ОФН РАН

Исследование общего потенциала Хиггса и ренормгрупповые потоки

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форма потенциала?
Расширенная ϕ^4 модель и двухдублетная модель. CP-нарушение.

Ограничения на параметризацию эффективных каплингов.

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Критические явления при эволюции поверхности минимумов потенциала Хиггса в системе с двумя дублетами.

Двухдублетная модель

В общей ДДМ[1] вводится система полей:

$$\phi_1 = \begin{pmatrix} -\mathrm{i}\omega_1^+ \\ \frac{1}{\sqrt{2}}(\upsilon_1 + \nu_1 + \mathrm{i}\chi_1) \end{pmatrix}, \quad \phi_2 = \mathrm{e}^{\mathrm{i}\xi} \begin{pmatrix} -\mathrm{i}\omega_2^+ \\ \frac{1}{\sqrt{2}}(\upsilon_2 \mathrm{e}^{\mathrm{i}\zeta} + \nu_2 + \mathrm{i}\chi_2) \end{pmatrix}, \qquad (1)$$

$$\langle \Phi_1 \rangle = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ \upsilon_1 \end{pmatrix}, \qquad \langle \Phi_2 \rangle = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ \upsilon_2 \end{pmatrix}. \qquad (2)$$

$$\upsilon^2 = \upsilon_1^2 + \upsilon_2^2 = 246^2\ \text{ГэВ}^2$$

[1] Akhmetzyanova E.N., Dolgopolov M.V, Dubinin M.N. Higgs bosons in the two-doublet model with CP violation // Physical Review D 2005. — Vol. 71. Issue 7. — P. 1-24 & CALC 2003 & SQS03́ Proc.

Мотивация. Эффективный потенциал общей модели

The most general renormalizable hermitian $\mathrm{SU}(2) \otimes \mathrm{U}(1)$ invariant potential:

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

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

$$+\frac{\lambda_5}{2}(\Phi_1^\dagger \Phi_2)(\Phi_1^\dagger \Phi_2) + \frac{\overset{*}{\lambda}_5}{2}(\Phi_2^\dagger \Phi_1)(\Phi_2^\dagger \Phi_1) + \lambda_6(\Phi_1^\dagger \Phi_1)(\Phi_1^\dagger \Phi_2) +$$

$$+ \overset{*}{\lambda}_6 (\Phi_1^\dagger \Phi_1)(\Phi_2^\dagger \Phi_1) + \lambda_7(\Phi_2^\dagger \Phi_2)(\Phi_1^\dagger \Phi_2) + \overset{*}{\lambda}_7 (\Phi_2^\dagger \Phi_2)(\Phi_2^\dagger \Phi_1)$$

with effective real parameters μ_1^2, μ_2^2, λ_1,...,λ_4 and complex parameters μ_{12}^2, λ_5, λ_6, λ_7.

В случае приближенном рассматривают: $\mu_{12} = \mu_2 = \lambda_6 = \lambda_7 = 0$, где ϕ_1, ϕ_2 - скалярные поля

Во общем случае: ϕ_1, ϕ_2 - дублеты

Boundary conditions

On the scale of the superpartners M_{SUSY}

$$\text{———————} m_t \text{———} \Leftarrow \text{——————————} M_{SUSY} \text{———————}$$

The effective potential method,
the method of Feynman diagrams
& finite-temperature corrections

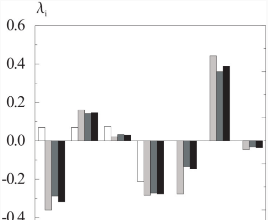
$$\lambda_1^{SUSY} = \lambda_2^{SUSY} = \frac{g_1^2 + g_2^2}{8}, \qquad \lambda_3^{SUSY} = \frac{g_2^2 - g_1^2}{4},$$

$$\lambda_4^{SUSY} = -\frac{g_2^2}{2}, \qquad \lambda_5^{SUSY} = \lambda_6^{SUSY} = \lambda_7^{SUSY} = 0.$$

The deviation from the parameters

$$\lambda_i = \lambda_i^{SUSY} - \triangle\lambda_i$$

Dolgopolov M., Dubinin M., Rykova E.
potential. Journal of Modern Physics. 2011.
Pp. 301-322



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

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

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

$$\mathcal{V}_{\Gamma} = \Gamma^{\rm D}_{\rm i} \left(\Phi^{\dagger}_{\rm i} \widetilde{\rm Q}\right) \widetilde{\rm D} + \Gamma^{\rm U}_{\rm i} \left({\rm i}\Phi^{\rm T}_{\rm i} \sigma_2 \widetilde{\rm Q}\right) \widetilde{\rm U} + \overset{*}{\Gamma}{}^{\rm D}_{\rm i} \left(\widetilde{\rm Q}^{\,\dagger} \Phi_{\rm i}\right) \widetilde{\rm D}^* - \overset{*}{\Gamma}{}^{\rm U}_{\rm i} \left({\rm i}\widetilde{\rm Q}^{\,\dagger} \sigma_2 \Phi^*_{\rm i}\right) \widetilde{\rm U}^*\,,$$

