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## Critical temperatures in extensions of Higgs sector

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# Outline

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### Minimal supersymmetric standard model

Effective Potential of MSSM → Free Energy density

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### Minimal supersymmetric standard model

Effective Potential of MSSM → Free Energy density

### Effective Potential parameters. One-loop temperature corrections

[Dolgopolov M.V., Dubinin M. N., Rykova E.N. Two-Higgs doublet potential of the MSSM at finite temperature and Higgs boson masses // Quarks 2008. V. 1.]. Abstract:

In the framework of MSSM the one-loop corrections to the parameters of effective two doublet Higgs potential at finite temperature are calculated. The scalar quarks mass splitting influences strongly on the effective parameters of temperature potential, providing interesting possibilities for the phase transition evidence. The physical masses vanish, when the temperature increases up to the critical values, which corresponds to the phase transition. In the limiting case, when the temperature is equal to zero and all mass parameters of the soft SUSY breaking sector are degenerated, the predictions for observables from two-doublet potential coincide with known previous results.

## Introduction

In the simple isoscalar model the standard-like Higgs potential

$$U(\varphi) = -\frac{1}{2}\mu^2\varphi^2 + \frac{1}{4}\lambda\varphi^4.$$

Two solutions

$$v(0) = 0 \text{ and } v^2(T) = \frac{\mu^2}{\lambda} - \frac{T^2}{4},$$

demonstrate the second order phase transition at the critical temperature

$$T_c = \frac{2\mu}{\sqrt{\lambda}} = 2v(0),$$

The thermal Higgs boson mass

$$m_h^2 = -\mu^2 + \lambda \frac{T^2}{4}.$$

## Introduction

Temperature loop corrections from the stop and other additional scalar states could be large and lead to the first order phase transition, the intensity of the latter depends on

$$\xi = \frac{v(T_c)}{T_c}, \text{ where } v(T_c) = \sqrt{v_1^2(T_c) + v_2^2(T_c)}$$

is the vacuum expectation value at the critical temperature  $T_c$ .  
The electroweak baryogenesis could be explained if

$$\frac{v(T_c)}{T_c} > 1,$$

the case of strong first order phase transition.

## Introduction

In a number of analyses the MSSM finite-temperature effective potential is taken in the representation

$$V_{eff}(v, T) = V_0(v_1, v_2, 0) + V_1(m(v), 0) + V_1(T) + V_{ring}(T), \quad (1)$$

- ▶  $V_0$  is the tree-level MSSM two-doublet potential at the SUSY scale
- ▶  $V_1$  is the (non-temperature) one-loop resummed Coleman-Weinberg term, dominated by stop and sbottom contributions
- ▶  $V_1(T)$  is the one-loop temperature term
- ▶  $V_{ring}$  is the correction of re-summed leading infrared contribution from multi-loop ring (or daisy) diagrams

## Effective Potential of MSSM → Free Energy density

In two-doublet model there are two identical  $SU(2)$  doublets of complex scalar fields  $\Phi_1$  and  $\Phi_2$

$$\Phi_1 = \begin{pmatrix} \phi_1^+(x) \\ \phi_1^0(x) \end{pmatrix}, \quad \Phi_2 = \begin{pmatrix} \phi_2^+(x) \\ \phi_2^0(x) \end{pmatrix}$$

with nonzero vacuum expectation values

$$\langle \Phi_1 \rangle = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v_1 \end{pmatrix}, \quad \langle \Phi_2 \rangle = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v_2 \end{pmatrix}.$$

Neutral components of doublets

$$\phi_1^0(x) = \frac{1}{\sqrt{2}}(v_1 + \eta_1 + i\chi_1), \quad \phi_2^0(x) = \frac{1}{\sqrt{2}}(v_2 + \eta_2 + i\chi_2).$$

## Effective Potential of MSSM

The most general renormalizable hermitian  $SU(2) \otimes U(1)$  invariant potential: [Akhmetzyanova E.N., M.V.D, Dubinin M.N. Soft SUSY Breaking and Explicit CP Violation in the THDM // CALC'2003 & SQS03 Proc.]

$$\begin{aligned} U(\Phi_1, \Phi_2) = & -\mu_1^2(\Phi_1^\dagger \Phi_1) - \mu_2^2(\Phi_2^\dagger \Phi_2) - \mu_{12}^2(\Phi_1^\dagger \Phi_2) - \mu_{12}^{*2}(\Phi_2^\dagger \Phi_1) + \\ & + \frac{\lambda_1}{2}(\Phi_1^\dagger \Phi_1)^2 + \frac{\lambda_2}{2}(\Phi_2^\dagger \Phi_2)^2 + \lambda_3(\Phi_1^\dagger \Phi_1)(\Phi_2^\dagger \Phi_2) + \lambda_4(\Phi_1^\dagger \Phi_2)(\Phi_2^\dagger \Phi_1) + \\ & + \frac{\lambda_5}{2}(\Phi_1^\dagger \Phi_2)(\Phi_1^\dagger \Phi_2) + \frac{\lambda_5^*}{2}(\Phi_2^\dagger \Phi_1)(\Phi_2^\dagger \Phi_1) + \lambda_6(\Phi_1^\dagger \Phi_1)(\Phi_1^\dagger \Phi_2) + \\ & + \lambda_6^*(\Phi_1^\dagger \Phi_1)(\Phi_2^\dagger \Phi_1) + \lambda_7(\Phi_2^\dagger \Phi_2)(\Phi_1^\dagger \Phi_2) + \lambda_7^*(\Phi_2^\dagger \Phi_2)(\Phi_2^\dagger \Phi_1) \end{aligned}$$

with effective real parameters  $\mu_1^2, \mu_2^2, \lambda_1, \dots, \lambda_4$  and complex parameters  $\mu_{12}^2, \lambda_5, \lambda_6, \lambda_7$ .

