# Higgs Bosons and CP Violation in the MSSM


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- **Introduction**

- **Renormalization-Group-improved effective potential for the MSSM Higgs sector with explicit CP violation**

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- **Conclusions**

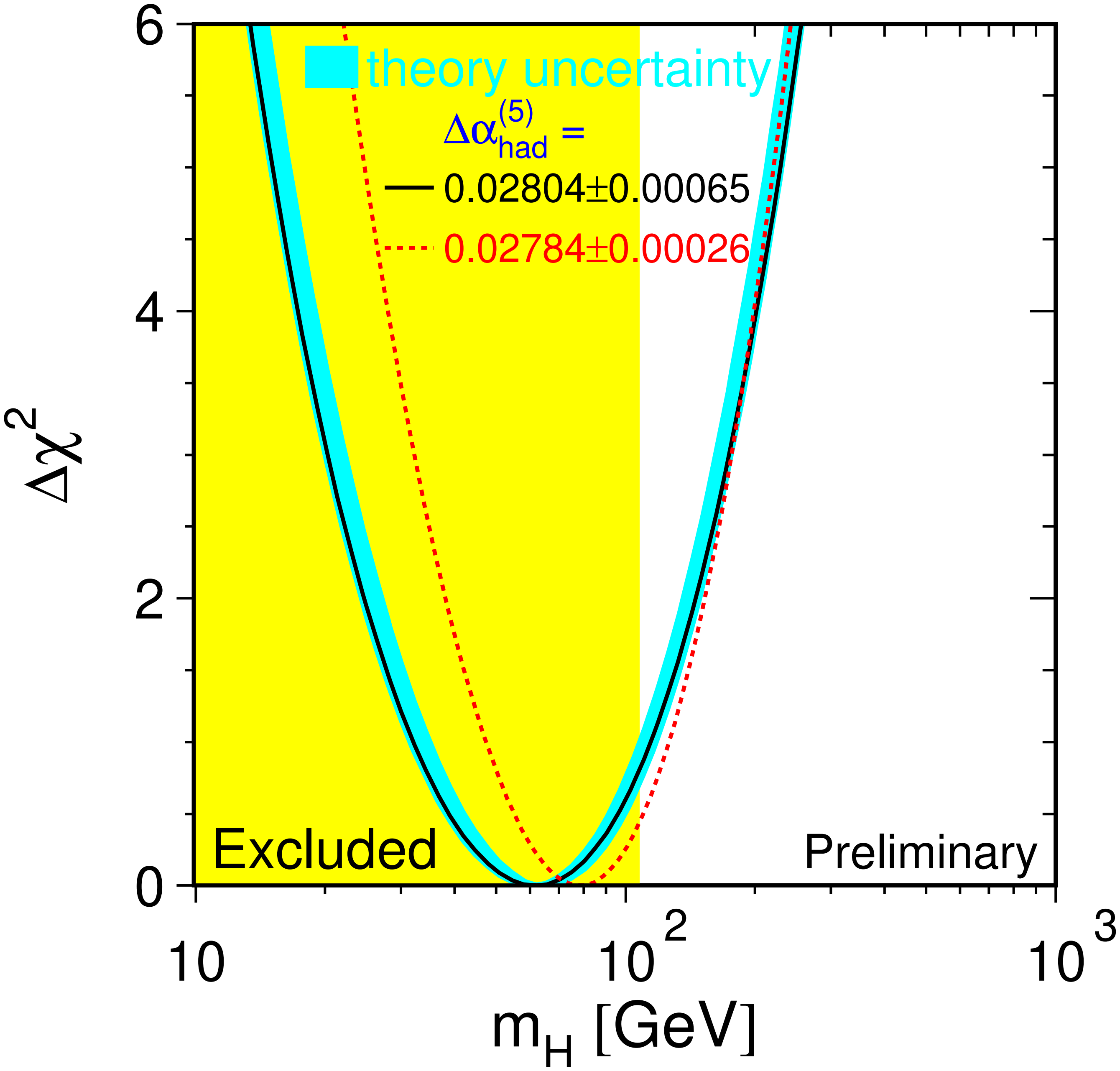
*Talk based on A.P., Phys. Rev. **D58** (1998) 096010; Phys. Lett. **B435** (1998) 88;

D. Chang, W.-Y. Keung, A.P., Phys. Rev. Lett. **82** (1999) 900;
A.P., Phys. Lett. **B471** (1999) 174; Phys. Rev. **D62** (2000) 016007;

A.P., C.E.M. Wagner, Nucl. Phys. **B553** (1999) 3;
M. Carena, J. Ellis, A.P., C.E.M. Wagner, Nucl. Phys. **B586** (2000) 92; hep-ph/0009212

## • Introduction

- SM has been vindicated to a high accuracy at LEP and the Tevatron. The only missing ingredient is the Higgs boson $H$. Direct and indirect analyses place lower and upper limits on its mass: 112 GeV $\lesssim M_H \lesssim 230$ GeV.



- Is the SM Higgs sector supersymmetric?
  - SUSY appears to be a compelling ingredient for the unification of all fundamental forces in nature including gravity, by means of supergravity and superstrings
  - SUSY provides an elegant solution to the gauge-hierarchy problem, thus giving rise to perturbative stability between the electroweak scale ($\sim 1$ TeV) and $M_{\rm Plank} \sim 10^{16}$ TeV

- Most of the predictions for the MSSM Higgs spectrum are obtained within the restricted framework of a CP-conserving Higgs potential:
  - $M_h \lesssim 110$ GeV, for $\tan\beta \lesssim 3$.
  - $M_h \lesssim 130$ GeV, for $\tan\beta \gtrsim 15$.

## CP-conserving MSSM Higgs potential: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## CP-violating MSSM Higgs potential:

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- S.-Y. Choi, M. Drees and J.-S. Lee, hep-ph/0002287.
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K.S. Babu, C. Kolda, J. March-Russell and F. Wilczek, Phys. Rev. **D59** (1999) 016004.

T. Ibrahim and P. Nath, Phys. Lett. **B418** (1998) 98, Phys. Rev. **D57** (1998) 478, **D58** (1998) 019901 (E), Phys. Rev. **D58** (1998) 111301 and hep-ph/9910553.

M. Brhlik, G.J. Good and G.L. Kane, Phys. Rev. **D59** (1999) 115004; M. Brhlik, L. Everett, G.L. Kane and J. Lykken, Phys. Rev. Lett. **83** (1999) 2124 and hep-ph/9908326.

B. Grzadkowski, J.F. Gunion and J. Kalinowski, Phys. Rev. **D60** (1999) 075011.

A. Dedes and S. Moretti, Phys. Rev. Lett. **84** (2000) 22 and Nucl. Phys. **B576** (2000) 29.

S.Y. Choi and M. Drees, Phys. Rev. Lett. **81** (1998) 5509.

S. Baek and P. Ko, Phys. Rev. Lett. **83** (1999) 488, Phys. Lett. **B462** (1999) 95 and hep-ph/9907572.

K. Freese and P. Gondolo, hep-ph/9908390; T. Falk, A. Frestl and K. Olive, hep-ph/9908311.

⋮

## • RG-improved effective potential for the MSSM Higgs sector with explicit CP violation

Tree-level Lagrangian of the MSSM Higgs potential:

$$\begin{aligned}
\mathcal{L}_V^0 \;=\; & \mu_1^2(\Phi_1^\dagger\Phi_1) + \mu_2^2(\Phi_2^\dagger\Phi_2) + m_{12}^2(\Phi_1^\dagger\Phi_2) \\
& + m_{12}^{*2}(\Phi_2^\dagger\Phi_1) + \lambda_1(\Phi_1^\dagger\Phi_1)^2 + \lambda_2(\Phi_2^\dagger\Phi_2)^2 \\
& + \lambda_3(\Phi_1^\dagger\Phi_1)(\Phi_2^\dagger\Phi_2) + \lambda_4(\Phi_1^\dagger\Phi_2)(\Phi_2^\dagger\Phi_1)\,,
\end{aligned}$$

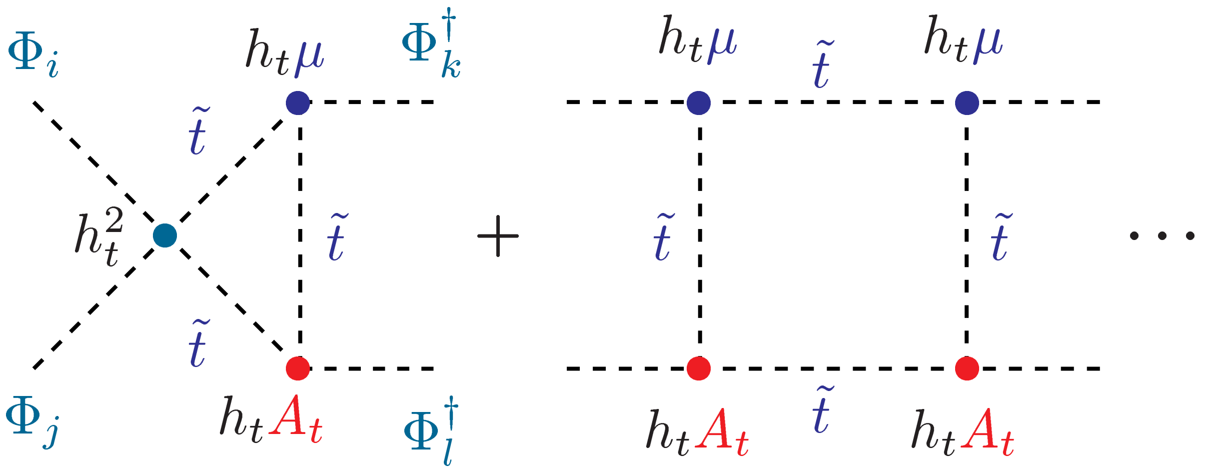
with

$$\begin{aligned}
m_{12}^2 \;&=\; B\mu\,, \quad \lambda_1 = \lambda_2 = -\frac{1}{8}(g_w^2 + g'^2)\,, \\
\lambda_3 \;&=\; -\frac{1}{4}(g_w^2 - g'^2)\,, \quad \lambda_4 = \frac{1}{2}g_w^2\,.
\end{aligned}$$

Since the CP-odd phase of $m_{12}^2$ can be absorbed into the definition of $\Phi_2$, the MSSM Higgs potential is invariant under CP at the tree level.

$\Rightarrow$ **CP violation in the Higgs sector can be induced through loop effects at the observable level**

**One-loop CP-violating contributions to the effective Higgs potential**:




$$\subset \quad \mathcal{L}_V(\Phi_1, \Phi_2)$$

The one-loop CP-violating effects are proportional to the rephasing-invariant combinations:

$$\boxed{\mathrm{Im}\,(\, m_{12}^{2*}\, \mu\, A_{t,b}\,) \;\neq\; 0}$$

## **Minimization of the effective Higgs potential $\mathcal{L}_V(\Phi_1, \Phi_2)$**

Linear decomposition of the Higgs fields:

$$\boldsymbol{\Phi_1} = \left[ \begin{array}{c} \phi_1^+ \\ \frac{1}{\sqrt{2}}(v_1 + \phi_1 + i a_1) \end{array} \right], \quad \boldsymbol{\Phi_2} = e^{i\xi} \left[ \begin{array}{c} \phi_2^+ \\ \frac{1}{\sqrt{2}}(v_2 + \phi_2 + i a_2) \end{array} \right]$$

Minimization conditions:

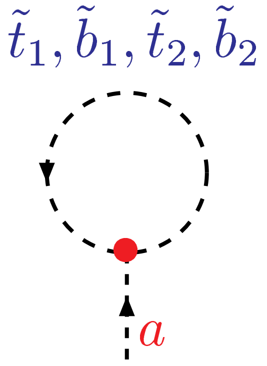
CP-even: $\quad T_{\phi_1(\phi_2)} \equiv \left\langle \dfrac{\partial \mathcal{L}_V}{\partial \phi_{1(2)}} \right\rangle = 0$

CP-odd: $\quad T_a \equiv \left\langle \dfrac{\partial \mathcal{L}_V}{\partial a} \right\rangle = 0\,,$

with $a = \cos\beta\, a_1 + \sin\beta\, a_2$; $\tan\beta = v_2/v_1$.

Vanishing of the CP-odd tadpole parameter:

$$-v\, \mathrm{Im}\,(\, m_{12}^2\, e^{i\xi}\,) \quad + $$




$$= \quad 0$$

$\xi$ can be absorbed into the CT of $m_{12}^2$, $\mathrm{Im}\,(\,\delta m_{12}^2\,)$ **!**

$\Rightarrow \xi = 0$ scheme of renormalization

## One-loop effective Higgs-boson mass matrices

Charged-Higgs-boson mass matrix:

$$(\mathcal{M}^2_{\pm})_{ij} \;=\; -\left\langle \frac{\partial^2 \mathcal{L}_V}{\partial\phi_i^+\,\partial\phi_j^-} \right\rangle , \quad i,j=1,2$$

Since $\det\,(\mathcal{M}^2_{\pm})=0$, the charged-Higgs-boson mass is given by

$$\mathcal{M}^2_{H^+} \;=\; -\,\frac{\langle(\mathcal{M}^2_{\pm})_{12}\rangle}{\sin\beta\,\cos\beta}$$

Neutral-Higgs-boson mass matrix:

$$\mathcal{M}^2_0 \;=\; \left( \begin{array}{cc} \mathcal{M}^2_S & \mathcal{M}^2_{SP} \\ (\mathcal{M}^2_{SP})^T & \mathcal{M}^2_P \end{array} \right) ,$$

in the weak basis $\{\phi_1,\phi_2,a_1,a_2\}$.

CP-conserving submatrices:

$$(\mathcal{M}^2_S)_{ij} = -\left\langle \frac{\partial^2 \mathcal{L}_V}{\partial\phi_i\,\partial\phi_j} \right\rangle , \quad (\mathcal{M}^2_P)_{ij} = -\left\langle \frac{\partial^2 \mathcal{L}_V}{\partial a_i\,\partial a_j} \right\rangle$$

CP-violating submatrix:

$$(\mathcal{M}^2_{SP})_{ij} = -\left\langle \frac{\partial^2 \mathcal{L}_V}{\partial\phi_i\,\partial a_j} \right\rangle$$

## RG-improved Higgs-boson mass matrices

The RG-improved Higgs-boson mass matrix $\mathcal{M}^2(m_t)$ may be written conceptually as a sum of two terms:

$$\mathcal{M}^2(m_t) \;=\; \overline{\mathcal{M}}^2(m_t) \;+\; \mathcal{M}^{2,\mathrm{th}}(m_t)$$

- $\overline{\mathcal{M}}^2(m_t)$ is the two-loop Born-improved mass matrix that contains the genuine logarithmic contributions determining the whole scale dependence of the one-loop effective potential:

  $$\overline{\mathcal{M}}^2(m_t) \;=\; \mathcal{M}^{2\,(0)}\left[\mathrm{Re}\,\bar{m}^2_{12}(m_t), \bar{\lambda}_i(m_t)\right],$$

  with $\mathrm{Re}\,\bar{m}^2_{12} = \mathrm{Re}\,m^2_{12} + \mathrm{Re}\,m^{2(1)}_{12} + \mathrm{Re}\,m^{2(2)}_{12}$ and $\bar{\lambda}_i \;=\; \lambda_i + \lambda_i^{(1)} + \lambda_i^{(2)}$.

