Evidence of CP-violation in MSSM: scenarios with nondegenerate mass parameters of the squark sector

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Online

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- Effective THDM potential with explicit CP violation
- Parameters of the effective potential
- Higgs bosons masses, intense-coupling regime
- Decay widths
- Summary

THDM: Fields

$$\Phi_1 = \begin{pmatrix} \phi_1^+(x) \\ \phi_1^0(x) \end{pmatrix} = \begin{pmatrix} -i\omega_1^+ \\ \frac{1}{\sqrt{2}}(v_1 + \eta_1 + i\chi_1) \end{pmatrix},$$

$$\Phi_2 = e^{i\xi} \begin{pmatrix} \phi_2^+(x) \\ \phi_2^0(x) \end{pmatrix} = e^{i\xi} \begin{pmatrix} -i\omega_2^+ \\ \frac{1}{\sqrt{2}}(v_2 e^{i\zeta} + \eta_2 + i\chi_2) \end{pmatrix}$$

$$\langle\Phi_1\rangle = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v_1 \end{pmatrix}, \qquad \langle\Phi_2\rangle = \frac{e^{i\xi}}{\sqrt{2}} \begin{pmatrix} 0 \\ v_2 e^{i\zeta} \end{pmatrix} \equiv \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v_2 e^{i\theta} \end{pmatrix}.$$

$$\mathrm{tg}\,\beta = \frac{v_2}{v_1}, \qquad v^2 \equiv v_1^2 + v_2^2 = (246 \text{ GeV })^2.$$

Effective THDM potential with explicit CP violation

The most general renormalized SU(2)xU(1) invariant potential

$$U(\Phi_1,\Phi_2) = -\mu_1^2(\Phi_1^\dagger\Phi_1) - \mu_2^2(\Phi_2^\dagger\Phi_2) - \mu_{12}^2(\Phi_1^\dagger\Phi_2) - \overset{*}{\mu}{}_{12}^2(\Phi_2^\dagger\Phi_1) +$$

$$+\frac{\lambda_1}{2}(\Phi_1^\dagger\Phi_1)^2 + \frac{\lambda_2}{2}(\Phi_2^\dagger\Phi_2)^2 + \lambda_3(\Phi_1^\dagger\Phi_1)(\Phi_2^\dagger\Phi_2) + \lambda_4(\Phi_1^\dagger\Phi_2)(\Phi_2^\dagger\Phi_1) +$$

$$+\frac{\lambda_5}{2}(\Phi_1^\dagger\Phi_2)(\Phi_1^\dagger\Phi_2) + \frac{\overset{*}{\lambda}_5}{2}(\Phi_2^\dagger\Phi_1)(\Phi_2^\dagger\Phi_1) +$$

$$+\lambda_6(\Phi_1^\dagger\Phi_1)(\Phi_1^\dagger\Phi_2) + \overset{*}{\lambda}_6(\Phi_1^\dagger\Phi_1)(\Phi_2^\dagger\Phi_1) +$$

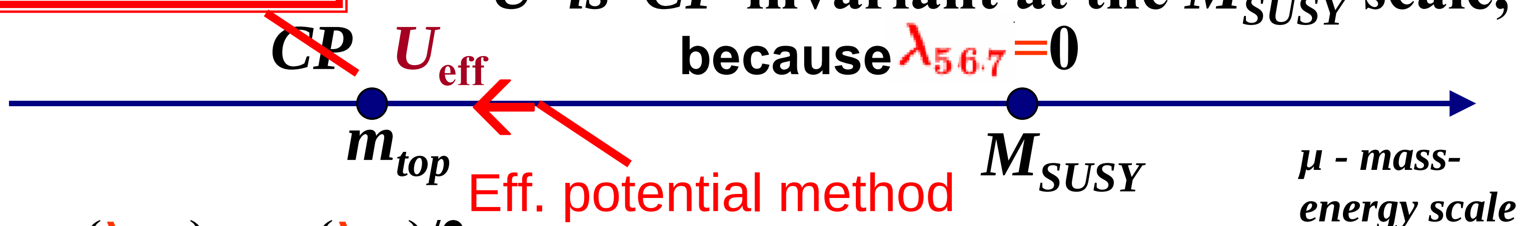
$$+\lambda_7(\Phi_2^\dagger\Phi_2)(\Phi_1^\dagger\Phi_2) + \overset{*}{\lambda}_7(\Phi_2^\dagger\Phi_2)(\Phi_2^\dagger\Phi_1)$$

$$\Phi_1^\dagger\Phi_2 \xrightarrow{CP} \Phi_2^\dagger\Phi_1$$

$$\lambda_{5,6,7} \xrightarrow{CP} \lambda_{5,6,7}$$

$\mu_{12}{}^2$,
$\lambda_5, \lambda_6, \lambda_7$
complex

***U* is *CP*-invariant at the M_{SUSY} scale,**
because $\lambda_{5,6,7}=0$



$\varphi=\arg(\lambda_{6,7})=\arg(\lambda_5)/2$

Scalar sector for MSSM

The main contribution to self-couplings due to Yukawa 3rd generation couplings.

The corresponding potential with CPV sources

$$\mathcal{V}^0 = \mathcal{V}_M + \mathcal{V}_\Gamma + \mathcal{V}_\Lambda + \mathcal{V}_{\widetilde{Q}} \,,$$

$$\mathcal{V}_M = (-1)^{i+j} m^2_{ij} \Phi^\dagger_i \Phi_j + M^2_{\widetilde{Q}} \left(\widetilde{Q}^{\,\dagger} \widetilde{Q} \right) + M^2_{\widetilde{U}} \widetilde{U}^* \widetilde{U} + M^2_{\widetilde{D}} \widetilde{D}^* \widetilde{D} \,,$$

$$\mathcal{V}_\Gamma = \Gamma^D_i \left(\Phi^\dagger_i \widetilde{Q} \right) \widetilde{D} + \Gamma^U_i \left(i \Phi^T_i \sigma_2 \widetilde{Q} \right) \widetilde{U} + \overset{*}{\Gamma}{}^D_i \left(\widetilde{Q}^{\,\dagger} \Phi_i \right) \widetilde{D}^* - \overset{*}{\Gamma}{}^U_i \left(i \widetilde{Q}^{\,\dagger} \sigma_2 \Phi^*_i \right) \widetilde{U}^*$$

$$\mathcal{V}_\Lambda = \Lambda^{jl}_{ik} \left(\Phi^\dagger_i \Phi_j \right) \left(\Phi^\dagger_k \Phi_l \right) + \left(\Phi^\dagger_i \Phi_j \right) \left[\Lambda^Q_{ij} \left(\widetilde{Q}^{\,\dagger} \widetilde{Q} \right) + \Lambda^U_{ij} \widetilde{U}^* \widetilde{U} + \Lambda^D_{ij} \widetilde{D}^* \widetilde{D} \right] +$$

$$+ \overline{\Lambda}^Q_{ij} \left(\Phi^\dagger_i \widetilde{Q} \right) \left(\widetilde{Q}^{\,\dagger} \Phi_j \right) + \frac{1}{2} \left[\Lambda \epsilon_{ij} \left(i \Phi^T_i \sigma_2 \Phi_j \right) \widetilde{D}^* \widetilde{U} + \text{э.c.} \right] \,, \quad i, j, k, l = 1, 2$$

$$\Gamma^U_{\{1;\,2\}} = h_U \{ -\mu^*; A_U \}, \qquad \Gamma^D_{\{1;\,2\}} = h_D \{ A_D ; -\mu^* \}$$