## Effective Potential of MSSM

In the tree approximation on the energy scale  $M_{SUSY}$ , the parameters  $\lambda_{1-7}$  are real and are expressed using the coupling constants  $g_1$  and  $g_2$  of electroweak group of the gauge symmetry  $SU(2) \otimes U(1)$  as follows:

$$\lambda_1(M_{SUSY}) = \lambda_2(M_{SUSY}) = \frac{1}{4} (g_2^2(M_{SUSY}) + g_1^2(M_{SUSY})) ,$$

$$\lambda_3(M_{SUSY}) = \frac{1}{4} (g_2^2(M_{SUSY}) - g_1^2(M_{SUSY})) ,$$

$$\lambda_4(M_{SUSY}) = -\frac{1}{2} g_2^2(M_{SUSY}),$$

$$\lambda_5(M_{SUSY}) = \lambda_6(M_{SUSY}) = \lambda_7(M_{SUSY}) = 0.$$

## Effective Potential of MSSM

The supersymmetric scalar potential of interaction of Higgs bosons with the third generation quark superpartners on the tree level has the form

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

$$\mathcal{V}_M = (-1)^{i+j} m_{ij}^2 \Phi_i^\dagger \Phi_j + M_{\tilde{Q}}^2 (\tilde{Q}^\dagger \tilde{Q}) + M_{\tilde{U}}^2 \tilde{U}^* \tilde{U} + M_{\tilde{D}}^2 \tilde{D}^* \tilde{D},$$

$$\mathcal{V}_\Gamma = \Gamma_i^D (\Phi_i^\dagger \tilde{Q}) \tilde{D} + \Gamma_i^U (i \Phi_i^T \sigma_2 \tilde{Q}) \tilde{U} + \Gamma_i^{D*} (\tilde{Q}^\dagger \Phi_i) \tilde{D}^* - \Gamma_i^{U*} (i \tilde{Q}^\dagger \sigma_2 \Phi_i^*) \tilde{U}^*,$$

$$\begin{aligned} \mathcal{V}_\Lambda &= \Lambda_{ik}^{jl} (\Phi_i^\dagger \Phi_j) (\Phi_k^\dagger \Phi_l) + (\Phi_i^\dagger \Phi_j) [\Lambda_{ij}^Q (\tilde{Q}^\dagger \tilde{Q}) + \Lambda_{ij}^U \tilde{U}^* \tilde{U} + \Lambda_{ij}^D \tilde{D}^* \tilde{D}] + \\ &+ \bar{\Lambda}_{ij}^Q (\Phi_i^\dagger \tilde{Q}) (\tilde{Q}^\dagger \Phi_j) + \frac{1}{2} [\Lambda \epsilon_{ij} (i \Phi_i^T \sigma_2 \Phi_j) \tilde{D}^* \tilde{U} + \text{CH.CF.}], \end{aligned} \quad i, j, k, l = 1, 2,$$

$\mathcal{V}_{\tilde{Q}}$  denotes the terms of interaction of four scalar quarks.

## Parameters of Effective Potential of MSSM

$$\begin{aligned}\Delta\lambda_1 = & C_{31}^4 I_2[m_Q, m_U] + C_{32}^4 I_2[m_Q, m_D] + \\ & + C_{31}^2 (C_{41} I_1[m_Q, m_U] + C_{43} I_1[m_U, m_Q]) + \\ & + C_{32}^2 (C_{42} I_1[m_Q, m_D] + C_{44} I_1[m_D, m_Q]).\end{aligned}$$

$$\begin{aligned}\Delta\lambda_2 = & C_{33}^4 I_2[m_Q, m_U] + C_{34}^4 I_2[m_Q, m_D] + \\ & + C_{33}^2 (C_{45} I_1[m_Q, m_U] + C_{47} I_1[m_U, m_Q]) + \\ & + C_{34}^2 (C_{46} I_1[m_Q, m_D] + C_{48} I_1[m_D, m_Q]).\end{aligned}$$

$$\begin{aligned}\Delta(\lambda_3 + \lambda_4) = & C_{31}^2 C_{33}^2 I_2[m_Q, m_U] + C_{32}^2 C_{34}^2 I_2[m_Q, m_D] + \\ & + (C_{31}^2 C_{45} + C_{33}^2 C_{41}) I_1[m_Q, m_U] + (C_{31}^2 C_{47} + C_{33}^2 C_{43}) I_1[m_U, m_Q] + \\ & + (C_{32}^2 C_{46} + C_{34}^2 C_{42}) I_1[m_Q, m_D] + (C_{32}^2 C_{48} + C_{34}^2 C_{44}) I_1[m_D, m_Q].\end{aligned}$$

$$\Delta\lambda_5 = C_{31}^2 C_{33}^2 I_2[m_Q, m_U] + C_{32}^2 C_{34}^2 I_2[m_Q, m_D].$$

