Rate asymmetries in chargino and charged Higgs decays as a probe of CP violation

HELMUT EBERL

HEPHY Vienna

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This talk is based on papers written with

E. Christova - INRNE, SOFIA

T. Gajdosik - INSTITUTE OF PHYSICS, VILNIUS

S. Kraml - HEPHY VIENNA/CERN

W. Majerotto and *B. Schraußer* - HEPHY VIENNA

- CP violating asymmetry in chargino decay into neutralino and W boson
  H. E., T. Gajdosik, W. Majerotto, B. Schraußer
  hep-ph/0502112
- CP violation in charged Higgs boson decays in the MSSM with complex parameters
  E. Christova, H. E., S. Kraml, W. Majerotto
  hep-ph/0205227
- CP violation in charged Higgs boson decays into tau and neutrino
  E. Christova, H. E., S. Kraml, W. Majerotto
  hep-ph/0211063

OUTLINE

- Introduction: MSSM, CP phases (mass matrices)
- Decay rate asymmetry
- New: $\tilde{\chi}_i^{\pm} \to \tilde{\chi}_j^0 W^{\pm}$
- Review of $H^{\pm} \to tb\,,\, \tau\nu_\tau$
- Conclusions

COMPLEX MSSM

- In the general MSSM
  complex parameters in Higgs potential and soft SUSY breaking terms
- Physical phases:

  $|\mu|e^{i\phi_\mu}$: higgsino mass parameter

  $|M_1|e^{i\phi_{M_1}}$: U(1) gaugino mass parameter

  (M_2 is made real by field-redefinition)

  $m_{\tilde{g}}\, e^{i\phi_3}$: SU(3) gaugino mass parameter

  $|A_f|e^{i\phi_{A_f}}$: trilinear coupling of sfermions
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[see e.g. Dine, Kusenko, hep-ph/0303065]

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    [see e.g. Dine, Kusenko, hep-ph/0303065]
  - but 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]

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  - formed by triple products asymmetries
  - full spin correlations between production and decay

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  $A_{\mathrm{CP}} \sim$ (imaginary part of coupling) $\times$ (absorptive part of loop-integral)

  is a loop effect! "Optical theorem"
- The observable is the decay rate, significance $\sim A_{\mathrm{CP}} \times \sqrt{\text{branching ratio}}$.
- If new channel opens: $A_{\mathrm{CP}} \Uparrow$, BR $\Downarrow$.

  $\Rightarrow$ always work in opposite directions
- Two types of loop-diagrams: vertex and self-energy – contributions only from $\tilde{\chi}_1^\pm - \tilde{\chi}_2^\pm$ or $H^\pm - W^\pm$ transitions

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- No renormalization - A_{CP} - denominator approximated by Γ^{tree}

CPV asymmetry

$$A_{\rm CP} \simeq \frac{\Gamma(\text{decay}^+) - \Gamma(\text{decay}^-)}{2\Gamma^{\rm tree}(\text{decay}^+)}$$

- The general structure of $A_{\rm CP}$ is

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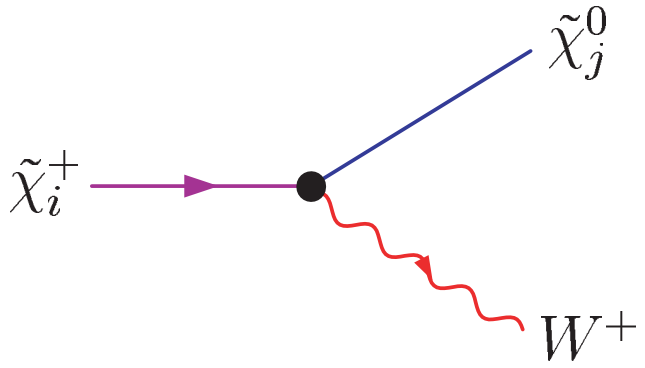
$\tilde{\chi}_i^+ \to \tilde{\chi}_j^0 W^+$

tree-level:



coupling $\sim \gamma^\mu (O_{ji}^R P_R + O_{ji}^L P_L)$

$$O_{ji}^R = g Z_{j2}^* U_{i1} + \frac{g}{\sqrt{2}} Z_{j3}^* U_{i2}, \qquad O_{ji}^L = g Z_{j2} V_{i1}^* - \frac{g}{\sqrt{2}} Z_{j4} V_{i2}^*$$

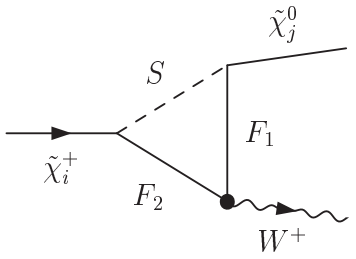
$$\Gamma^{\mathrm{tree}} = \frac{\sqrt{\lambda}}{32\pi m_i^3} \left(\left(\frac{\lambda}{m_W^2} + 3X \right) (|O^R|^2 + |O^L|^2) - 12 m_i m_j \mathrm{Re}[O^{R*} O^L] \right)$$

$X = m_i^2 + m_j^2 - m_W^2$, $\lambda = \lambda(m_i^2, m_j^2, m_W^2)$ with $\lambda(x,y,z) = (x-y-z)^2 - 4yz$

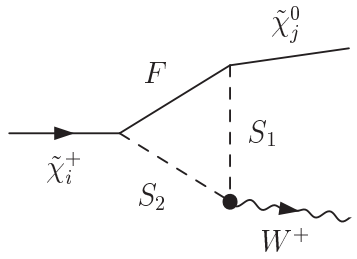
- dependence on ϕ_μ and ϕ_{M_1}
- no bino coupling - Γ^{tree} small for bino-like neutralino! $\longrightarrow$ BR to zero

One-loop graphs

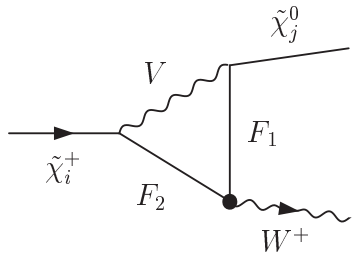
Sources for CP violation in $\tilde{\chi}_i^+ \to \tilde{\chi}_j^0 W^+$ decays at one-loop level in the MSSM with complex couplings