- $\mathcal{M}^{2,\mathrm{th}}(m_t)$ describes the threshold effect of the decoupling of the heavier stop and sbottom squarks:

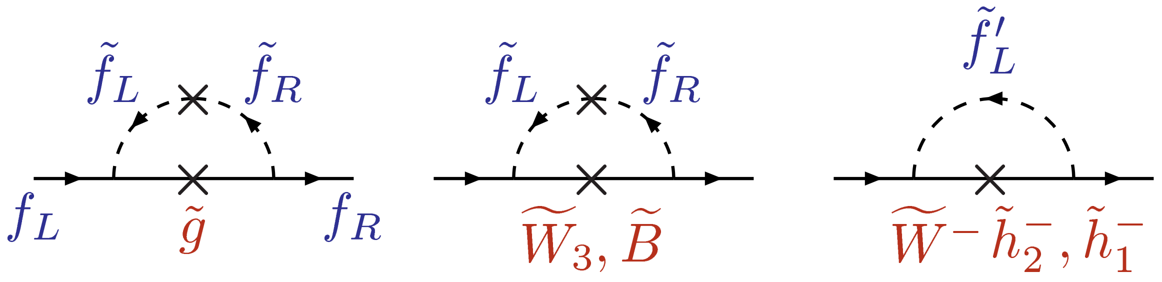
  $$\mathcal{M}^{2,\mathrm{th}}_{ij}(m_t) \;=\; \Delta\mathcal{M}^2_{ij}(Q_{tb})\,\xi_i^{-1}(m_t)\,\xi_j^{-1}(m_t)\,,$$

  where $Q_{tb}$ is the decoupling scale, $\xi_{1,2}$ are the Higgs-boson anomalous-dimension factors, and $\Delta\mathcal{M}^2(Q_{tb}) \equiv \mathcal{M}^{2,\mathrm{th}}(Q_{tb})$, with

  $$\Delta\mathcal{M}^2(Q_{tb}) \;=\; \mathcal{M}^{2\,(1)}(Q_{tb}) - \mathcal{M}^{2\,(0)}\left[\mathrm{Re}\,m^{2(1)}_{12}(Q_{tb}), \lambda_i^{(1)}(Q_{tb})\right]$$

## • Electric Dipole Moment constraints

One-loop contributions to the EDMs:




with $f = e,\ u,\ d$.

Crude estimate of the one-loop contributions to the neutron and electron EDMs:

$$\left(\frac{d_f}{e}\right)^{1-\mathrm{loop}} \sim (10^{-25}\ \mathrm{cm}) \times \frac{\{\mathrm{Im}\,\mu,\ \mathrm{Im}\,A_f\}}{\max(M_{\tilde{f}}, m_\lambda)} \times \left(\frac{1\ \mathrm{TeV}}{\max(M_{\tilde{f}}, m_\lambda)}\right)^2 \left(\frac{m_f}{10\ \mathrm{MeV}}\right)$$

with $\lambda = \tilde{g}, \widetilde{W}^-, \tilde{h}^-_{1,2}$.

Schemes for resolving the one-loop CP crisis:

- $\mathrm{Im}\,\mu/|\mu|,\ \mathrm{Im}\,A_f/|A_f| \lesssim 10^{-2}$, with $M_{\tilde{f}}, m_\lambda \sim 200$ GeV
- CP phases $\sim 1$, <u>but</u> $M_{\tilde{f}} \gtrsim 1$ TeV, for $\tilde{f} = \tilde{u}, \tilde{d}, \tilde{e}, \tilde{\nu}_L$
- Cancellations between the different EDM terms

**Contributions to $e$ and $n$ EDMs:**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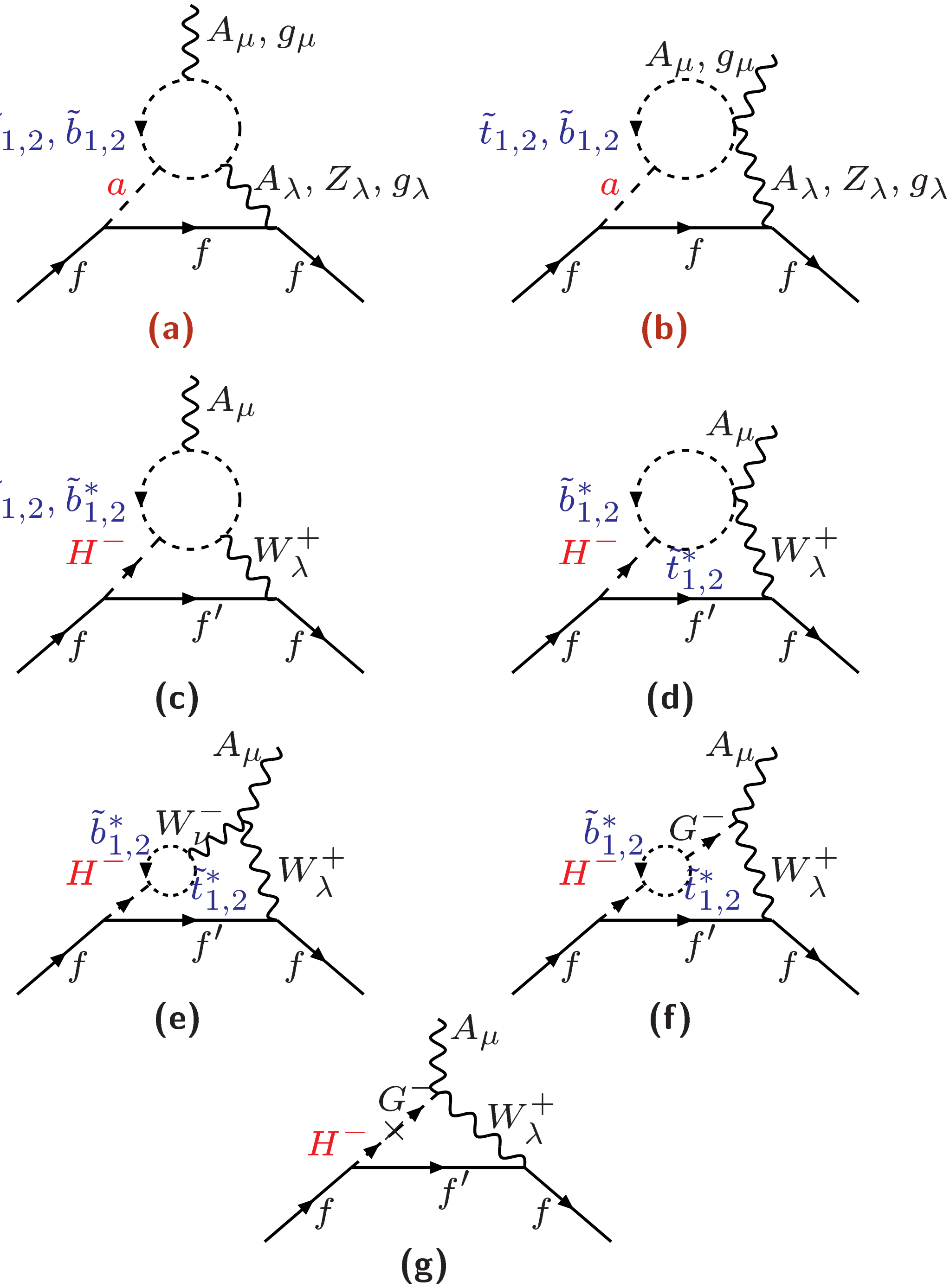
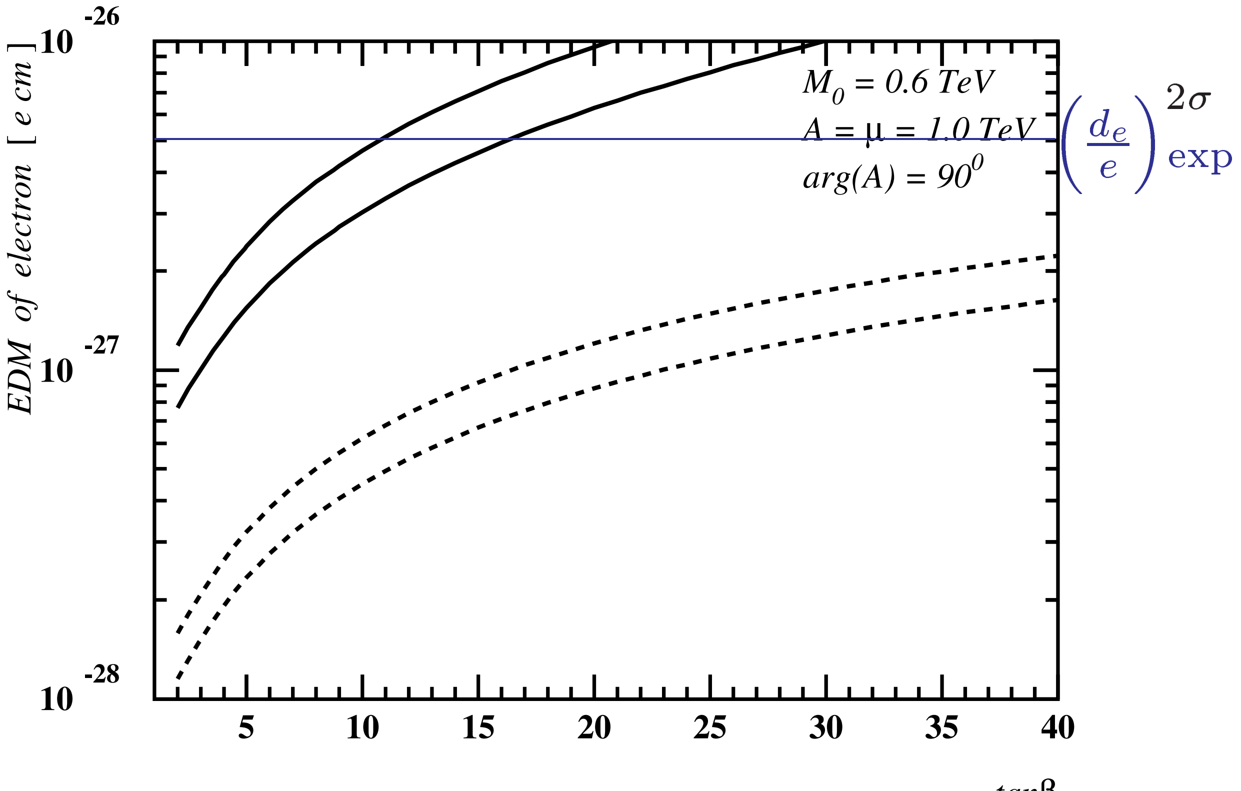
- A. Pilaftsis, hep-ph/9912253.

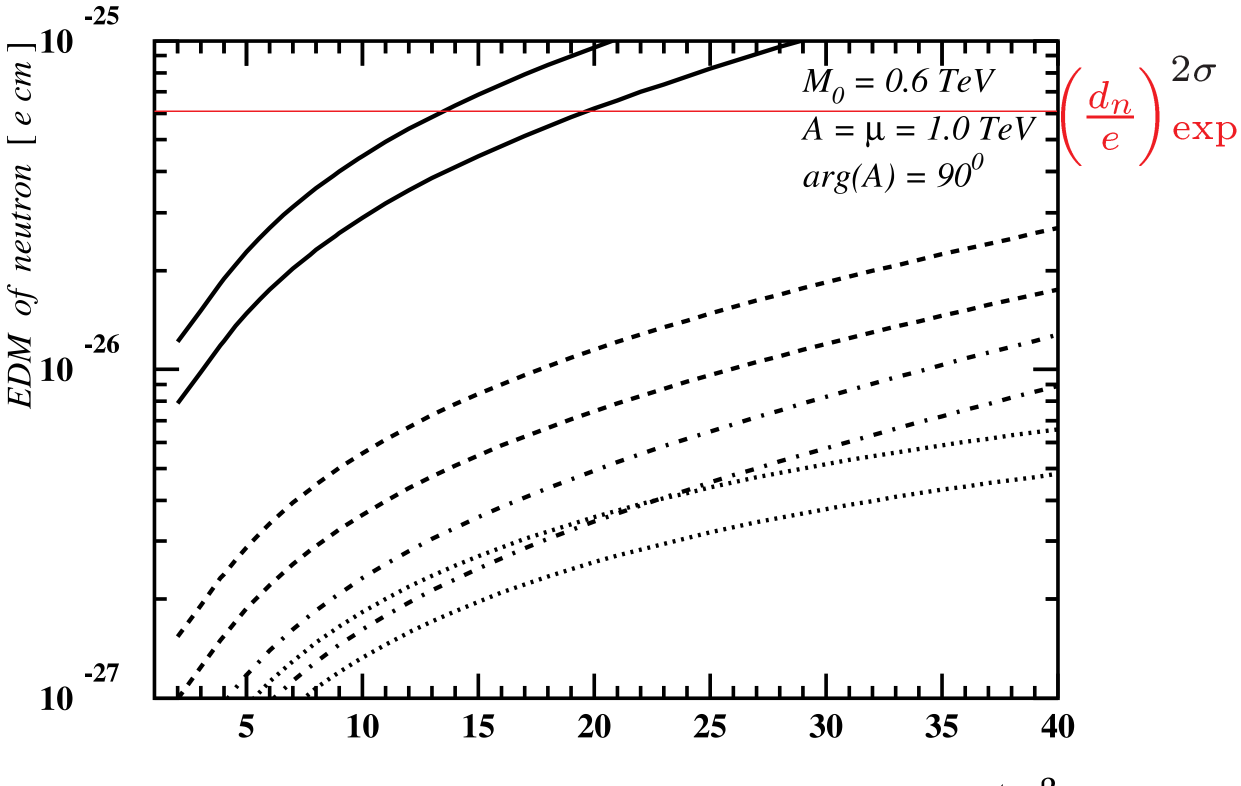
**Higgs-boson two-loop contributions to EDM and CEDM of a fermion in the Feynman–'t Hooft gauge;** $f'$ represents the conjugate fermion of $f$ under $T_z^f$ [ D. Chang, W.-Y. Keung, A.P., Phys. Rev. Lett. **82** (1999) 900; A.P., Phys. Lett. **B471** (1999) 174. ]



