Impact of SUSY CP Phases on Stop, Sbottom and Stau decays

Stefan Hesselbach
Institut für Theoretische Physik der Universität Wien

A. Bartl, K. Hidaka, T. Kernreiter, W. Porod

hep-ph/0204071, hep-ph/0207186, hep-ph/0306281, hep-ph/0307317, hep-ph/0311338

Meeting on CP Violation and Nonstandard Higgs Physics

CERN, May 14, 2004

Outline

- Introduction
  - MSSM with complex parameters
  - Complex parameters in sfermion and chargino/neutralino sectors
  - Higgs sector
  - Constraints from EDMs and $B(b \to s\gamma)$
- Impact of CP phases on 3rd generation sfermion sector
  - Branching ratios of staus, stops and sbottoms
  - Parameter determination via global fit
- Summary

Introduction

MSSM with complex parameters

- General MSSM:

  Complex parameters in Higgs potential and soft SUSY breaking terms

- Physical phases of the parameters

  A_f : trilinear couplings of sfermions

  μ : Higgs-higgsino mass parameter

  M_1 : U(1) gaugino mass parameter

  $m_{\tilde{g}}$: gluino mass

- Introduction of CP violation
  - may help to explain baryon asymmetry of universe
  - constraints from electric dipole moments (EDMs)

Introduction

Complex parameters in $\tilde{f}$ sector

Sfermion mass matrix:

$$\mathcal{L}_M^{\tilde{f}} = -(\tilde{f}_L^*, \tilde{f}_R^*) \begin{pmatrix} M^2_{\tilde{f}_{LL}} & M^2_{\tilde{f}_{LR}} \\ M^2_{\tilde{f}_{RL}} & M^2_{\tilde{f}_{RR}} \end{pmatrix} \begin{pmatrix} \tilde{f}_L \\ \tilde{f}_R \end{pmatrix}$$

with

$$M^2_{\tilde{f}_{RL}} = (M^2_{\tilde{f}_{LR}})^* = m_f \left(A_f - \mu^* (\tan\beta)^{-2T_f^3} \right)$$

A_f : trilinear couplings of sfermions $\to |A_f|, \varphi_{A_f}$

μ : Higgs-higgsino mass parameter $\to |\mu|, \varphi_\mu$

$\tan\beta = \frac{v_2}{v_1}$: ratio of Higgs vevs

- Phase in sfermion sector:

$$\varphi_{\tilde{f}} = \arg\left[M^2_{\tilde{f}_{RL}}\right] = \arg\left[A_f - \mu^*(\tan\beta)^{-2T^3_f}\right]$$

- Mass eigenstates: $\begin{pmatrix}\tilde{f}_1\\ \tilde{f}_2\end{pmatrix} = \mathcal{R}^{\tilde{f}}\begin{pmatrix}\tilde{f}_L\\ \tilde{f}_R\end{pmatrix}$

  with mixing matrix $\mathcal{R}^{\tilde{f}} = \begin{pmatrix} e^{i\varphi_{\tilde{f}}}\cos\theta_{\tilde{f}} & \sin\theta_{\tilde{f}} \\ -\sin\theta_{\tilde{f}} & e^{-i\varphi_{\tilde{f}}}\cos\theta_{\tilde{f}} \end{pmatrix}$

  and sfermion mixing angle $\theta_{\tilde{f}}$

- φ_{A_f}, φ_μ influence $\varphi_{\tilde{f}}$ and $\theta_{\tilde{f}}$

Introduction

Complex parameters in $\tilde{\chi}^{\pm,0}$ sectors

- Chargino mass matrix: $X = \begin{pmatrix} M_2 & \sqrt{2}\, m_W s_\beta \\ \sqrt{2}\, m_W c_\beta & \mu \end{pmatrix}$

- Neutralino mass matrix:

$$Y = \begin{pmatrix} M_1 & 0 & -m_Z s_W c_\beta & m_Z s_W s_\beta \\ 0 & M_2 & m_Z c_W c_\beta & -m_Z c_W s_\beta \\ -m_Z s_W c_\beta & m_Z c_W c_\beta & 0 & -\mu \\ m_Z c_W c_\beta & -m_Z c_W s_\beta & -\mu & 0 \end{pmatrix}$$

$s_\beta \equiv \sin\beta$, $c_\beta \equiv \cos\beta$

μ : Higgs-higgsino mass parameter $\rightarrow |\mu|$, φ_μ

M_1 : U(1) gaugino mass parameter $\rightarrow |M_1|$, φ_{M_1}

M_2 : SU(2) gaugino mass parameter

Introduction Higgs sector

- $\tilde{t}$ and $\tilde{b}$ loops $\Rightarrow$ explicit CP violation in Higgs sector

- CP-even and CP-odd Higgs mix
  $\rightarrow$ 3 neutral mass eigenstates (H_1, H_2, H_3)