$$\mathcal{V}_{\Lambda} = \Lambda^{\rm jl}_{\rm ik} \left(\Phi^{\dagger}_{\rm i} \Phi_{\rm j}\right)\left(\Phi^{\dagger}_{\rm k} \Phi_{\rm l}\right) + \left(\Phi^{\dagger}_{\rm i} \Phi_{\rm j}\right)\left[\Lambda^{\rm Q}_{\rm ij} \left(\widetilde{\rm Q}^{\,\dagger} \widetilde{\rm Q}\right) + \Lambda^{\rm U}_{\rm ij} \widetilde{\rm U}^* \widetilde{\rm U} + \Lambda^{\rm D}_{\rm ij} \widetilde{\rm D}^* \widetilde{\rm D}\,\right] +$$

$$+ \overline{\Lambda}{}^{\rm Q}_{\rm ij} \left(\Phi^{\dagger}_{\rm i} \widetilde{\rm Q}\right)\left(\widetilde{\rm Q}^{\,\dagger} \Phi_{\rm j}\right) + \frac{1}{2}\left[\Lambda \epsilon_{\rm ij} \left({\rm i}\Phi^{\rm T}_{\rm i} \sigma_2 \Phi_{\rm j}\right) \widetilde{\rm D}^* \widetilde{\rm U} + {\rm h.c.}\right]\,, \ {\rm i}, {\rm j}, \ {\rm k}, {\rm l} = 1, 2\,,$$

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

The most general Hermitian form of the renormalized $\mathrm{SU}(2)\times\mathrm{U}(1)$ invariant potential for system of fields has the form:

$$\mathrm{U}(\Phi_1,\Phi_2,\mathrm{S}) = -\mu_1^2(\Phi_1^\dagger\Phi_1) - \mu_2^2(\Phi_2^\dagger\Phi_2) - \mu_3^2\mathrm{S}^*\mathrm{S} - (\mu_{12}^2(\Phi_1^\dagger\Phi_2) + \mathrm{h.c.})$$

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

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

$$+\lambda_6(\Phi_1^\dagger\Phi_1)(\Phi_1^\dagger\Phi_2) + \lambda_7(\Phi_2^\dagger\Phi_2)(\Phi_1^\dagger\Phi_2) + \mathrm{h.c.}$$

$$+\mathrm{k}_1(\Phi_1^\dagger\Phi_1)\mathrm{S}^*\mathrm{S} + \mathrm{k}_2(\Phi_2^\dagger\Phi_2)\mathrm{S}^*\mathrm{S} + (\mathrm{k}_3(\Phi_1^\dagger\Phi_2)\mathrm{S}^*\mathrm{S} + \mathrm{h.c.})$$

$$\mathrm{k}_4(\mathrm{S}^*\mathrm{S})^2 + + \mathrm{k}_5(\Phi_1^\dagger\Phi_1)\mathrm{S} + \mathrm{k}_6(\Phi_2^\dagger\Phi_2)\mathrm{S} + \mathrm{k}_7(\Phi_1^\dagger\Phi_2)\mathrm{S} + \overset{*}{\mathrm{k}}_7(\Phi_2^\dagger\Phi_1)\mathrm{S}^* + \mathrm{k}_8\mathrm{S}^3.$$

Parameters of Effective Potential of NMSSM

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

$$|y_u(\widetilde{Q}\epsilon H_u)|^2 + |y_d(\widetilde{Q}\epsilon H_d)|^2 + |y_u\widetilde{u}^*_R H^0_u - y_d\widetilde{d}^*_R H^-_d|^2 + |y_d\widetilde{d}^*_R H^0_d - y_d\widetilde{u}^*_R H^+_u|^2 -$$

$$-y_u(\widetilde{u}_R\widetilde{u}^*_L\lambda S H^0_d + \widetilde{u}_R\widetilde{d}^*_L\lambda S H^-_d + \text{c.c.}) - y_d(\widetilde{d}_R\widetilde{d}^*_L\lambda S H^0_u + \widetilde{d}_R\widetilde{d}^*_L\lambda S H^+_u + \text{c.c.}) +$$

$$+\frac{g_2^2}{8}(4|H^\dagger_d\widetilde{Q}|^2 - 2(H^\dagger_d H_d)(\widetilde{Q}^\dagger\widetilde{Q}) + 4|H^\dagger_u\widetilde{Q}|^2 - 2(H^\dagger_u H_u)(\widetilde{Q}^\dagger\widetilde{Q})) +$$

$$+\frac{g_1^2}{2}(\frac{1}{6}(\widetilde{Q}^\dagger\widetilde{Q}) - \frac{2}{3}\widetilde{u}^*_R\widetilde{u}_R + \frac{1}{3}\widetilde{d}^*_R\widetilde{d}_R + \frac{1}{2}(H^\dagger_u H_u) - \frac{1}{2}(H^\dagger_d H_d))^2 +$$

$$+(\widetilde{u}^*_R y_u A_u(\widetilde{Q}^T\epsilon H_u) - \widetilde{d}_R y_d A_d(\widetilde{Q}^T\epsilon H_d) + \text{c.c.})$$

Finite temperature corrections of squarks

In the early, high temperature stages of the Universe, the environment had a non-negligible matter and radiation density, making the hypotheses of conventional field theories impracticable. For that reason the methods of conventional field theories are no longer in use, and should be replaced by others, closer to thermodynamics, where the background state is a thermal bath. This field has been called field theory at finite temperature and it is extremely useful to study all phenomena which happened in the early Universe: phase transitions, inflationary cosmology, ...

