Higgs production and decay in SUSY with CP violation

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based on

S. Moretti, S. Munir, P. Poulose, PLB 649 (2007) 206 [hep-ph/0702242]

SH, S. Moretti, S. Munir, P. Poulose, arXiv:0706.4269

SUSY07, Karlsruhe, July 27, 2007

Outline

- Introduction
  - MSSM with complex parameters
  - Higgs sector in complex MSSM
- Di-photon decay $H_1 \to \gamma\gamma$ in complex MSSM
  - Focus on BR($H_1 \to \gamma\gamma$)
  - Impact of light SUSY particles
  - Dependence on SUSY parameters
- Outlook
  - Full production and decay $gg \to H_i \to \gamma\gamma$ at LHC
  - CP-violating NMSSM

Introduction MSSM with complex parameters

- General MSSM:

  Many parameters can be complex

- Explicit CP violation
  - May help to explain baryon asymmetry of universe
  - Constraints from electric dipole moments (EDMs) of e, n, Hg, Tl

    [Ibrahim, Nath, '99; Barger, Falk, Han, Jiang, Li, Plehn, '01; Abel, Khalil, Lebedev, '01]
    [Oshima, Nihei, Fujita, '05; Pospelov, Ritz, '05; Olive, Pospelov, Ritz, Santoso, '05]
    [Abel, Lebedev, '05; Yaser Ayazi, Farzan, '06, '07]

- Global U(1) symmetries: some phases eliminated

  $\longrightarrow$ e.g. phase of one gaugino mass parameter M_i

- Physical phases in Higgs sector

  μ : Higgs-higgsino mass parameter

  A_f : trilinear couplings of sfermions

Introduction — Higgs sector in complex MSSM

- MSSM: 2 Higgs doublets

  $\longrightarrow$ 5 physical Higgs particles at tree-level ($h, H, A, H^{\pm}$)

- $\tilde{t}$ and $\tilde{b}$ loops $\Rightarrow$ explicit CP violation in Higgs sector [Pilaftsis, '98]

  [Pilaftsis, Wagner, '99; Demir, '99, Carena, Ellis, Pilaftsis, Wagner, '00, '01; Choi, Drees, Lee, '00]

- CP-even (h, H) and CP-odd (A) neutral Higgs mix

  $\longrightarrow$ 3 neutral mass eigenstates (H_1, H_2, H_3), mixing matrix O

- Impact on Higgs search [LEP Higgs Working Group, hep-ex/0602042]

  $\longrightarrow$ MSSM Higgs search at LEP: no universal limit on m_{H_1}

- Spectrum calculation (masses m_{H_i} and mixing matrix O)

  - CPSUPERH [Carena, Ellis, Pilaftsis, Wagner '00]

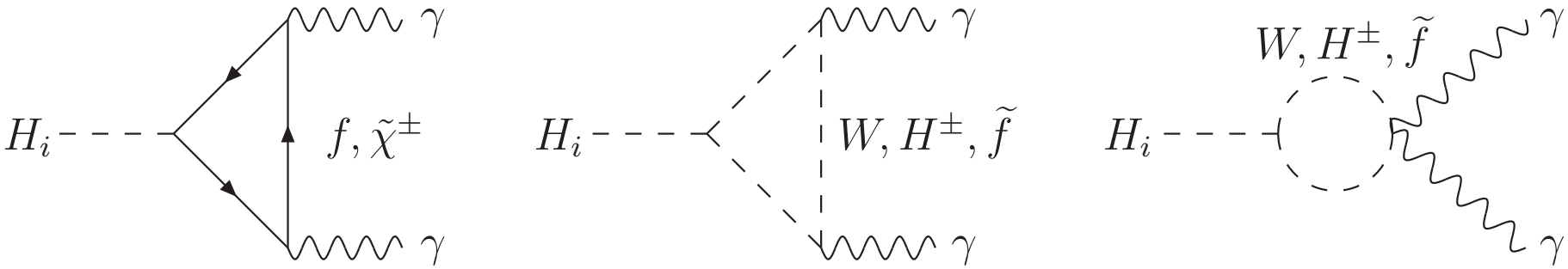
    [Lee, Pilaftsis, Carena, Choi, Drees, Ellis, Wagner '03; Ellis, Lee, Pilaftsis, '06]