$M_a = \ 150, \ 300$ GeV

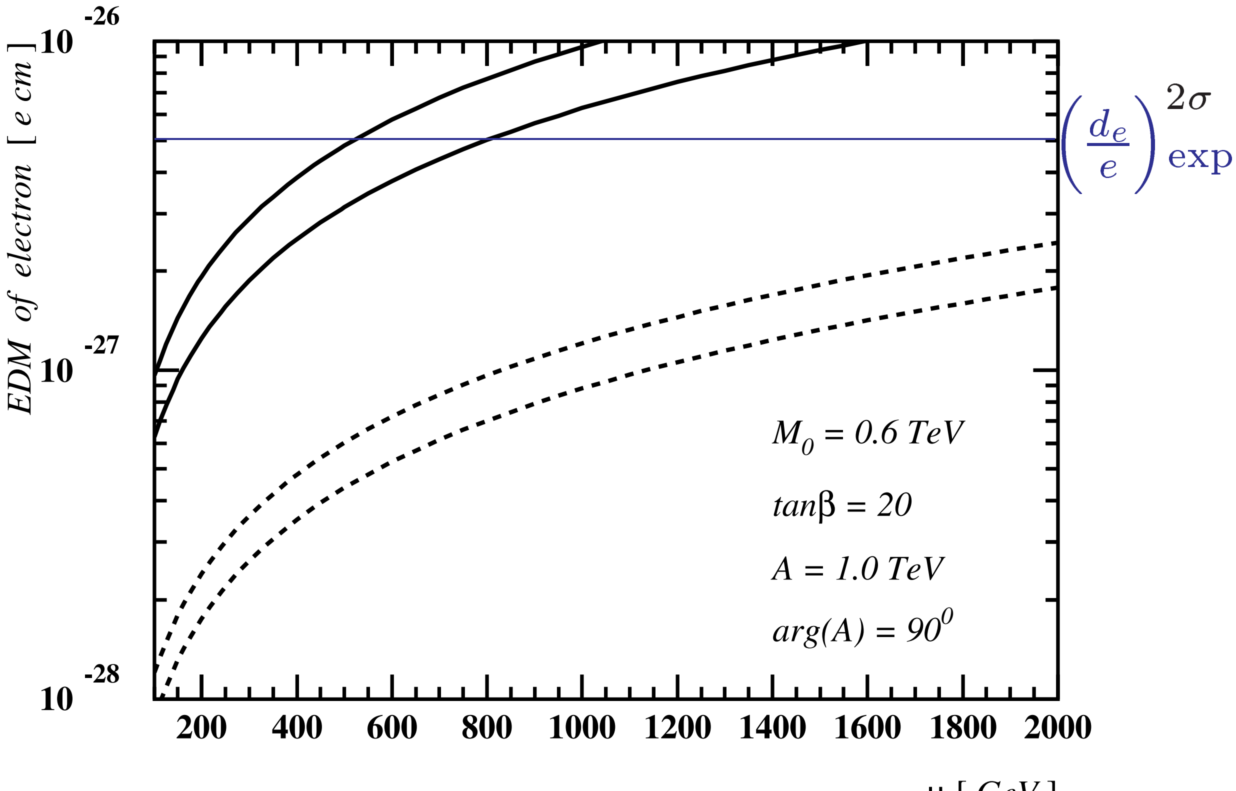



**(a)**

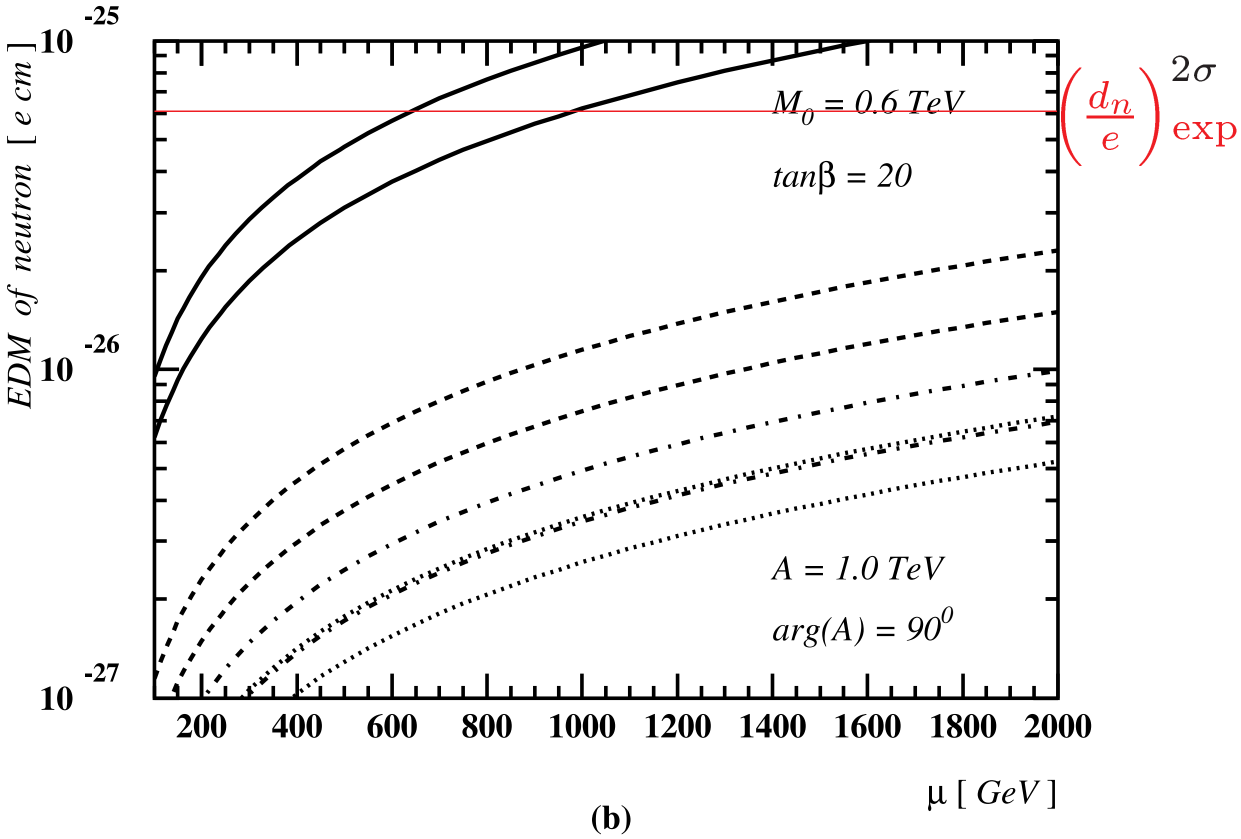



**(b)**

$M_a = 150, \ 300$ GeV




(a)

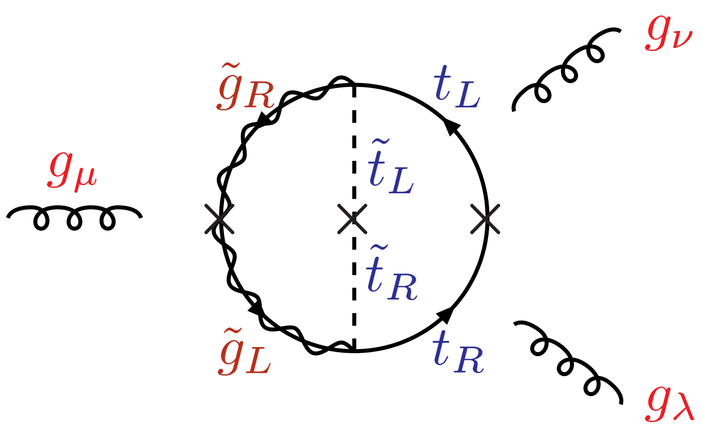



(b)

## Three-loop contribution to EDMs

Induced by Weinberg's three-gluon operator:

$$\mathcal{L}_{3g} = -\frac{1}{3!}\, d_{3g}\, f^{abc}\, \widetilde{G}^{a\,\mu}_{\nu}\, G^{b\,\nu}_{\lambda}\, G^{c\,\lambda}_{\mu}$$




An estimate based on naive dimensional analysis gives

$$d_{3g} \sim \frac{g_s^3}{4\pi}\,\frac{3\alpha_s^2}{16\pi^2}\,\frac{m_{\tilde{g}}\, m_t^2\, \mathrm{Im}\,(A_t - \mu^*\cot\beta)}{m_{\tilde{g}}^4\, M_{\tilde{t}}^2}$$

and

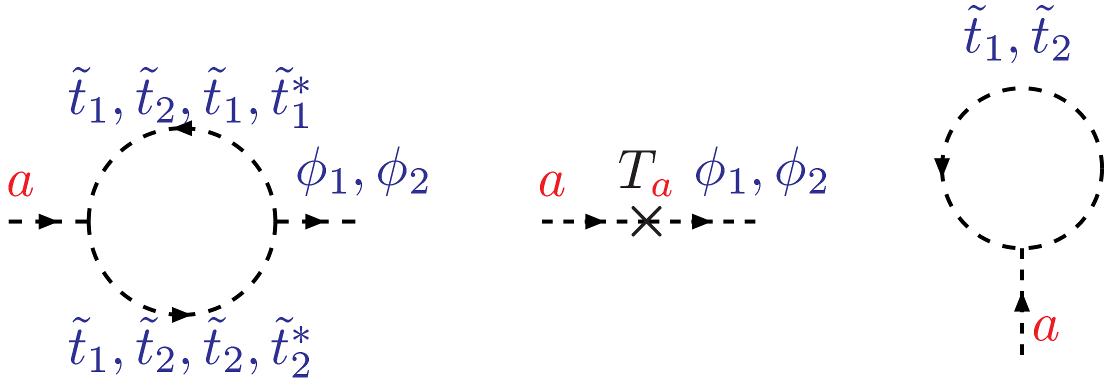
$$\left(\frac{d_n}{e}\right)^{3g} \sim (10^{-26}\ \mathrm{cm}) \times \left(\frac{0.5\ \mathrm{TeV}}{m_{\tilde{g}}}\right)^2 \frac{m_t^2\, \mathrm{Im}\,(A_t - \mu^*\cot\beta)}{M_{\tilde{t}}^2\, m_{\tilde{g}}}$$

EDM constraint: $m_{\tilde{g}} \gtrsim 400$ GeV.

**• Phenomenological implications for direct Higgs-boson searches at LEP2 and the Tevatron**

Two major effects of CP violation on the Higgs sector:
– CP-violating self-energy effects
– CP-violating vertex effects

**– CP-violating self-energy effects:**




$$\begin{aligned}\mathcal{M}^2_{SP} \quad &\sim \quad \frac{m_t^4}{v^2}\,\frac{\mathrm{Im}\,(\mu A_t)}{32\pi^2 Q_t^2}\\ &\times \left(6,\ \frac{|A_t|^2}{Q_t^2},\ \frac{|\mu|^2}{\tan\beta\ Q_t^2},\ \frac{2\mathrm{Re}\,(\mu A_t)}{Q_t^2}\right)\\ &\lesssim \quad (100\ \mathrm{GeV})^2\end{aligned}$$

**The mixing of the three neutral Higgs bosons**

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

$O$ is a $3\times 3$ orthogonal matrix which also describes the mixing of the Higgs bosons with different CP parities.

In analogy to the case of neutrinos and quarks, Higgs bosons with mixed CP parities are ordered according to their weights:

$$\boxed{M_{H_1} \leq M_{H_2} \leq M_{H_3}}$$

At the one-loop level, $M_{H_i}$ (with $i = 1, 2, 3$) and $O$ are analytically determined by the input parameters:

$$M_{H^+}(m_t)\,, \quad \tan\beta(m_t)\,,$$

$$\mu(Q_{tb})\,, \quad A_t(Q_{tb})\,, \quad A_b(Q_{tb})\,,$$

$$\widetilde{M}_Q^2(Q_{tb})\,, \quad \widetilde{M}_t^2(Q_{tb})\,, \quad \widetilde{M}_b^2(Q_{tb})\,.$$

## CP-conserving versus CP-violating MSSM parameters:

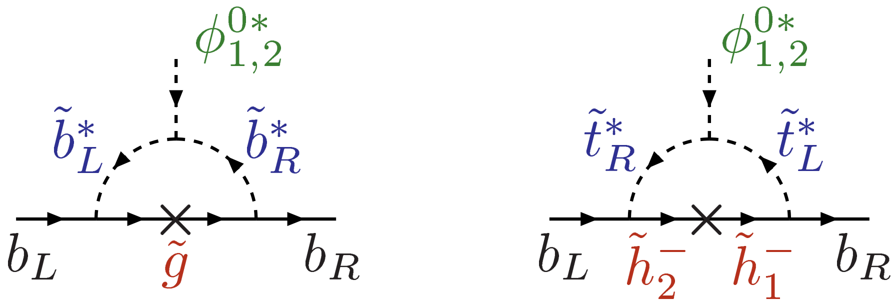
| CP-conserving: | CP-violating: |
|---|---|
| $\tan\beta$ | $\tan\beta$ , with $\xi = 0$ |
| $\widetilde{M}_Q^2$ , $\widetilde{M}_t^2$ , $\widetilde{M}_b^2$ | $\widetilde{M}_Q^2$ , $\widetilde{M}_t^2$ , $\widetilde{M}_b^2$ |
| $\mu$ | $\lvert\mu\rvert$ , $\arg(\mu)$ |
| $A_{t,b}$ | $\lvert A_{t,b}\rvert$ , $\arg(A_{t,b})$ |
| $M_A$ | $M_{H^+}$ |

At two loops:

| | |
|---|---|
| $m_{\tilde{g}}$ | $\lvert m_{\tilde{g}}\rvert$ and $\arg(m_{\tilde{g}})$ |

## – CP-violating vertex effects:

**Effective $H_1 bb$-coupling**




$$-\mathcal{L}^{\rm eff}_{\phi^0 \bar{b} b} = (h_b + \delta h_b)\, \phi_1^{0*}\, \bar{b}_R b_L + \Delta h_b\, \phi_2^{0*}\, \bar{b}_R b_L \; + \; \text{h.c.}$$

with

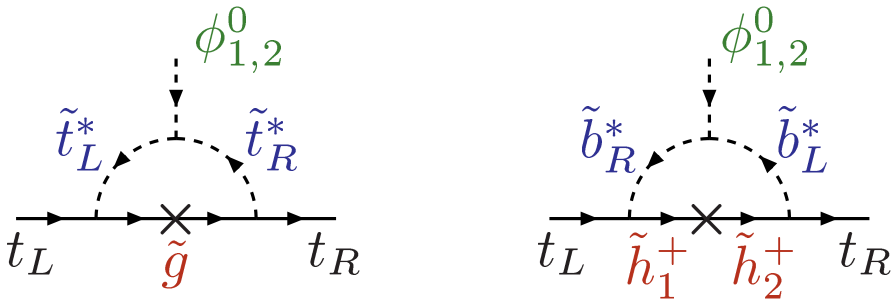
$$\frac{\delta h_b}{h_b} \sim -\frac{2\alpha_s}{3\pi} \frac{m^*_{\tilde{g}} A_b}{\max\,(Q_b^2, |m_{\tilde{g}}|^2)} - \frac{|h_t|^2}{16\pi^2} \frac{|\mu|^2}{\max\,(Q_t^2, |\mu|^2)}$$

$$\frac{\Delta h_b}{h_b} \sim \frac{2\alpha_s}{3\pi} \frac{m^*_{\tilde{g}} \mu^*}{\max\,(Q_b^2, |m_{\tilde{g}}|^2)} + \frac{|h_t|^2}{16\pi^2} \frac{A_t^* \mu^*}{\max\,(Q_t^2, |\mu|^2)}$$

and

$$h_b = \frac{g_w m_b}{\sqrt{2} M_W \cos\beta\, [\, 1 + \delta h_b / h_b + (\Delta h_b / h_b) \tan\beta\, ]}$$

## Effective $H_1 tt$-coupling




$$-\mathcal{L}^{\rm eff}_{\phi^0 \bar{t} t} = \Delta h_t\, \phi^0_1\, \bar{t}_R t_L + (h_t + \delta h_t)\, \phi^0_2\, \bar{t}_R t_L \;+\; \text{h.c.}$$

with

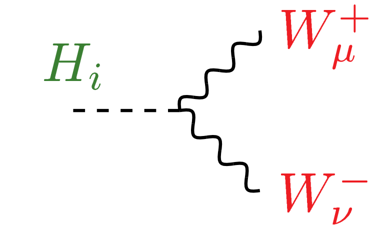
$$\frac{\Delta h_t}{h_t} \sim \frac{2\alpha_s}{3\pi} \frac{m^*_{\tilde{g}} \mu^*}{\max\left(Q_t^2, |m_{\tilde{g}}|^2\right)} + \frac{|h_b|^2}{16\pi^2} \frac{A^*_b \mu^*}{\max\left(Q_b^2, |\mu|^2\right)}$$

$$\frac{\delta h_t}{h_t} \sim -\frac{2\alpha_s}{3\pi} \frac{m^*_{\tilde{g}} A_t}{\max\left(Q_t^2, |m_{\tilde{g}}|^2\right)} - \frac{|h_b|^2}{16\pi^2} \frac{|\mu|^2}{\max\left(Q_b^2, |\mu|^2\right)}$$