- In this work:
  m_{H_i} and mixing matrix computed with FeynHiggs-2.0.2
  [Heinemeyer '01; Frank, Heinemeyer, Hollik, Weiglein '02]
  and cph.f (CPsuperH)
  [Carena, Ellis, Pilaftsis, Wagner '00; Lee, Pilaftsis, Carena, Choi, Drees, Ellis, Wagner '03]

Introduction Constraints

- Electric dipole moments (EDMs) of e, n, Hg, Tl

  [Ibrahim, Nath, '99; Barger, Falk, Han, Jiang, Li, Plehn, '01; Abel, Khalil, Lebedev, '01]

  - φ_μ: one loop contributions of $\tilde{\chi}^0$, $\tilde{\chi}^\pm$ $\Rightarrow$ strong constraints
  - φ_{A_f}: two loop contributions $\Rightarrow$ constraints less severe

  [Chang, Keung, Pilaftsis '99, Pilaftsis '02]

- Branching ratio $B(b \to s\gamma)$: $2.0 \times 10^{-4} < B(b \to s\gamma) < 4.5 \times 10^{-4}$

  [Abe et. al (Belle) '01; Chen at al. (Cleo) '01]

  $\Rightarrow$ constraints on φ_{A_t} and φ_μ

  [Bertolini et al. '91; Kagan, Neubert '98; Hurth, Lunghi, Porod '03]

Branching ratios of sfermions

Impact of phases φ_{A_f}, φ_{M_1}, φ_μ on two-body decays of $\tilde{\tau}$, $\tilde{t}$ and $\tilde{b}$

- Fermionic decays: $\tilde{f}_i \to \tilde{\chi}^\pm_j f'$, $\tilde{f}_i \to \tilde{\chi}^0_j f$
- Bosonic decays: $\tilde{f}_i \to \tilde{f}'_j H^\pm$, $\tilde{f}_i \to \tilde{f}'_j W^\pm$, $\tilde{f}_2 \to \tilde{f}_1 H_i$, $\tilde{f}_2 \to \tilde{f}_1 Z$
- Emphasis on φ_{A_τ}, φ_{A_t}, φ_{A_b}

  $\to$ possible determination of $|A_f|$, φ_{A_f} or Re(A_f), Im(A_f)
- Estimation of parameter reconstruction:

  Global fit of many observables

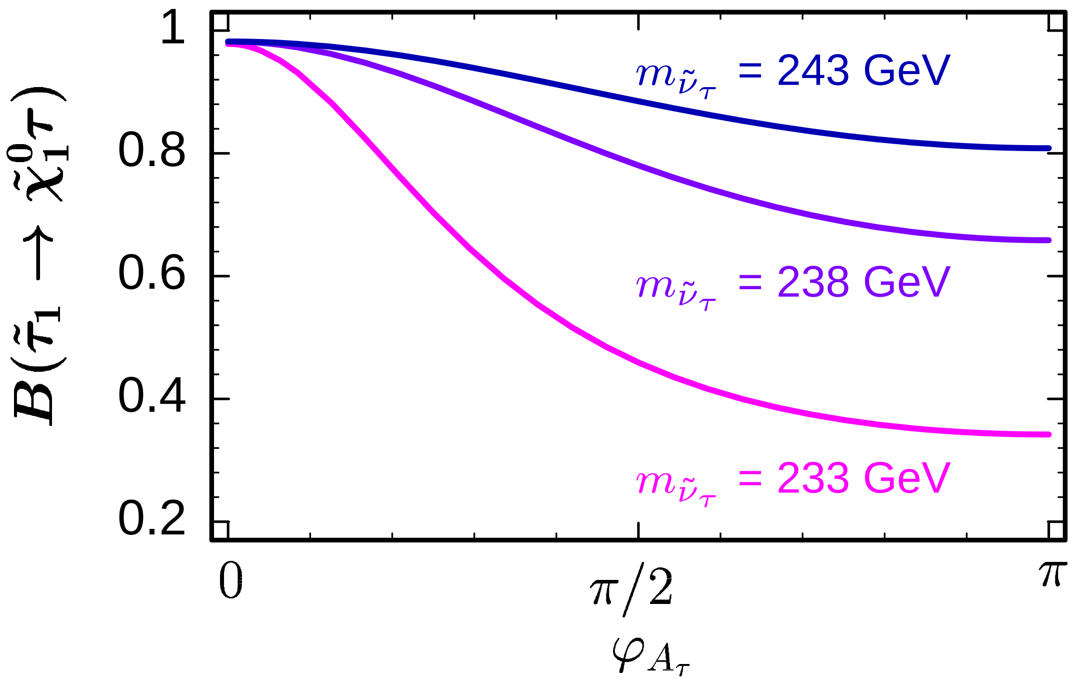
  including also masses and production cross sections

Branching ratios of $\tilde{\tau}_1$

Branching ratio $B(\tilde{\tau}_1 \to \tilde{\chi}^0_1 \tau)$ in scenario: [Bartl, Hidaka, Kernreiter, Porod, '02]