  - FEYNHIGGS [Heinemeyer '01; Frank, Heinemeyer, Hollik, Weiglein '02]

    [Frank, Hahn, Heinemeyer, Hollik, Rzehak, Weiglein, '06]

$H_1 \to \gamma\gamma$

- $pp \to H \to \gamma\gamma$: important search channel at LHC for $m_H \lesssim$ 150 GeV
- Decay at 1-loop via f, W, $H^\pm$, $\tilde{f}$, $\tilde{\chi}^\pm$ loops in MSSM



- CP violation (CPV) enters via phase dependence of
  - Masses $m_{H_i} \to$ small
  - Mixing matrix $O \leftrightarrow H_i$ couplings (also to SM particles)
  - $\tilde{f}$, $\tilde{\chi}^\pm$ sector (masses, couplings to H_i)

$H_1 \to \gamma\gamma$ Production and decay in CPV MSSM

- Production $gg \to H_i$ at LHC [Choi, Lee, '99; Dedes, Moretti, '99]

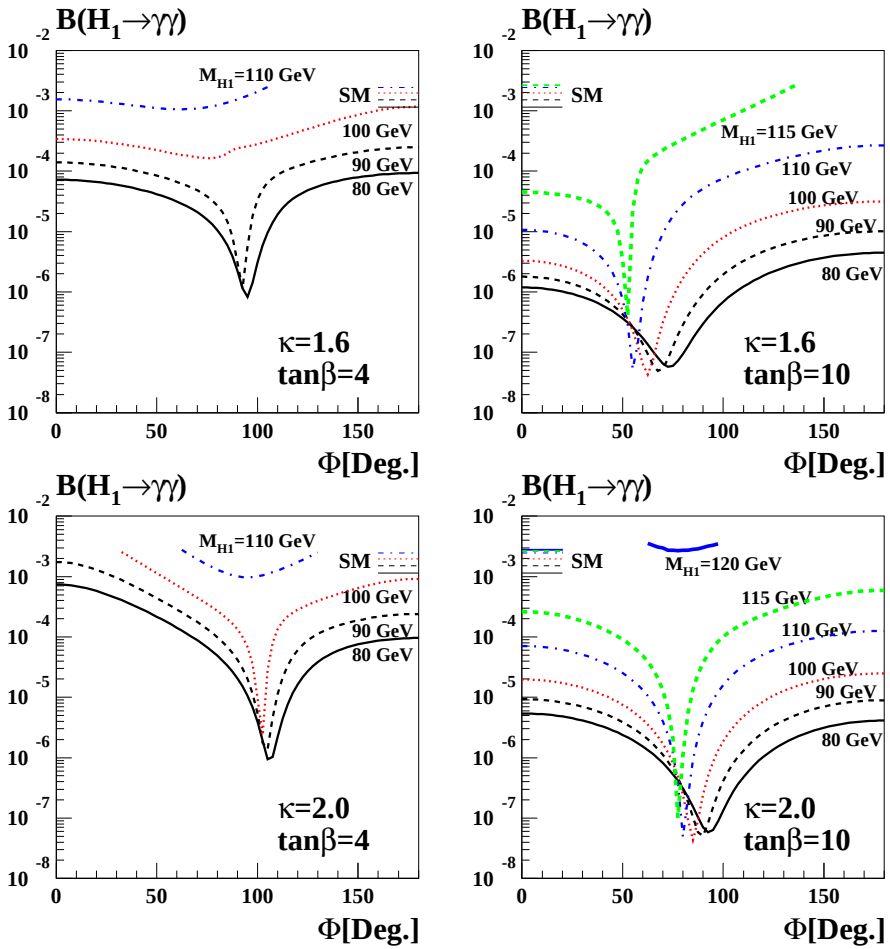
  $\to$ factor 2–5 enhancement/reduction of σ with φ_μ and φ_{A_t}