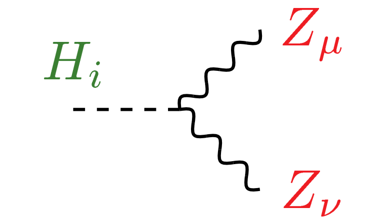
and

$$h_t = \frac{g_w m_t}{\sqrt{2} M_W \sin\beta\, [\, 1 + \delta h_t / h_t + (\Delta h_t / h_t) \cot\beta\, ]}$$

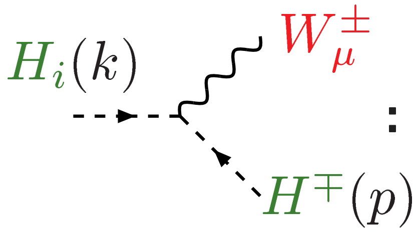
## Effective Higgs-boson couplings to gauge bosons and fermions



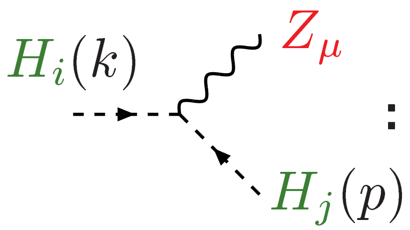

$$: \quad i g_w M_W \left( c_\beta O_{1i} + s_\beta O_{2i} \right) g_{\mu\nu}$$



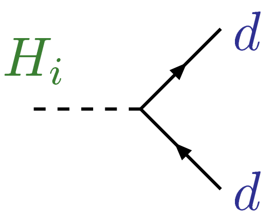

$$: \quad i g_w \frac{M_W^2}{M_Z} \left( c_\beta O_{1i} + s_\beta O_{2i} \right) g_{\mu\nu}$$



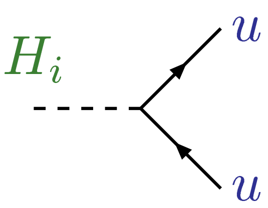

$$: \quad \pm \tfrac{i}{2} g_w \left( c_\beta O_{2i} - s_\beta O_{1i} + i O_{3i} \right) (p-k)_\mu$$



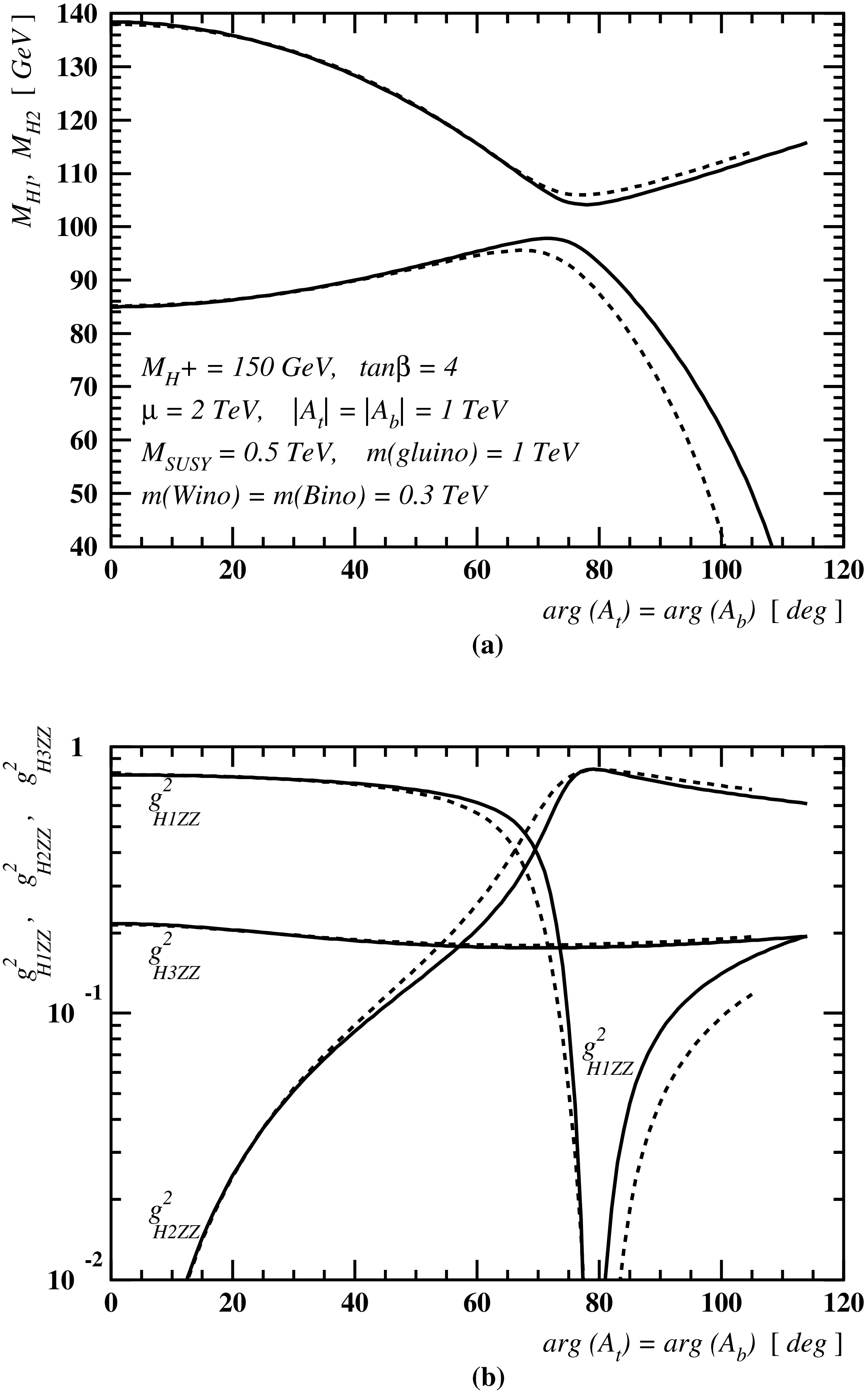

$$: \quad -\frac{i g_w M_Z}{2 M_W} \Big[ O_{3i} \left( c_\beta O_{2j} - s_\beta O_{1j} \right) - (i \leftrightarrow j) \Big] (p-k)_\mu$$




$$: \quad -\frac{i g_w m_d}{2 M_W \, c_\beta} \left( O_{1i} - i s_\beta \, O_{3i} \, \gamma_5 \right) + \cdots$$




$$: \quad -\frac{i g_w m_u}{2 M_W \, s_\beta} \left( O_{2i} - i c_\beta \, O_{3i} \, \gamma_5 \right) + \cdots$$



140
130
120
110
100
90
80
70
60
50
40
0
20
40
60
80
100
120
M_H1, M_H2 [ GeV ]
M_H+ = 150 GeV, tanβ = 4
μ = 2 TeV, |A_t| = |A_b| = 1 TeV
M_SUSY = 0.5 TeV, m(gluino) = 1 TeV
m(Wino) = m(Bino) = 0.3 TeV
arg (A_t) = arg (A_b) [ deg ]
(a)
1
10^-1
10^-2
g^2_H1ZZ, g^2_H2ZZ, g^2_H3ZZ
g^2_H1ZZ
g^2_H3ZZ
g^2_H2ZZ
g^2_H1ZZ
arg (A_t) = arg (A_b) [ deg ]
(b)

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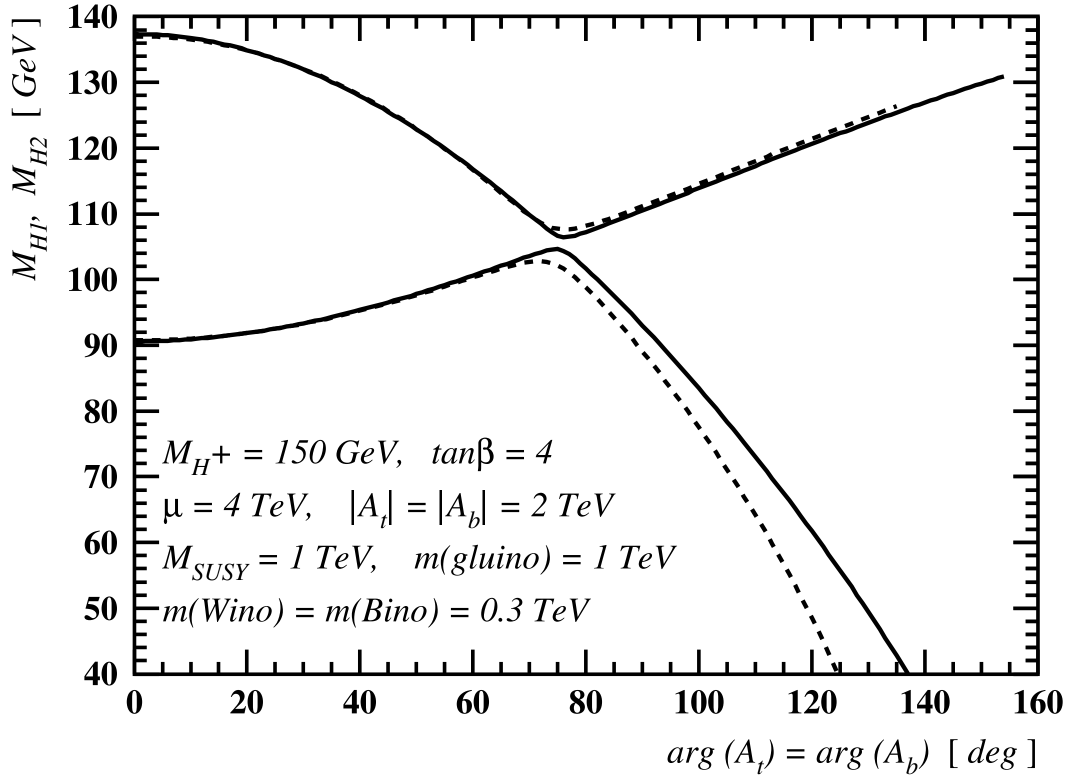
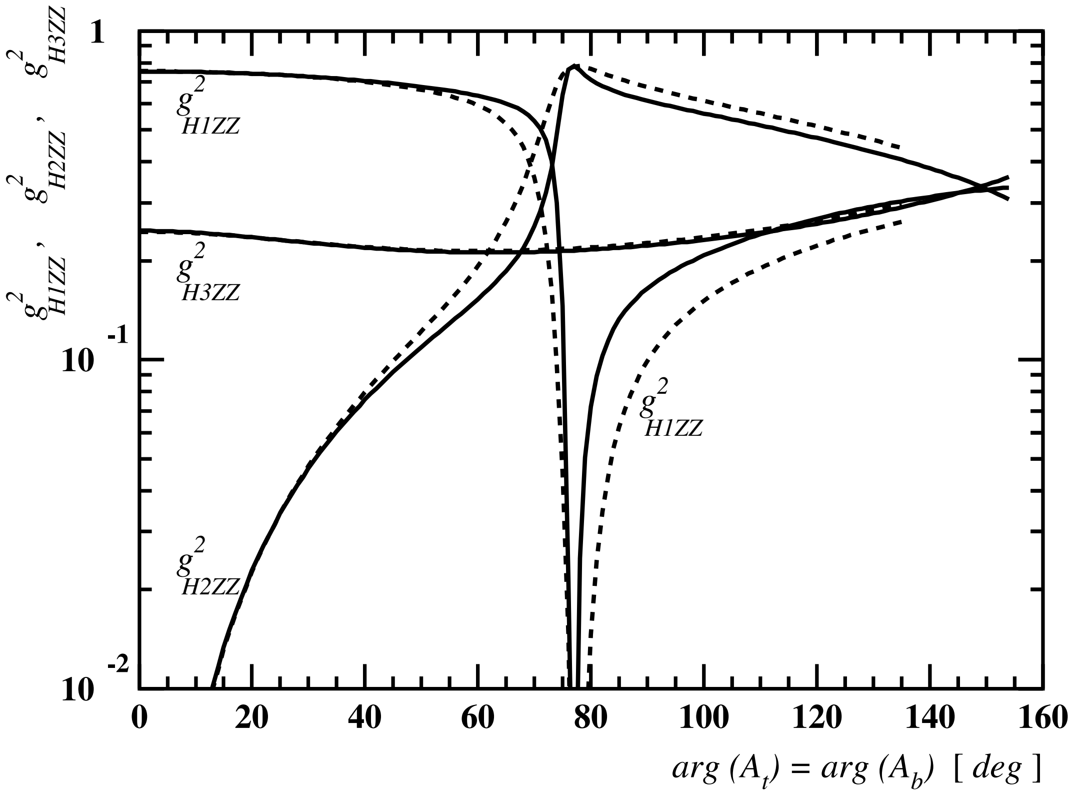