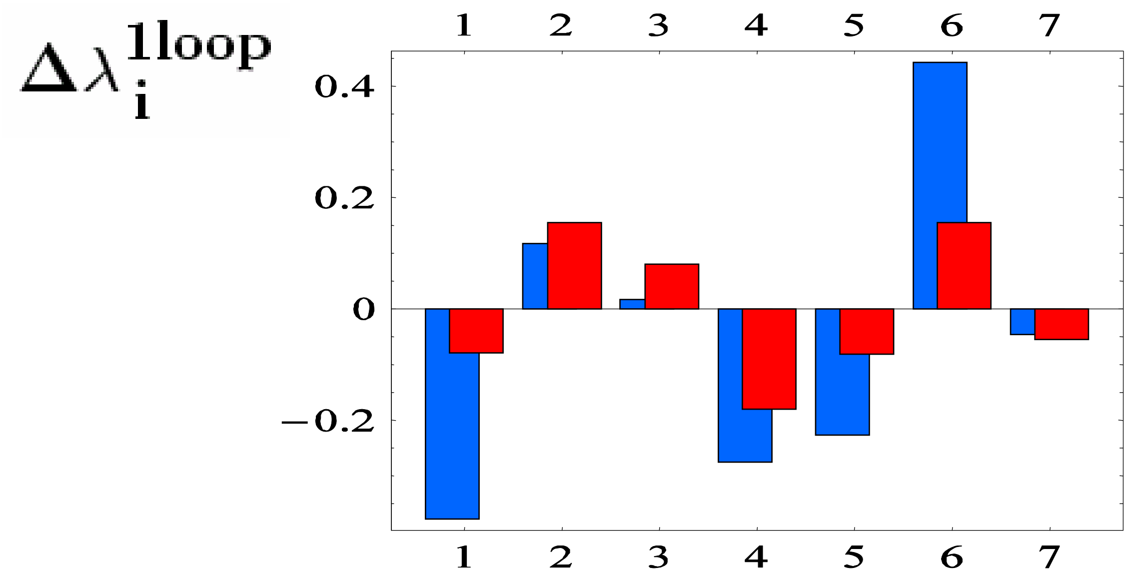
Parameters of the effective potential

$$\Delta\lambda_5 = 3h_t^4\mu^2A^2I_2[m_Q,m_t] + 3h_b^4\mu^2A^2I_2[m_Q,m_b]$$

$$\Delta\lambda_6 = -3h_t^4\mu A|\mu|^2I_2[m_Q,m_t] - 3h_b^4\mu A|A|^2I_2[m_Q,m_b]+$$
$$+h_t^2\mu A(\frac{g_1^2-3g_2^2}{4}I_1[m_Q,m_t] - g_1^2I_1[m_t,m_Q])+$$
$$+h_b^2\mu A(\frac{-12h_b^2+g_1^2+3g_2^2}{4}I_1[m_Q,m_b] - \frac{6h_b^2-g_1^2}{2}I_1[m_b,m_Q])$$

$$\Delta\lambda_7 = -3h_t^4\mu A|A|^2I_2[m_Q,m_t] - 3h_b^4\mu A|\mu|^2I_2[m_Q,m_b]+$$
$$+h_b^2\mu A(-\frac{g_1^2+3g_2^2}{4}I_1[m_Q,m_b] - \frac{g_1^2}{2}I_1[m_b,m_Q])+$$
$$+h_t^2\mu A(\frac{12h_t^2+g_1^2-3g_2^2}{4}I_1[m_Q,m_t] - (3h_t^2-g_1^2)I_1[m_t,m_Q])$$

Parameters of the effective potential



Msusy=500GeV

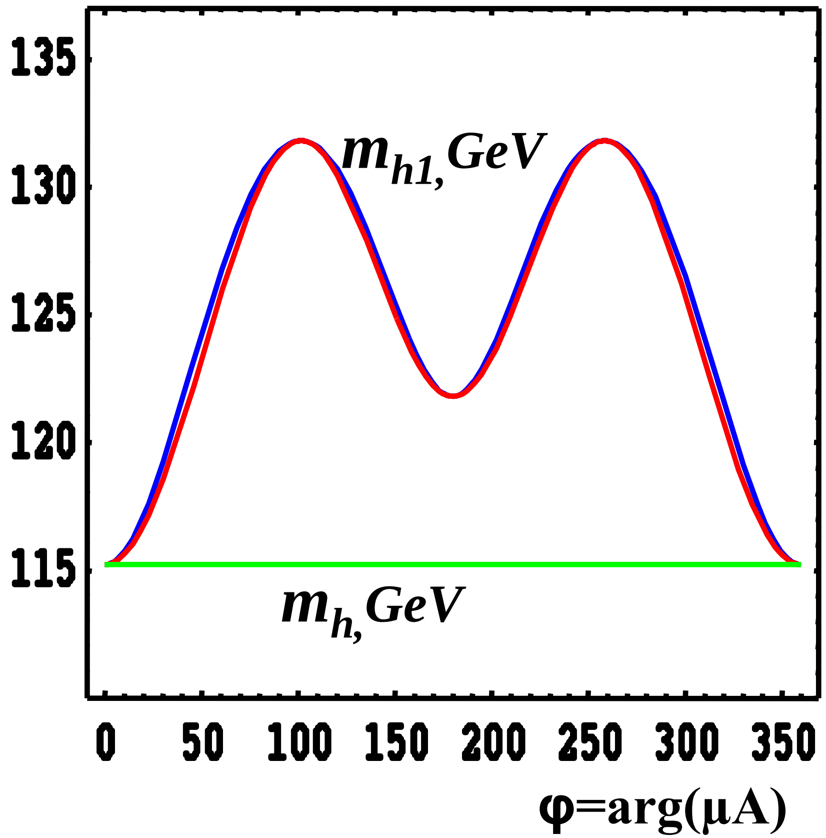
mQ=500GeV, mU=800GeV, mD=200GeV

[1] H.E.Haber, R.Hempfling, Phys.Rev. D48 (1993) 4280

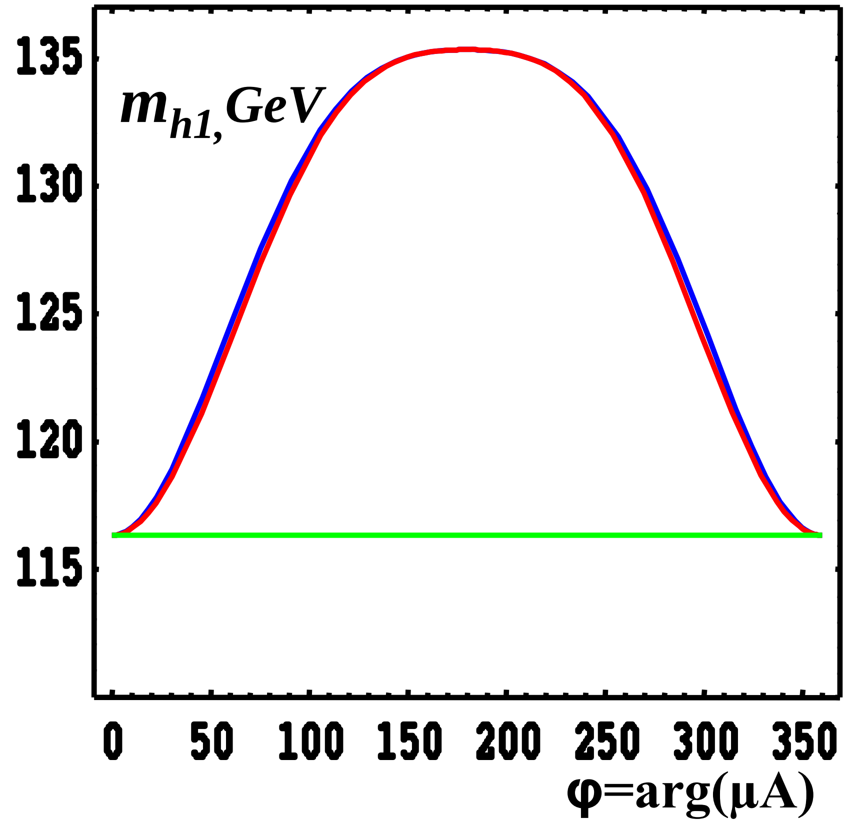
[2] A.Pilaftsis, C.E.M.Wagner, Nucl.Phys. B553 (1999) 3