- $gg \to H_i \to \gamma\gamma$ at LHC in CPV MSSM [Choi, Hagiwara, Lee, '01]
  - Heavy sparticles ($\tilde{f}$, $\tilde{\chi}^\pm$)

    $\leftrightarrow$ CPV in H_i couplings
  - $\mathcal{O}(10^2$–$10^3)$ suppression

    of BR($H_1 \to \gamma\gamma$) possible

    $\Rightarrow$ suppression of $\sigma \times$ BR



for

$M_{\tilde{Q},\tilde{U},\tilde{D}} = m_{\tilde{g}} = M_{\text{SUSY}} = 0.5$ TeV,

$|A_t| = |A_b| = \kappa M_{\text{SUSY}}$, $|\mu| = 2|A_t|$,

$\Phi = \text{Arg}(A_t\mu) = \text{Arg}(A_b\mu)$

$H_1 \to \gamma\gamma$ Analysis of Branching Ratio

- Here:
  - Investigate possible effects of light sparticles
  - Calculation of m_{H_i}, O, $\Gamma(H_i)$, BR(H_i) with CPSUPERH
  - Detailed discussion of A_f, μ, $\tan\beta$ dependence
  - Leading contributions to (h, H)-A mixing $\propto$ Im(μA_f)

    $\to$ $\varphi_{\text{eff}} = \varphi_\mu + \varphi_{A_f}$

    $\to$ Choosing A_f real, analyzing $\varphi_{\text{eff}} = \varphi_\mu$ effects in the following
  - First step: analysis of BR$(H_1 \to \gamma\gamma)$

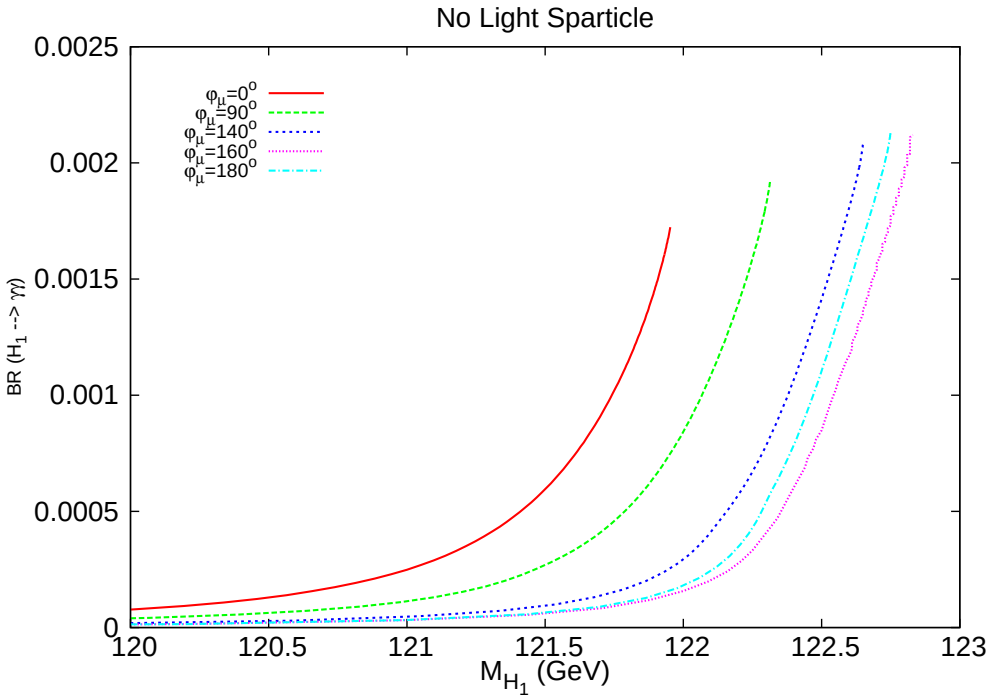
- Scan over MSSM parameters [Moretti, Munir, Poulose, '07]