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

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

k is the three-dimensional momentum in a system with the temperature T.

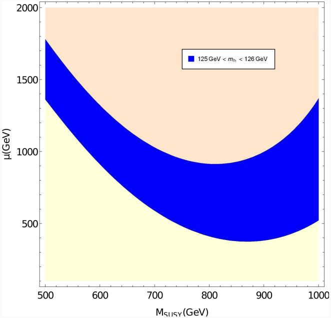
At $n \neq 0$ the result is

$$I[m_1, m_2, ..., m_b] = 2T\,(2\pi T)^{3-2b}\ \frac{(-1)^b \pi^{3/2}}{(2\pi)^3}\ \frac{\Gamma(b-3/2)}{\Gamma(b)}\ S(M, b-3/2), \tag{4}$$

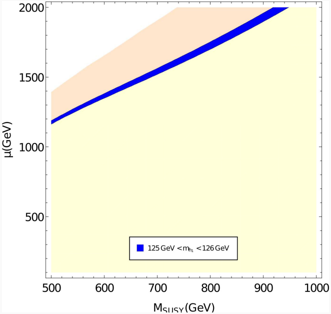
where

$$S(M, b-3/2) = \int \{dx\} \sum_{n=1}^{\infty} \frac{1}{(n^2 + M^2)^{b-3/2}}, \qquad M^2 \equiv \left(\frac{m}{2\pi T}\right)^2.$$

Restrictions on the parameters of the MSSM



a) $\tan\beta = 5$



b) $\tan\beta = 50$

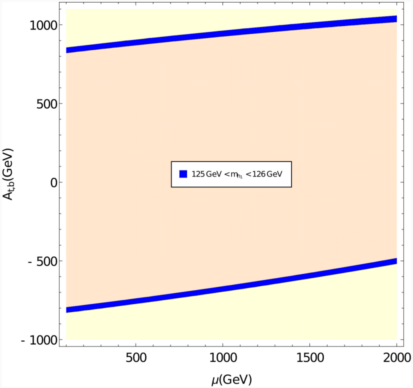
Contour plot in $\mu - \mathrm{M_{SUSY}}$ plane.

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

Fixed parameters:

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

Restrictions on the parameters of the MSSM



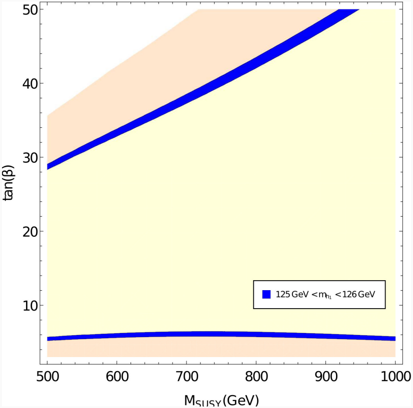
Contour plot in $\mu - \mathrm{A_{t,b}}$ plane.

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

Fixed parameters:

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

Restrictions on the parameters of the MSSM



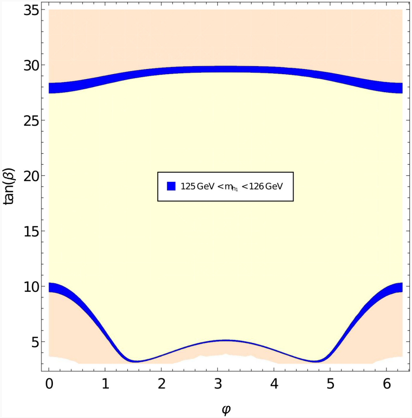
Contour plot in M_{SUSY} - $\tan\beta$ plane.

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

Fixed parameters:

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

Restrictions on the parameters of the MSSM



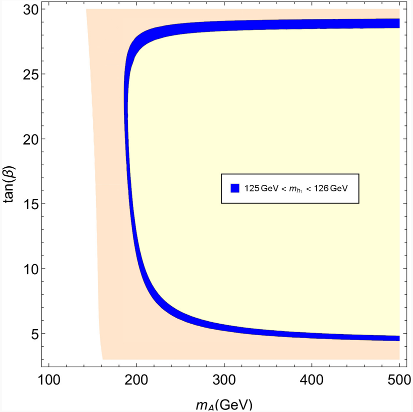
Contour plot in $\varphi - \tan\beta$ plane.

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

Fixed parameters:

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

Restrictions on the parameters of the MSSM



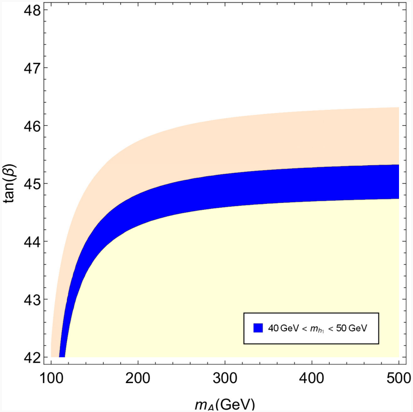
Contour plot in $\mathrm{m_A} - \tan\beta$ plane.