## Finite temperature corrections of squarks

In the finite temperature field theory Feynman diagrams with boson propagators, containing Matsubara frequencies  $\omega_n = 2\pi nT$  ( $n = 0, \pm 1, \pm 2, \dots$ ), lead to structures of the form

$$I[m_1, m_2, \dots, m_b] = T \sum_{n=-\infty}^{\infty} \int \frac{d\mathbf{k}}{(2\pi)^3} \prod_{i=1}^b \frac{(-1)^b}{(\mathbf{k}^2 + \omega_n^2 + m_j^2)}, \quad (2)$$

$\mathbf{k}$  is the three-dimensional momentum in a system with the temperature  $T$ .

# Parameters of Effective Potential of MSSM

$\varphi_1^0 \tilde{u}_L \tilde{u}_R$	$-h_u v_3 \lambda$	$C_{31}$
$\varphi_1^{0*} \tilde{d}_L \tilde{d}_R$	$h_d A_d$	$C_{32}$
$\varphi_2^{0*} \tilde{u}_L \tilde{u}_R$	$h_u A_u$	$C_{33}$
$\varphi_2^{0*} d_L d_R$	$-h_d v_3 \lambda$	$C_{34}$
$\varphi_1^{0*} \varphi_1^0 \tilde{u}_L^* \tilde{u}_L$	$\frac{g_2^2}{4} - \frac{g_1^2}{12}$	$C_{41}$
$\varphi_1^{0*} \varphi_1^0 \tilde{d}_L^* \tilde{d}_L$	$-\frac{g_1^2}{12} - \frac{g_2^2}{4} + h_d^2$	$C_{42}$
$\varphi_1^{0*} \varphi_1^0 \tilde{u}_R^* \tilde{u}_R$	$\frac{g_1^2}{3}$	$C_{43}$
$\varphi_1^{0*} \varphi_1^0 \tilde{d}_R^* \tilde{d}_R$	$h_d^2 - \frac{g_1^2}{6}$	$C_{44}$
$\varphi_2^{0*} \varphi_2^0 \tilde{u}_L^* \tilde{u}_L$	$\frac{g_1^2}{12} - \frac{g_2^2}{4} + h_u^2$	$C_{45}$
$\varphi_2^{0*} \varphi_2^0 \tilde{d}_L^* \tilde{d}_L$	$\frac{g_1^2}{12} + \frac{g_2^2}{4}$	$C_{46}$
$\varphi_2^{0*} \varphi_2^0 \tilde{u}_R^* \tilde{u}_R$	$h_u^2 - \frac{g_1^2}{3}$	$C_{47}$
$\varphi_2^{0*} \varphi_2^0 \tilde{d}_R^* \tilde{d}_R$	$\frac{g_1^2}{6}$	$C_{48}$

## Parameters of Effective Potential of MSSM

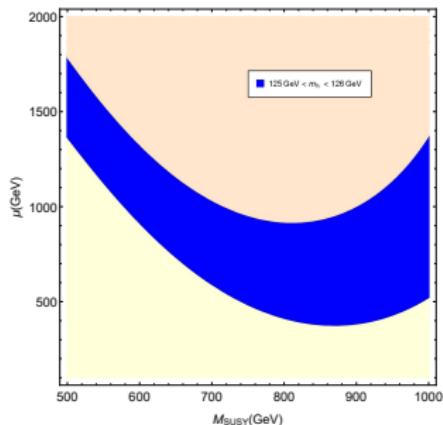
The one loop corrections to the parameters of effective potential

$$\begin{aligned}\Delta\lambda_1 = & h_u^4 \lambda^4 v_3^4 I_2[m_Q, m_U] + h_d^4 A_d^4 I_2[m_Q, m_D] + \\ & + h_u^2 \lambda^2 v_3^2 \left( \left( \frac{g_2^2}{4} - \frac{g_1^2}{12} \right) I_1[m_Q, m_U] + \frac{1}{3} g_1^2 I_1[m_U, m_Q] \right) + \\ & + h_d^2 A_d^2 \left( \left( h_d^2 - \frac{g_1^2}{12} - \frac{g_2^2}{4} \right) I_1[m_Q, m_D] + \left( h_d^2 - \frac{g_1^2}{6} \right) I_1[m_D, m_Q] \right) \\ \Delta\lambda_2 = & h_u^4 A_u^4 I_2[m_Q, m_U] + h_d^4 \lambda^4 v_3^4 I_2[m_Q, m_D] + \\ & + h_u^2 A_u^2 \left( \left( \frac{g_1^2}{12} - \frac{g_2^2}{4} \right) I_1[m_Q, m_U] + \left( h_u^2 - \frac{1}{3} g_1^2 I_1[m_U, m_Q] \right) + \right. \\ & \left. + h_d^2 \lambda^2 v_3^2 \left( \left( \frac{g_1^2}{12} + \frac{g_2^2}{4} \right) I_1[m_Q, m_D] + \frac{g_1^2}{6} I_1[m_D, m_Q] \right) \right)\end{aligned}$$

