Higgs masses and constraints on the parameter space in the R-broken SUSY model with right-handed neutrino

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Outline

MSSM

MSSM + neutrino Yukawa interactions

MSSM + neutrino Yukawa interactions + R-parity breaking

The Higgs potential

Higgs boson masses

RG evolution of model parameters

Neutrino-neutralino mixing

Constraints on the model parameters

Conclusions

Supersymmetric Standard Model

	Superfield	Bosons	Fermions	$SU_c(3)$	$SU_L(2)$	$U_Y(1)$
Gauge	G^a	gluon g^a	gluino $\tilde{g}^a$	8	1	0
	V^k	Weak W^k $(W^\pm, Z)$	wino, zino $\tilde{w}^k$ $(\tilde{w}^\pm, \tilde{z})$	1	3	0
	V'	Hypercharge B (γ)	bino $\tilde{b}(\tilde{\gamma})$	1	1	0
Matter	L_i	sleptons $\tilde{L}_i = (\tilde{\nu}, \tilde{e})_L$	leptons $L_i = (\nu, e)_L$	1	2	-1
	E_i	$\tilde{E}_i = \tilde{e}_R$	$E_i = e_R$	1	1	2
	Q_i	squarks $\tilde{Q}_i = (\tilde{u}, \tilde{d})_L$	quarks $Q_i = (u, d)_L$	3	2	1/3
	U_i	$\tilde{U}_i = \tilde{u}_R$	$U_i = u^c_R$	3*	1	$-4/3$
	D_i	$\tilde{D}_i = \tilde{d}_R$	$D_i = d^c_R$	3*	1	2/3
Higgs	H_1	Higgses H_1 $(h, H, A, H^\pm)$	higgsinos $\tilde{H}_1$ $(\tilde{h}_1, \tilde{h}_2, \tilde{h}^\pm)$	1	2	-1
	H_2	H_2	$\tilde{H}_2$	1	2	1

Higgs bosons in the MSSM

- At the tree level the MSSM Higgs potential has the form

$$V_{tree}(H_1, H_2) = m_1^2 \, | H_1 |^2 + m_2^2 \, | H_2 |^2 - m_3^2 (H_1 H_2 + h.c.) + \frac{g^2 + g'^2}{8} (| H_1 |^2 - | H_2 |^2)^2 + \frac{g^2}{2} | H_1^+ H_2 |^2$$

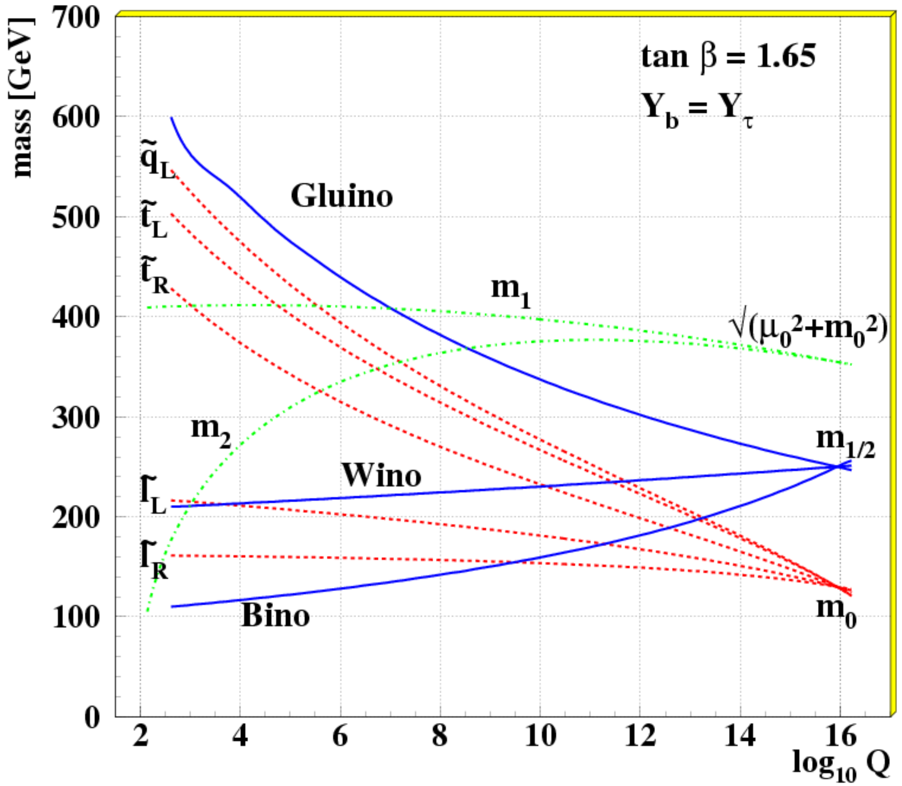
Note: the Higgs self-interaction coupling constant is fixed and is determined by the gauge interactions, this case differs from the Standard Model.