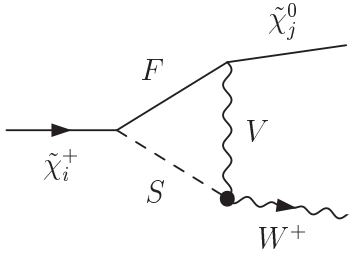
SF_1F_2 :
$\tilde{f}ff'$, $\phi^0\tilde{\chi}^0\tilde{\chi}^+$, $\phi^+\tilde{\chi}^+\tilde{\chi}^0$



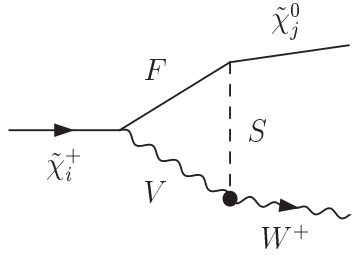
FS_1S_2 :
$f\tilde{f}\tilde{f}'$, $\tilde{\chi}^0\phi^0\phi^+$, $\tilde{\chi}^+\phi^+\phi^0$



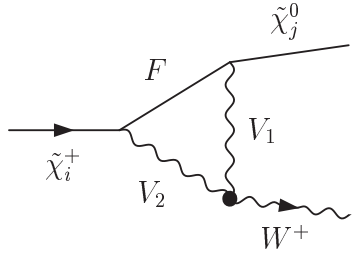
VF_1F_2 :
$Z^0\tilde{\chi}^0\tilde{\chi}^+$, $W^+\tilde{\chi}^+\tilde{\chi}^0$



FVS :
$\tilde{\chi}^0 Z^0 G^+$, $\tilde{\chi}^+ W^+ H_n^0$



FSV :
$\tilde{\chi}^0 H_n^0 W^+$, $\tilde{\chi}^+ G^+ Z^0$



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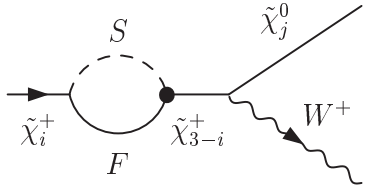

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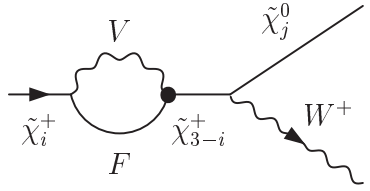
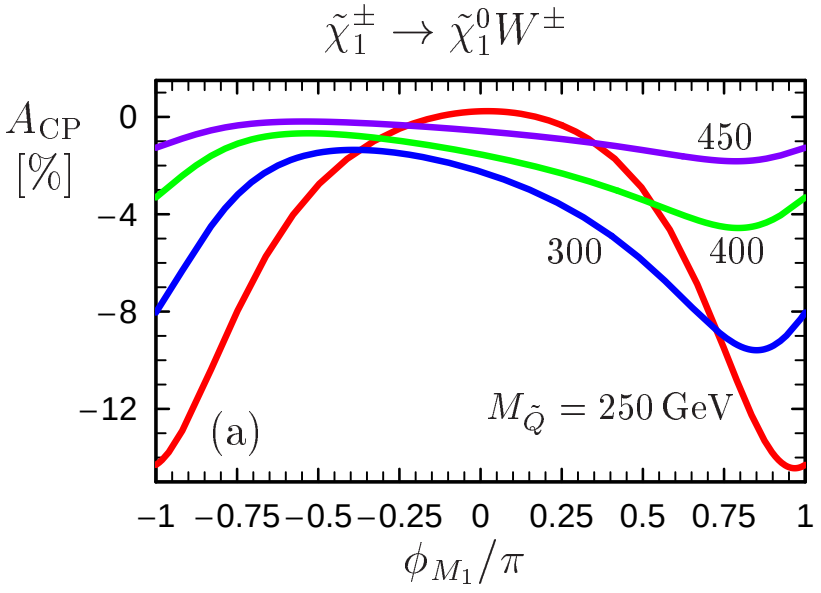
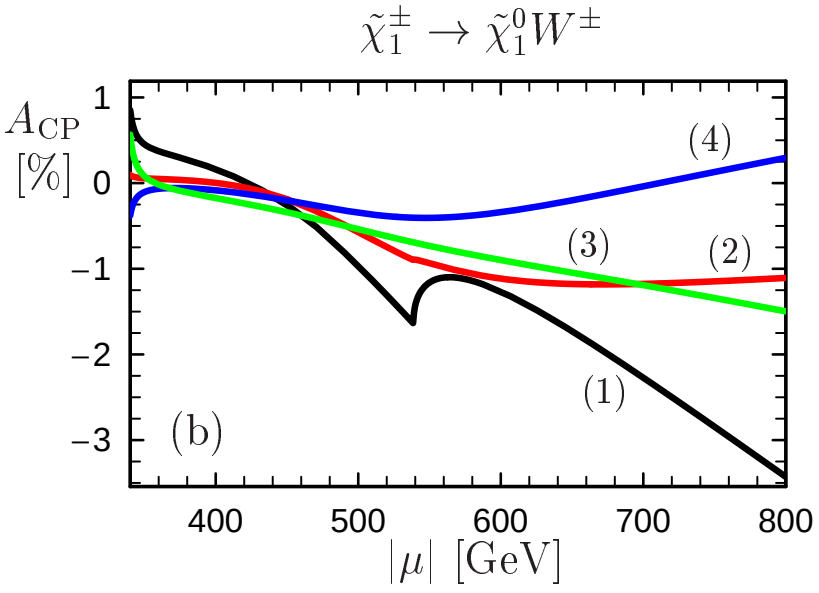


VF :
$Z^0\tilde{\chi}^+$, $W^+\tilde{\chi}^0$

$\tan\beta = 10$, $m_{A^0} = 300$ GeV, $\phi_\mu = \frac{\pi}{10}$
$M_2 = 500$ GeV,
$|A| = 400$ GeV, $\phi_A = -\frac{\pi}{4}$





$|\mu| = 600$ GeV, $\phi_{M_1} = \frac{\pi}{4}$, $M_{\tilde{Q}} = 350$ GeV

(1) vertex contribution with third gen. (s)quarks
(2) chargino selfenergy contribution with with third gen. (s)quarks
(3) all other (s)fermions in the loop
(4) remaining contributions