## Restrictions on the parameters of the MSSM

Parameters	Values
$\mu$	$100 \div 2000$ (GeV)
$A_{t,b}$	$-1000 \div 1000$ (GeV)
$M_{SUSY}$	$500 \div 1000$ (GeV)
$m_A$	$100 \div 500$ (GeV)
$\tan \beta$	$3 \div 50$
$\varphi$	$0 \div 2\pi$
$T$	$10 \div 500$ (GeV)

# Restrictions on the parameters of the MSSM



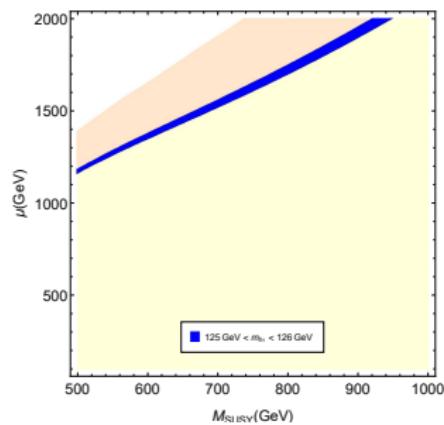
a) $\tan \beta = 5$

Contour plot in  $\mu - M_{\text{SUSY}}$  plane.

Selected region:  $125 \text{ GeV} < m_{h_1} < 126 \text{ GeV}$  (blue region).

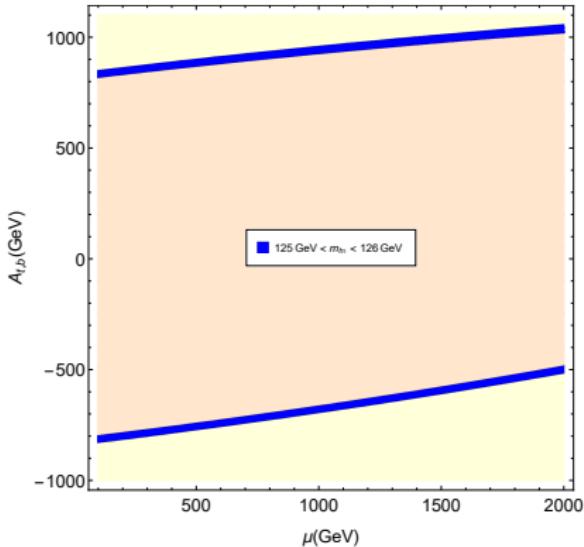
Fixed parameters:

$$A_{t,b} = 1000 \text{ GeV}, m_{H^\pm} = 300 \text{ GeV}, \varphi = \frac{\pi}{3}.$$



b) $\tan \beta = 50$

## Restrictions on the parameters of the MSSM



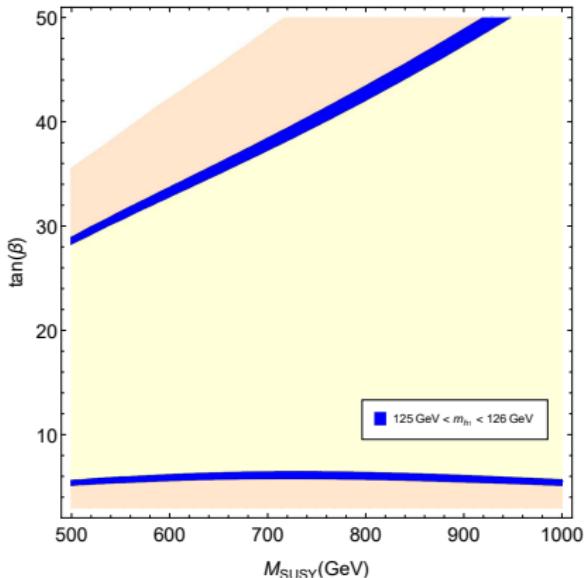
Contour plot in  $\mu - A_{t,b}$  plane.

Selected region:  $125 \text{ GeV} < m_{h_1} < 126 \text{ GeV}$  (blue region).

Fixed parameters:

$$M_{SUSY} = 500 \text{ GeV}, m_{H^\pm} = 300 \text{ GeV}, \varphi = \frac{\pi}{3}, \tan \beta = 5.$$

## Restrictions on the parameters of the MSSM



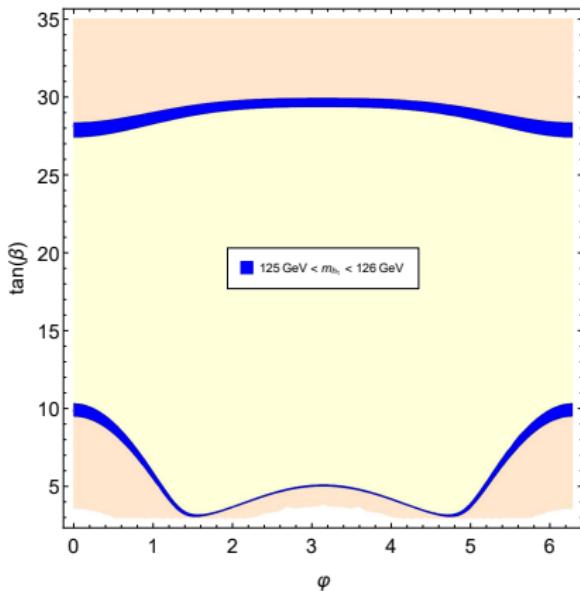
Contour plot in  $M_{\text{SUSY}}$  -  $\tan \beta$  plane.