$m_{\tilde{\tau}_1}$ = 240 GeV, $|A_\tau|$ = 1 TeV, $|\mu|$ = 300 GeV, φ_μ = 0,
M_2 = 200 GeV, $|M_1|/M_2$ = 5/3 tan$^2\theta_W$, φ_{M_1} = 0, tan β = 3

- $\rightarrow$ strong phase dependence
- $\rightarrow$ caused by mixing angle
- $\rightarrow$ $\tilde{\tau}_1$: $\tilde{\tau}_R \to \tilde{\tau}_L$ for $m_{\tilde{\nu}_\tau}$ = 233 GeV
- $\rightarrow$ occurs for $M_{\tilde{\tau}_{LL}} \approx M_{\tilde{\tau}_{RR}}$ *and* $|A_\tau| \approx |\mu|$ tan β



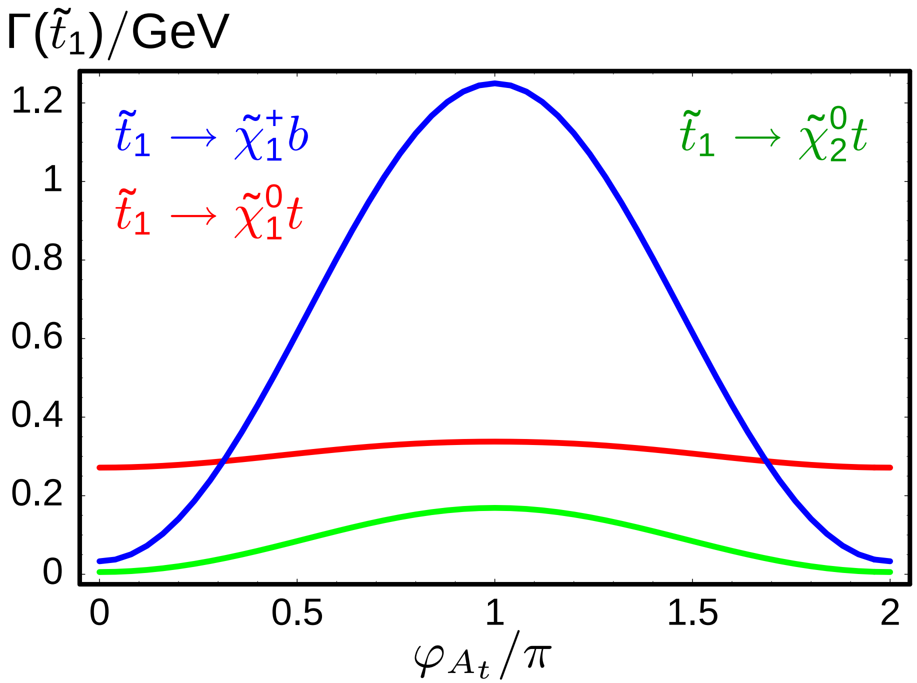
Branching ratios of $\tilde{t}_1$

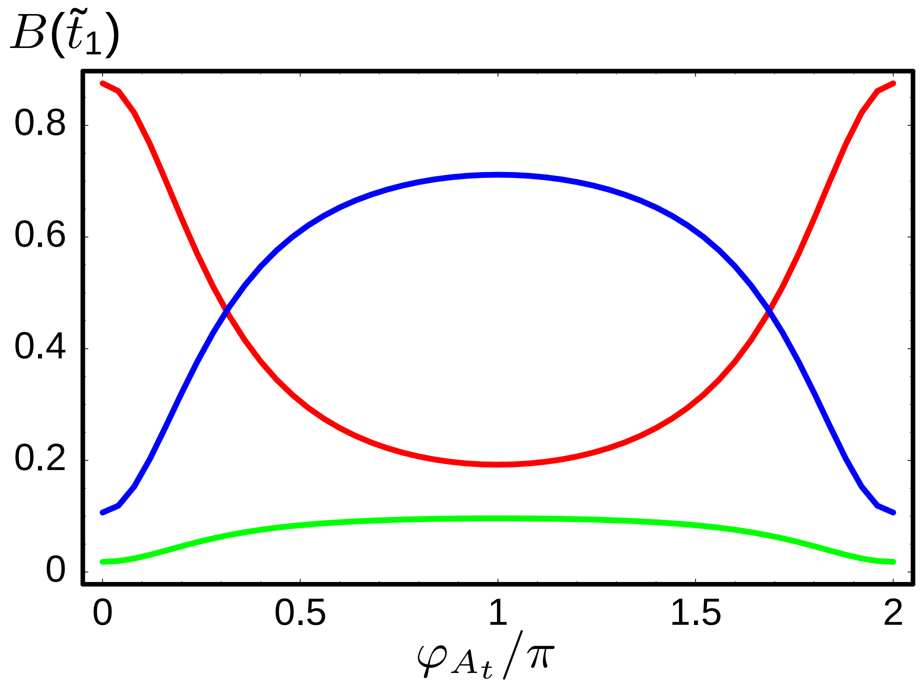
Partial decay widths $\Gamma(\tilde{t}_1)$ and branching ratios $B(\tilde{t}_1)$