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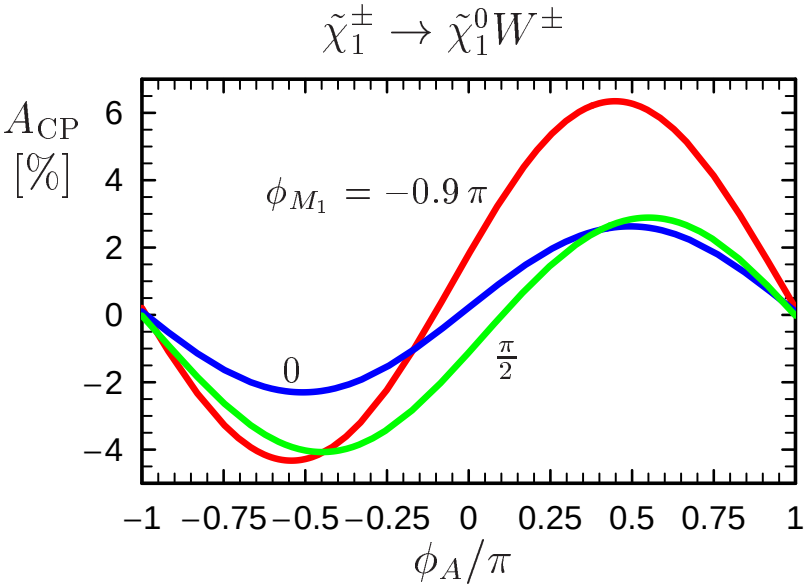

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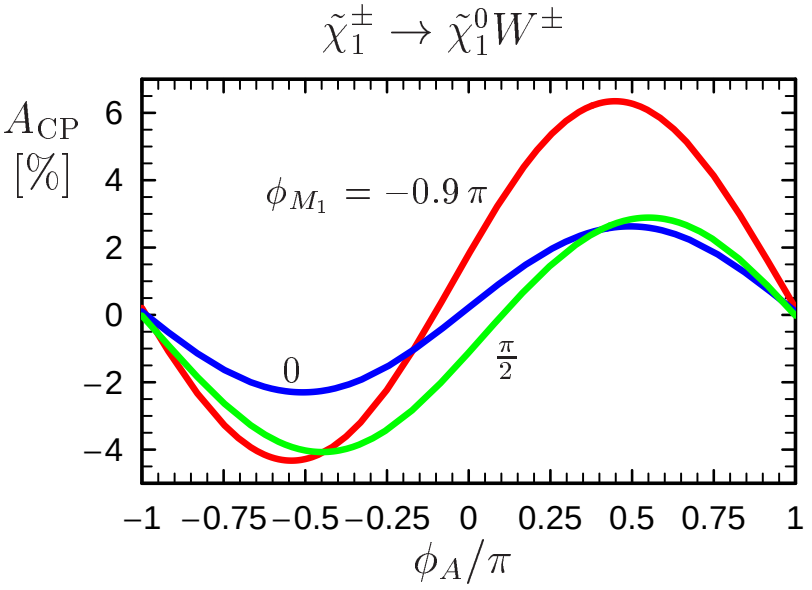

Assuming at LHC n = $\sim 2.4 \times 10^5$ of $\tilde{\chi}_1^\pm$
(40% of gluinos decay into a $\tilde{\chi}_1^+$ or $\tilde{\chi}_1^-$)
significance := $A_{CP} \times \sqrt{n\,BR}$

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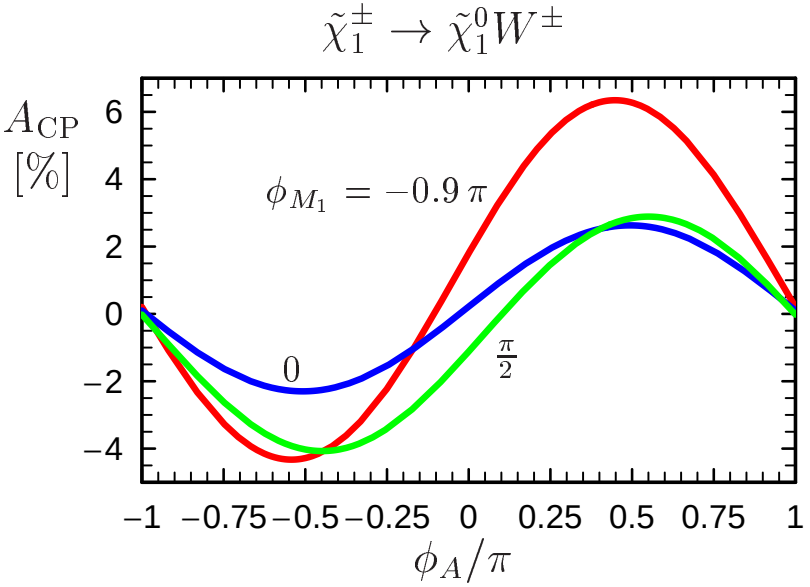