[3] E.A., M.Dolgopolov, M.Dubinin, Phys.Rev. D71 (2005) 075008

Mass of the lightest Higgs boson

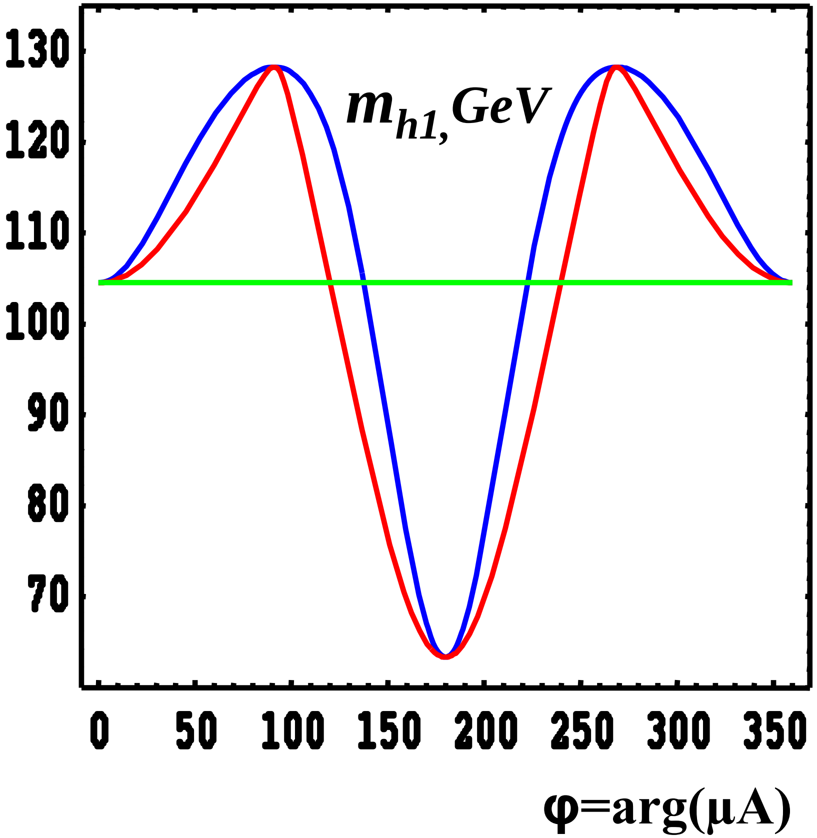


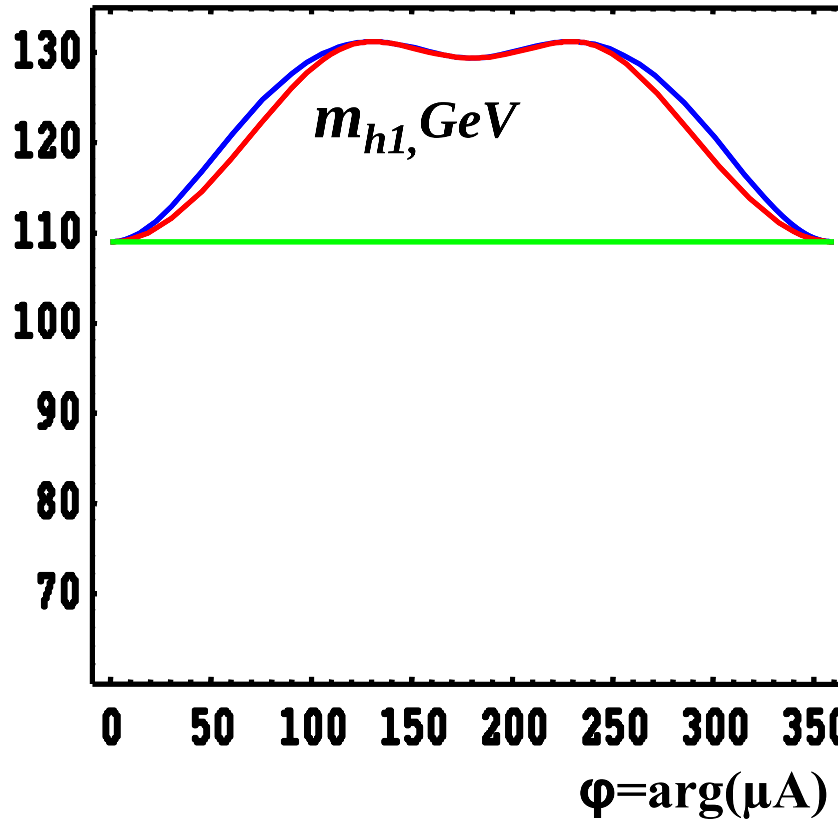
Msusy=500GeV
m_H±=300GeV



mQ=500GeV, mU=800GeV,
mD=200GeV

Mass of the lightest Higgs boson

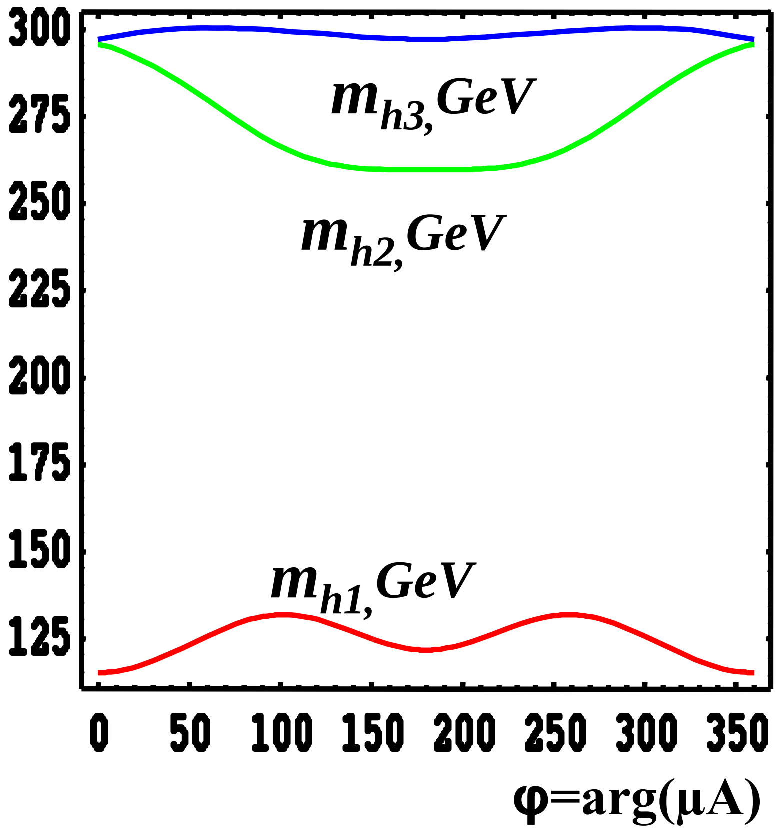


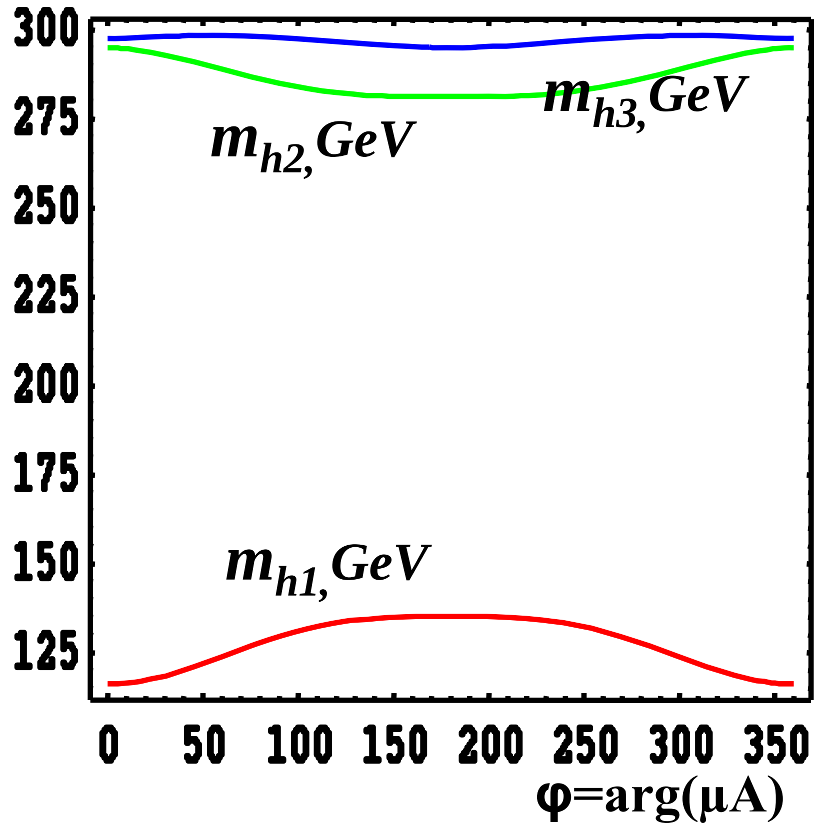


Msusy=500GeV
m_{H}±=190GeV

mQ=500GeV, mU=800GeV, mD=200GeV