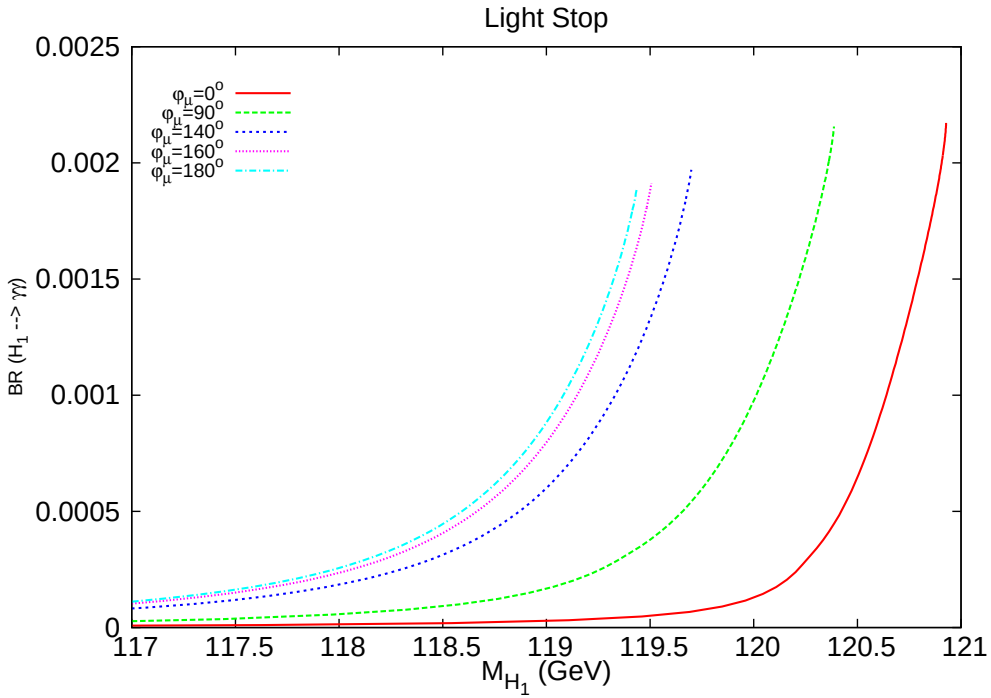
  $\to$ in average $\sim$ 50% deviation between CPV and CPC case possible for parameter points with m_{H_1} in bins of size 4 GeV

$H_1 \to \gamma\gamma$ Numerical results

BR($H_1 \to \gamma\gamma$) as function of m_{H_1}

for $M_{(\tilde{Q}_3,\tilde{D}_3,\tilde{L}_3,\tilde{E}_3)}$ = 1 TeV, $|\mu|$ = 1 TeV, A_f = 1.5 TeV, tan β = 20





→ $M_{\tilde{U}_3}$ = 1 TeV (no light sparticles)

→ CP effects from H_1 couplings to W, t, b in loops

→ $M_{\tilde{U}_3}$ = 250 GeV ($m_{\tilde{t}_1} \sim$ 200 GeV)