Selected region:  $125 \text{ GeV} < m_{h_1} < 126 \text{ GeV}$  (blue region).

Fixed parameters:

$$\mu = 2000 \text{ GeV}, A_{t,b} = 1000 \text{ GeV}, m_{H^\pm} = 300 \text{ GeV}, \varphi = \frac{\pi}{3}.$$

## Restrictions on the parameters of the MSSM



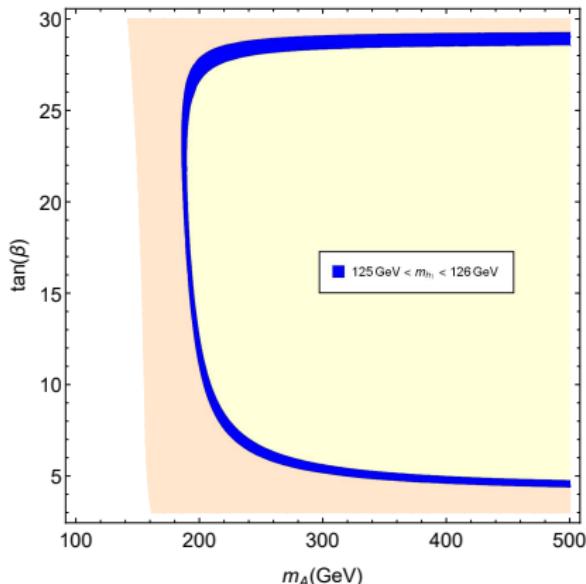
Contour plot in  $\varphi - \tan\beta$  plane.

Selected region:  $125 \text{ GeV} < m_{h_1} < 126 \text{ GeV}$  (blue region).

Fixed parameters:

$$\mu = 2000 \text{ GeV}, A_{t,b} = 1000 \text{ GeV}, M_{SUSY} = 500 \text{ GeV}, m_{H^\pm} = 300 \text{ GeV}.$$

## Restrictions on the parameters of the MSSM



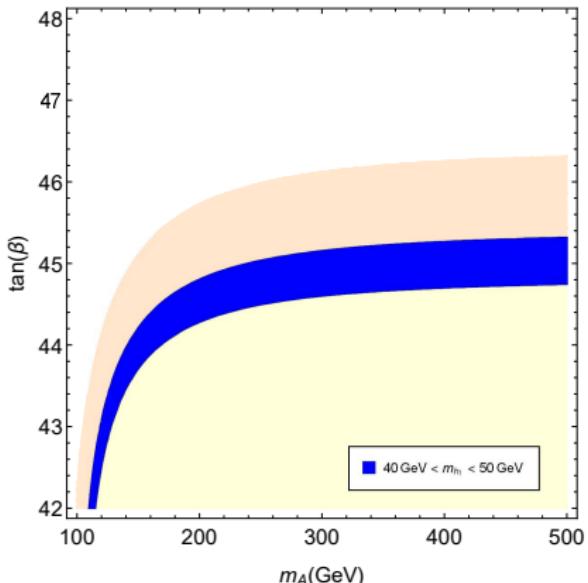
Contour plot in  $m_A$  -  $\tan\beta$  plane.

Selected region:  $125 \text{ GeV} < m_{h_1} < 126 \text{ GeV}$  (blue region).

Fixed parameters:

$$\mu = 2000 \text{ GeV}, A_{t,b} = 1000 \text{ GeV}, M_{SUSY} = 500 \text{ GeV}, \varphi = \frac{\pi}{3}.$$

## Restrictions on the parameters of the MSSM



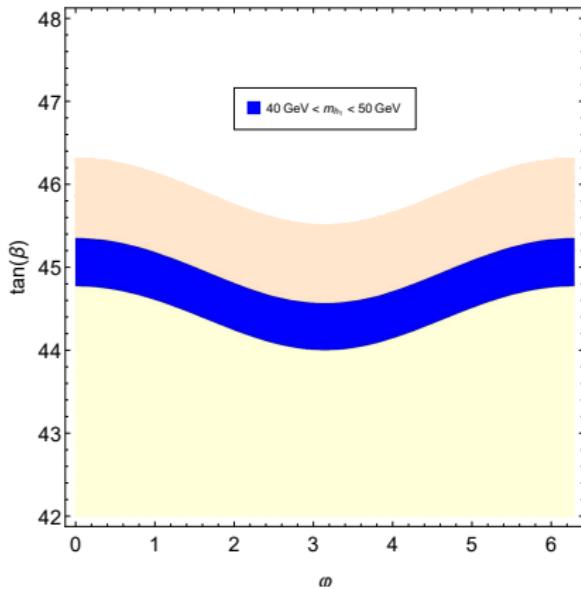
Contour plot in  $m_A$  -  $\tan\beta$  plane.