Masses of the Higgs bosons

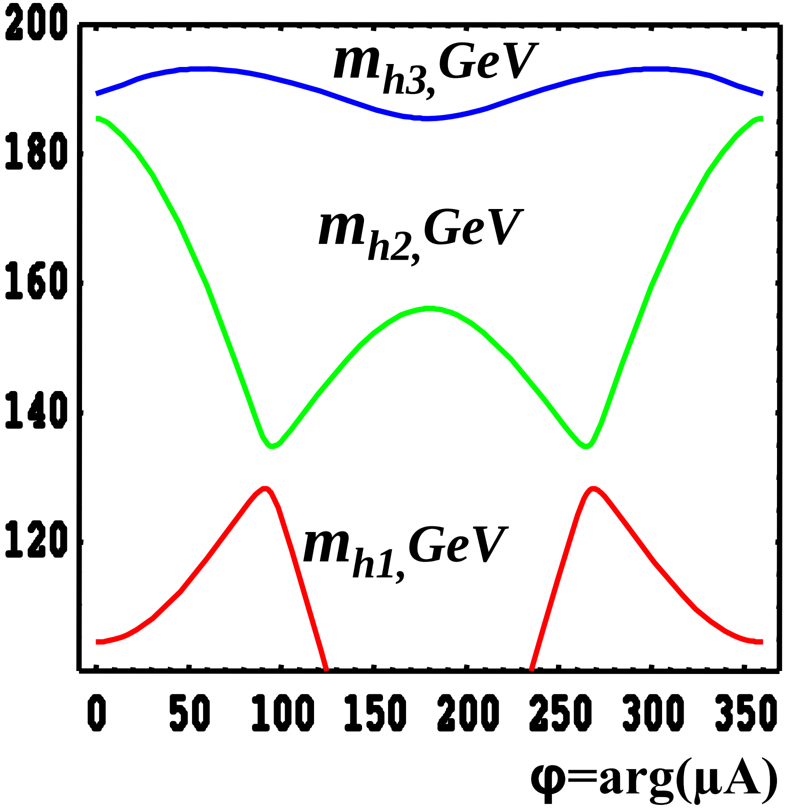


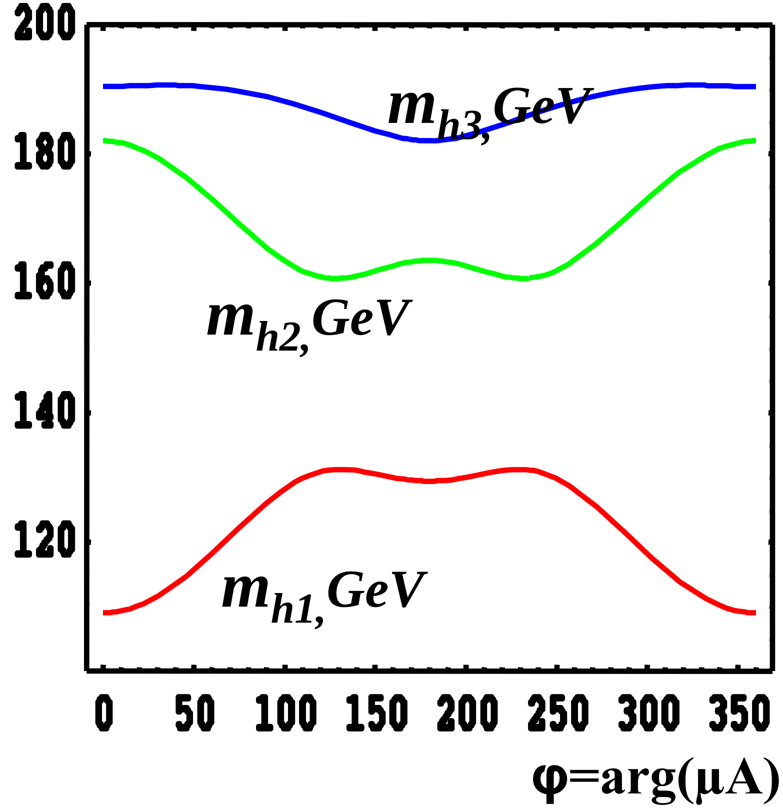


Msusy=500GeV
$m_{H}\pm$=300GeV

mQ=500GeV, mU=800GeV,
mD=200GeV

Masses of the Higgs bosons





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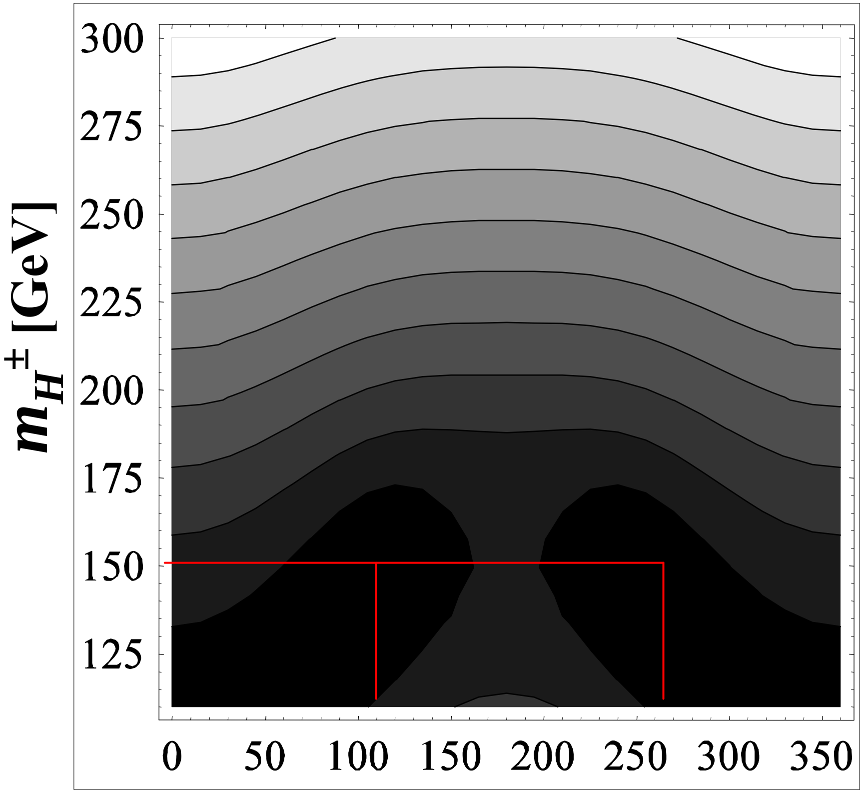
Masses of the Higgs bosons

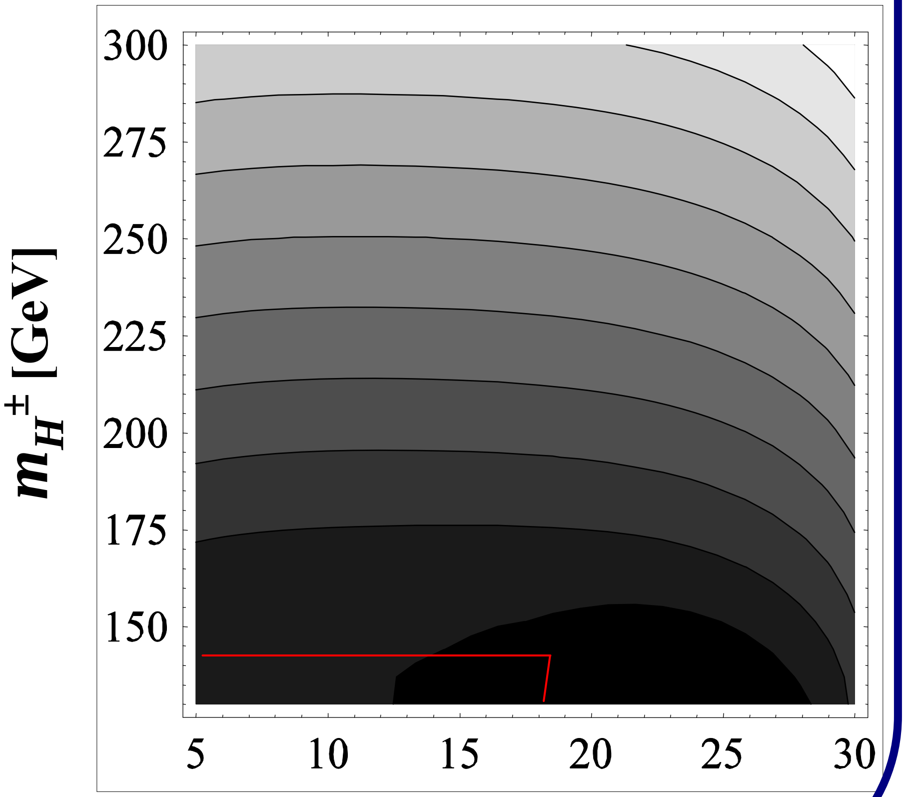


φ=arg(μA) [rad]