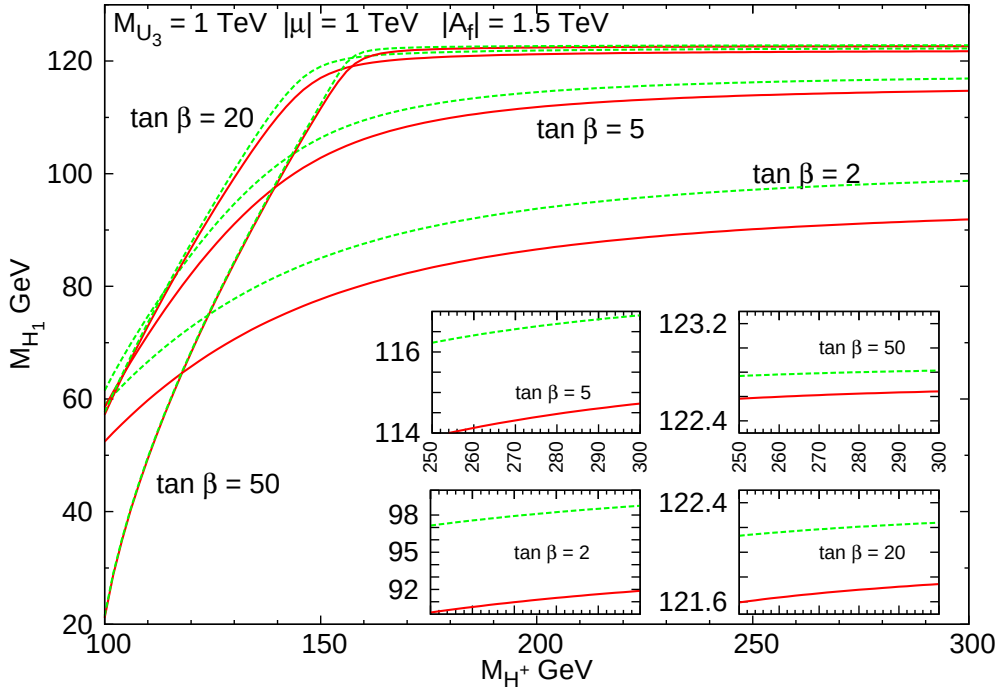
→ additional effects from light $\tilde{t}_1$

$H_1 \to \gamma\gamma$ Numerical results

m_{H_1} as function of $m_{H^\pm}$

for $M_{(\tilde{Q}_3,\tilde{D}_3,\tilde{L}_3,\tilde{E}_3)}$ = 1 TeV, $|\mu|$ = 1 TeV, A_f = 1.5 TeV, φ_μ = 0, φ_μ = 90°

$M_{\tilde{U}_3}$ = 1 TeV



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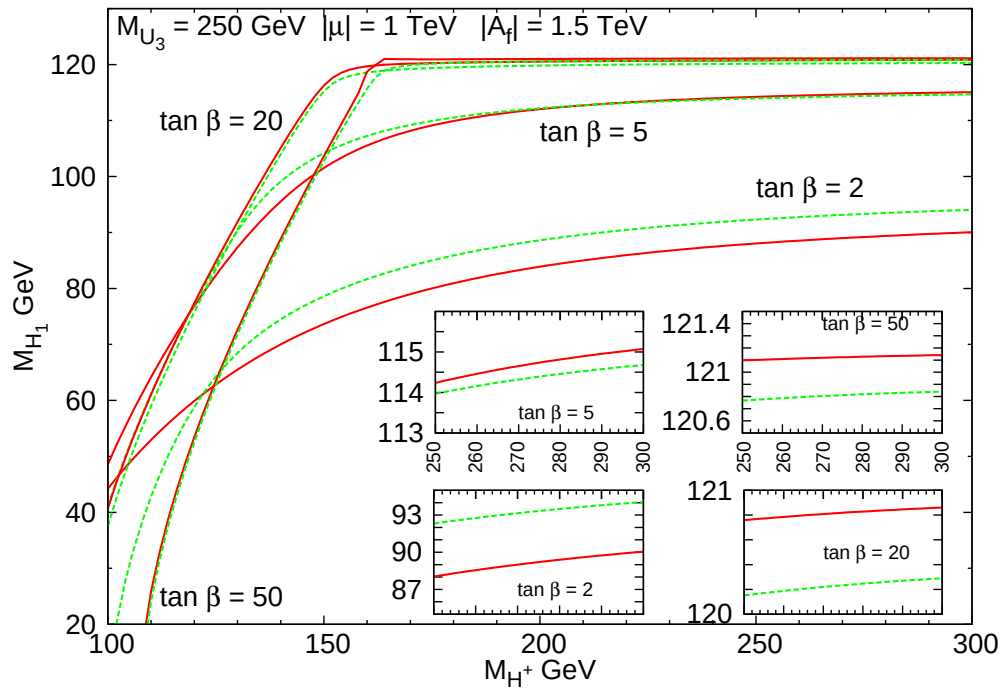