Selected region:  $40 \text{ GeV} < m_{h_1} < 50 \text{ GeV}$  (blue region).

Fixed parameters:

$$\mu = 2000 \text{ GeV}, A_{t,b} = 1000 \text{ GeV}, M_{SUSY} = 500 \text{ GeV}, \varphi = \frac{\pi}{3}.$$

## Restrictions on the parameters of the MSSM



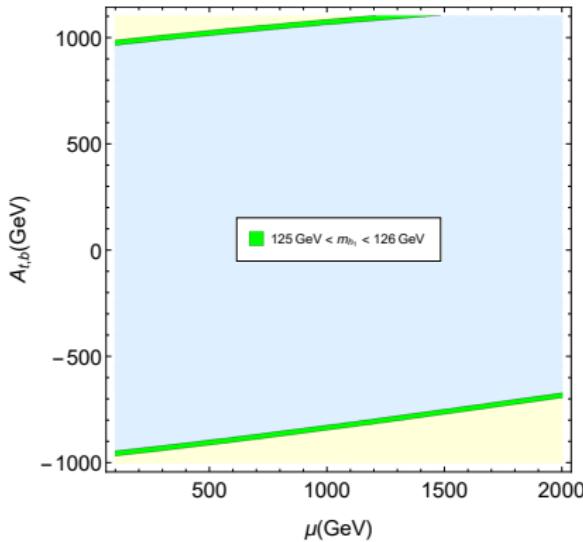
Contour plot in  $\varphi - \tan\beta$  plane.

Selected region:  $40 \text{ GeV} < m_{h_1} < 50 \text{ GeV}$  (blue region).

Fixed parameters:

$\mu = 2000 \text{ GeV}$ ,  $A_{t,b} = 1000 \text{ GeV}$ ,  $MSUSY = 500 \text{ GeV}$ ,  $m_{H^\pm} = 300 \text{ GeV}$ .

## Restrictions on the parameters of the MSSM



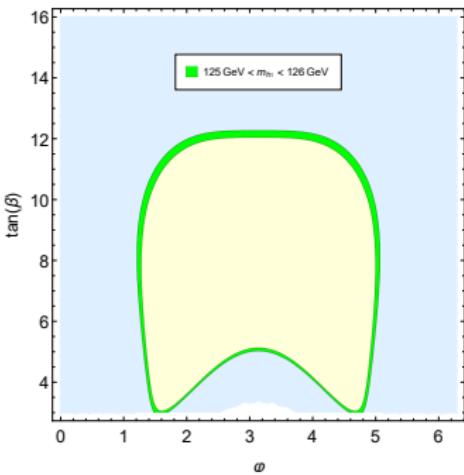
Contour plot in  $m_A - \tan\beta$  plane.

Selected region:  $125 \text{ GeV} < m_{h_1} < 126 \text{ GeV}$  (green region).

Fixed parameters:

$m_Q = 500 \text{ GeV}$ ,  $m_t = 800 \text{ GeV}$ ,  $m_b = 200 \text{ GeV}$ ,  $m_{H^\pm} = 300 \text{ GeV}$ ,  $\varphi = \frac{\pi}{3}$ ,  $\tan\beta = 5$ ,  
 $T = 500 \text{ GeV}$ .

## Restrictions on the parameters of the MSSM



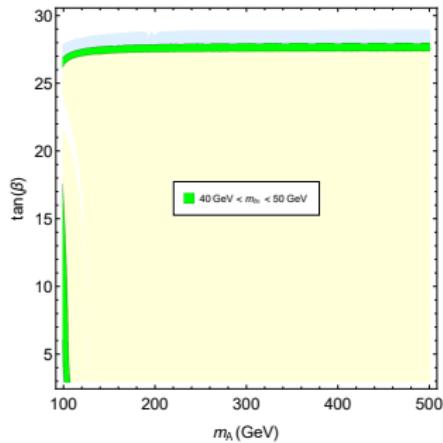
Contour plot in  $\varphi - \tan \beta$  plane.

Selected region:  $125 \text{ GeV} < m_{h_1} < 126 \text{ GeV}$  (green region).

Fixed parameters:

$\mu = 2000 \text{ GeV}$ ,  $A_{t,b} = 1000 \text{ GeV}$ ,  $m_Q = 500 \text{ GeV}$ ,  $m_t = 800 \text{ GeV}$ ,  $m_b = 200 \text{ GeV}$ ,  $m_{H^\pm} = 300 \text{ GeV}$ ,  $T = 500 \text{ GeV}$ .