[Bartl, SH, Hidaka, Kernreiter, Porod, '03]

in scenario:

$m_{\tilde{t}_L} > m_{\tilde{t}_R}$, $m_{\tilde{t}_1}$ = 379 GeV , $m_{\tilde{t}_2}$ = 575 GeV, $m_{\tilde{b}_1}$ = 492 GeV, (SPS 1a inspired)
$|A_t|$ = 466 GeV, $|A_b|$ = 759 GeV, φ_{A_b} = 0, $|\mu|$ = 352 GeV, φ_μ = 0,
M_2 = 193 GeV, $|M_1|/M_2 = 5/3 \tan^2\theta_W$, φ_{M_1} = 0, $\tan\beta$ = 10





$\rightarrow$ pronounced phase dependence of $\Gamma(\tilde{t}_1 \to \tilde{\chi}_1^+ b)$: effect of $\varphi_{\tilde{t}} \sim \varphi_{A_t}$

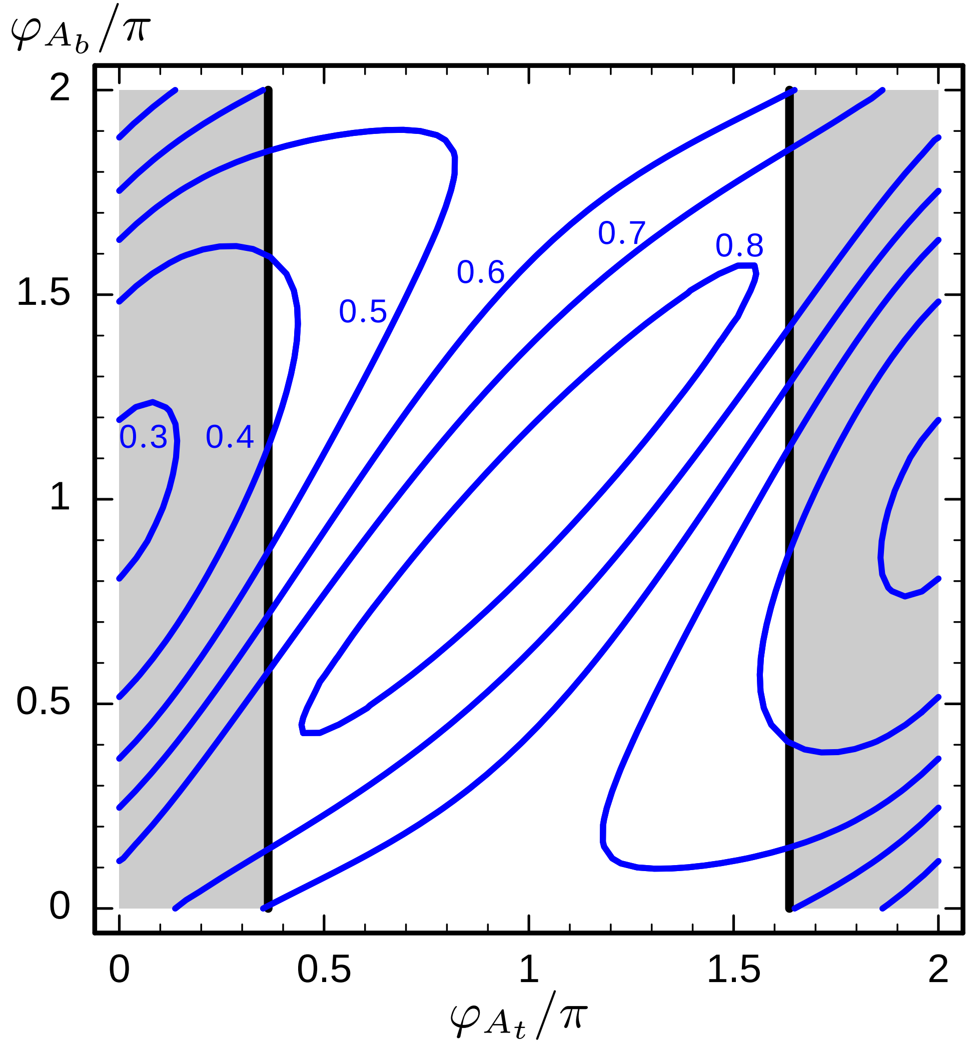
Branching ratios of $\tilde{t}_1$

Contours of $B(\tilde{t}_1 \to \tilde{\chi}_1^+ b)$

in scenario:

$M_Q > M_U$, $m_{\tilde{t}_1}$ = 350 GeV
$m_{\tilde{t}_2}$ = 700 GeV, $m_{\tilde{b}_1}$ = 170 GeV
$|A_t| = |A_b|$ = 600 GeV, M_2 = 300 GeV
$|\mu|$ = 300 GeV, $\varphi_\mu = \pi$, $\tan\beta$ = 30
$m_{H^\pm}$ = 160 GeV
$\to \tilde{t}_1 \to \tilde{b}_1 H^+$ open

shaded area:
$B(b \to s\gamma) < 2.0 \times 10^{-4}$



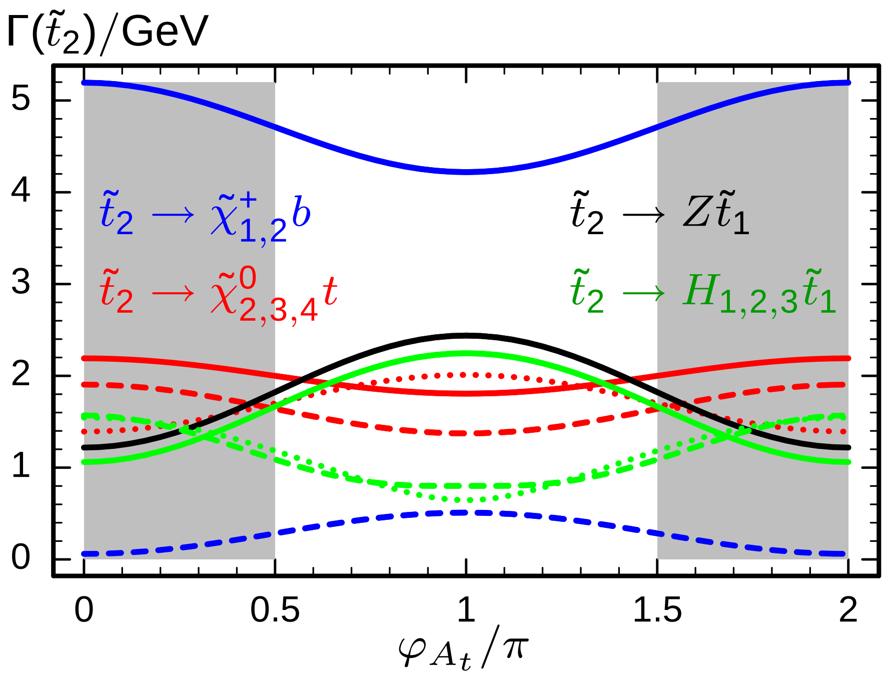
$\to$ remarkable correlation between φ_{A_t} and φ_{A_b}:
effect of $\varphi_{A_t}, \varphi_{A_b}$ dependence of $H^\pm \tilde{t}\tilde{b}$ coupling

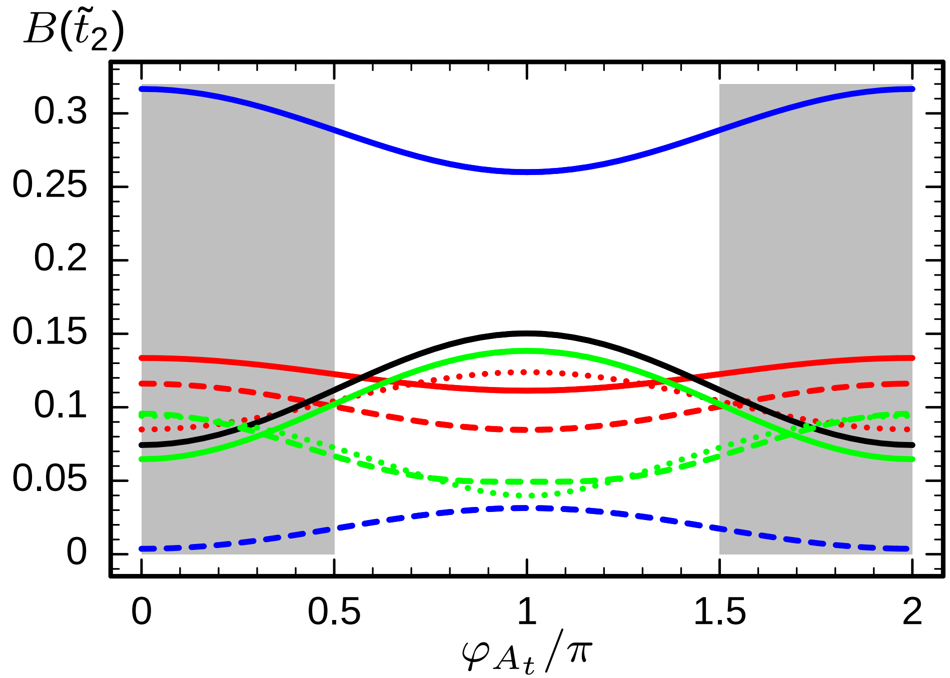
Branching ratios of $\tilde{t}_2$

Partial decay widths $\Gamma(\tilde{t}_2)$ and branching ratios $B(\tilde{t}_2)$

in scenario:

$M_Q > M_U$, $m_{\tilde{t}_1}$ = 350 GeV , $m_{\tilde{t}_2}$ = 800 GeV, $m_{\tilde{b}_1}$ = 170 GeV, $|A_t|$ = $|A_b|$ = 500 GeV, φ_{A_b} = 0, $|\mu|$ = 500 GeV, φ_μ = 0, M_2 = 300 GeV, $|M_1|/M_2$ = 5/3 $\tan^2\theta_W$, φ_{M_1} = 0, $\tan\beta$ = 6, $m_{H^\pm}$ = 350 GeV





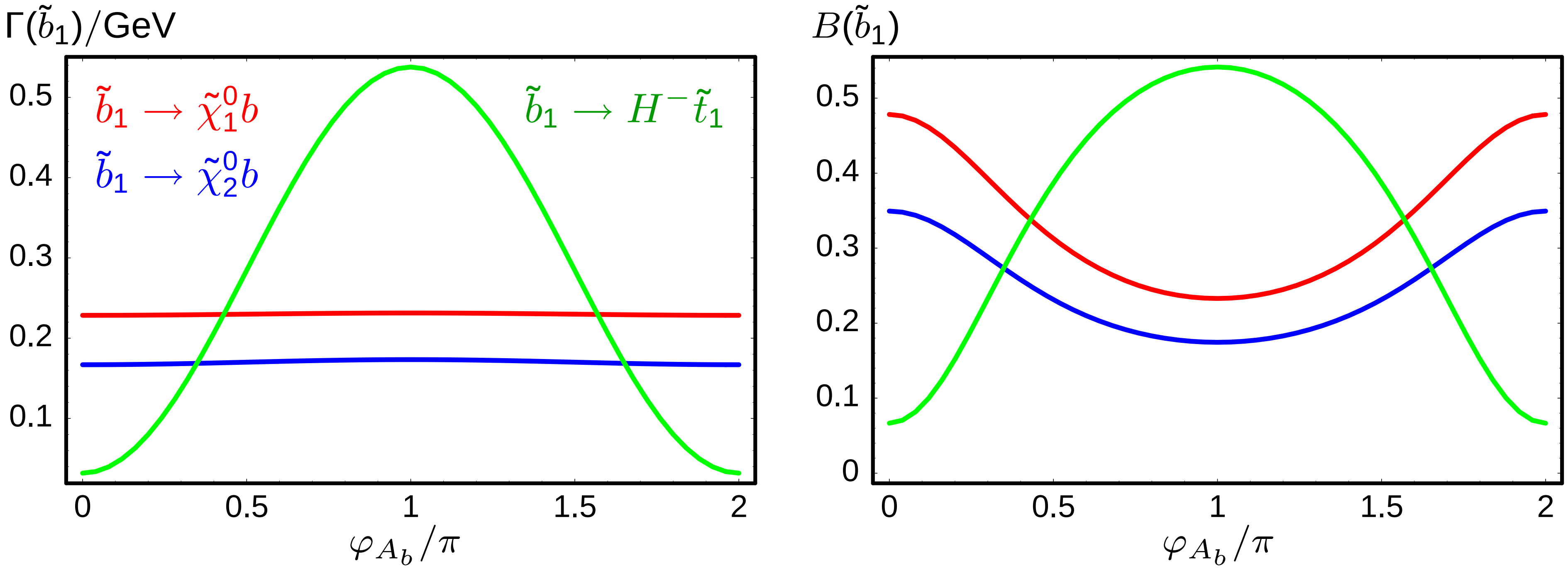
shaded area: $B(b \to s\gamma) > 4.5 \times 10^{-4}$

Branching ratios of $\tilde{b}_1$

Partial decay widths $\Gamma(\tilde{b}_1)$ and branching ratios $B(\tilde{b}_1)$

in scenario:

$M_Q > M_D$, $m_{\tilde{b}_1}$ = 350 GeV , $m_{\tilde{b}_2}$ = 700 GeV, $m_{\tilde{t}_1}$ = 170 GeV, $|A_t| = |A_b|$ = 600 GeV,
φ_{A_t} = 0, $|\mu|$ = 300 GeV, $\varphi_\mu = \pi$, M_2 = 200 GeV, $|M_1|/M_2 = 5/3 \tan^2\theta_W$, φ_{M_1} = 0,
$\tan\beta$ = 30, $m_{H^\pm}$ = 150 GeV