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

Fixed parameters:

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

Restrictions on the parameters of the MSSM



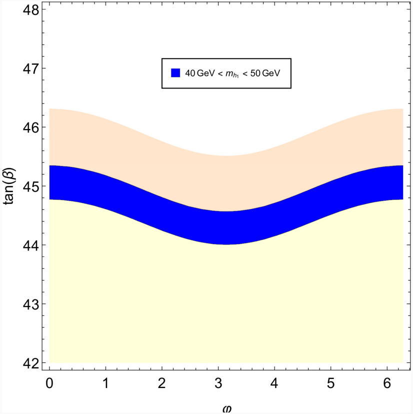
Contour plot in $m_A - \tan\beta$ plane.

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

Fixed parameters:

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

Restrictions on the parameters of the MSSM



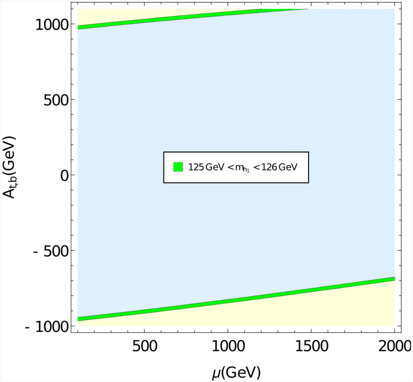
Contour plot in $\varphi - \tan\beta$ plane.

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

Fixed parameters:

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

Restrictions on the parameters of the MSSM



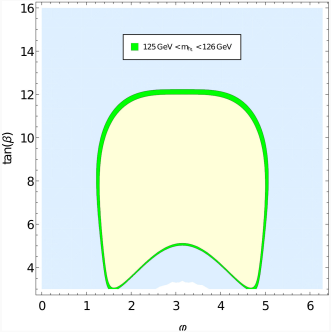
Contour plot in $\mathrm{m_A} - \tan\beta$ plane.

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

Fixed parameters:

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

Restrictions on the parameters of the MSSM



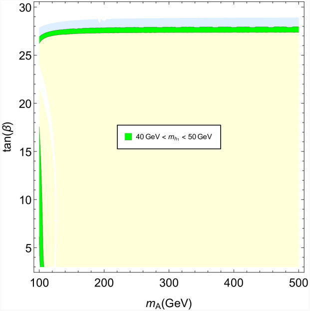
Contour plot in $\varphi - \tan\beta$ plane.

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

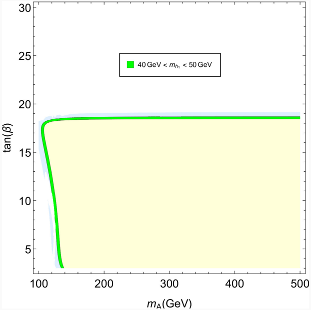
Fixed parameters:

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

Restrictions on the parameters of the MSSM



a)T = 10GeV



b)T = 500GeV

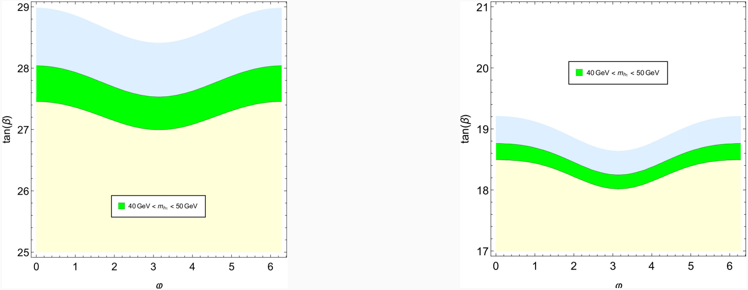
Contour plot in $\varphi - \tan\beta$ plane.

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

Fixed parameters:

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

Restrictions on the parameters of the MSSM



a)$\mathrm{T} = 10\mathrm{GeV}$ b)$\mathrm{T} = 500\mathrm{GeV}$

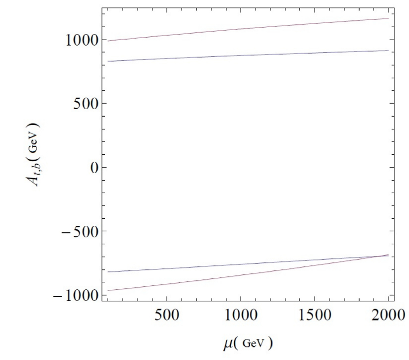
Contour plot in $\mathrm{m_A} - \tan\beta$ plane.

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

Fixed parameters:

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

Restrictions on the parameters of the MSSM



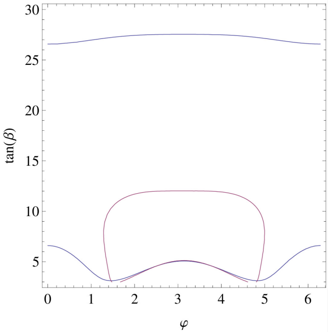
Contour plots in μ – $A_{t,b}$ plane.