→ deviations $\Delta m_{H_1}(\varphi_\mu)$ within experimental uncertainty

$H_1 \to \gamma\gamma$ Numerical results

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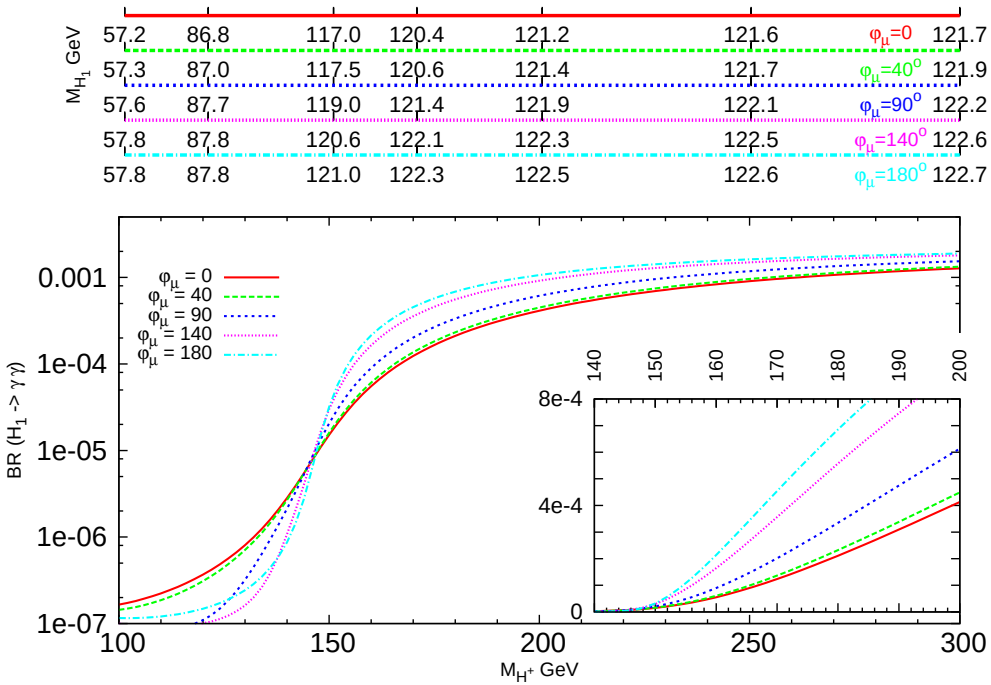