- The MSSM Higgs potential is positively defined and has no non-trivial non-zero minimum.

Higgs bosons in the MSSM

- Running of the Higgs masses leads to the phenomena known as radiative electroweak symmetry breaking.

$$V_{tree}(H_1, H_2)$$
$$= m_1^2 |H_1|^2 - |m_2^2| |H_2|^2$$
$$- m_3^2 (H_1 H_2 + h.c.)$$
$$+ \frac{g^2 + g'^2}{8} (|H_1|^2 - |H_2|^2)^2$$



- One obtains conditions for the electroweak symmetry

Higgs bosons in the MSSM

- The physical spectrum of the MSSM Higgs sector consists of 5 states:

$$
\begin{array}{ll}
G^0 = -\cos\beta P_1 + \sin\beta P_2 & \textit{Goldstone boson} \rightarrow Z_0 \\
A = \sin\beta P_1 + \cos\beta P_2 & \textit{Neutral CP} = -1 \textit{ Higgs} \\
G^+ = -\cos\beta (H_1^-)^* + \sin\beta H_2^+ & \textit{Goldstone boson} \rightarrow W^+ \\
H^+ = \sin\beta (H_1^-)^* + \cos\beta H_2^+ & \textit{Charged Higges} \\
h = -\sin\alpha S_1 + \cos\alpha S_2 & \text{SM } \textit{Higgs boson CP} = 1 \\
H = \cos\alpha S_1 + \sin\alpha S_2 & \textit{Extra heavy Higgs boson}
\end{array}
$$

- Compare to the Standard Model with 1 Higgs boson.

Higgs bosons in the MSSM

- One can calculate the Higgs masses diagonalizing corresponding mass matrices.

- Masses of the CP-odd and charged Higgs bosons

$$m_A^2 = m_1^2 + m_2^2$$
$$m_{H^\pm}^2 = m_A^2 + M_W^2$$

- Masses of the CP-even Higgs bosons

$$m_{h,H}^2 = \frac{1}{2}[m_A^2 + M_Z^2 \pm \sqrt{(m_A^2 + M_Z^2)^2 - 4m_A^2 M_Z^2 \cos^2 2\beta}\,]$$

- If $m_A \gg M_Z$, the lightest Higgs boson is lighter than Z-boson !

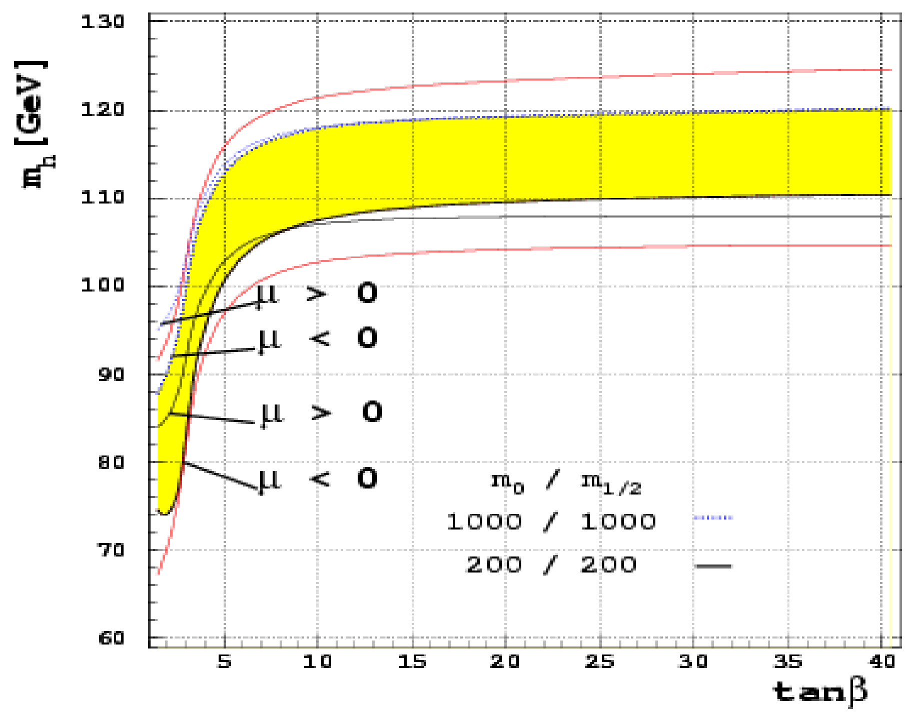
$$m_h \approx M_Z \,|\cos 2\beta|\; < \; M_Z$$

Higgs bosons in the MSSM

- The inequality $m_h \approx M_Z \, |\cos 2\beta| < M_Z$ is spoiled by radiative corrections