Selected region: m_{h_1}=126 GeV (T = 0GeV - blue line; T ≠ 0GeV - 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 GeV (T = 0GeV - blue line; T ≠ 0GeV - purple line).

Fixed parameters:

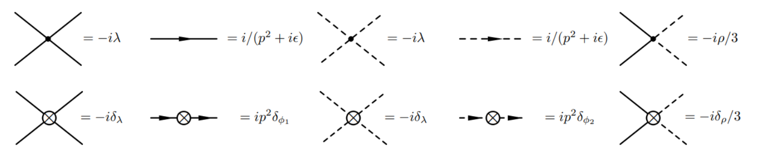
$\mu = 2000$ GeV, $A_{t,b} = 1000$ GeV,m_Q=500 GeV, m_t=800 GeV, m_b=200 GeV,$m_{H^\pm} = 300$ GeV.

Модель с двумя скалярными полями

Рассмотрим лагранжиан с двумя скалярными полями ϕ_1 и ϕ_2, при этом тут два каплинга [2], [3]:

$$\mathrm{L} = \frac{1}{2}((\partial_\mu \phi_1)^2 + (\partial_\mu \phi_2)^2) - \frac{\lambda}{4!}(\phi_1^4 + \phi_2^4) - \frac{2\rho}{4!}(\phi_1^2 \phi_2^2). \tag{5}$$

Тогда правила Фейнмана для нашего случая:

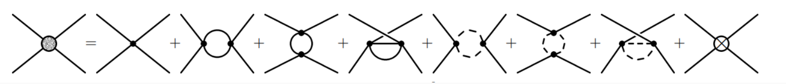


[2] Боголюбов Н.Н., Ширков Д.В. Введение в теорию квантованных полей. // 4-е изд. М.: Наука 1984.

[3] Пескин М., Шредер Д. Введение в квантовую теорию поля. // Ижевск: НИЦ «Регулярная и хаотическая динамика», 2001, 784 стр.

β-функции для λ и ρ. Контрчлены перенормировки δ_λ и δ_ρ

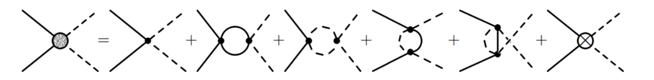
В однопетлевом порядке:



$$= -\mathrm{i}\lambda + (-\mathrm{i}\lambda)^2(\mathrm{V}(\mathrm{t}) + \mathrm{V}(\mathrm{s}) + \mathrm{V}(\mathrm{u})) + \left(-\mathrm{i}\frac{\rho}{3}\right)^2 (\mathrm{V}(\mathrm{t}) + \mathrm{V}(\mathrm{s}) + \mathrm{V}(\mathrm{u})) - \mathrm{i}\delta_\lambda =$$

$$= -\mathrm{i}\lambda - \left(\lambda^2 + \frac{\rho^2}{9}\right)(\mathrm{V}(\mathrm{t}) + \mathrm{V}(\mathrm{s}) + \mathrm{V}(\mathrm{u})) - \mathrm{i}\delta_\lambda.$$

Для ρ в однопетлевом порядке:



$$\delta_\rho = \frac{1}{16\pi^2}[\lambda\rho + 2\rho^2/3] \log \frac{\Lambda^2}{M^2}$$

$$\beta_\rho = \frac{1}{8\pi^2}[\lambda\rho + 2\rho^2/3]$$

Уравнение Каллана-Симанчика

Уравнение Каллана-Симанчика для двухточечной функции:

$$[\mathrm{M}\frac{\partial}{\partial \mathrm{M}} + \beta(\lambda)\frac{\partial}{\partial \mathrm{M}} + 2\gamma(\lambda)]\mathrm{G}^{(2)}(\mathrm{p}) = 0$$

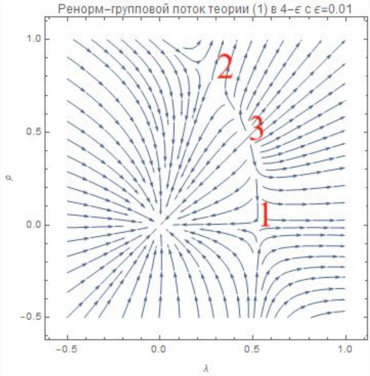
$$\beta_{\rho/\lambda} = \frac{1}{\lambda^2}[\beta_\rho \lambda - \beta_\lambda \rho] = -\frac{\rho}{48\pi^2}(\rho/\lambda - 3)(\rho/\lambda - 1)$$

Функция имеет нули в точке $\rho/\lambda = 0,\ 1,\ 3$.