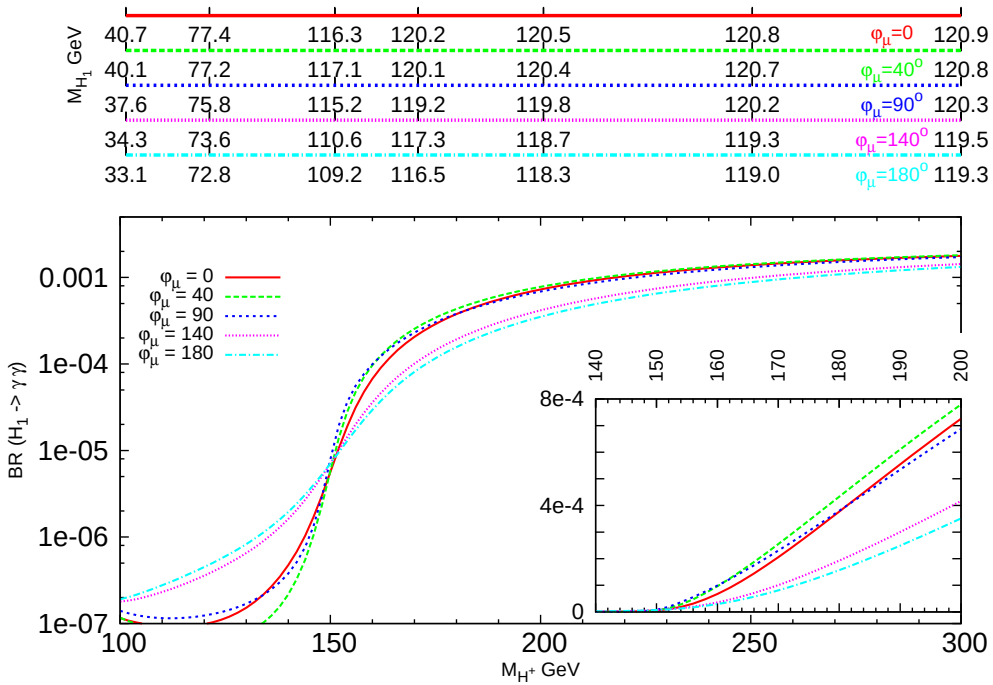

$\to$ $M_{\tilde{U}_3}$ = 1 TeV (no light sparticles)

$\to$ CP effects from H_1 couplings to W, t, b in loops

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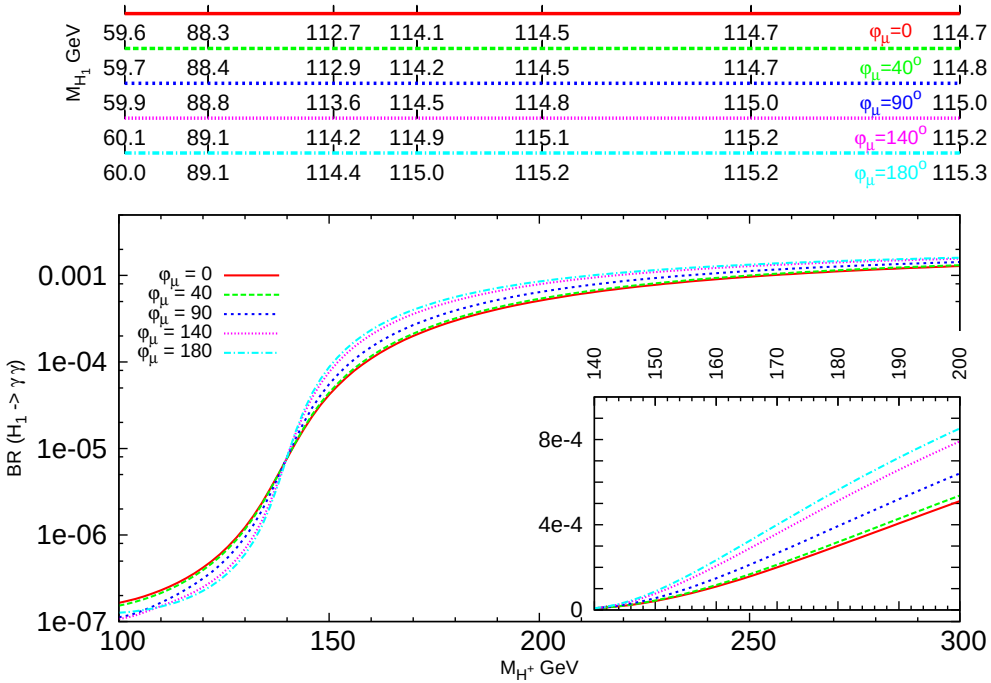