**(a)**




**(b)**

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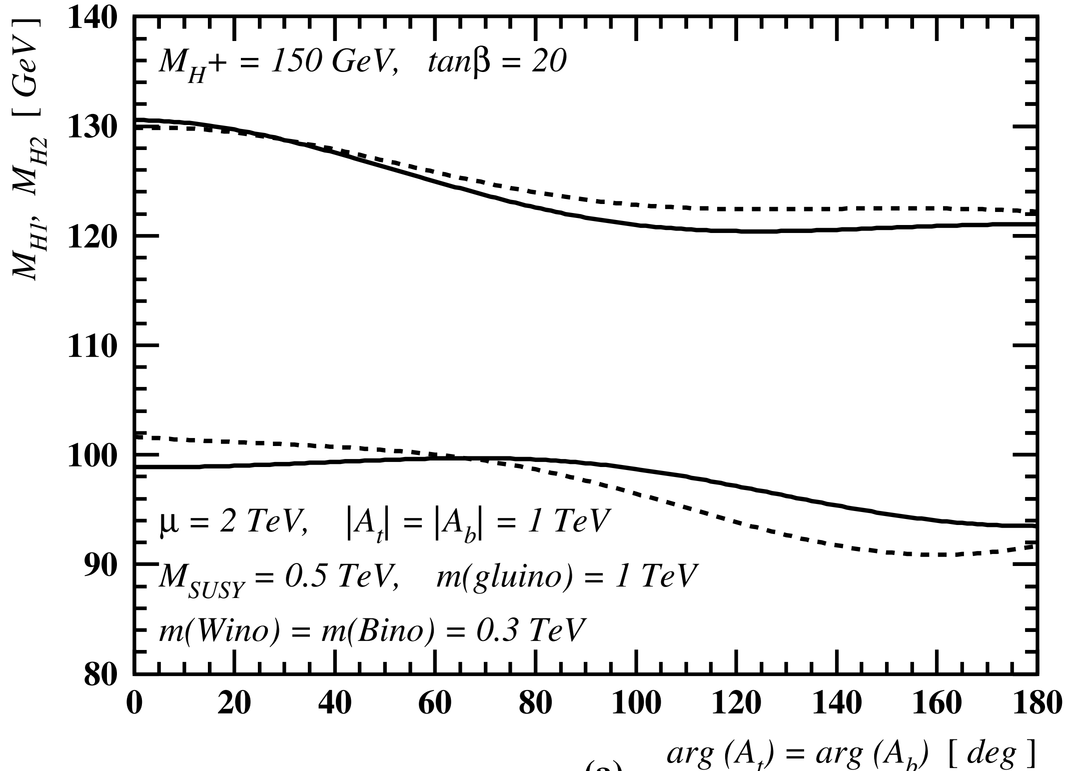
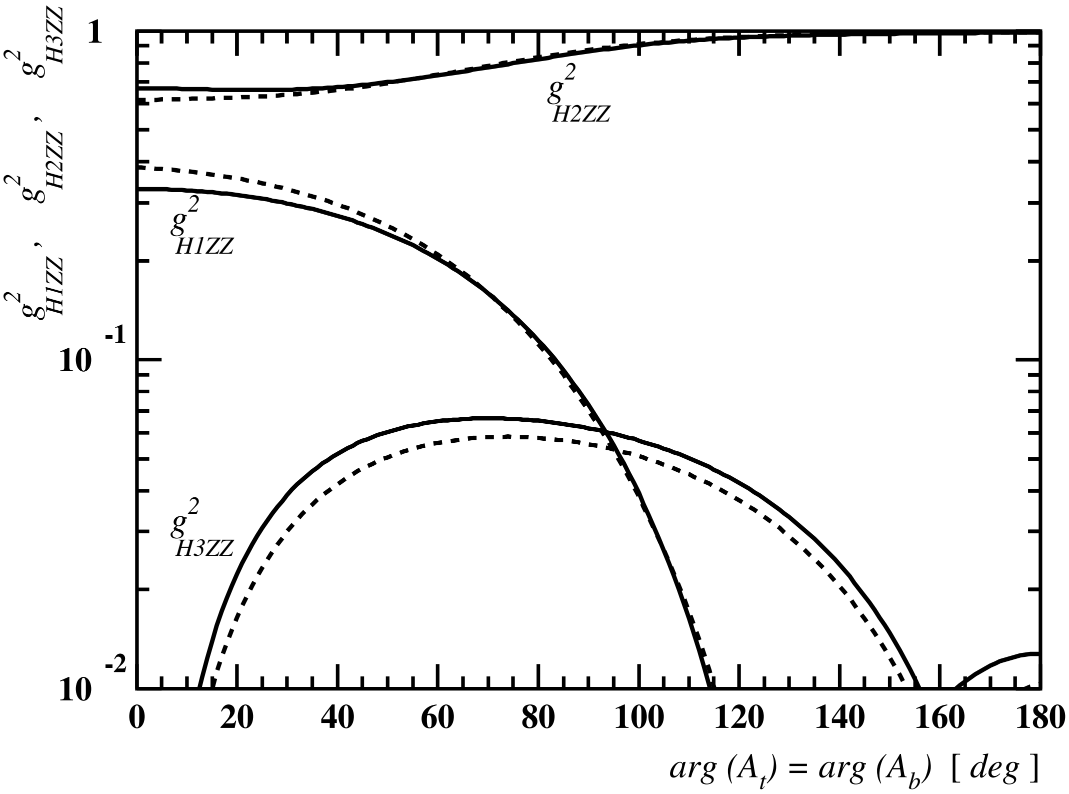



**(a)**




**(b)**

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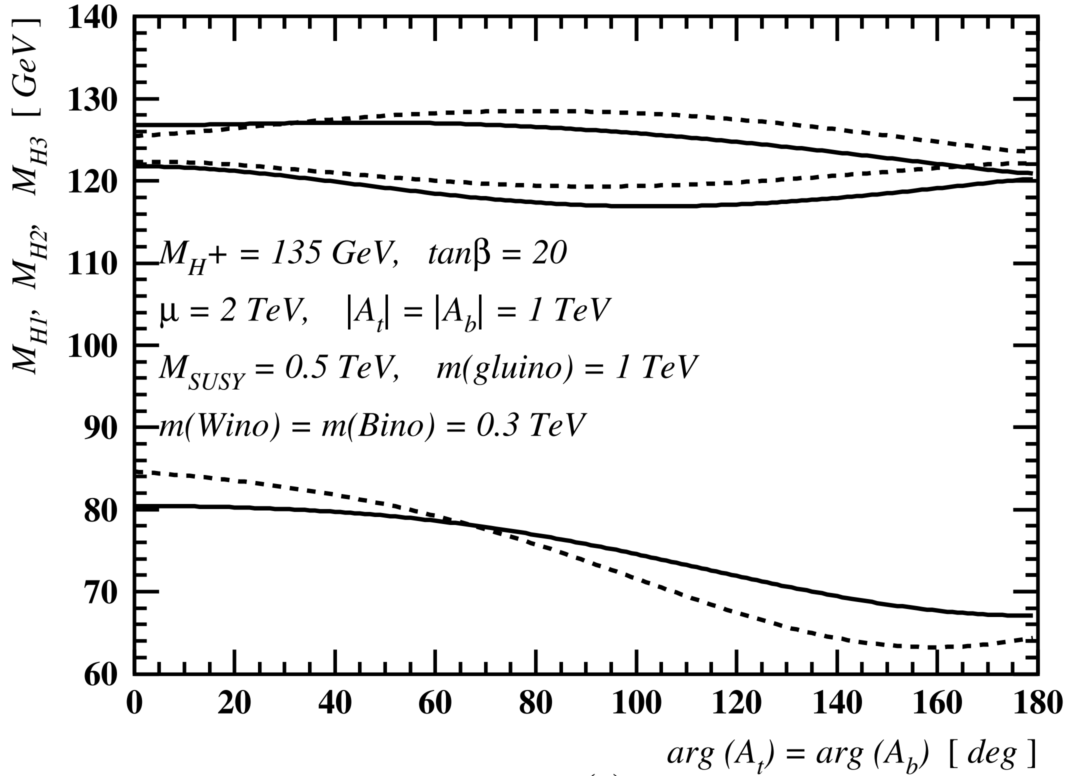
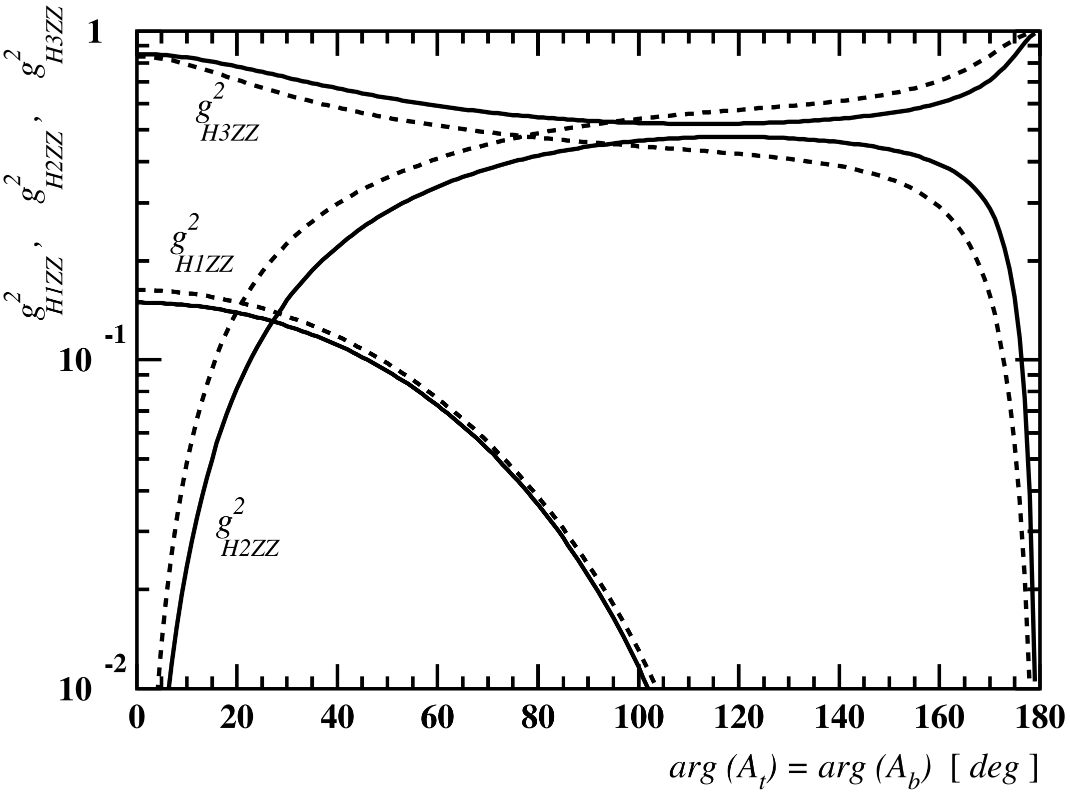
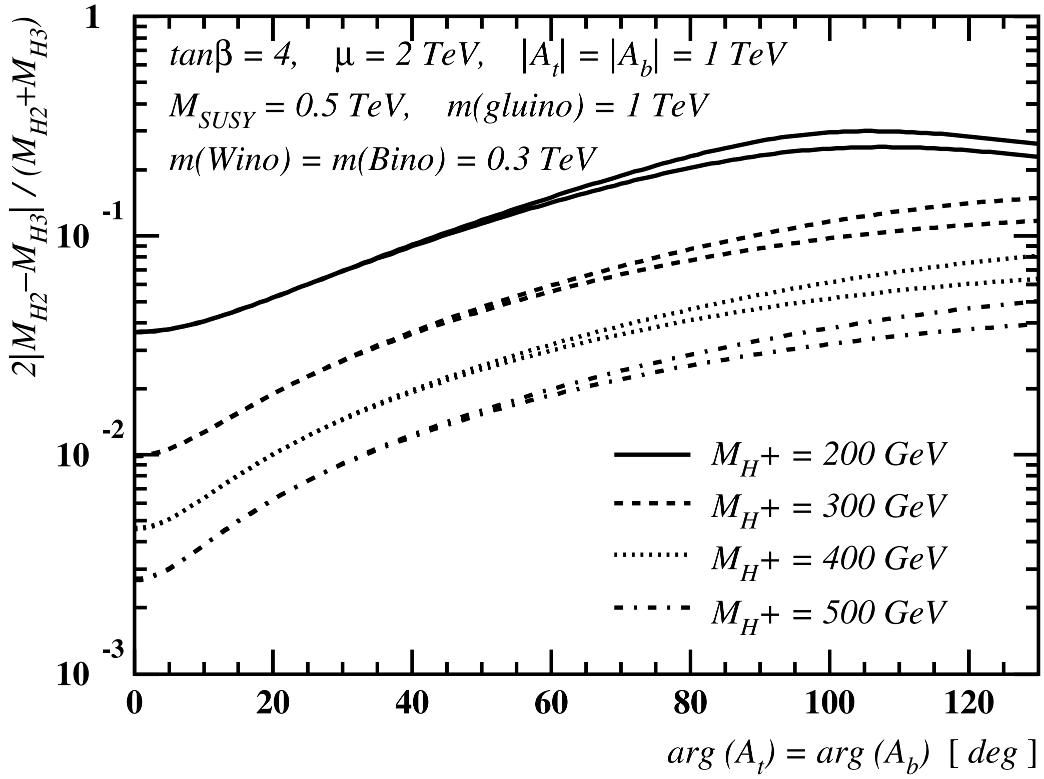


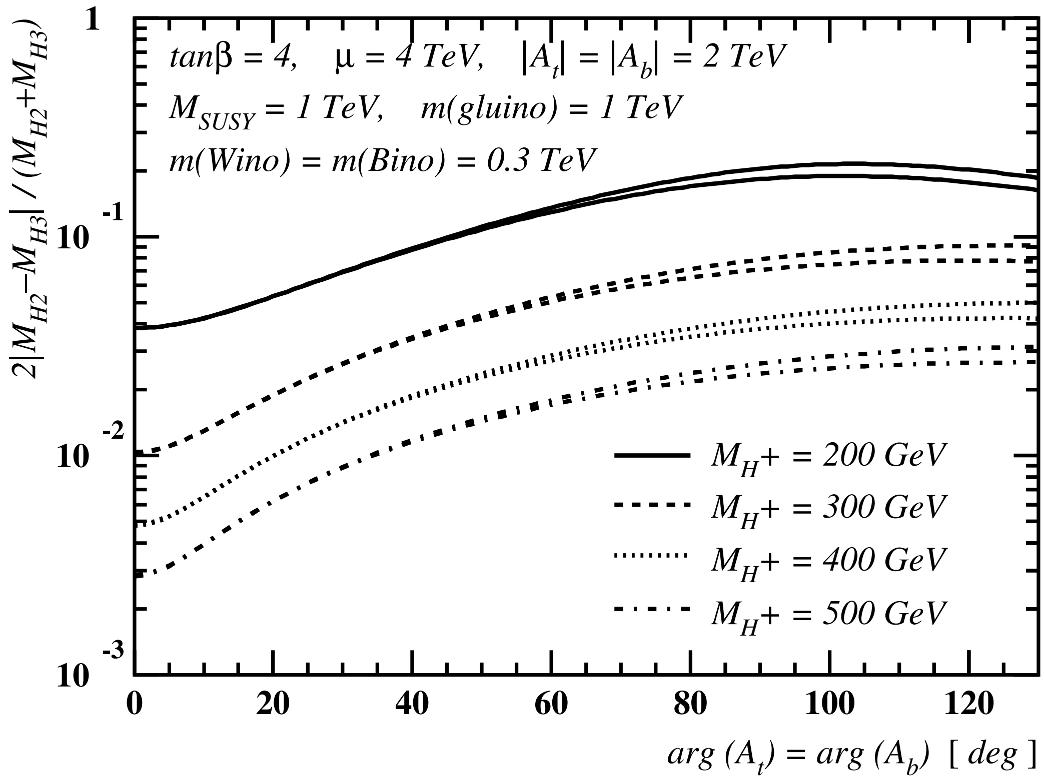

(a)




(b)