В $4 - \epsilon$:

$$\beta_\lambda = -\epsilon\lambda + \frac{3\lambda^2 + \rho^2/3}{(4\pi)^2}; \tag{6}$$

$$\beta_\rho = -\epsilon\rho + \frac{2\lambda\rho + 4\rho^2/3}{(4\pi)^2}. \tag{7}$$



Три нетривиальные неподвижные точки на графике получаются из нулей β-функции:

1. $\lambda_{\mathrm{B}} = \frac{16\pi^2}{3}\epsilon, \qquad \rho_{\mathrm{B}} = 0,$ Седло

2. $\lambda_{\mathrm{C}} = \frac{8\pi^2}{3}\epsilon, \qquad \rho_{\mathrm{C}} = 8\pi^2\epsilon,$ Седло

3. $\lambda_{\mathrm{D}} = \frac{24\pi^2}{5}\epsilon, \qquad \rho_{\mathrm{D}} = \frac{24\pi^2}{5}\epsilon,$ Неустойчивый узел

В отличие от этих трех точек, четвертая точка (0,0) является ИК стабильной. Это вырожденный устойчивый узел. $(\lambda_{\mathrm{A}} = \rho_{\mathrm{A}} = 0)$.

Потоки ренормализационных групп

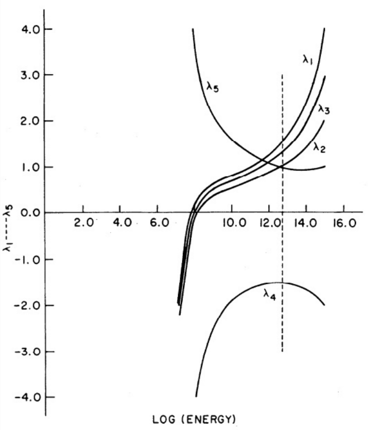
Для целей наших исследований РГ удобно определить [4].

$$\rho_{\rm i}(\mu) = \frac{\lambda_{\rm i}(\mu)}{g_3^2(\mu)}, \qquad \rho_{\rm t}(\mu) = \frac{h_{\rm t}(\mu)}{g_3^2(\mu)}, \qquad R_{\rm i}(\mu) = \frac{\rho_{\rm i}(\mu)}{\rho_{\rm t}(\mu)} = \frac{\lambda_{\rm i}(\mu)}{h_{\rm t}^2(\mu)} \tag{8}$$

Взаимодействия собственных состояний Хиггса с топ-кварком $g_{t\bar{t}h_i}$ также могут быть представлены как произведение соответствующего взаимодействия СМ и R-взаимодействия $R_{t\bar{t}h_i}$:

$$R_{t\bar{t}h_1} = \frac{\cos\alpha}{\sin\beta}, \qquad R_{t\bar{t}h_2} = \frac{\sin\alpha}{\cos\beta} \tag{9}$$

[4] Froggatt C.D., Nevzorov R., Nielsen H.B., Thompson D. Fixed point scenario in the Two Higgs Doublet Model inspired by degenerate vacua // Phys.Lett. - 2007. - B 657. - P.95-102.



1. G. K. Yeghiyan, M. Jurcisin and D. I. Kazakov, Mod. Phys. Lett. A 14 (1999) 601;

2. S. Codoban, M. Jurcisin and D. Kazakov, Phys. Lett. B 477 (2000) 223.

3. M. Jurcisin and D. I. Kazakov, Mod. Phys. Lett. A 14 (1999) 671.

4. C. T. Hill, C. N. Leung and S. Rao, Nucl. Phys. B 262 (1985) 517

Потоки $U(\phi_1, \phi_2)$ от каплингов $\lambda_1, \lambda_2, \lambda_3, \lambda_4$

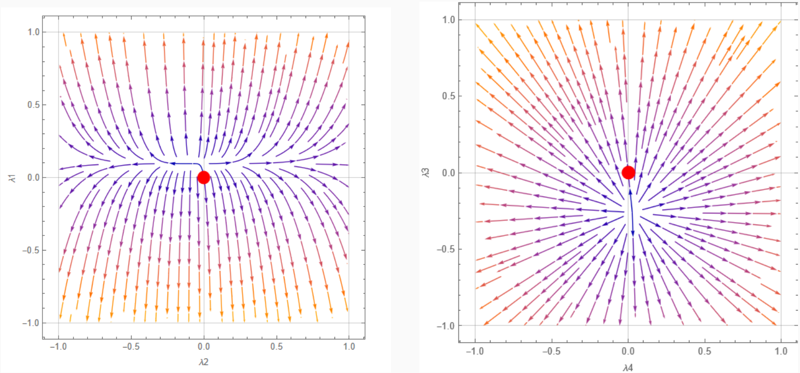
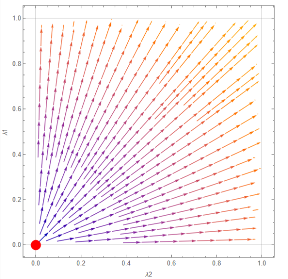
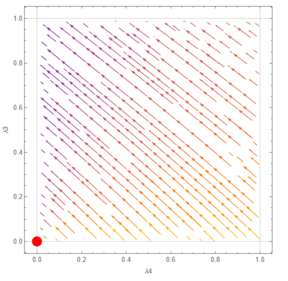
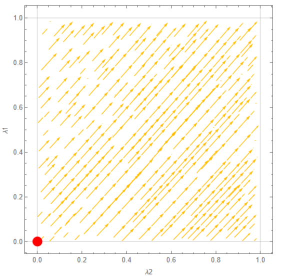