CPX, tan β=5

(mh2+mh3)/2-mh1

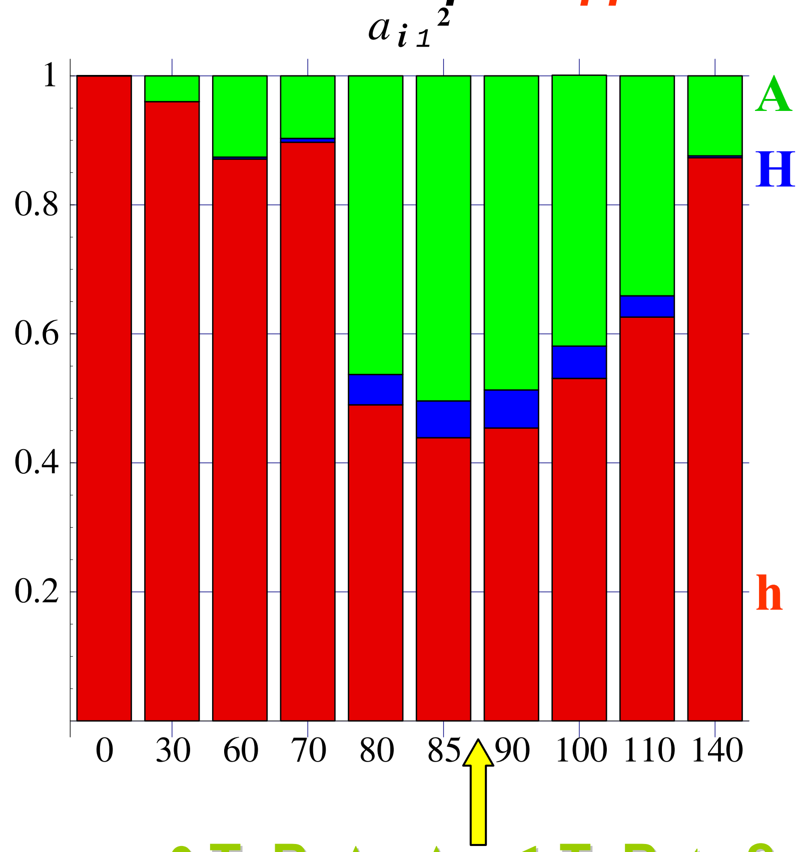
CPX, φ=1.4 [rad]

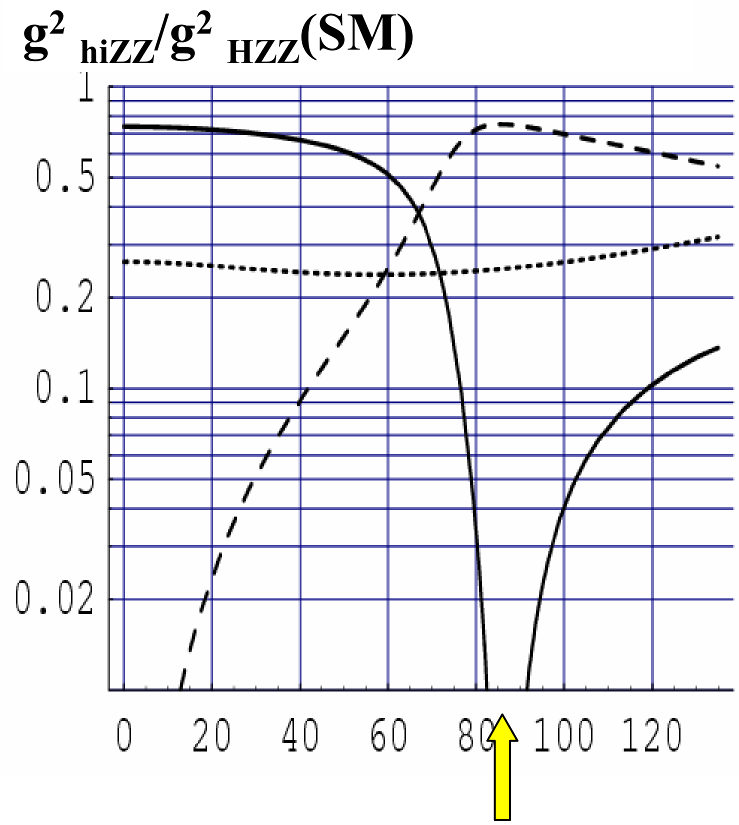


tan β

Matrix elements a_{i1} and coupling with Z-boson

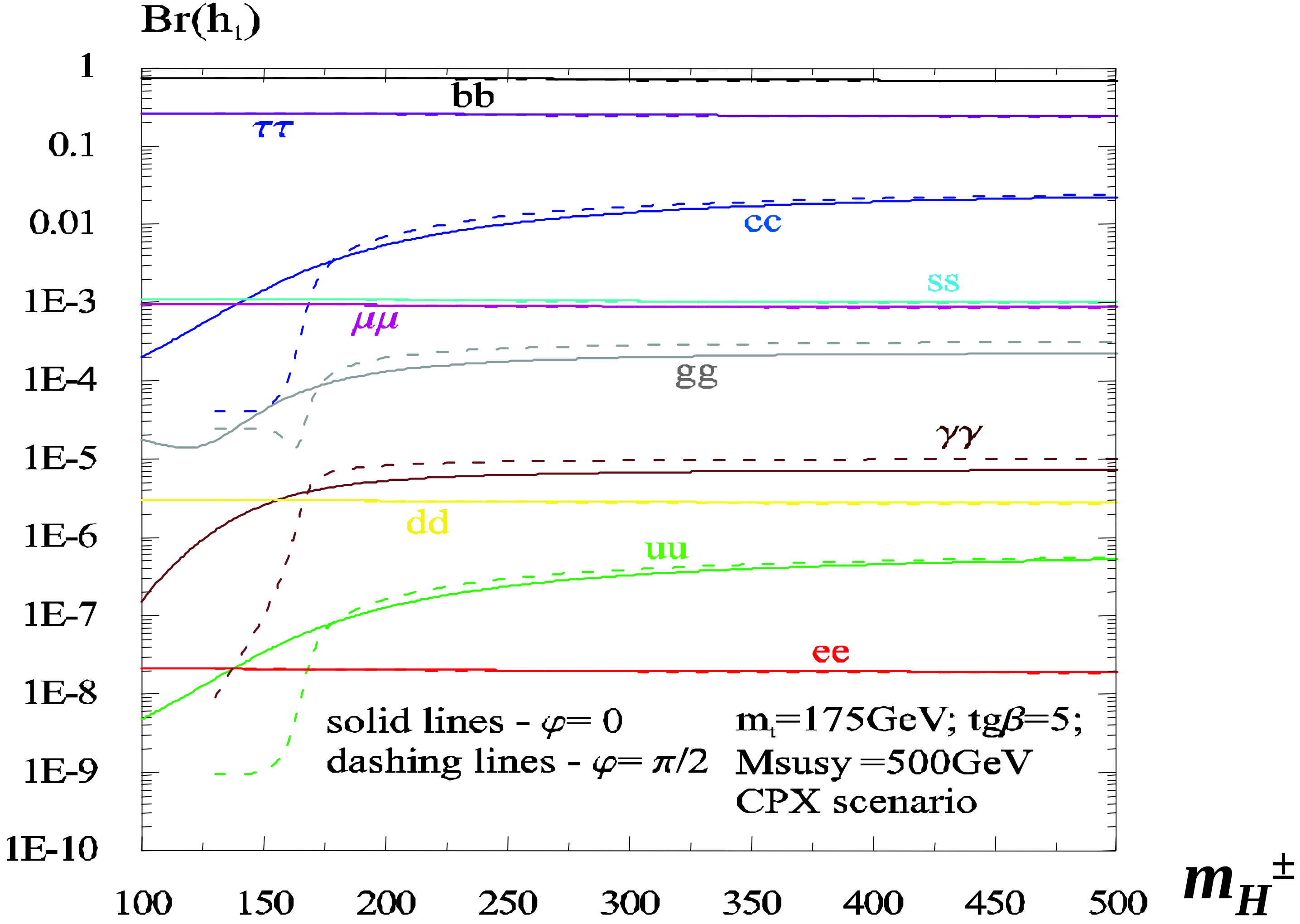
$$h_1 = a_{11}\, h + a_{21}\, H + a_{31}\, A$$