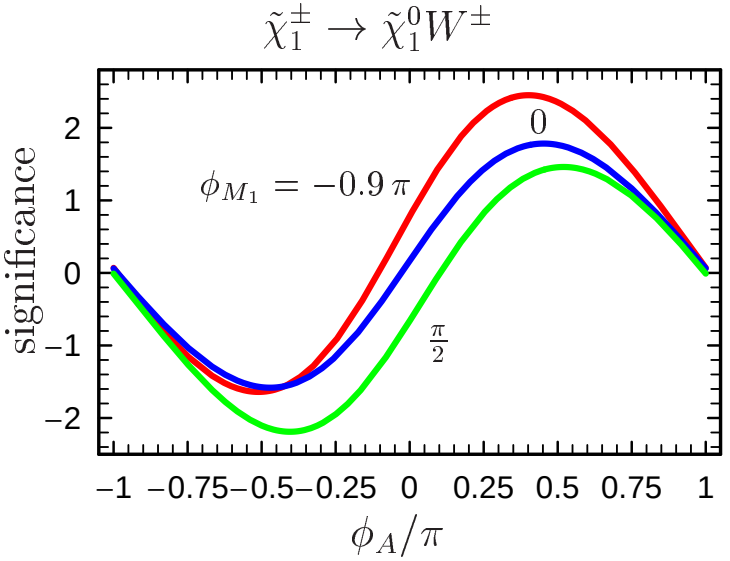

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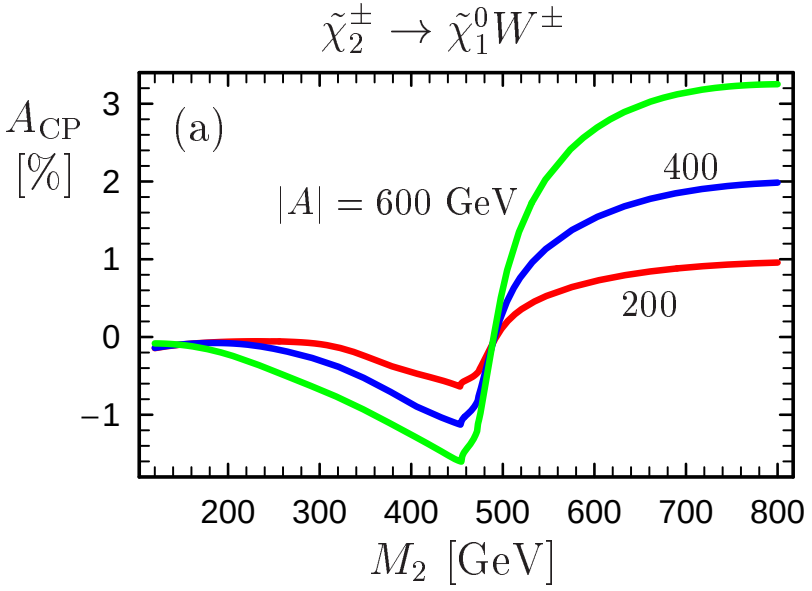

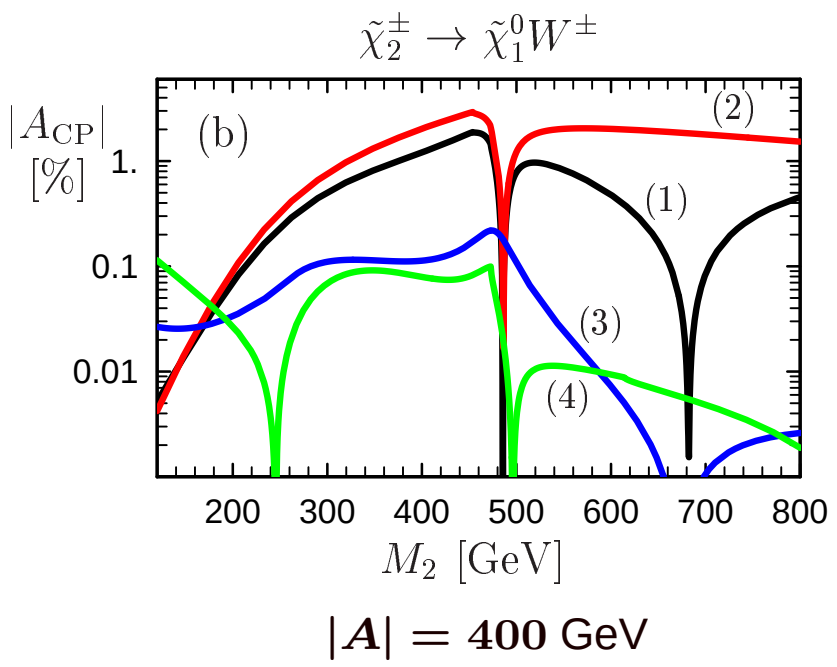

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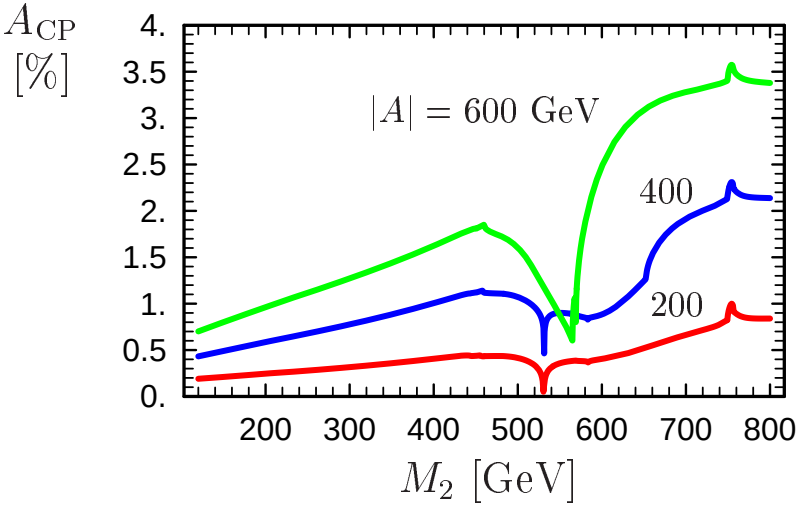
$\tilde{\chi}_2^\pm \to \tilde{\chi}_2^0 W^\pm$



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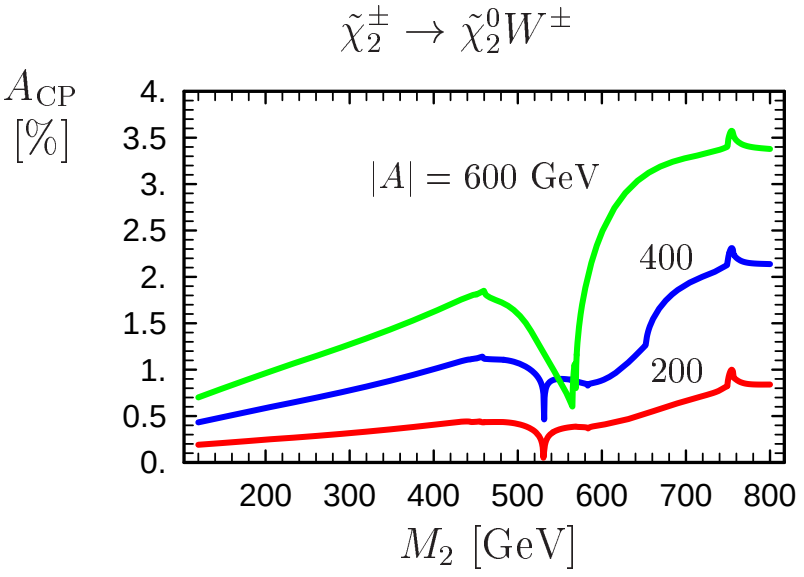