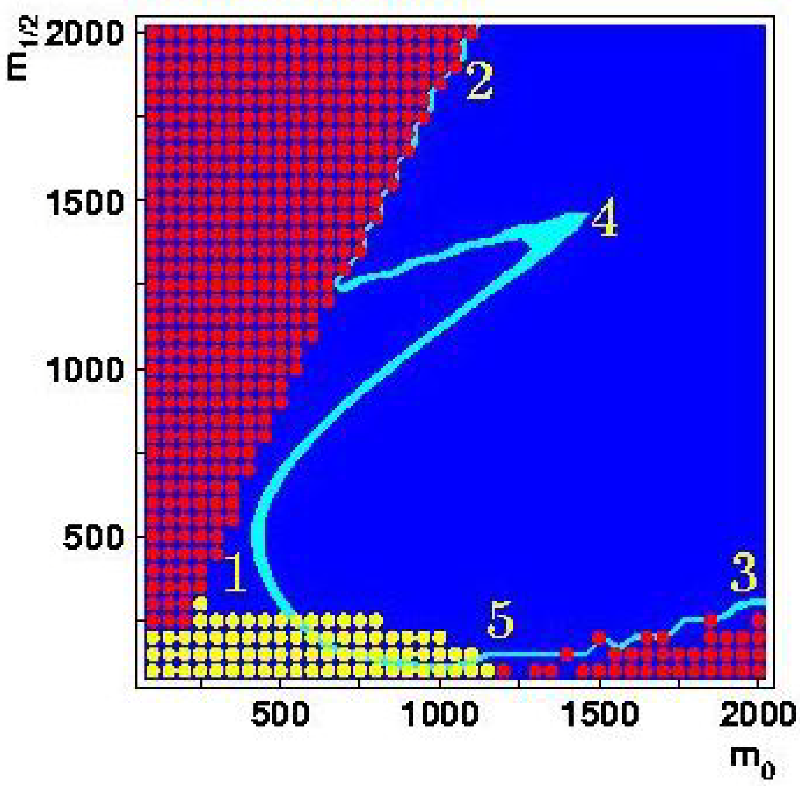
$$m_h^2 \approx M_Z^2 \cos^2 2\beta + \frac{3g^2 m_t^4}{16\pi^2 M_W^2} \log \frac{\tilde{m}_{t_1}^2 \tilde{m}_{t_2}^2}{m_t^4} + 2 \; loops$$

- 1-loop contribution is very and positive
- 2-loop contribution is much and negative



Constrained MSSM

- 1. Bulk region (low m_0 and low $m_{1/2}$)
- 2. Stau-coannihilation region (moderate m_0 but large $m_{1/2}$)
- 3. Focus point region (large m_0 and low to moderate $m_{1/2}$)
- 4. A-annihilation funnel region (the region reguires large tan β)
- 5. EGRET region (consistent with astrophysical data on diffuse gamma rays flux)



Supersymmetric Standard Model

Superpotential

$$\mathcal{W}_R = y_{\rm u}^{ij}\bar{u}_i Q_j \cdot H_{\rm u} - y_{\rm d}^{ij}\bar{d}_i Q_j \cdot H_{\rm d} - y_{\rm e}^{ij}\bar{e}_i L_j \cdot H_{\rm d} + \mu H_{\rm u} \cdot H_{\rm d},$$

SUSY breaking

$$-\frac{1}{2}(M_3 \tilde{g}^\alpha \tilde{g}^\alpha + M_2 \tilde{W}^\alpha \tilde{W}^\alpha + M_1 \tilde{B}\tilde{B} + \text{h.c.}),$$

$$-m^2_{\tilde{\rm Q}ij}\tilde{Q}_i^\dagger \cdot \tilde{Q}_j - m^2_{\tilde{\bar{\rm u}}ij}\tilde{\bar{u}}_i^\dagger \tilde{\bar{u}}_j - m^2_{\tilde{\bar{\rm d}}ij}\tilde{\bar{d}}_i^\dagger \tilde{\bar{d}}_j,$$

$$-m^2_{\tilde{\rm L}ij}\tilde{L}_i^\dagger \cdot \tilde{L}_j - m^2_{\tilde{\bar{\rm e}}ij}\tilde{\bar{e}}_i^\dagger \tilde{\bar{e}}_j.$$

$$-m^2_{\rm H_u} H_{\rm u}^\dagger \cdot H_{\rm u} - m^2_{\rm H_d} H_{\rm d}^\dagger \cdot H_{\rm d} - (b H_{\rm u} \cdot H_{\rm d} + \text{h.c.})$$

$$-a_{\rm u}^{ij}\tilde{\bar{u}}_i \tilde{Q}_j \cdot H_{\rm u} + a_{\rm d}^{ij}\tilde{\bar{d}}_i \tilde{Q}_j \cdot H_{\rm d} + a_{\rm e}^{ij}\tilde{\bar{e}}_i \tilde{L}_j \cdot H_{\rm d} + \text{h.c.}$$