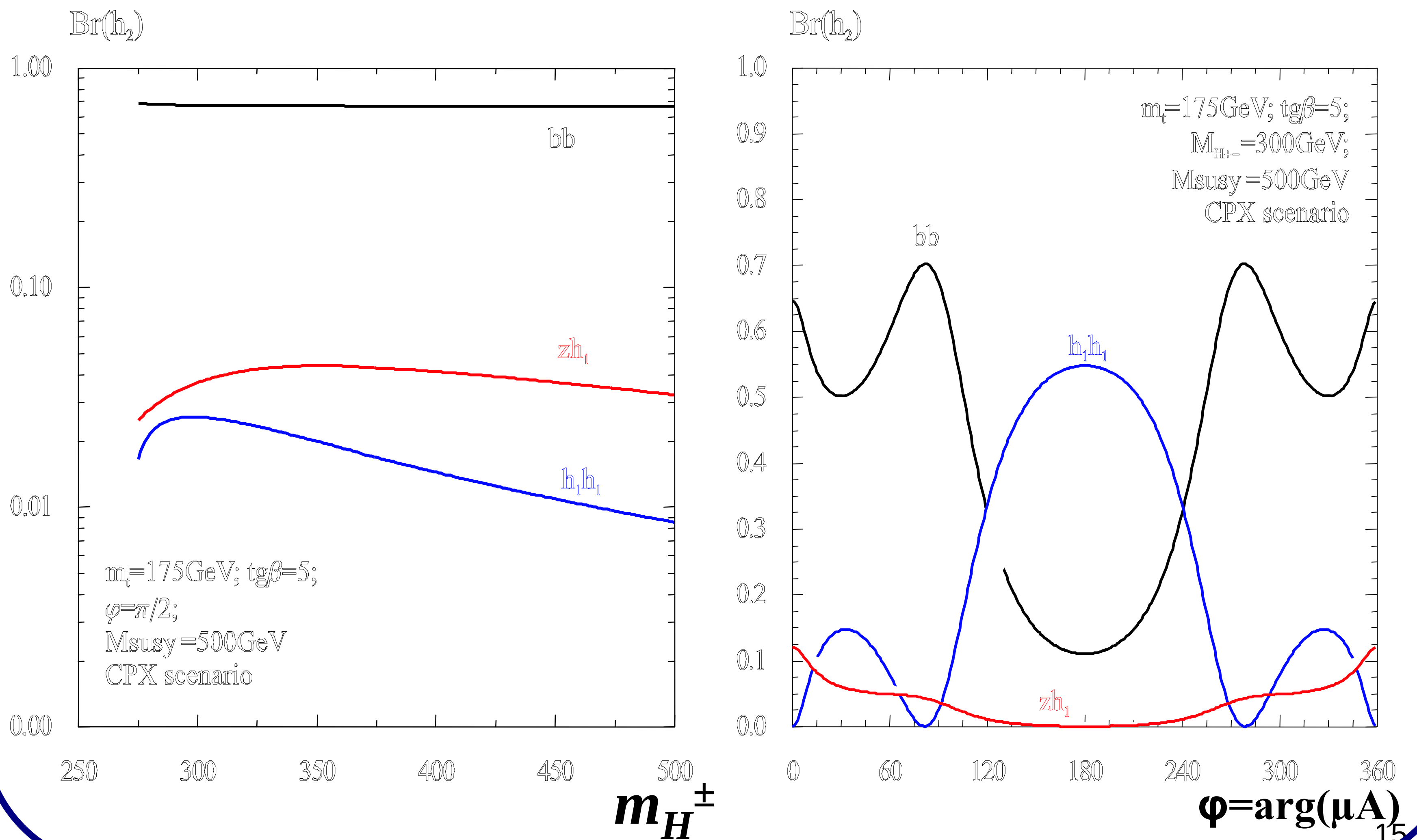


μ = 2 ТэВ, $A_t = A_b$ = 1 ТэВ, tg β =5, M_{SUSY} =0.5 ТэВ, $m_{H^\pm}$=150 ГэВ

Branching ratios



Branching ratios



ELECTROWEAK BARYOGENESIS

Baryon asymmetry in the present Universe

$$\eta_B \equiv \frac{n_B}{s} = (8.7 \pm 0.3) \cdot 10^{-11}$$

$$\frac{n_B}{n_\gamma} = 6.1 \cdot 10^{-10}$$

from cosmic microwave background and

large scale structure

in reasonable agreement with

primordial nucleosynthesis

Sakharov's Conditions for Baryogenesis

- *Necessary* requirements for baryogenesis:
  - Baryon number violation
  - CP violation
  - Non-equilibrium
  - $\Rightarrow \Gamma\,(\Delta B>0) > \Gamma(\Delta\, B<0)$
- Possible new consequences in
  - Proton decay
  - CP violation

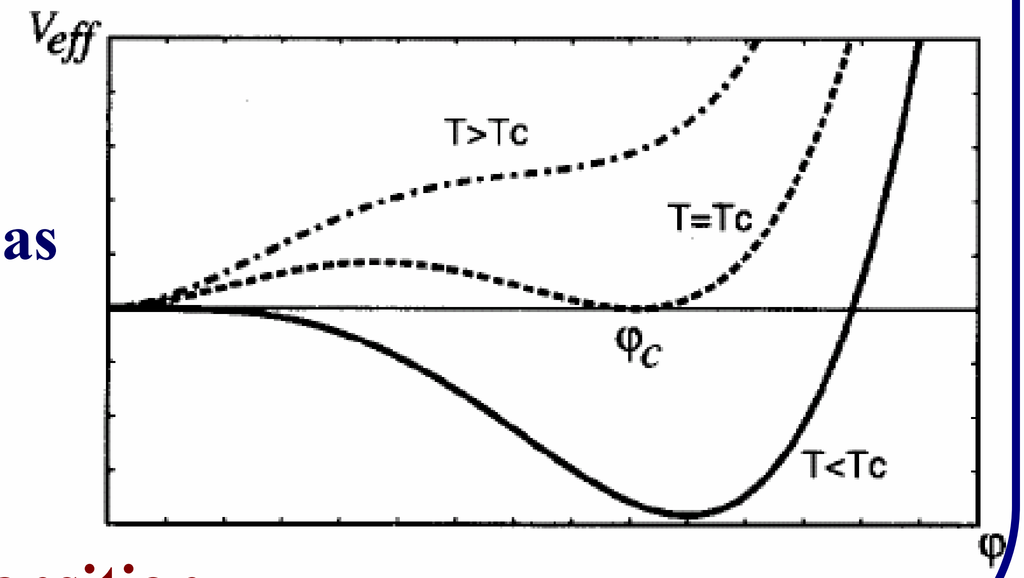
Condition of the strong first order transition

The first order phase transition is needed for a bubble nucleation.

The sphaleron transition rate should be suppressed in the broken phase at the critical temperature, in order not to erase the created baryon number.