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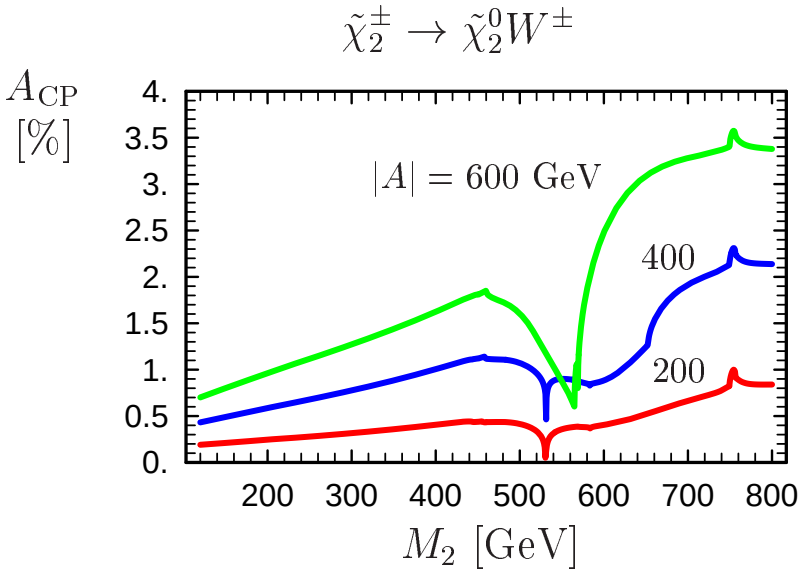

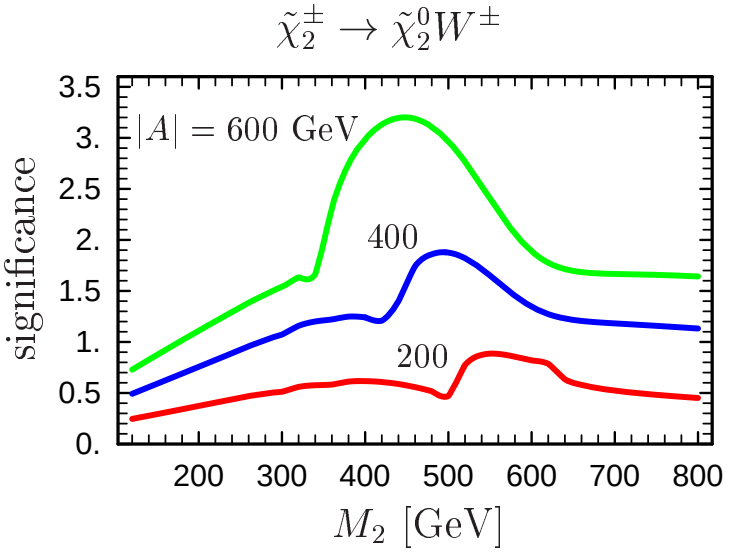

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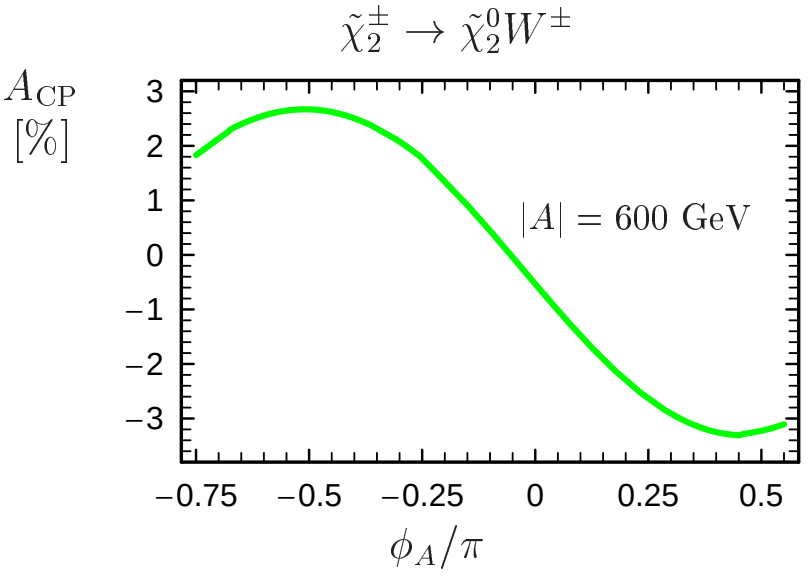

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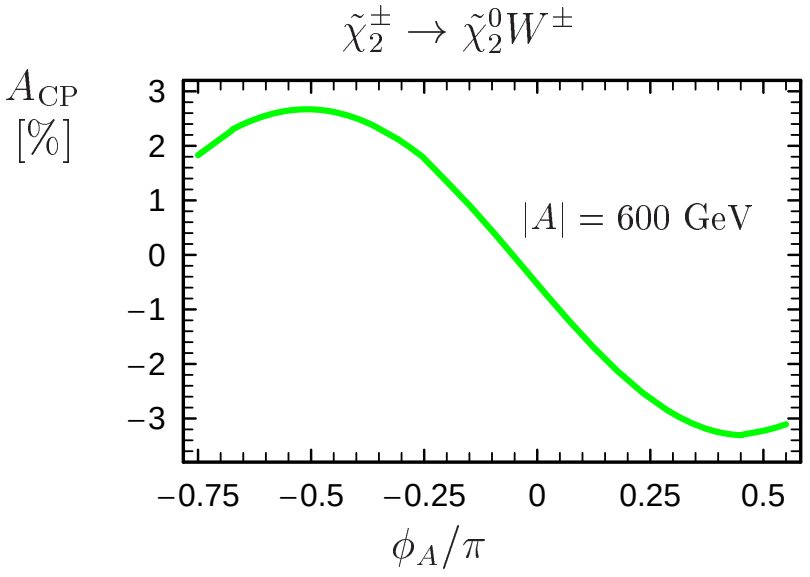
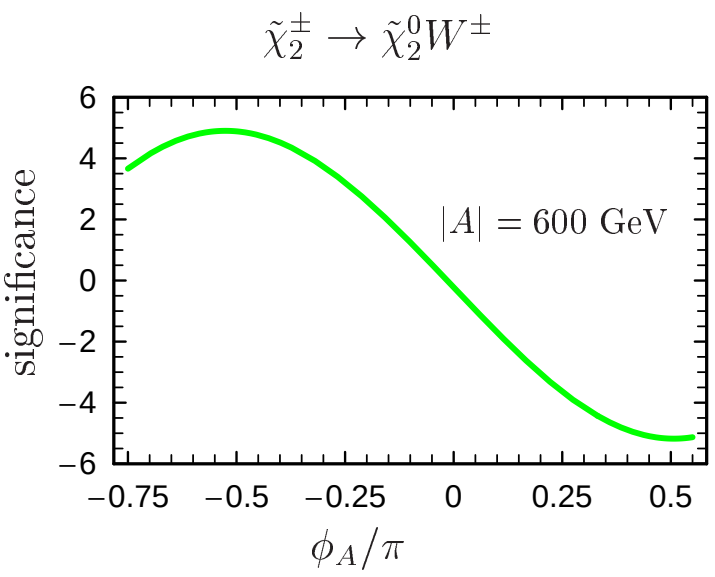
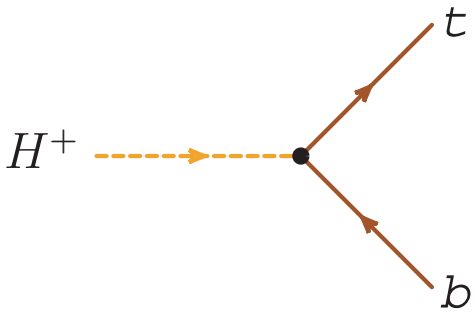