Supersymmetric Standard Model

Superpotential (R-parity conserving)

$$\mathcal{W}_R = y_{\mathrm{u}}^{ij}\bar{u}_i Q_j \cdot H_{\mathrm{u}} - y_{\mathrm{d}}^{ij}\bar{d}_i Q_j \cdot H_{\mathrm{d}} - y_{\mathrm{e}}^{ij}\bar{e}_i L_j \cdot H_{\mathrm{d}} + \mu H_{\mathrm{u}} \cdot H_{\mathrm{d}},$$

Superpotential (R-parity breaking)

$$W_{\Delta L=1} = \lambda_e^{ijk} L_i \cdot L_j \bar{e}_k + \lambda_L^{ijk} L_i \cdot Q_j \bar{d}_k + \mu_L^i L_i \cdot H_{\mathrm{u}},$$
$$W_{\Delta B=1} = \lambda_B^{ijk} \bar{u}_i \bar{d}_j \bar{d}_k.$$

$$R = (-1)^{3(B-L)+2S}$$

Supersymmetric Standard Model

Superpotential (R-parity conserving)

$$\mathcal{W}_R = y_{\mathrm{u}}^{ij}\bar{u}_i Q_j \cdot H_{\mathrm{u}} - y_{\mathrm{d}}^{ij}\bar{d}_i Q_j \cdot H_{\mathrm{d}} - y_{\mathrm{e}}^{ij}\bar{e}_i L_j \cdot H_{\mathrm{d}} + \mu H_{\mathrm{u}} \cdot H_{\mathrm{d}},$$

Right-handed neutrino contributions to the superpotential and SUSY breaking terms

$$y_{\nu}^{ij}\bar{\nu}_i L_j \cdot H_{\mathrm{u}},$$

$$\lambda_{\nu}^{i}\bar{\nu}_i H_{\mathrm{u}} \cdot H_{\mathrm{d}}.$$

$$-\, a_{\nu}^{ij}\tilde{\bar{\nu}}_i \tilde{L}_j \cdot H_{\mathrm{u}} - a_{\not{R}\nu}^{i}\tilde{\bar{\nu}}_i H_{\mathrm{u}} \cdot H_{\mathrm{d}},$$

The Higgs Potential

The Higgs potential then reads

$$\mathcal{V} = (|\mu|^2 + m^2_{\mathrm{H_u}})(|H^+_{\mathrm{u}}|^2 + |H^0_{\mathrm{u}}|^2) + (|\mu|^2 + m^2_{\mathrm{H_d}})(|H^0_{\mathrm{d}}|^2 + |H^-_{\mathrm{d}}|^2) +$$
$$+ [b(H^+_{\mathrm{u}} H^-_{\mathrm{d}} - H^0_{\mathrm{u}} H^0_{\mathrm{d}}) + \mathrm{h.c.}] + \frac{g^2 + g'^2}{8}(|H^+_{\mathrm{u}}|^2 + |H^0_{\mathrm{u}}|^2 - |H^0_{\mathrm{d}}|^2 - |H^-_{\mathrm{d}}|^2)^2 +$$
$$+ \frac{g^2}{2}|H^+_{\mathrm{u}} H^{0\dagger}_{\mathrm{d}} + H^0_{\mathrm{u}} H^{-\dagger}_{\mathrm{d}}|^2 + |\lambda^i_\nu \lambda^i_\nu|\, |H^+_{\mathrm{u}} H^-_{\mathrm{d}} - H^0_{\mathrm{u}} H^0_{\mathrm{d}}|^2. \qquad (35)$$

To find minima consider its part containing neutral components

$$\mathcal{V}_{\mathrm{n}} = (|\mu|^2 + m^2_{\mathrm{H_u}})|H^0_{\mathrm{u}}|^2 + (|\mu|^2 + m^2_{\mathrm{H_d}})|H^0_{\mathrm{d}}|^2 - (bH^0_{\mathrm{u}} H^0_{\mathrm{d}} + \mathrm{h.c.}) +$$
$$+ \frac{g^2 + g'^2}{8}\left(|H^0_{\mathrm{u}}|^2 - |H^0_{\mathrm{d}}|^2\right)^2 + |\lambda^i_\nu \lambda^i_\nu|\, |H^0_{\mathrm{u}} H^0_{\mathrm{d}}|^2.$$