This condition is expressed as

$$\phi_C/T_C \geq 1$$

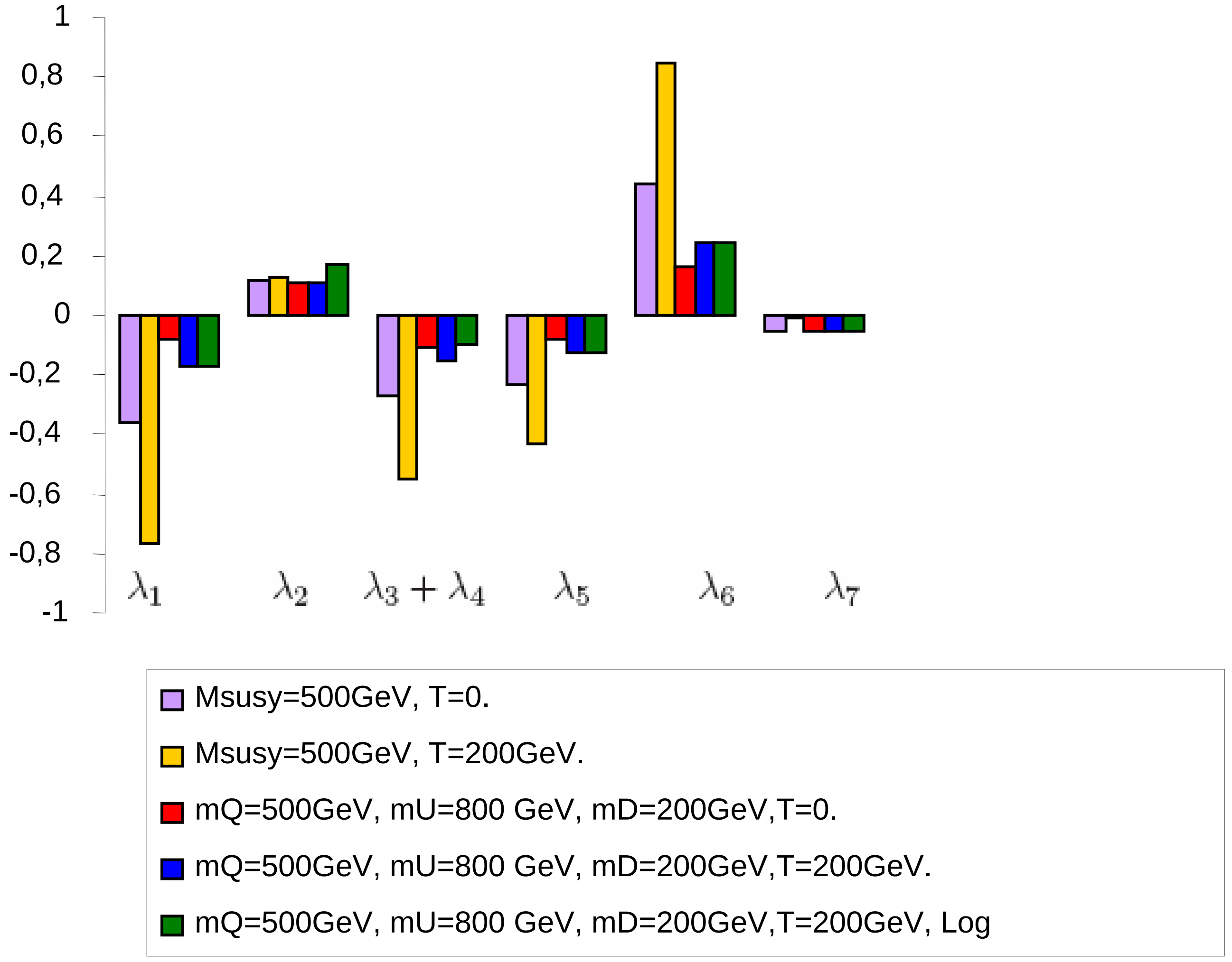


Strong first order phase transition.

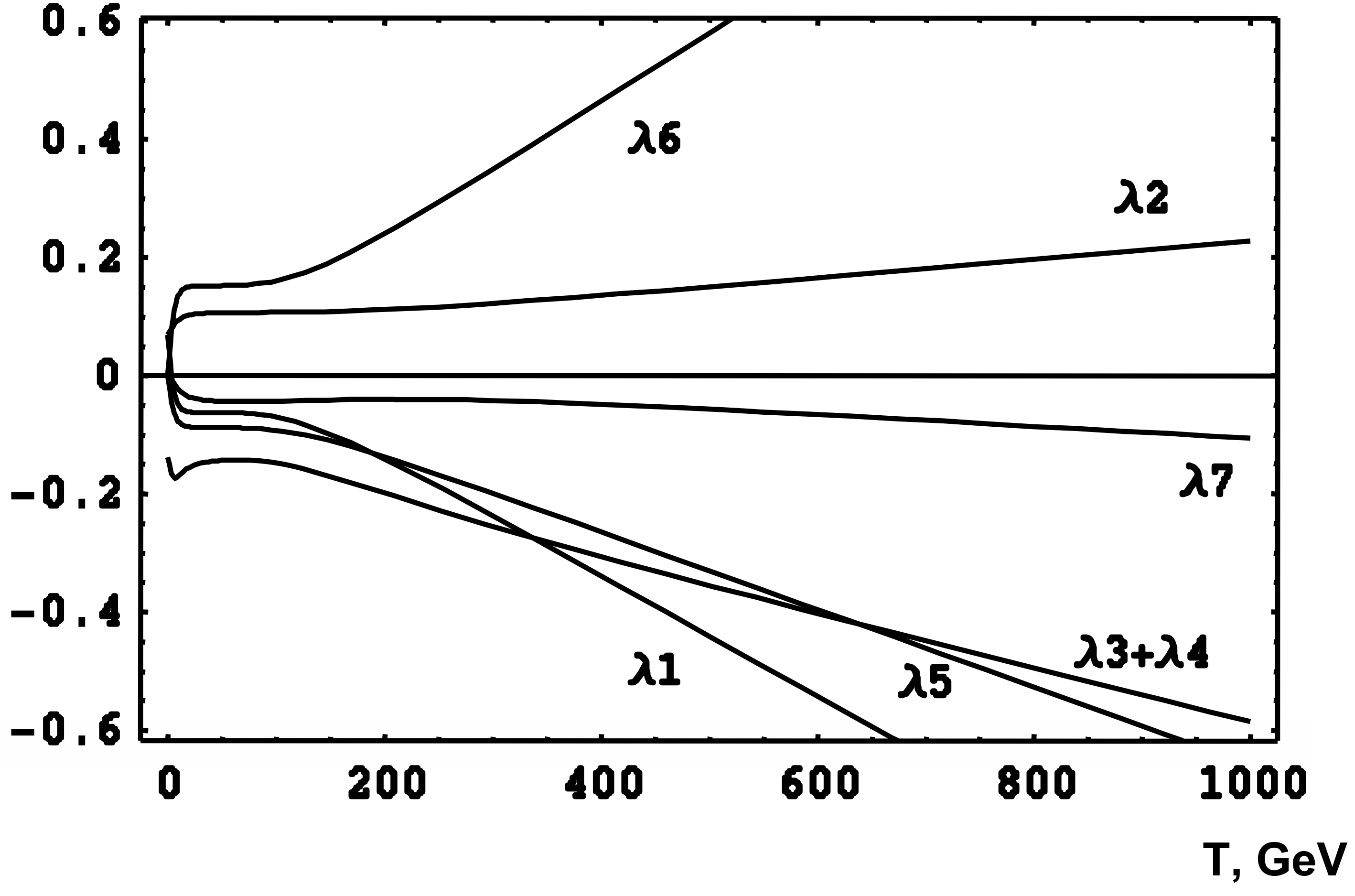
Electroweak Baryogenesis

- **Two problems in the Standard Model**
  - **First order phase transition requires m_h < 50 GeV**
  - **Need new source of CP violation because**
- **Minimal Supersymmetric Standard Model**
  - **First order phase transition possible if** $m_{\tilde{t}_R} < 160\mathrm{GeV}$
  - **New CP violating phase**

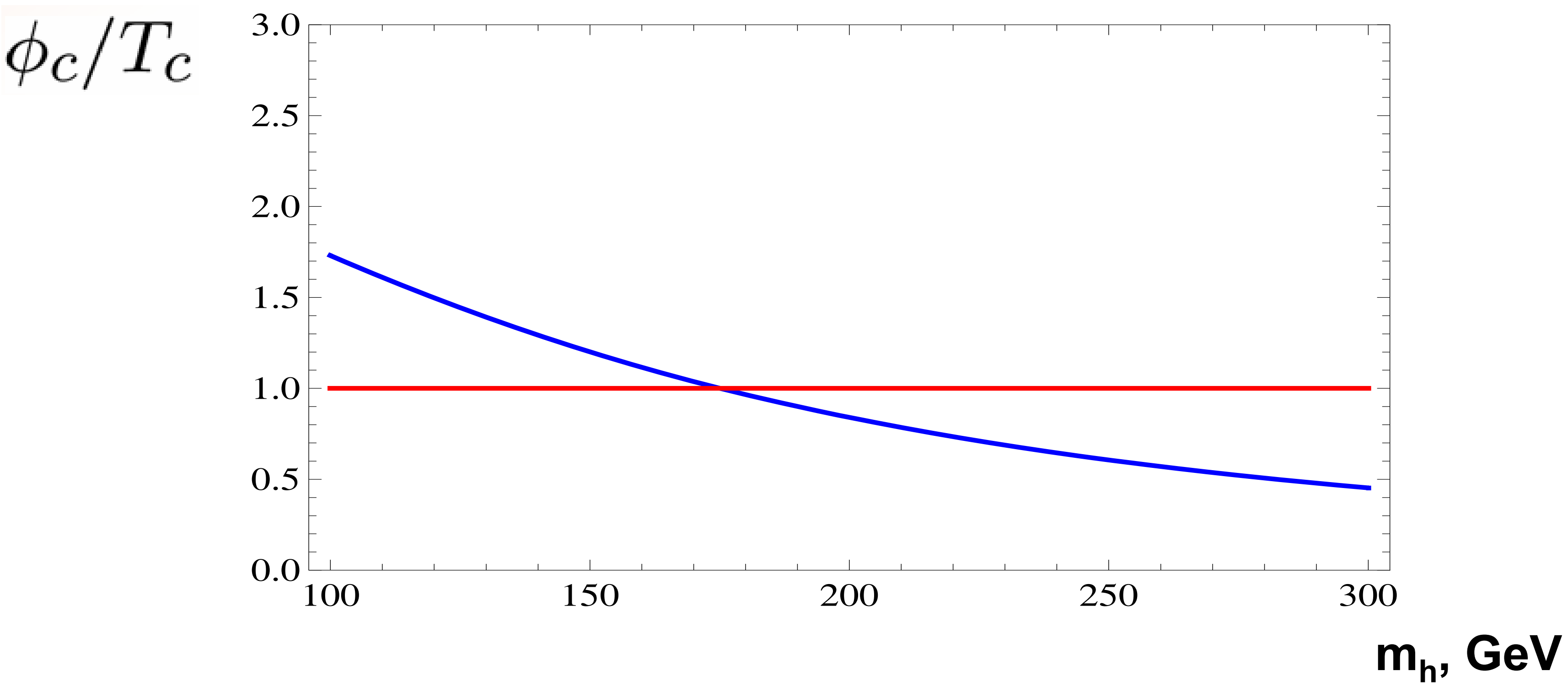
Parameters of the finite temperature effective potential