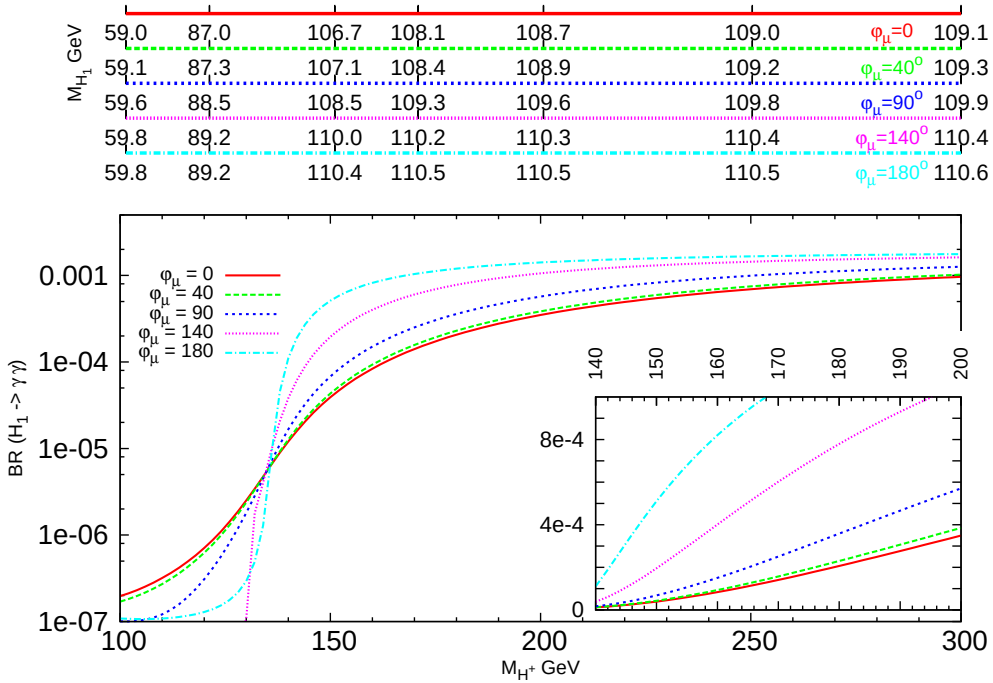

$\to$ $M_{\tilde{U}_3}$ = 1 TeV (no light sparticles)

$\to$ $M_{\tilde{U}_3}$ = 250 GeV ($m_{\tilde{t}_1} \sim$ 200 GeV)

$\to$ strong A_f dependence

Summary: SUSY parameter dependence

BR($H_1 \to \gamma\gamma$) in CP-violating MSSM

- Impact of light sparticles

  $\to$ light stops ($\tilde{t}_1$): possibly large effect

  $\to$ other light sparticles ($\tilde{b}_1$, $\tilde{\tau}_1$, $\tilde{\chi}_1^{\pm}$): small effect

- Strong A_f dependence

- $|\mu|$ dependence

  $\to$ φ_μ dependence decreases for smaller $|\mu|$ = 500 GeV

- tan β dependence

  $\to$ sensitivity to φ_μ considerably reduced for smaller tan β = 5

- Conclusion: Strong phase dependence of BR($H_1 \to \gamma\gamma$)

  Increase or decrease depends on SUSY scenario

Outlook

Projects within

New connections between Experiment and Theory

(NExT) Institute

(Southampton University $\leftrightarrow$ PPD, RAL)

`http://www.hep.phys.soton.ac.uk/next/NEXT_web/NEXT_web.htm`

- Analysis of full production + decay process $gg \to H_i \to \gamma\gamma$
  - Enhancement or cancellation between production + decay?
  - Impact of Higgs mixing in propagator [Ellis, Lee, Pilaftsis, '04]

  $\longrightarrow$ Net effect for Higgs search at LHC

- Explicit CP violation in NMSSM Higgs sector

  $\longrightarrow$ 3 CP-even and 2 CP-odd Higgs states mix $\Rightarrow$ 5 mass eigenstates