The Higgs Potential

Minimization conditions

$$(|\mu|^2 + m_{\mathrm{H_u}}^2)v_{\mathrm{u}} = bv_{\mathrm{d}} + \frac{1}{4}(g^2 + g'^2)(v_{\mathrm{d}}^2 - v_{\mathrm{u}}^2)v_{\mathrm{u}} - |\lambda|^2 v_{\mathrm{d}}^2 v_{\mathrm{u}},$$
$$(|\mu|^2 + m_{\mathrm{H_d}}^2)v_{\mathrm{d}} = bv_{\mathrm{u}} - \frac{1}{4}(g^2 + g'^2)(v_{\mathrm{d}}^2 - v_{\mathrm{u}}^2)v_{\mathrm{d}} - |\lambda|^2 v_{\mathrm{d}} v_{\mathrm{u}}^2.$$

$$|\mu|^2 + m_{\mathrm{H_u}}^2 = b\,\mathrm{ctg}\,\beta + \frac{m_{\mathrm{Z}}^2}{2}\cos 2\beta - \varepsilon^2 2m_{\mathrm{Z}}^2\cos^2\beta$$
$$|\mu|^2 + m_{\mathrm{H_d}}^2 = b\,\mathrm{tg}\,\beta - \frac{m_{\mathrm{Z}}^2}{2}\cos 2\beta - \varepsilon^2 2m_{\mathrm{Z}}^2\sin^2\beta,$$

$$m_{\mathrm{Z}}^2 = \frac{1}{2}(g^2 + g'^2)(v_{\mathrm{u}}^2 + v_{\mathrm{d}}^2),$$

$$\mathrm{tg}\,\beta \equiv \frac{v_{\mathrm{u}}}{v_{\mathrm{d}}},$$

$$\varepsilon^2 = \frac{|\lambda|^2}{g^2 + g'^2}.$$

CP-odd neutral Higgs

Mass of the CP-odd Higgs boson A

$$\mathcal{V}_{\mathrm{A}} = (|\mu|^2 + m^2_{\mathrm{H_u}})(\mathrm{Im}H^0_{\mathrm{u}})^2 + (|\mu|^2 + m^2_{\mathrm{H_d}})(\mathrm{Im}H^0_{\mathrm{d}})^2 + 2b(\mathrm{Im}H^0_{\mathrm{u}})(\mathrm{Im}H^0_{\mathrm{d}}) +$$
$$+ \frac{g^2 + g'^2}{8}\left[(\mathrm{Re}H^0_{\mathrm{u}})^2 + (\mathrm{Im}H^0_{\mathrm{u}})^2 - (\mathrm{Re}H^0_{\mathrm{d}})^2 - (\mathrm{Im}H^0_{\mathrm{d}})^2\right]^2 +$$
$$+ |\lambda|^2\left[(\mathrm{Re}H^0_{\mathrm{u}})^2 + (\mathrm{Im}H^0_{\mathrm{u}})^2\right]\left[(\mathrm{Re}H^0_{\mathrm{d}})^2 + (\mathrm{Im}H^0_{\mathrm{d}})^2\right].$$

$$(\mathrm{M}^{\mathrm{sq}}_{\mathrm{A}})_{11} = |\mu|^2 + m^2_{\mathrm{H_u}} + \frac{g^2 + g'^2}{4}(v^2_{\mathrm{u}} - v^2_{\mathrm{d}}) + \lambda^2 v^2_{\mathrm{d}} = b\,\mathrm{ctg}\,\beta.$$

$$\mathrm{M}^{\mathrm{sq}}_{\mathrm{A}} = b\begin{pmatrix}\mathrm{ctg}\,\beta & 1 \\ 1 & \mathrm{tg}\,\beta\end{pmatrix}.$$

$$m^2_{+} = 0, \quad m^2_{-} = \frac{2b}{\sin 2\beta}.$$

CP-even neutral Higgses

Masses of the CP-even Higgs bosons h, H

$$\mathcal{V}_{\mathrm{H}} = (|\mu|^2 + m^2_{\mathrm{H_u}})(\mathrm{Re}H^0_{\mathrm{u}})^2 + (|\mu|^2 + m^2_{\mathrm{H_d}})(\mathrm{Re}H^0_{\mathrm{d}})^2 - 2b(\mathrm{Re}H^0_{\mathrm{u}})(\mathrm{Re}H^0_{\mathrm{d}}) +$$
$$+ \frac{g^2 + g'^2}{8}[(\mathrm{Re}H^0_{\mathrm{u}})^2 + (\mathrm{Im}H^0_{\mathrm{u}})^2 - (\mathrm{Re}H^0_{\mathrm{d}})^2 - (\mathrm{Im}H^0_{\mathrm{d}})^2]^2 +$$
$$+ \lambda^2 \left((\mathrm{Re}H^0_{\mathrm{u}})^2 + (\mathrm{Im}H^0_{\mathrm{u}})^2\right)\left((\mathrm{Re}H^0_{\mathrm{d}})^2 + (\mathrm{Im}H^0_{\mathrm{d}})^2\right).$$

$$M^{\mathrm{sq}}_{11} = |\mu|^2 + m^2_{\mathrm{H_u}} + \frac{g^2 + g'^2}{4}(2v^2_{\mathrm{u}} - v^2_{\mathrm{d}}) + \lambda^2 v^2_{\mathrm{d}} = b\,\mathrm{ctg}\,\beta + m^2_{\mathrm{Z}}\sin^2\beta,$$
$$M^{\mathrm{sq}}_{12} = -b - \frac{g^2 + g'^2}{2}v_{\mathrm{u}}v_{\mathrm{d}} + 2\lambda^2 v_{\mathrm{u}}v_{\mathrm{d}} = -b - \frac{1}{2}m^2_{\mathrm{Z}}(1 - 4\varepsilon^2)\sin 2\beta,$$
$$M^{\mathrm{sq}}_{22} = |\mu|^2 + m^2_{\mathrm{H_d}} + \frac{g^2 + g'^2}{4}(2v^2_{\mathrm{d}} - v^2_{\mathrm{u}}) + \lambda^2 v^2_{\mathrm{u}} = b\,\mathrm{tg}\,\beta + m^2_{\mathrm{Z}}\cos^2\beta.$$