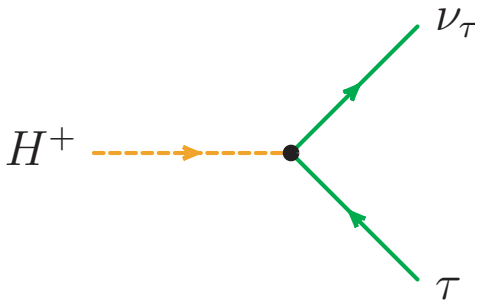


$H^+ \to t\bar{b},\ \nu_\tau \tau^+$

tree-level:



$$\sim \underbrace{h_t \cos\beta}_{y_t} P_R + \underbrace{h_b \sin\beta}_{y_b} P_L$$



$$\sim \underbrace{h_\tau \sin\beta}_{y_\tau} P_L$$

$$\Gamma^{\rm tree}(H^+ \to t\bar{b}) = \frac{3\sqrt{\lambda}}{16\pi m_{H+}^3}\left((m_{H+}^3 - m_t^2 - m_b^2)(y_t^2 + y_b^2) - 4 m_t m_b y_t y_b\right)$$

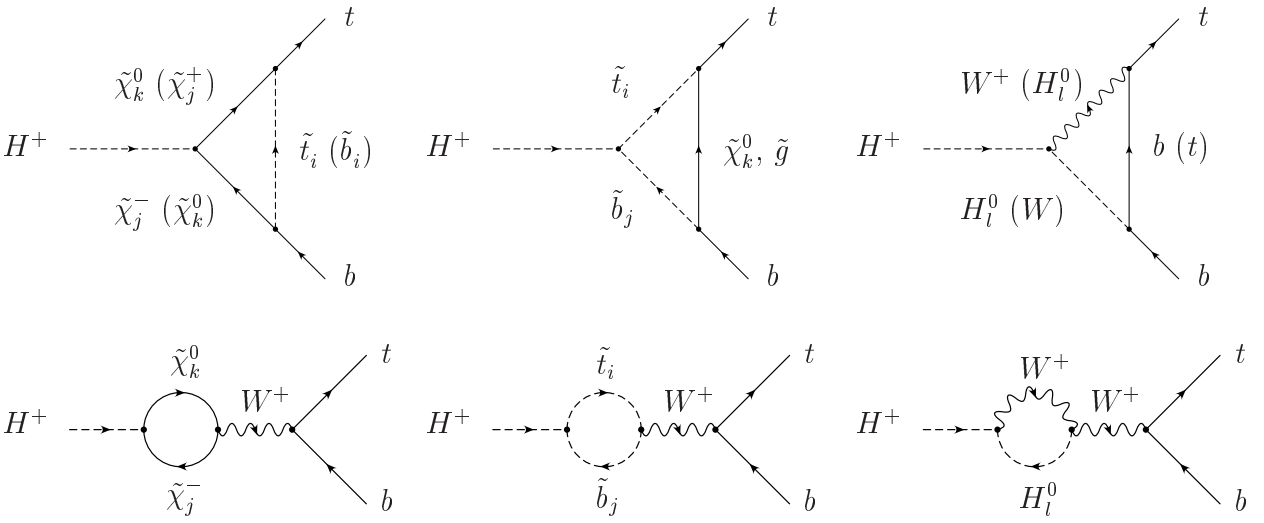
$$\Gamma^{\rm tree}(H^+ \to \nu_\tau \tau^+) = \frac{\sqrt{\lambda}}{16\pi m_{H+}^3}(m_{H+}^3 - m_\tau^2) y_\tau^2$$

$h_t = g m_t/(\sqrt{2} m_W \sin\beta)$, $h_{b,\tau} = g m_{b,\tau}/(\sqrt{2} m_W \cos\beta)$