Parameters of the effective potential



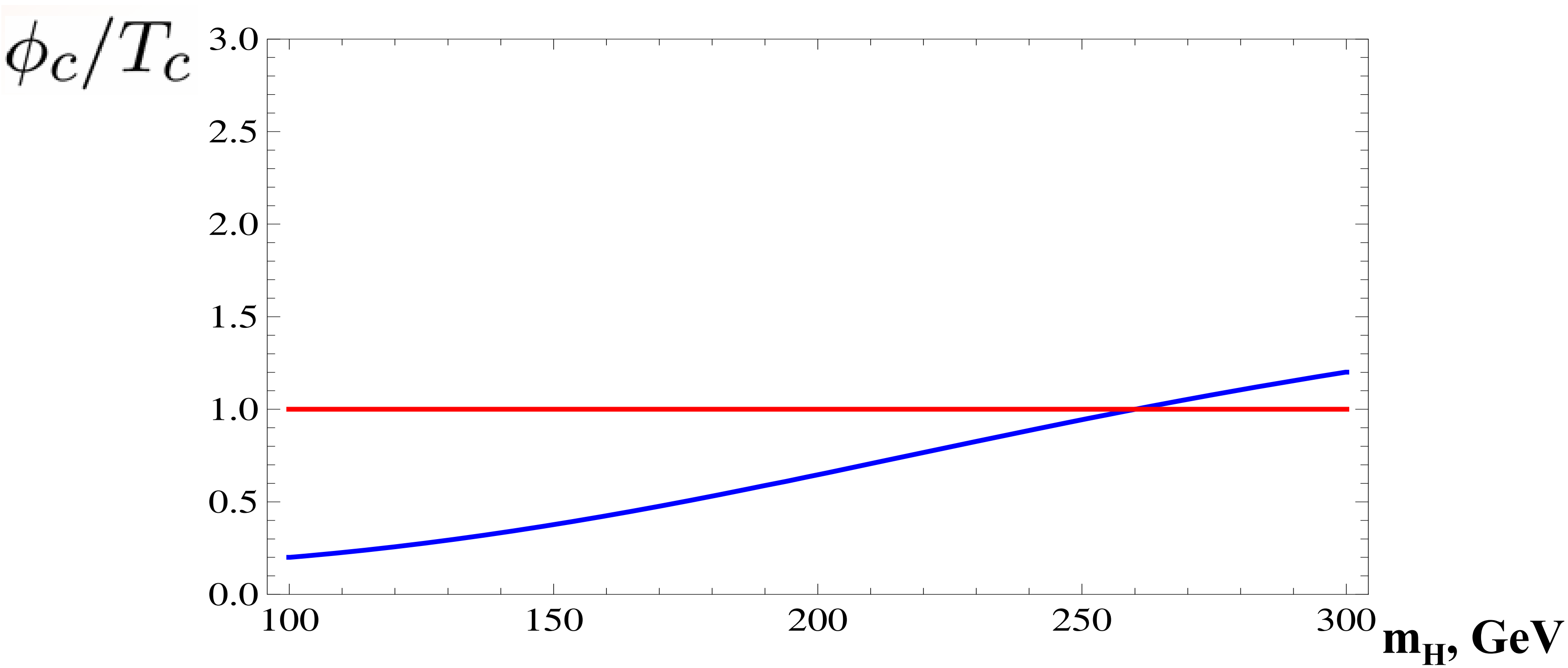
m_h in the THDM



$\phi_c/T_c \geq 1$ → m_h<190 GeV

LEP → m_h>114.4 GeV

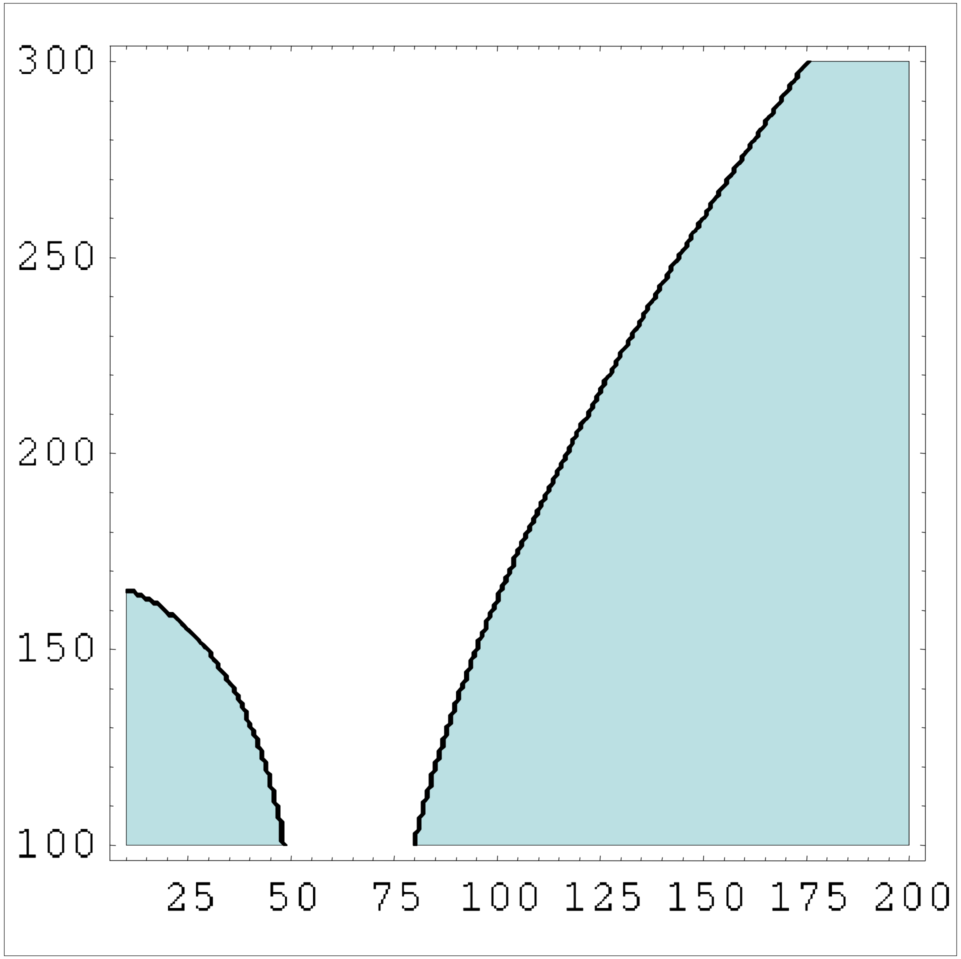
m_H in the THDM



$$\phi_c/T_c \geq 1$$ → **m_H>200 GeV**

m_h and m_H in the THDM

m_H, GeV



m_h, GeV

Summary

1.The potential of the THDM in the general case is not CP-invariant and the parameters $\lambda_{5,6,7}$ of the two-doublet MSSM sector should be taken complex.

2.The deviations of the observable effects in the scenario with nongenerate mass of the squark sector from the phenomenology of the standard scenario can be substantial mainly due to changed masses in comparison with the case of generate scalar quarks mass.

3.The deviations are particularly strong if the power terms $|\mu A_t|/M_{SUSY}$ are large and the charged Higgs boson mass does not exceed 150-200 GeV, being rather weakly dependent on the value of tan β.

4.Such models could lead in principle to a reconsideration of the experimental properties for the signal of the Higgs boson production at the modern and future colliders.