CP-even neutral Higgses

Masses of the CP-even Higgs bosons h, H

$$\mathrm{M}^{\mathrm{sq}}_{\mathrm{H,h}} = \begin{pmatrix} b\,\mathrm{ctg}\,\beta + m_{\mathrm{Z}}^2 \sin^2\beta & -b - \frac{1}{2} m_{\mathrm{Z}}^2 (1 - 4\varepsilon^2) \sin 2\beta \\ -b - \frac{1}{2} m_{\mathrm{Z}}^2 (1 - 4\varepsilon^2) \sin 2\beta & b\,\mathrm{tg}\,\beta + m_{\mathrm{Z}}^2 \cos^2\beta \end{pmatrix}$$

$$m^2_{\mathrm{H^0,h^0}} = \frac{1}{2}\left(m^2_{\mathrm{A^0}} + m^2_{\mathrm{Z}} \pm \sqrt{(m^2_{\mathrm{A^0}} + m^2_{\mathrm{Z}})^2 - 4 m^2_{\mathrm{A^0}} m^2_{\mathrm{Z}} \cos^2 2\beta + \Delta_\varepsilon}\right)$$

$$\Delta_\varepsilon = -8 m^2_{\mathrm{A^0}} m^2_{\mathrm{Z}} \varepsilon^2 \sin^2 2\beta - 8 m^4_{\mathrm{Z}} \varepsilon^2 (1 - 2\varepsilon^2) \sin^2 2\beta.$$

CP-even neutral Higgses

Masses of the CP-even Higgs bosons h, H

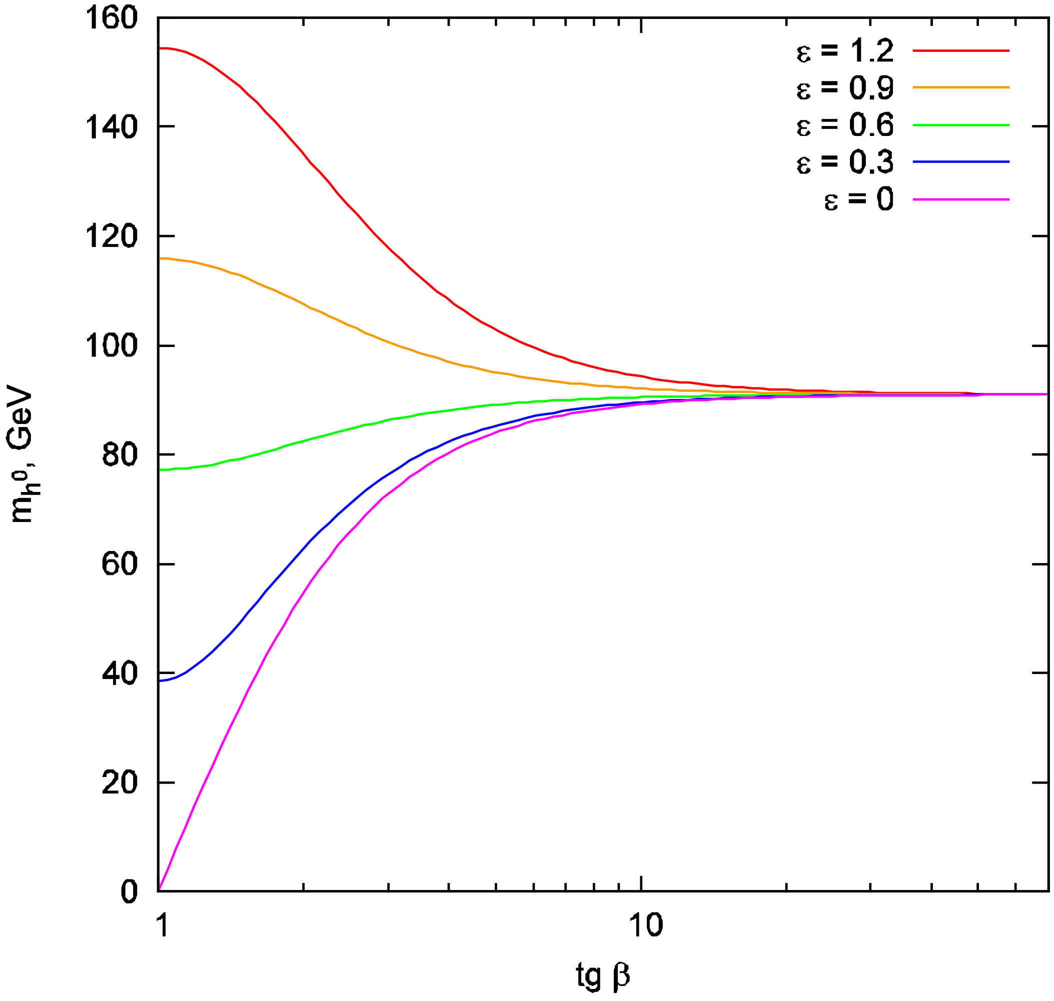
$$m_{\mathrm{h}^0}^2 < m_{\mathrm{Z}}^2 \left(\cos^2 2\beta + 2\varepsilon^2 \sin^2 2\beta\right)$$