- independent of phases.
- only two SUSY parameters: m_{H+} and $\tan\beta$

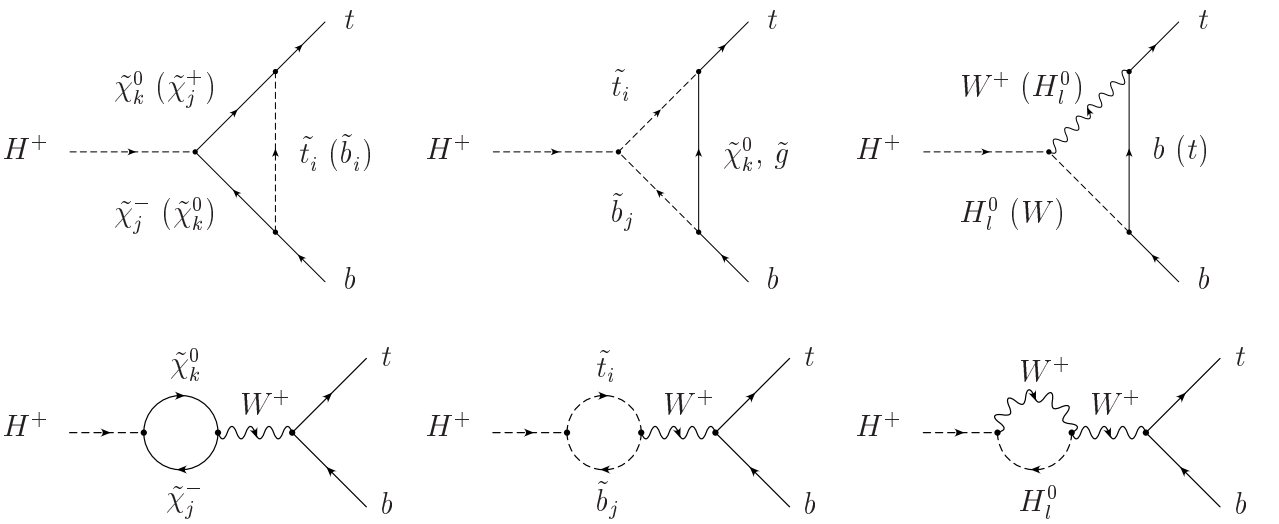
One-loop graphs

Sources for CP violation in $H^+ \to t\bar{b}$ decays at one-loop level in the MSSM with complex couplings

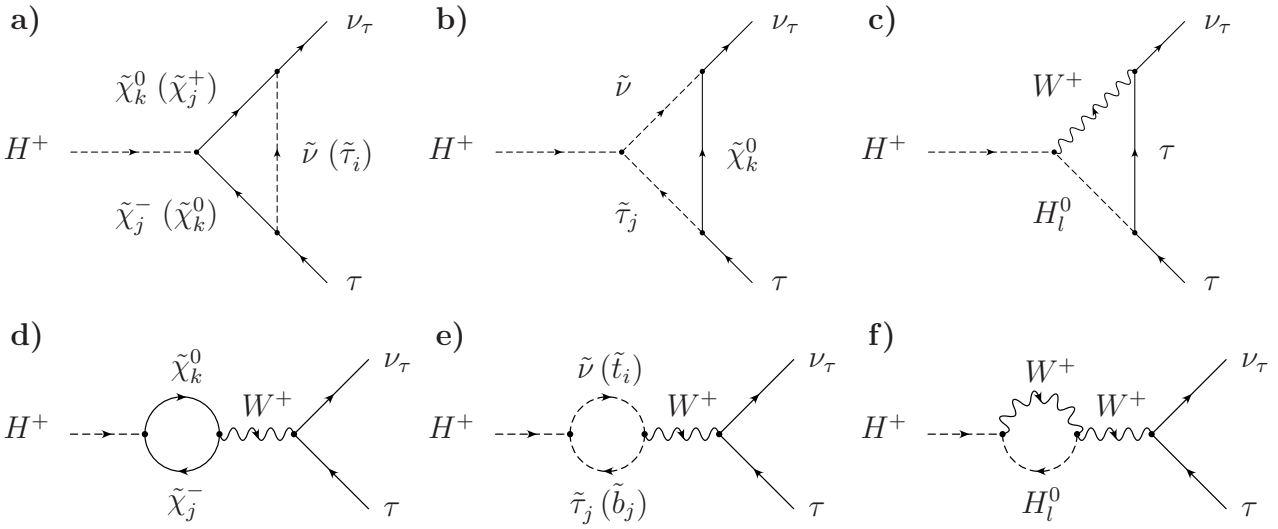


One-loop graphs

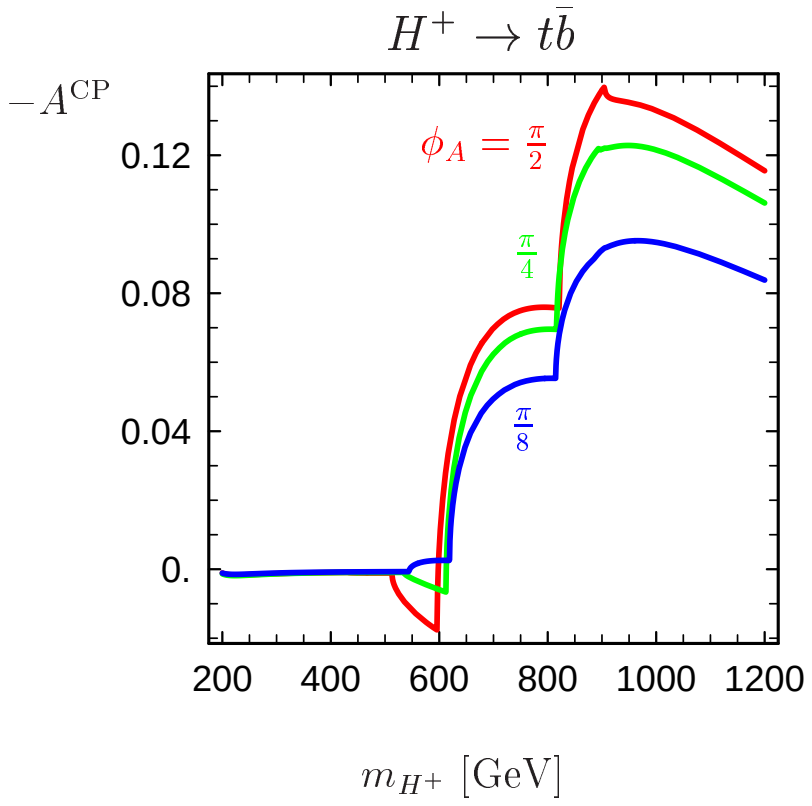
Sources for CP violation in $H^+ \to t\bar{b}$ decays at one-loop level in the MSSM with complex couplings



