamma$

- M_{H_i} itself depends on M_{H^-}. But for the parameter we considered between CP-conserving and CP-violating cases the deviations are within the expected experimental uncerainty.





Summary & Outlook

- $H_1 \rightarrow \gamma\gamma$ is used to study the CP-violating MSSM.
- The sensitivity comes through scalar - pseudo-scalar mixing, as well as changed couplings of the Higgs with sparticles.
- It is important to include the production, especially the gluon fusion. This will tell us whether there is an enhancement or cancellation of the effects between the production and decay.
- Mixing in the propagator itself, when considered at one-loop or above, will give additional effects.
- Extending to Next-to-MSSM.