$$m_{\mathrm{h}^0}^2 < m_{\mathrm{Z}}^2 \cos^2 2\beta.$$

The situation is similar to the NMSSM case with a singlet Higgs superfield

$$m_{\mathrm{h}^0}^2 \simeq m_{\mathrm{Z}}^2 \cos^2 2\beta + \lambda^2 v^2 \sin^2 2\beta,$$

The lightest Higgs mass



The mass of the lightest Higgs boson as a function of tan β

$$\varepsilon^2 = \frac{|\lambda|^2}{g^2 + g'^2}.$$

Charged Higgses

Masses of charged Higgs bosons

$$\mathcal{V} = (|\mu|^2 + m^2_{\mathrm{H_u}})(|H^+_{\mathrm{u}}|^2 + |H^0_{\mathrm{u}}|^2) + (|\mu|^2 + m^2_{\mathrm{H_d}})(|H^0_{\mathrm{d}}|^2 + |H^-_{\mathrm{d}}|^2) +$$
$$+ [b(H^+_{\mathrm{u}} H^-_{\mathrm{d}} - H^0_{\mathrm{u}} H^0_{\mathrm{d}}) + \mathrm{h.c.}] + \frac{g^2 + g'^2}{8}(|H^+_{\mathrm{u}}|^2 + |H^0_{\mathrm{u}}|^2 - |H^0_{\mathrm{d}}|^2 - |H^-_{\mathrm{d}}|^2)^2 +$$
$$+ \frac{g^2}{2}|H^+_{\mathrm{u}} H^{0\dagger}_{\mathrm{d}} + H^0_{\mathrm{u}} H^{-\dagger}_{\mathrm{d}}|^2 + |\lambda^i_\nu \lambda^i_\nu|\,|H^+_{\mathrm{u}} H^-_{\mathrm{d}} - H^0_{\mathrm{u}} H^0_{\mathrm{d}}|^2. \qquad (35)$$

$$\mathrm{M}^{\mathrm{sq}}_{\mathrm{ch}} = \left[b + v_{\mathrm{u}} v_{\mathrm{d}} \left(\frac{g^2}{2} - |\lambda|^2\right)\right] \begin{pmatrix} \mathrm{ctg}\,\beta & 1 \\ 1 & \mathrm{tg}\,\beta \end{pmatrix}$$

$$\boxed{m^2_{\mathrm{H}^\pm} = m^2_{\mathrm{A}^0} + m^2_{\mathrm{W}} - 2\varepsilon^2 m^2_{\mathrm{Z}}.}$$

RG evolution of model parameters

RG equations for Yukawa couplings

$$\beta_{y_t} \equiv \frac{d}{dt}y_t = \frac{y_t}{16\pi^2}\left(6y_t^*y_t + y_b^*y_b + y_\nu^*y_\nu + \lambda_\nu^*\lambda_\nu - \frac{16}{3}g_3^2 - 3g_2^2 - \frac{13}{15}g_1^2\right)$$

$$\beta_{y_b} \equiv \frac{d}{dt}y_b = \frac{y_b}{16\pi^2}\left(6y_b^*y_b + y_t^*y_t + y_\tau^*y_\tau + \lambda_\nu^*\lambda_\nu - \frac{16}{3}g_3^2 - 3g_2^2 - \frac{7}{15}g_1^2\right)$$