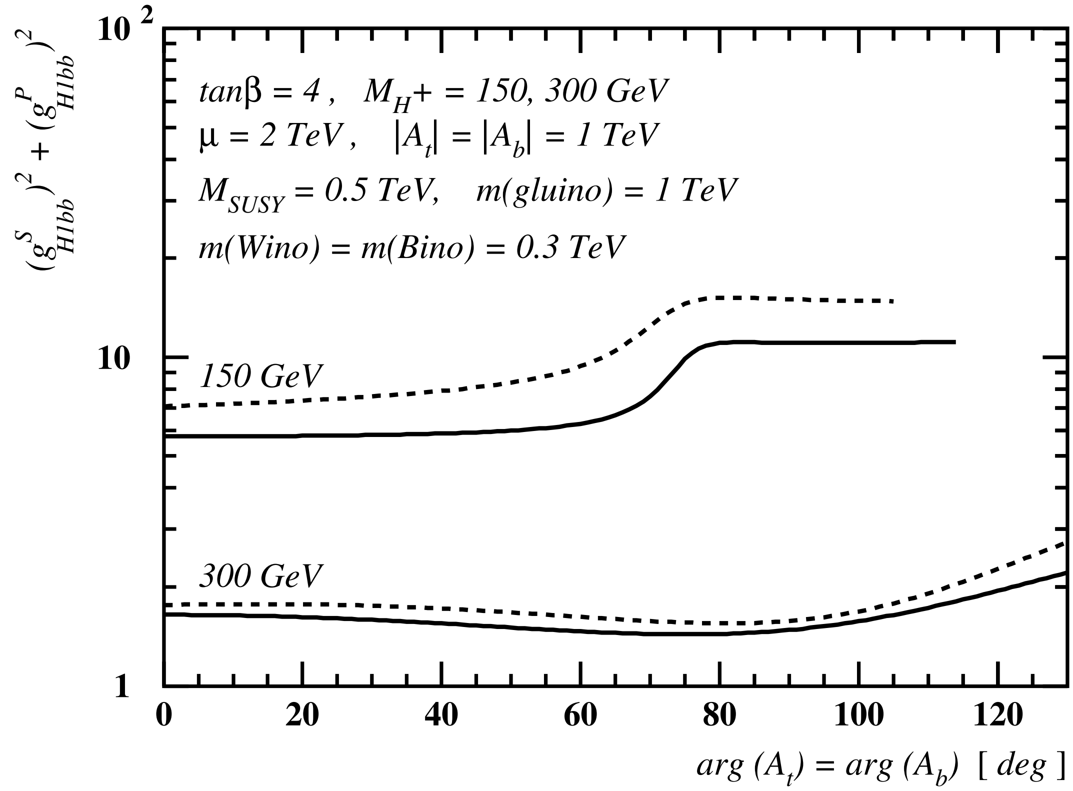

tanβ = 4, μ = 2 TeV, |A_t| = |A_b| = 1 TeV
M_SUSY = 0.5 TeV, m(gluino) = 1 TeV
m(Wino) = m(Bino) = 0.3 TeV
2|M_H2−M_H3| / (M_H2+M_H3)
1
10^-1
10^-2
10^-3
0
20
40
60
80
100
120
arg (A_t) = arg (A_b) [ deg ]
M_H+ = 200 GeV
M_H+ = 300 GeV
M_H+ = 400 GeV
M_H+ = 500 GeV

**(a)**

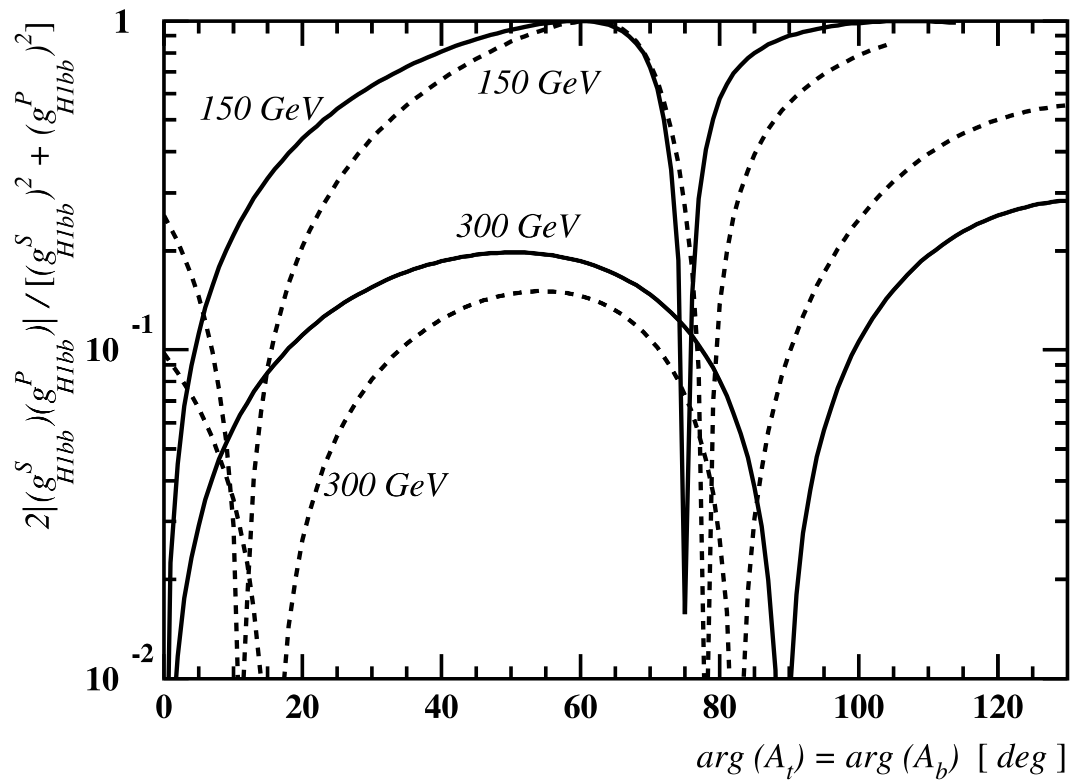

tanβ = 4, μ = 4 TeV, |A_t| = |A_b| = 2 TeV
M_SUSY = 1 TeV, m(gluino) = 1 TeV
m(Wino) = m(Bino) = 0.3 TeV
2|M_H2−M_H3| / (M_H2+M_H3)
1
10^-1
10^-2
10^-3
0
20
40
60
80
100
120
arg (A_t) = arg (A_b) [ deg ]
M_H+ = 200 GeV
M_H+ = 300 GeV
M_H+ = 400 GeV
M_H+ = 500 GeV

**(b)**

Generated with cph.f

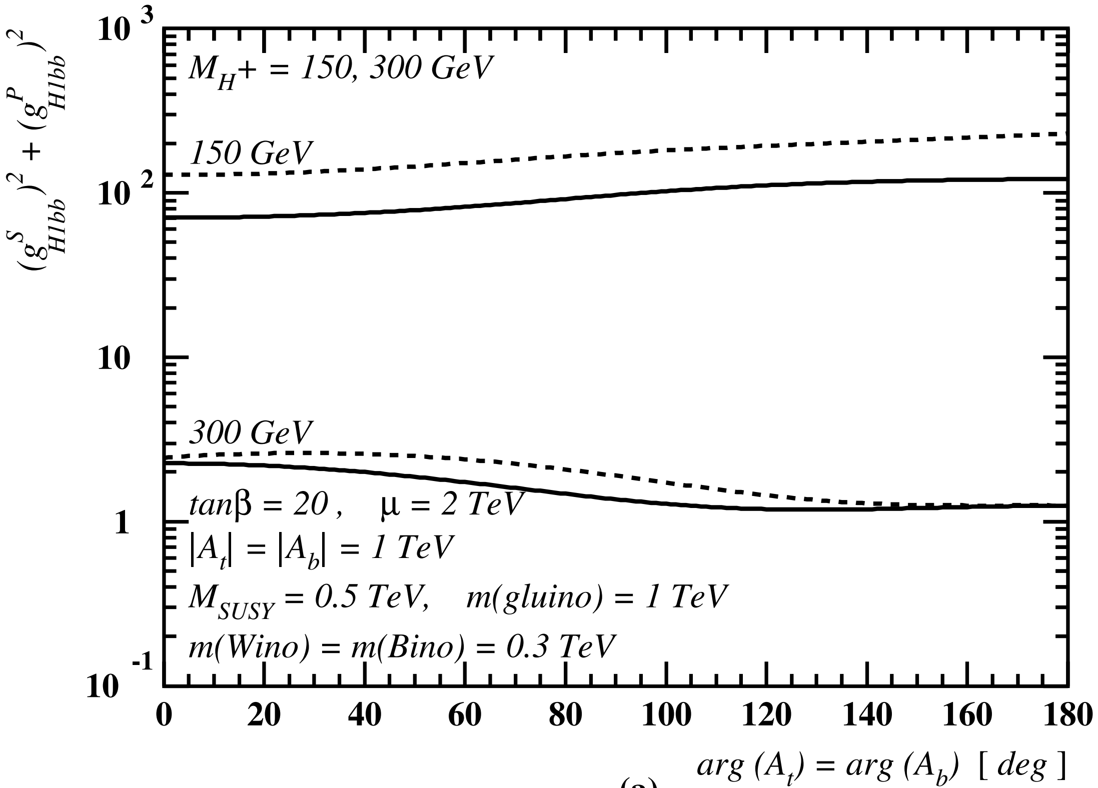



**(a)**

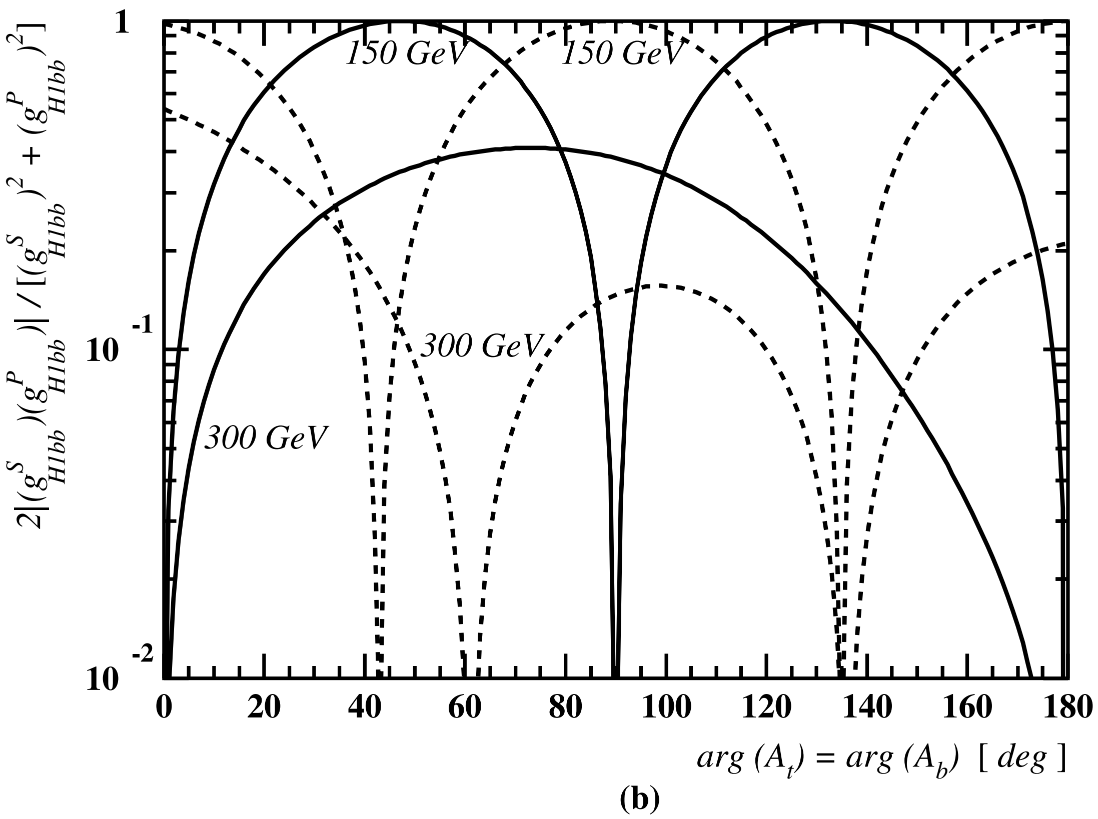



**(b)**

Generated with cph.f

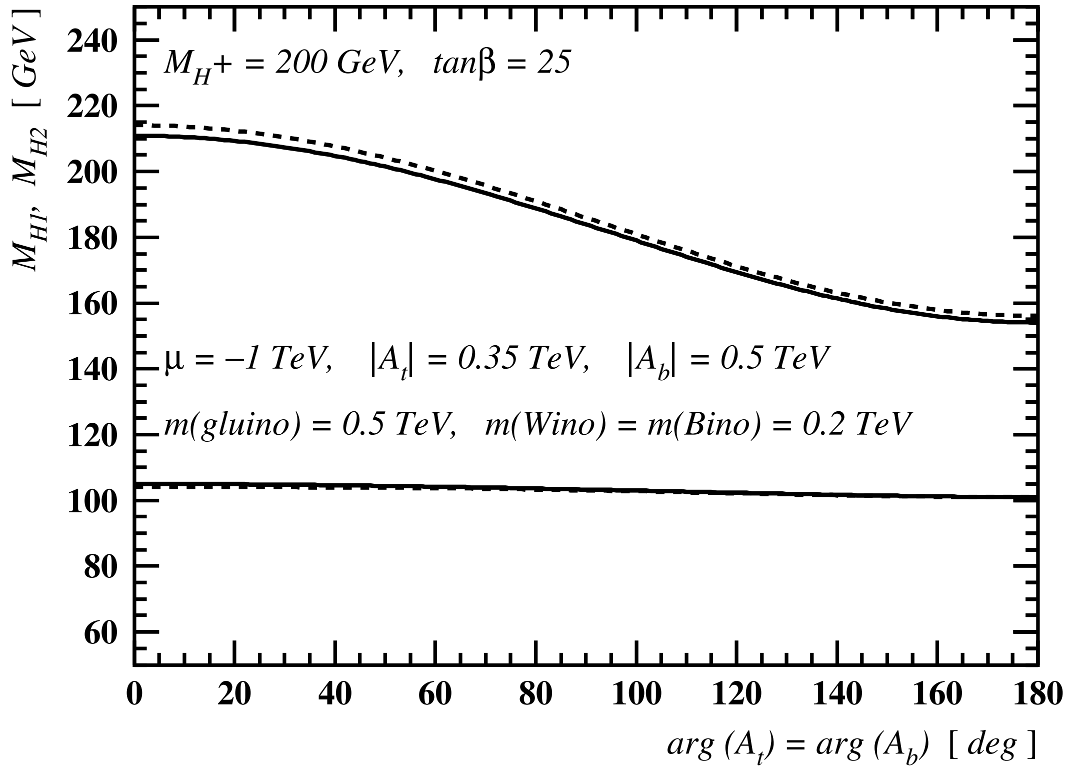



(a)

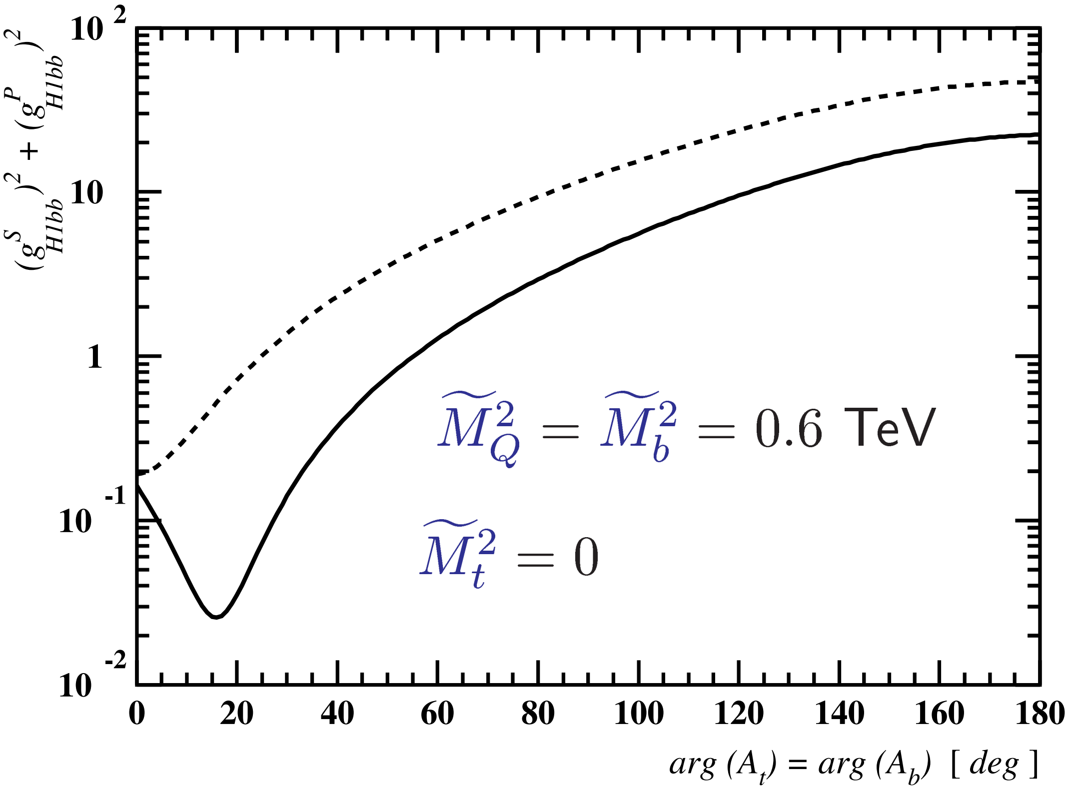



(b)