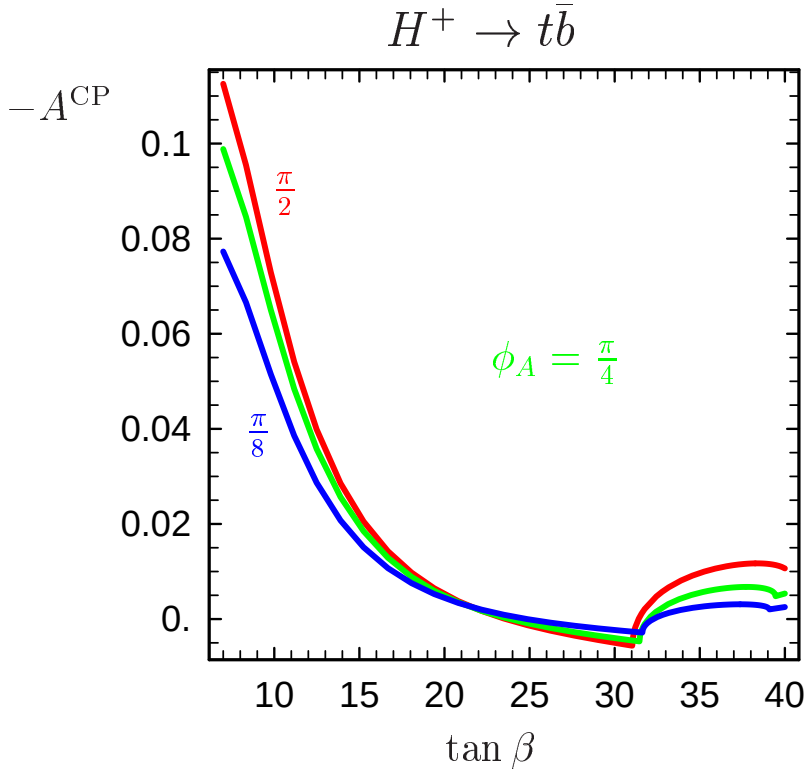
Sources for CP violation in $H^+ \to \tau\bar{\nu}_\tau$ decays at one-loop level in the MSSM with complex couplings



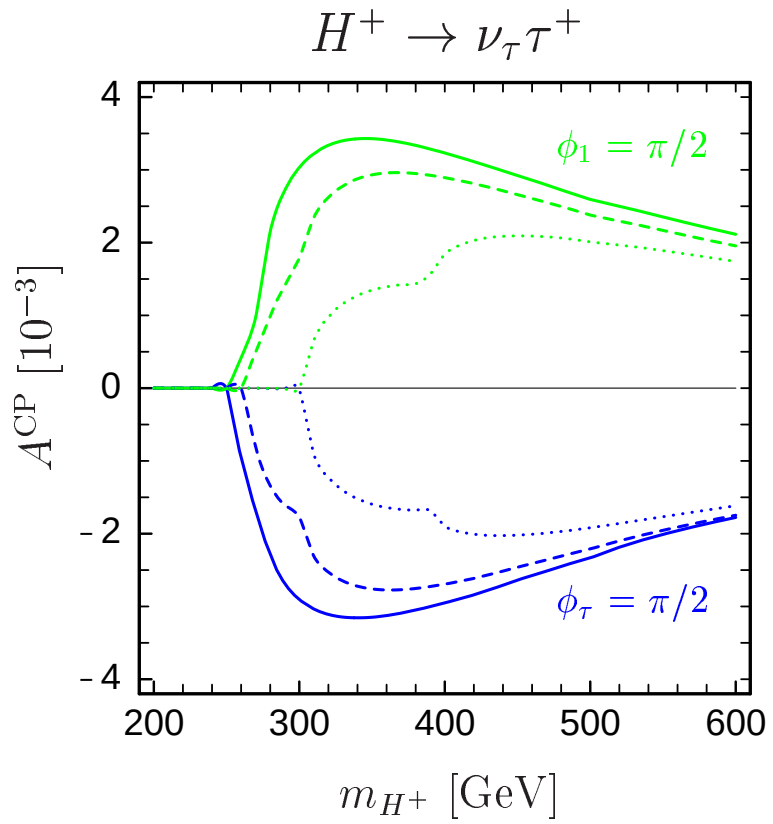
$\tan\beta = 10$, $M_2 = 300$ GeV, $\phi_{M_1} = 0$, $|\mu| = 600$ GeV, $\phi_\mu = \frac{\pi}{10}$,
$M_{\tilde{Q}} = 350$ GeV, $|A| = 600$ GeV



$M_{H^+} = 700$ GeV, $M_2 = 300$ GeV, $\phi_{M_1} = 0$, $|\mu| = 600$ GeV, $\phi_\mu = \frac{\pi}{10}$,
$M_{\tilde{Q}} = 350$ GeV, $|A| = 600$ GeV



$M_2 = 200\ \mathrm{GeV},\ \mu = 300\ \mathrm{GeV},\ M_{\tilde{E}} = M_{\tilde{L}} - 5\ \mathrm{GeV} \to m_{\tilde{\tau}} = 135\ \mathrm{GeV}$,
$|A_\tau| = 400\ \mathrm{GeV}, M_{\tilde{Q}} = 500\ \mathrm{GeV},\ M_{\tilde{U}} = 450\ \mathrm{GeV},\ M_{\tilde{D}} = 550\ \mathrm{GeV},\ A_t = A_b = -500\ \mathrm{GeV}$.



$\phi_\tau = \pi/2$, $\phi_1 = 0$ ($A_{\mathrm{CP}} < 0$), and for $\phi_1 = \pi/2$, $\phi_\tau = 0$ ($A_{\mathrm{CP}} > 0$),
$\tan\beta$ =5 (full), 10 (dashed), 30 (dotted).

Conclusions

- A_{CP} - simple measurement - only total decay rates
- SUSY loop effect – vertex and selfenergy contributions
- $\tilde{\chi}_i^\pm \to \tilde{\chi}_j^0 W^\pm$: A_{CP} order of several percent. $\tilde{\chi}_1^0$ must not be very bino like.
- $H^\pm \to tb$: A_{CP} up to $\sim 10\%$, high m_{H^+} necessary (> 500 GeV), $\tan\beta \Uparrow$ — $A_{CP} \Downarrow$ and BR $\Downarrow$, stop-sbottom channel, gluino exchange important.
- $H^\pm \to \nu_\tau \tau^\pm$: A_{CP} smaller than 0.5%, rel. low m_{H^+} (300 GeV), $\tan\beta \Uparrow$ — $A_{CP} \Downarrow$ but BR $\Uparrow$, stau-snu channel important.
- If A_{CP} becomes large, total (renormalized) one-loop result is maybe necessary.
- Combined study with production, BR and A_{CP} necessary.