# Restrictions on the parameters of the MSSM



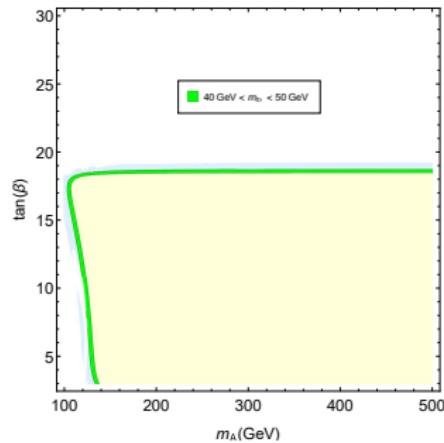
a)  $T = 10 \text{ GeV}$

Contour plot in  $\varphi - \tan \beta$  plane.

Selected region:  $40 \text{ GeV} < m_{h_1} < 50 \text{ GeV}$  (green region).

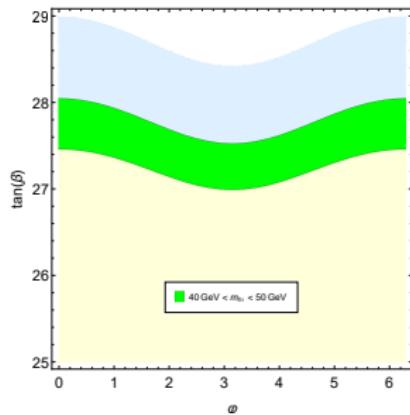
Fixed parameters:

$\mu = 2000 \text{ GeV}$ ,  $A_{t,b} = 1000 \text{ GeV}$ ,  $m_Q = 500 \text{ GeV}$ ,  $m_t = 800 \text{ GeV}$ ,  $m_b = 200 \text{ GeV}$ ,  $m_{H^\pm} = 300 \text{ GeV}$ .

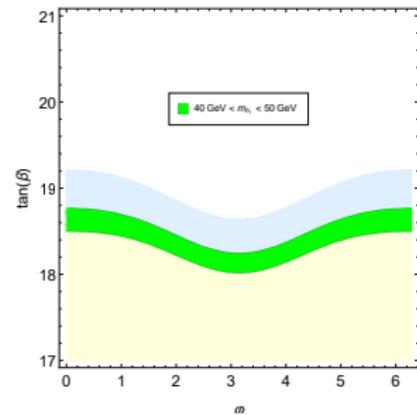


b)  $T = 500 \text{ GeV}$

# Restrictions on the parameters of the MSSM



a)  $T = 10 \text{ GeV}$



b)  $T = 500 \text{ GeV}$

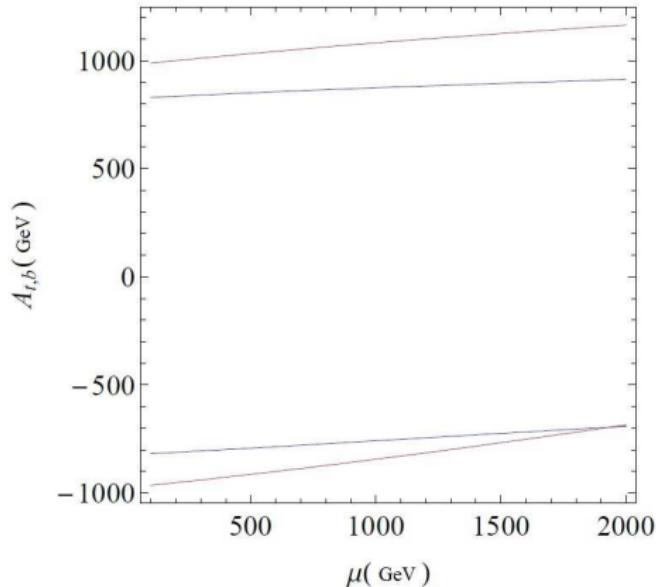
Contour plot in  $m_A$  –  $\tan \beta$  plane.

Selected region:  $40 \text{ GeV} < m_{h_1} < 50 \text{ GeV}$  (green region).

Fixed parameters:

$\mu = 2000 \text{ GeV}$ ,  $A_{t,b} = 1000 \text{ GeV}$ ,  $m_Q = 500 \text{ GeV}$ ,  $m_t = 800 \text{ GeV}$ ,  $m_b = 200 \text{ GeV}$ ,  
 $\varphi = \frac{\pi}{3}$ .

## Restrictions on the parameters of the MSSM

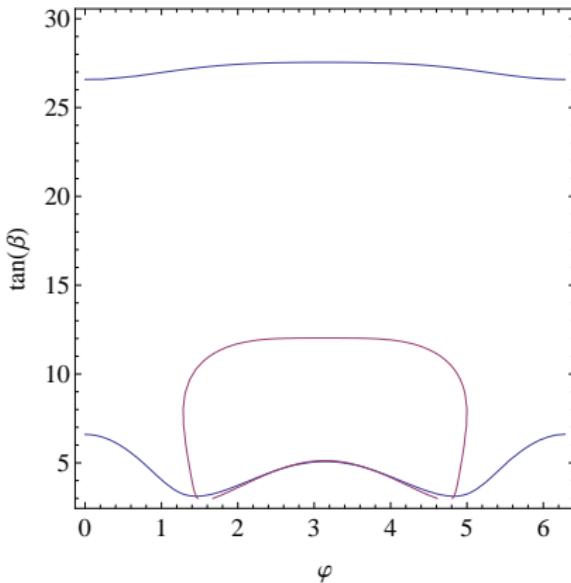


Contour plots in  $\mu - A_{t,b}$  plane.