Generated with cph.f




(a)




(b)

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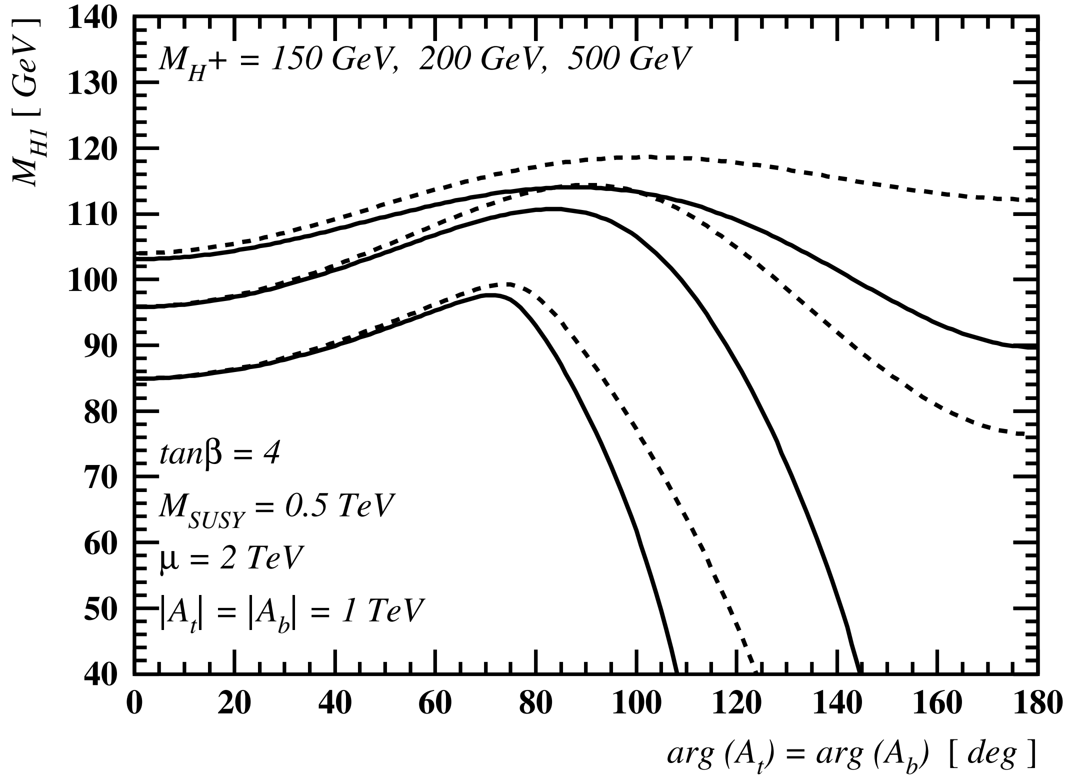
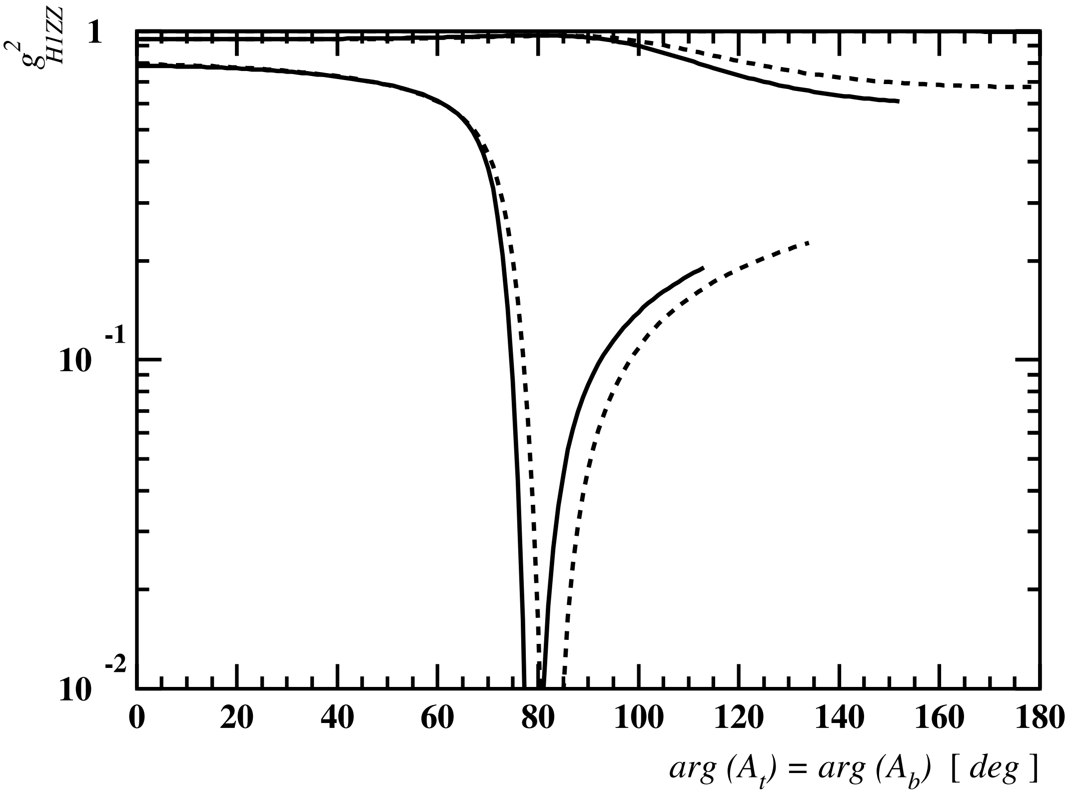



**(a)**




**(b)**

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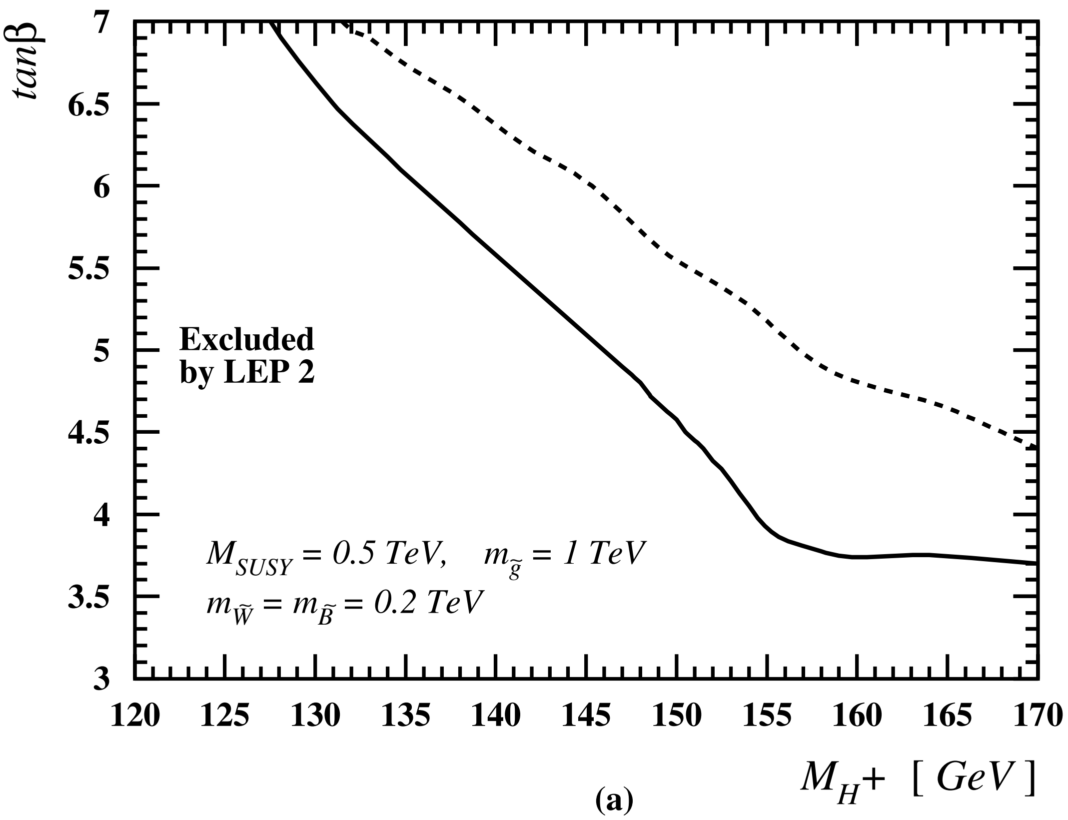
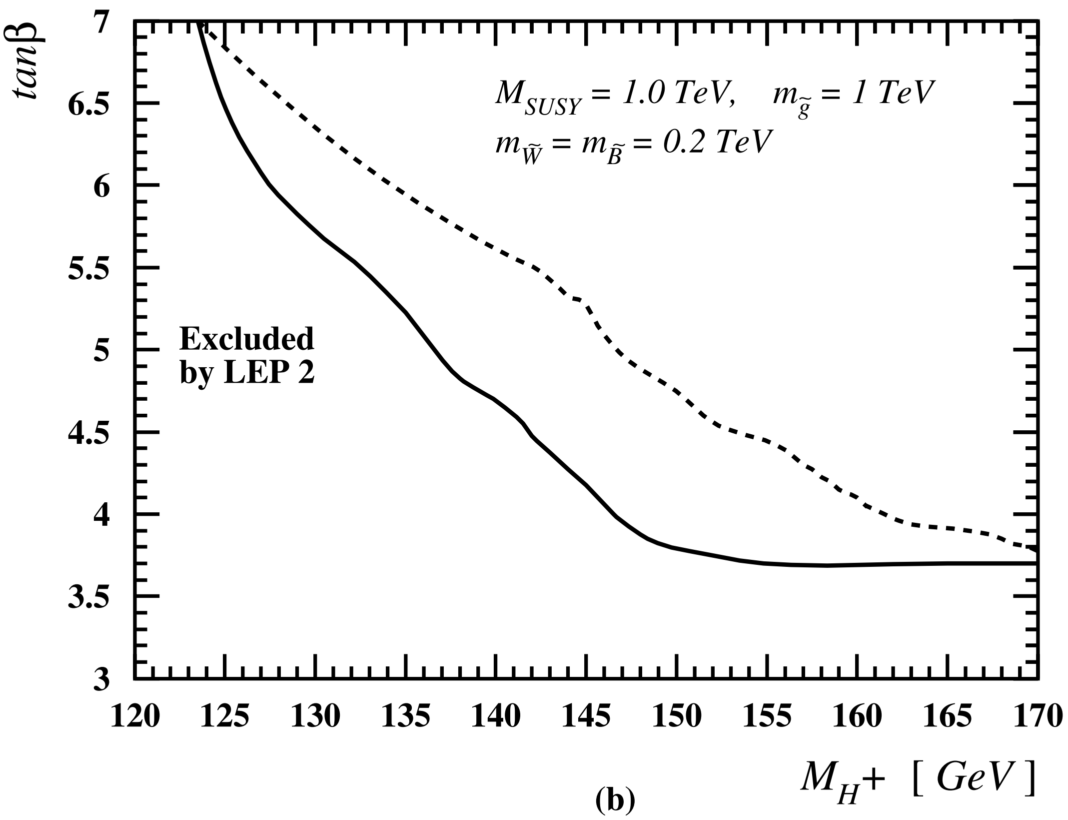



(a)

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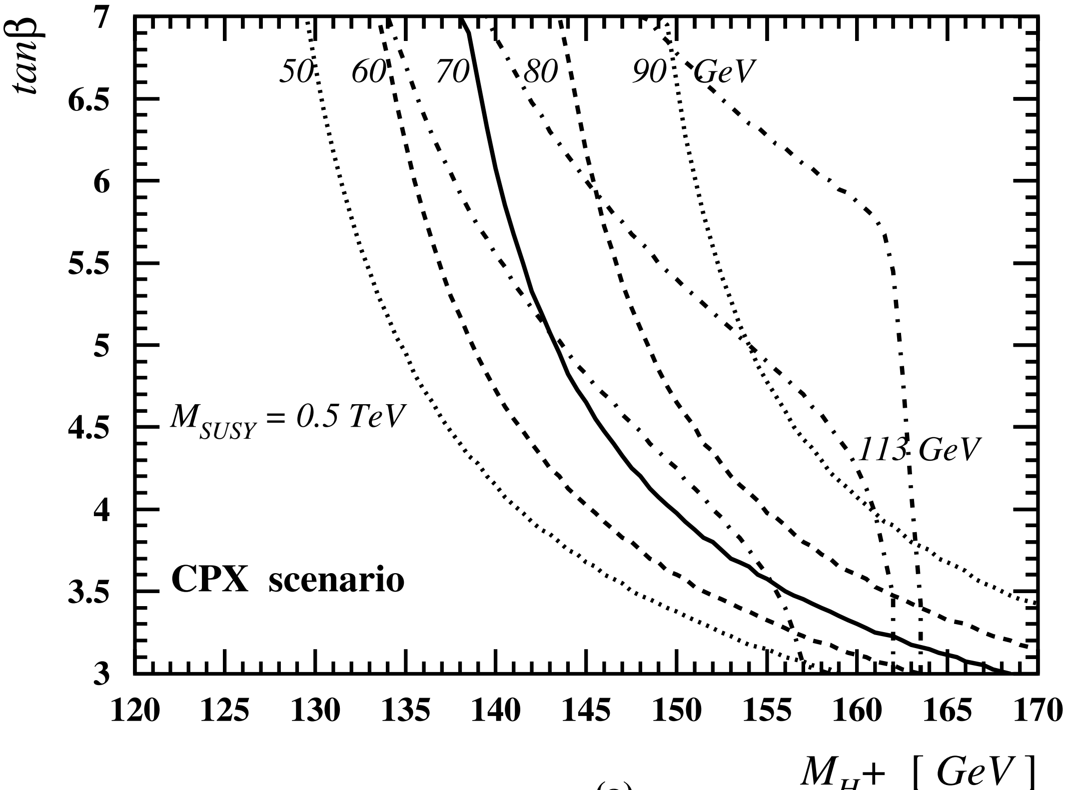
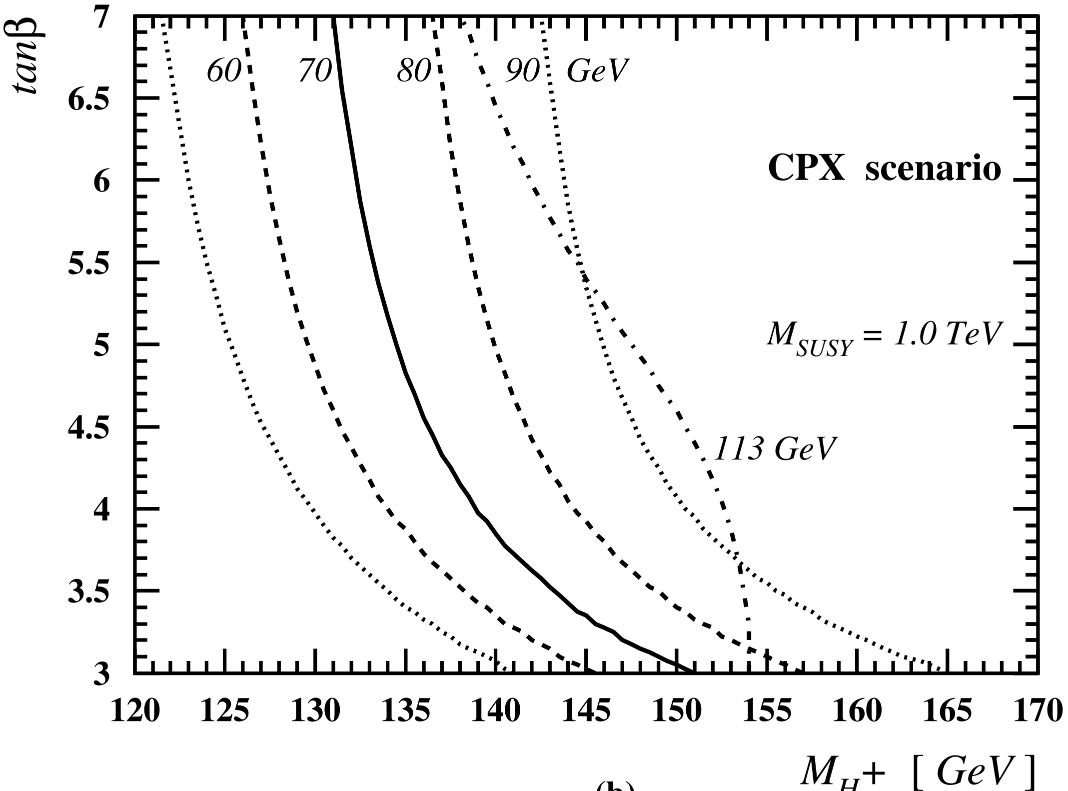