Figure 1: Ренормгрупповые потоки для каплингов 1,2 (слева) и 3,4 (справа)

Результаты: потоки $R_i(\mu)$ от каплингов $\lambda_1, \lambda_2, \lambda_3, \lambda_4$ и $R_{t\bar{t}h_i}$ от каплингов λ_1, λ_2







Потоки для модели E. Senaha 2023

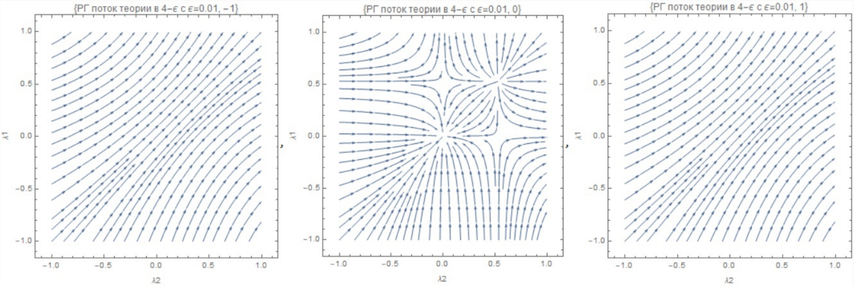


Figure 2: Ренормгрупповые потоки для каплингов 1,2 от 3 слева $\lambda_3 = -1$, по центру $\lambda_3 = 0$, справа $\lambda_3 = 1$

Потоки каплингов λ_1, λ_2 при изменении λ_5 в пробной модели

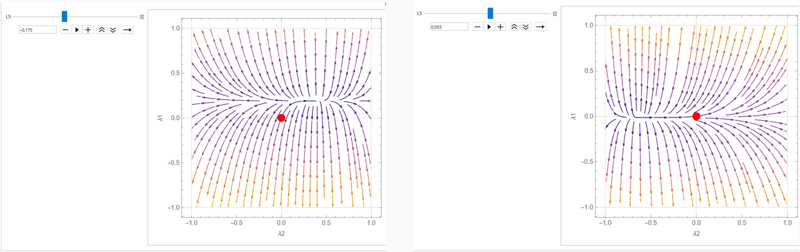


Figure 3: Ренормгрупповые потоки для каплингов 1,2 от 5 слева $\lambda_5 = -0.175$ справа $\lambda_5 = 0.055$

Conclusion

- Our analysis of the effective MSSM and NMSSM finite-temperature potentials is based on the diagram calculation of various one-loop temperature corrections for the case of nonzero trilinear parameters A_t, A_b and Higgs superfield parameter μ.
- Quantum corrections are incorporated in control parameters $\lambda_{1,...7}$...(T) of the effective two-doublet (+singlet) potential, which is then explicitly rewritten in terms of Higgs boson mass eigenstates.
- Types bifurcation sets for the two-Higgs-doublet(+singlet) potential $U_{eff}(v_1, v_2)$ are determined.
- Bifurcation sets for Higgs potential in the case of Peccei–Quinn symmetry are obtained. These sets always describe the system at the local minimum (critical morse point).

- Constrains on MSSM and NMSSM allowed parameter space are evaluated

Предварительные выводы.

1. Были получены и исследованы ренормгрупповые уравнения для моделей с двумя скалярными полями и двумя дублетами комплексных скалярных полей.

2. Для ряда каплингов наблюдается смещение РГ потоков, что связано с наличием дополнительной фазы или количеством каплингов. Определено инфракрасное асимптотическое поведение критической точки.

Дальнейшая перспектива: Интерфейс РГ потоков для индуцированных переходов и сравнение с экспериментальными данными по самодействию при энергиях СМ.

Finite temperature corrections of squarks

We calculate the integral

$$J_0[a_1, a_2] = \int \frac{dk}{(2\pi)^3} \frac{1}{(k^2 + a_1^2)(k^2 + a_2^2)} = \frac{1}{4\pi(a_1 + a_2)},$$

taking a residue in the spherical coordinate system. Dolgopolov M., Dubinin M., Rykova E., Journal of Modern Physics. Vol. 2. No. 5. P. 301-322. (2011).

$a_{1;2}^2$ are the sums of squared frequency and squared mass. Derivatives of J_0 with respect to a_1 and a_2 can be used for calculation of integrals

$$J_1[a_1, a_2] = \int \frac{dk}{(2\pi)^3} \frac{1}{(k^2 + a_1^2)^2(k^2 + a_2^2)} = \frac{1}{8\pi a_1 (a_1 + a_2)^2},$$

$$J_2[a_1, a_2] = \int \frac{dk}{(2\pi)^3} \frac{1}{(k^2 + a_1^2)^2(k^2 + a_2^2)^2} = \frac{1}{8\pi a_1 a_2 (a_1 + a_2)^3}.$$