Selected region:  $m_{h_1} = 126$  GeV ( $T = 0$  GeV - blue line;  $T \neq 0$  GeV - purple line).  
Fixed parameters:

$m_Q = 500$  GeV,  $m_t = 800$  GeV,  $m_b = 200$  GeV,  $m_{H^\pm} = 300$  GeV,  $\varphi = \frac{\pi}{3}$ ,  $\tan \beta = 5$ .

## Restrictions on the parameters of the MSSM



Contour plots in  $\varphi - \tan \beta$  plane.

Selected region:  $m_{h_1} = 126 \text{ GeV}$  ( $T = 0\text{GeV}$  - blue line;  $T \neq 0\text{GeV}$  - purple line ).  
Fixed parameters:

$\mu = 2000 \text{ GeV}$ ,  $A_{t,b} = 1000 \text{ GeV}$ ,  $m_Q = 500 \text{ GeV}$ ,  $m_t = 800 \text{ GeV}$ ,  $m_b = 200 \text{ GeV}$ ,  $m_{H^\pm} = 300 \text{ GeV}$ .

\* \* \* The NMSSM case ( $v_1 \neq 0, v_2 \neq 0, v_3 \neq 0$ ):

$$\begin{aligned}
& - \frac{k_5 v_1 v_2}{v_3} + 8k_4 v_3^2 + 6k_6 v_3 - v_3(k_3 v_3 + k_5) \frac{v_1^2 + v_2^2}{v_1 v_2} + \lambda_1 v_1^2 + \lambda_2 v_2^2 > 0, \\
& \frac{1}{v_1 v_2 v_3} \cdot \left( v_3 \left( k_5 v_2 + 2k_1 v_1 v_3 + 2k_3 v_2 v_3 \right) \left( v_1 v_2 \left( k_5 v_1 + 2k_3 v_1 v_3 + 2k_2 v_2 v_3 \right) \times \right. \right. \\
& \times \left( k_3 v_3^2 + k_5 v_3 + v_1 v_2 (\lambda_3 + \lambda_4) \right) - v_1 \left( k_5 v_2 + 2k_1 v_1 v_3 + 2k_3 v_2 v_3 \right) \left( -k_3 v_1 v_3^2 - \right. \\
& \left. \left. -k_5 v_1 v_3 + \lambda_2 v_2^3 \right) \right) - v_3 \left( k_5 v_1 + 2k_3 v_1 v_3 + 2k_2 v_2 v_3 \right) \left( v_2 \left( k_5 v_1 + 2k_3 v_1 v_3 + \right. \right. \\
& \left. \left. + 2k_2 v_2 v_3 \right) \left( -k_3 v_2 v_3^2 - k_5 v_2 v_3 + \lambda_1 v_1^3 \right) - v_1 v_2 \left( k_5 v_2 + 2k_1 v_1 v_3 + 2k_3 v_2 v_3 \right) \times \right. \\
& \times \left. \left( k_3 v_3^2 + k_5 v_3 + v_1 v_2 (\lambda_3 + \lambda_4) \right) \right) + \left( 8k_4 v_3^3 + 6k_6 v_3^2 - k_5 v_1 v_2 \right) \left( \left( -k_3 v_2 v_3^2 - \right. \right. \\
& \left. \left. -k_5 v_2 v_3 + \lambda_1 v_1^3 \right) \left( -k_3 v_1 v_3^2 - k_5 v_1 v_3 + \lambda_2 v_2^3 \right) - v_1 v_2 \left( k_3 v_3^2 + k_5 v_3 + \right. \right. \\
& \left. \left. + v_1 v_2 (\lambda_3 + \lambda_4) \right)^2 \right) \Bigg) > 0.
\end{aligned}$$

## Conclusion

- ▶ Our analysis of the effective MSSM and NMSSM finite-temperature potentials is based on the calculation of various one-loop temperature corrections from the squark-Higgs boson sector for the case of nonzero trilinear parameters  $A_t$ ,  $A_b$  and Higgs superfield parameter  $\mu$ .
  - ▶ Quantum corrections are incorporated in control parameters  $\lambda_{1,\dots,7\dots}(T)$  of the effective two-doublet (+singlet) potential, which is then explicitly rewritten in terms of Higgs boson mass eigenstates.
  - ▶ Bifurcation sets types for the two-Higgs-doublet(+singlet) potential  $U_{eff}(v_1, v_2)$  are determined.
  - ▶ Bifurcation sets for Higgs potential at the case of Peccei–Quinn symmetry are obtain. These sets always describe system in the **local minimum** with the **critical morse point**.
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- ▶ Constrains on MSSM and NMSSM **allowed parameter space** are evaluated  
at the presence of the effective potential local minimum.
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- ▶ **Higgs prepotential** as canonical morse form and non-morse term (**catastrophe function** at critical temperature) are reconstructed.