(a)

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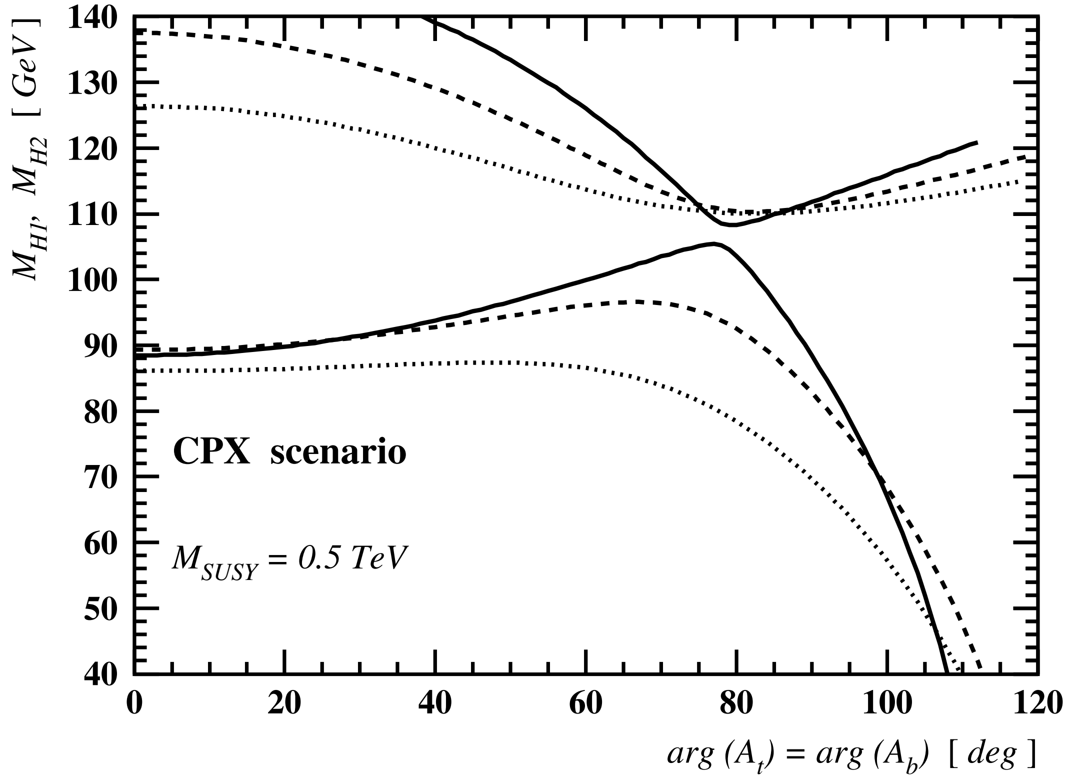
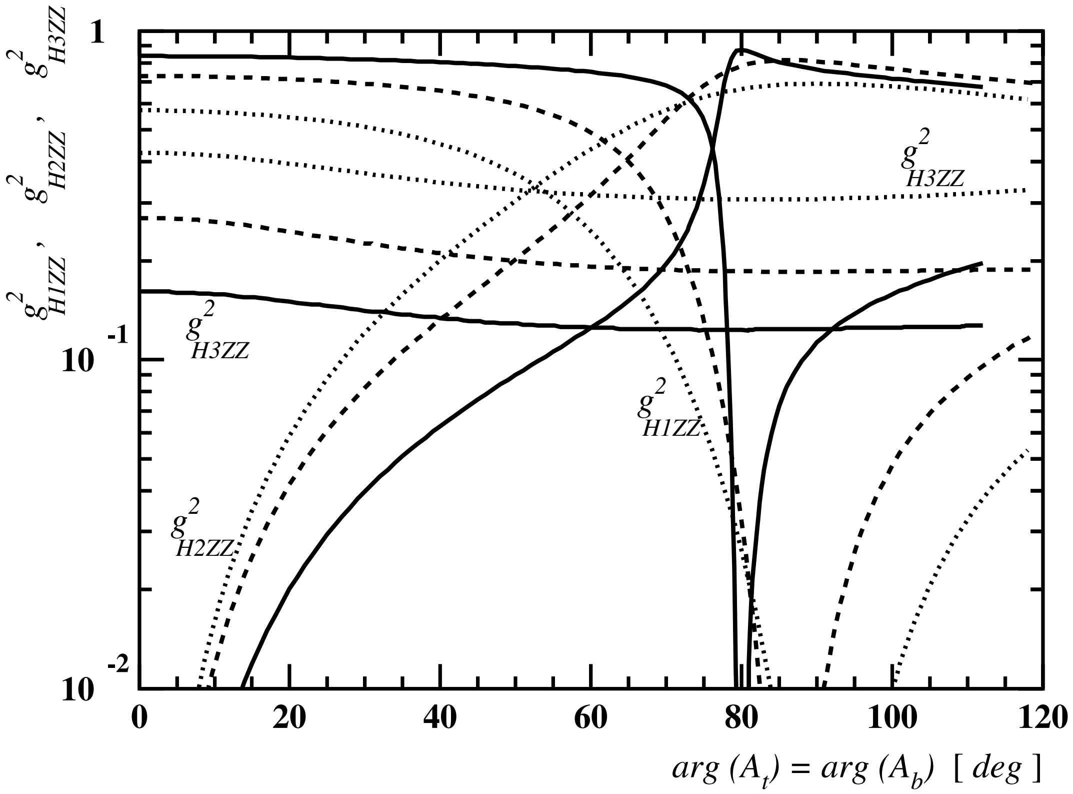



(a)




(b)

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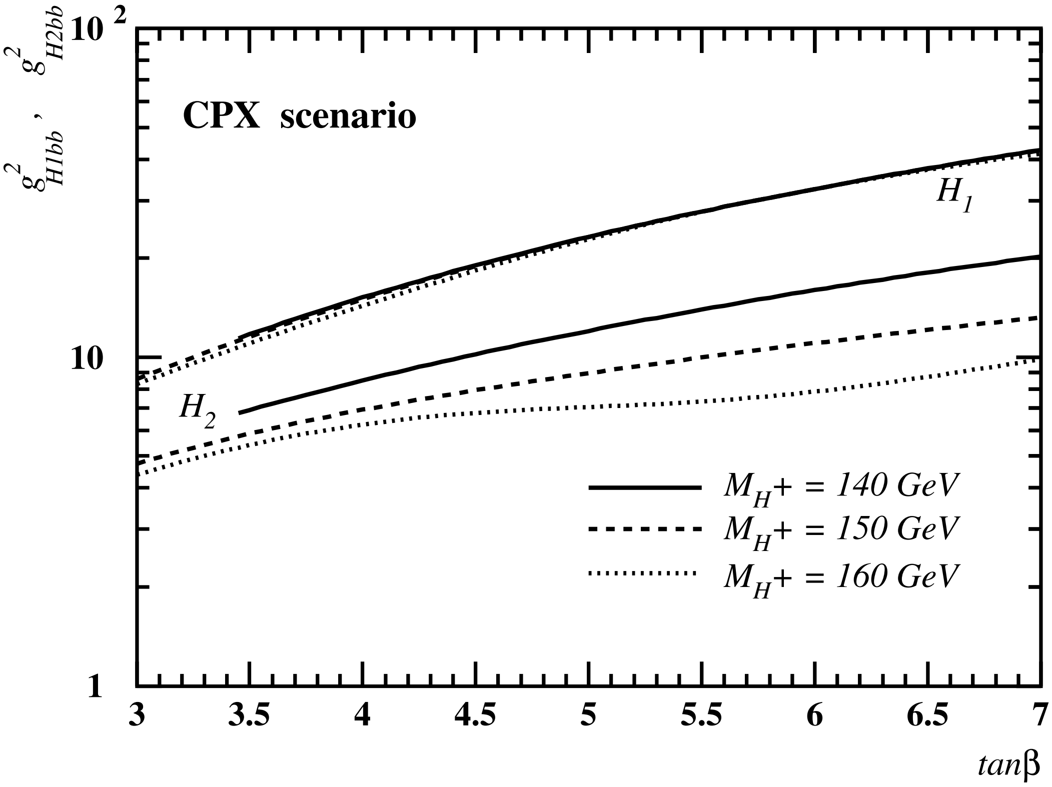


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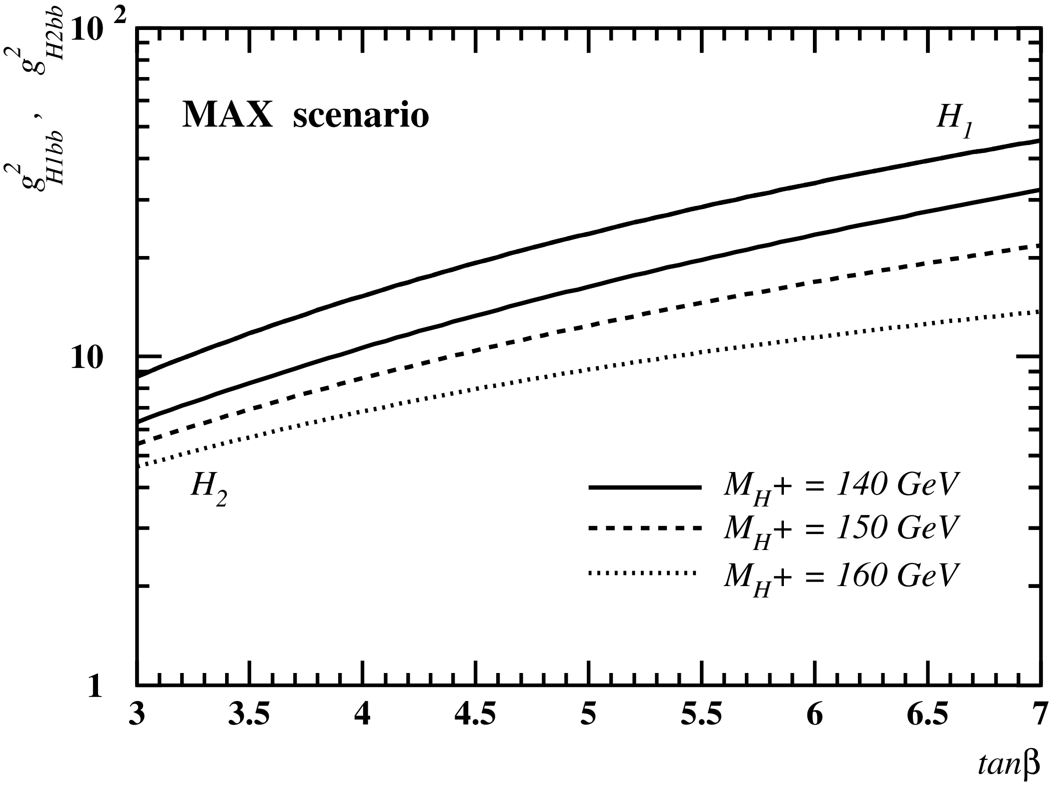


(b)

## • Conclusions

- The mass upper bound of the lightest Higgs boson $H_1$ predicted in the CP-violating MSSM is identical to that already known from the CP-invariant theory, for both low and high values of $\tan\beta$.

- Important input in the analysis is the one-loop RG-improved charged Higgs-boson mass.

- Large radiative effects of CP violation can drastically modify the Higgs-boson couplings to fermions and to the $W^{\pm}$ and $Z$ bosons. In particular, for $120 \lesssim M_{H^+} \lesssim 160$ GeV and $\tan\beta \lesssim 4$, even a neutral Higgs boson as light as 60 GeV may escape detection at LEP2. The upgraded Tevatron collider will reduce/close most of such 'open' windows in $M_{H_1}$.

- The CP-odd gluino phase $\arg(m_{\tilde{g}})$ enters the Higgs potential at the two-loop level. In addition, a non-trivial $\arg(m_{\tilde{g}})$ can suppress the $H_1 bb$-coupling, and so $B(H_1 \to b\bar{b})$.

- CP violation decouples from the lightest Higgs sector for $M_{H^+} \gg M_Z$, but it does not decouple from the heaviest one, opening up new possibilities for studying CP-violating phenomena at the LHC, NLC or the FMC.

- Implications for (i) $B$-meson physics, (ii) dark-matter searches, (iii) electroweak baryogenesis.

**Experimental information needed for a more precise analysis:**

- Exclusion plots for $(g^2_{H_1ZZ},\ M_{H_1})$ at the 95% CL, and at the 3-$\sigma$ and 5-$\sigma$ levels.
- Exclusion plots for $[\,g^2_{H_1H_2Z},\ \frac{1}{2}(M_{H_1}+M_{H_2})\,]$ at the 95% CL, and at the 3-$\sigma$ and 5-$\sigma$ levels.
- If possible, exclusion plots including $B(H_1 \to \tau^+\tau^-)$ into the analysis