Parameters of Effective Potential of MSSM

$$\Delta\lambda_1 = \mathrm{C}_{31}^4 \mathrm{I}_2[\mathrm{m_Q}, \mathrm{m_U}] + \mathrm{C}_{32}^4 \mathrm{I}_2[\mathrm{m_Q}, \mathrm{m_D}] + \\ + \mathrm{C}_{31}^2 (\mathrm{C}_{41} \mathrm{I}_1[\mathrm{m_Q}, \mathrm{m_U}] + \mathrm{C}_{43} \mathrm{I}_1[\mathrm{m_U}, \mathrm{m_Q}]) + \\ + \mathrm{C}_{32}^2 (\mathrm{C}_{42} \mathrm{I}_1[\mathrm{m_Q}, \mathrm{m_D}] + \mathrm{C}_{44} \mathrm{I}_1[\mathrm{m_D}, \mathrm{m_Q}]).$$

$$\Delta\lambda_2 = \mathrm{C}_{33}^4 \mathrm{I}_2[\mathrm{m_Q}, \mathrm{m_U}] + \mathrm{C}_{34}^4 \mathrm{I}_2[\mathrm{m_Q}, \mathrm{m_D}] + \\ + \mathrm{C}_{33}^2 (\mathrm{C}_{45} \mathrm{I}_1[\mathrm{m_Q}, \mathrm{m_U}] + \mathrm{C}_{47} \mathrm{I}_1[\mathrm{m_U}, \mathrm{m_Q}]) + \\ + \mathrm{C}_{34}^2 (\mathrm{C}_{46} \mathrm{I}_1[\mathrm{m_Q}, \mathrm{m_D}] + \mathrm{C}_{48} \mathrm{I}_1[\mathrm{m_D}, \mathrm{m_Q}]).$$

$$\Delta(\lambda_3 + \lambda_4) = \mathrm{C}_{31}^2 \mathrm{C}_{33}^2 \mathrm{I}_2[\mathrm{m_Q}, \mathrm{m_U}] + \mathrm{C}_{32}^2 \mathrm{C}_{34}^2 \mathrm{I}_2[\mathrm{m_Q}, \mathrm{m_D}] + \\ + (\mathrm{C}_{31}^2 \mathrm{C}_{45} + \mathrm{C}_{33}^2 \mathrm{C}_{41}) \mathrm{I}_1[\mathrm{m_Q}, \mathrm{m_U}] + (\mathrm{C}_{31}^2 \mathrm{C}_{47} + \mathrm{C}_{33}^2 \mathrm{C}_{43}) \mathrm{I}_1[\mathrm{m_U}, \mathrm{m_Q}] + \\ + (\mathrm{C}_{32}^2 \mathrm{C}_{46} + \mathrm{C}_{34}^2 \mathrm{C}_{42}) \mathrm{I}_1[\mathrm{m_Q}, \mathrm{m_D}] + (\mathrm{C}_{32}^2 \mathrm{C}_{48} + \mathrm{C}_{34}^2 \mathrm{C}_{44}) \mathrm{I}_1[\mathrm{m_D}, \mathrm{m_Q}].$$

$$\Delta\lambda_5 = \mathrm{C}_{31}^2 \mathrm{C}_{33}^2 \mathrm{I}_2[\mathrm{m_Q}, \mathrm{m_U}] + \mathrm{C}_{32}^2 \mathrm{C}_{34}^2 \mathrm{I}_2[\mathrm{m_Q}, \mathrm{m_D}].$$

СПАСИБО ЗА ВНИМАНИЕ!

Интеграл:

$$V(k) = \frac{1}{2}\int \frac{d^dk}{(4\pi)^d}\frac{i}{(k^2+i\epsilon)}\frac{i}{((p-k)^2+i\epsilon)} = -\frac{1}{2}\int_0^1 dx \frac{i}{(4\pi)^d/2}\frac{\Gamma(2-d/2)}{\Lambda^{2-d/2}}$$

$$\underset{d\to 4}{\sim} -\frac{i}{32\pi^2}\frac{2}{\epsilon} \to -\frac{i}{32\pi^2}\log\frac{\Lambda^2}{M^2}$$

При этом мы сделали замены $\Lambda = x(1-x)$, $p^2 = -M^2$. Применяя условия перенормировки, мы видим, что

$$i\delta_\lambda = \frac{3}{32\pi^2}[\lambda^2 + (\rho/3)^2]\log\frac{\Lambda^2}{M^2}$$

Поскольку в этой теории нет расходящихся диаграмм собственной энергии до однопетлевого порядка, мы можем записать β-функцию:

$$\beta_\lambda = \frac{3}{16\pi^2}[\lambda^2 + (\rho/3)^2]$$

Aoki M., Komatsu T., Shibuya H., Possibility of a multi-step electroweak phase transition in the two-Higgs doublet models, Prog. Theor. Exp. Phys. 2022, 063B05. (2022).

Dolgopolov M., Dubinin M., Rykova E., Threshold corrections to the MSSM finite-temperature Higgs potential, Journal of Modern Physics. Vol. 2. No. 5. P. 301-322. (2011).

Allakhverdieva A.E., Dolgopolov M.V., Rykova E.N., Restrictions on parameters of minimal supersymmetric standard model, Journal of Mathematical Sciences. 264. № 6. C. 672-683. (2022).