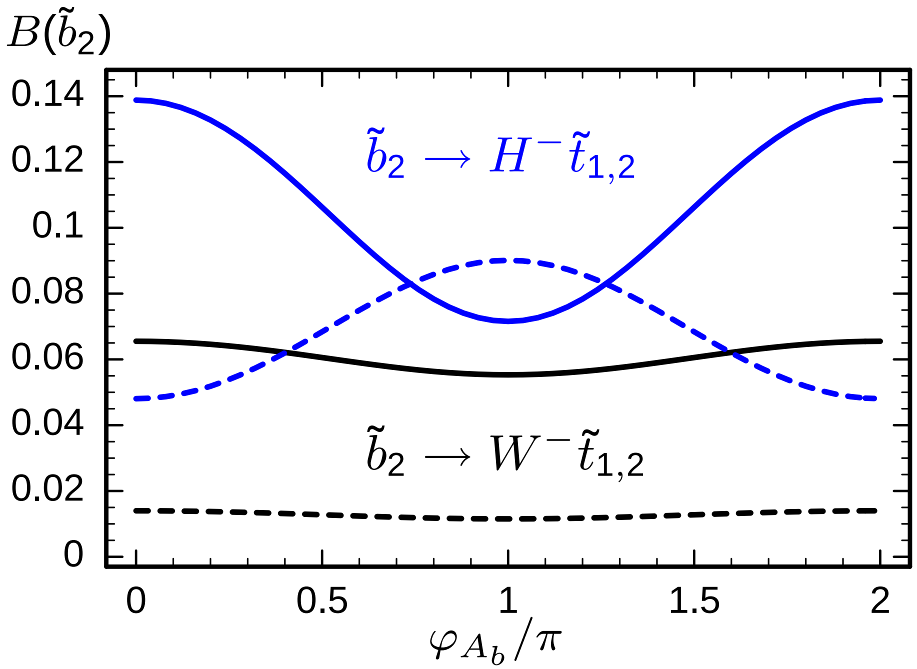
$\longrightarrow$ strong phase φ_{A_b} dependence of $\Gamma(\tilde{b}_1 \to H^- \tilde{t}_1)$

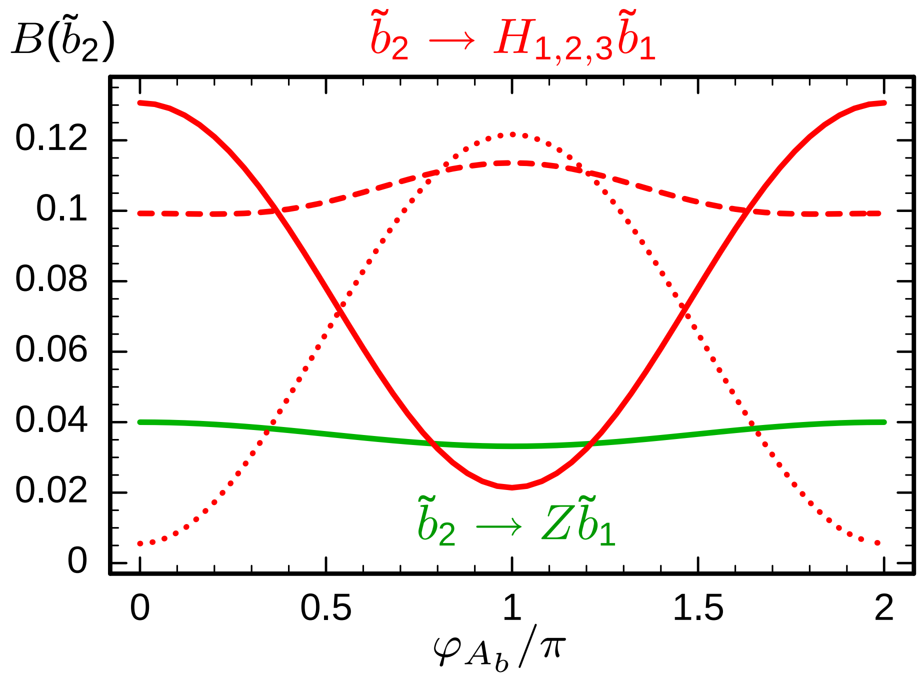
Branching ratios of $\tilde{b}_2$

Branching ratios $B(\tilde{b}_2)$

in scenario:

$M_Q < M_D$, $m_{\tilde{b}_1}$ = 350 GeV , $m_{\tilde{b}_2}$ = 700 GeV, $m_{\tilde{t}_1}$ = 170 GeV, $|A_t|$ = $|A_b|$ = 600 GeV, φ_{A_t} = π, $|\mu|$ = 300 GeV, φ_μ = π, M_2 = 200 GeV, $|M_1|/M_2$ = 5/3 $\tan^2\theta_W$, φ_{M_1} = 0, $\tan\beta$ = 30, $m_{H^\pm}$ = 150 GeV





Parameter determination in $\tilde{\tau}$ sector

Global fit of many observables

$\rightarrow$ masses, branching ratios, production cross sections $\sigma(e^+e^- \rightarrow \tilde{\tau}_i\tilde{\tau}_j)$

for $\sqrt{s}$ = 800 GeV and polarized beams in scenarios:

$\tan\beta = 3$, $m_{\tilde{\tau}_1}$ = 155.0 GeV, $m_{\tilde{\tau}_2}$ = 352.6 GeV, $|A_\tau|$ = 800 GeV, $\varphi_{A_\tau} = 1.5\pi$
$|\mu|$ = 250 GeV, $\varphi_\mu = 0$, M_2 = 280 GeV, $|M_1|/M_2 = 5/3\tan^2\theta_W$, $\varphi_{M_1} = 0$, m_{H^+} = 170 GeV

$\Rightarrow$ $\delta(\mathrm{Im}(A_\tau))/|A_\tau| = 9\,\%$, $\delta(\mathrm{Re}(A_\tau))/|A_\tau| = 22\,\%$

$\delta(\tan\beta)/\tan\beta = 1\,\%$, $\delta(M_E)/M_E \sim \delta(M_L)/M_L \sim 0.5\,\%$

$\tan\beta = 30$, $m_{\tilde{\tau}_1}$ = 150.6 GeV, $m_{\tilde{\tau}_2}$ = 355.7 GeV, $|A_\tau|$ = 800 GeV, $\varphi_{A_\tau} = 1.5\pi$
$|\mu|$ = 250 GeV, $\varphi_\mu = 0$, M_2 = 280 GeV, $|M_1|/M_2 = 5/3\tan^2\theta_W$, $\varphi_{M_1} = 0$, m_{H^+} = 160 GeV

$\Rightarrow$ $\delta(\mathrm{Im}(A_\tau))/|A_\tau| = 3\,\%$, $\delta(\mathrm{Re}(A_\tau))/|A_\tau| = 7\,\%$

$\delta(\tan\beta)/\tan\beta = 2\,\%$, $\delta(M_E)/M_E \sim \delta(M_L)/M_L \sim 1\,\%$

Parameter determination in $\tilde{t}$, $\tilde{b}$ sector

Global fit of many observables

$\rightarrow$ masses, branching ratios, production cross sections $\sigma(e^+e^- \rightarrow \tilde{q}_i\tilde{q}_j)$

for $\sqrt{s}$ = 2 TeV and polarized beams in scenarios:

$\tan\beta = 6$, $M_Q > M_U$, $m_{\tilde{t}_1}$ = 350 GeV, $m_{\tilde{t}_2}$ = 700 GeV, $m_{\tilde{b}_1}$ = 170 GeV, $|A_t| = |A_b|$ = 800 GeV, $\varphi_{A_t} = \varphi_{A_b} = 0.25\pi$, M_2 = 300 GeV, $|M_1|/M_2 = 5/3\tan^2\theta_W$, $\varphi_{M_1} = 0$, $\mu = |350|$ GeV, $\varphi_\mu = \pi$, $m_{\tilde{g}}$ = 1000 GeV, m_{H^+} = 900 GeV

$\tan\beta = 30$, $M_Q > M_U$, $m_{\tilde{t}_1}$ = 210 GeV, $m_{\tilde{t}_2}$ = 729 GeV, $m_{\tilde{b}_1}$ = 350 GeV, $|A_t|$ = 600 GeV, $\varphi_{A_t} = 0.25\pi$, $|A_b|$ = 1000 GeV, $\varphi_{A_b} = 1.5\pi$, M_2 = 200 GeV, $|M_1|/M_2 = 5/3\tan^2\theta_W$, $\varphi_{M_1} = 0$, $|\mu|$ = 350 GeV, $\varphi_\mu = \pi$, $m_{\tilde{g}}$ = 1000 GeV, m_{H^+} = 350 GeV

$\Rightarrow$ $\delta(\mathrm{Im}(A_t))/|A_t| = 2-3\,\%$, $\delta(\mathrm{Re}(A_t))/|A_t| = 2-3\,\%$

$\delta(\mathrm{Im}(A_b))/|A_b| \sim 50\,\%$, $\delta(\mathrm{Re}(A_b))/|A_b| \sim 50\,\%$

$\delta(\tan\beta)/\tan\beta = 3\,\%$, $\delta(M_D)/M_D \sim \delta(M_U)/M_U \sim \delta(M_Q)/M_Q \sim 1\,\%$

Summary

- Branching ratios of stops, sbottoms and staus
  - Large mixing in $\tilde{t}$ sector, $\varphi_{\tilde{t}} \sim \varphi_{A_t}$
    $\rightarrow$ pronounced φ_{A_t} dependence of $\tilde{t}$ branching ratios
  - Strong φ_{A_b} (φ_{A_τ}) dependence possible
    of $\tilde{b}$ *and* $\tilde{t}$ ($\tilde{\tau}$) decays into Higgs channels

- Estimation of expected accuracy by global fit
  - A_τ: error 5 – 20 %; M_E, M_L: error $\lesssim$ 1 %; tan β: error 1 – 2 %
  - A_t: error 2 – 3 %; A_b: error 50 – 100 %;
    M_D, M_U, M_Q: error $\sim$ 1 %; tan β: error 3 %