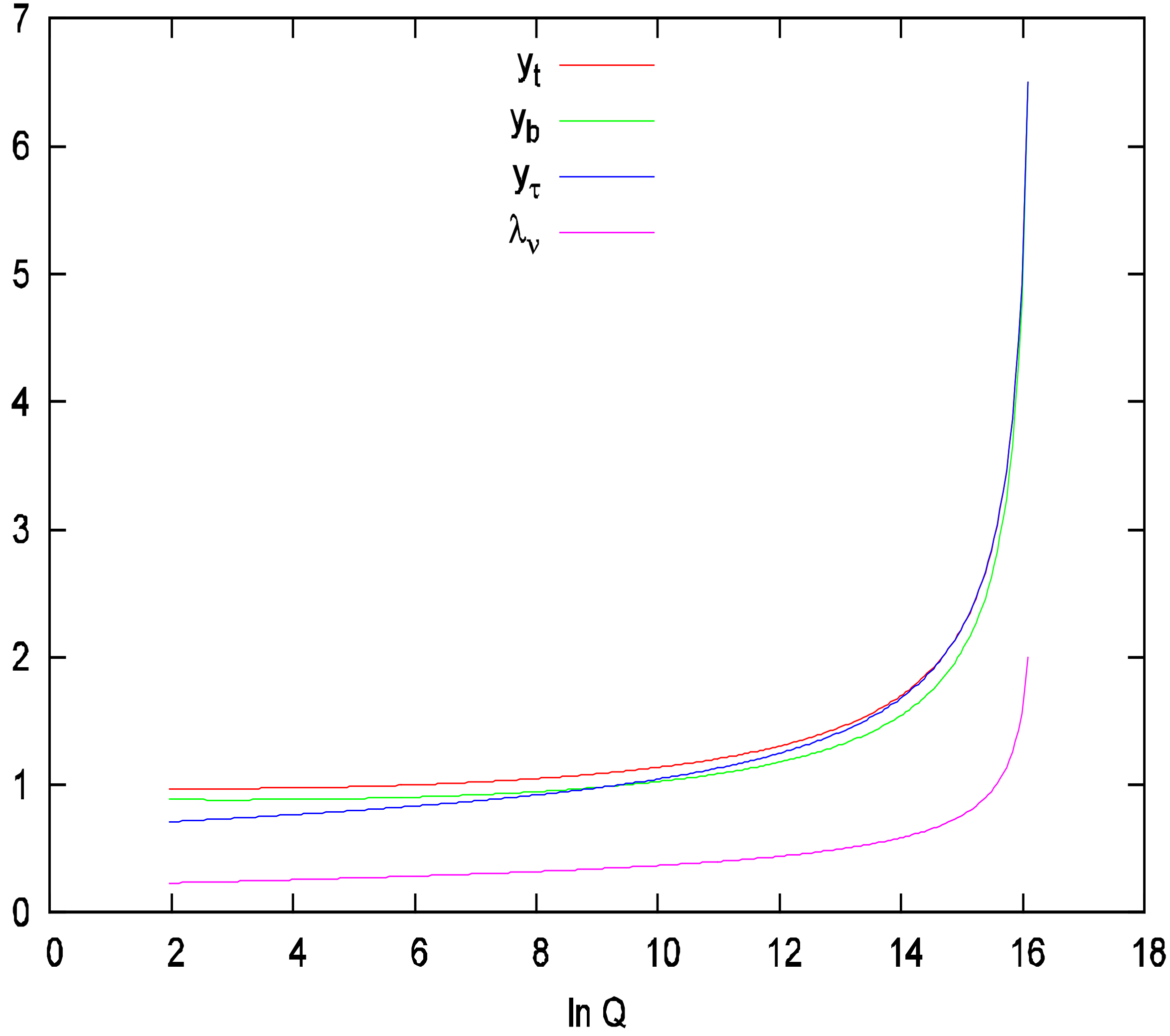
$$\beta_{y_\tau} \equiv \frac{d}{dt}y_\tau = \frac{y_\tau}{16\pi^2}\left(4y_\tau^*y_\tau + 3y_b^*y_b + y_\nu^*y_\nu + \lambda_\nu^*\lambda_\nu - 3g_2^2 - \frac{9}{5}g_1^2\right),$$

$$\beta_{y_\nu} \equiv \frac{d}{dt}y_\nu = \frac{y_\nu}{16\pi^2}\left(3y_\tau^*y_\tau + y_b^*y_b + 4y_\nu^*y_\nu + 4\lambda_\nu^*\lambda_\nu - 3g_2^2 - \frac{3}{5}g_1^2\right),$$

$$\beta_{\lambda_\nu} \equiv \frac{d}{dt}\lambda_\nu = \frac{\lambda_\nu}{16\pi^2}\left(3y_\tau^*y_\tau + 3y_b^*y_b + 4y_\nu^*y_\nu + 4\lambda_\nu^*\lambda_\nu - 3g_2^2 - \frac{3}{5}g_1^2\right),$$

$$\beta_\mu \equiv \frac{d}{dt}\mu = \frac{\mu}{16\pi^2}\left(3y_t^*y_t + 3y_b^*y_b + y_\tau^*y_\tau + y_\nu^*y_\nu + 2\lambda_\nu^*\lambda_\nu - 3g_2^2 - \frac{3}{5}g_1^2\right)$$

RG evolution of model parameters



RG evolution of Yukawa couplings

RG evolution of model parameters

RG equations for SUSY breaking parameters

$$16\pi^2 \frac{d}{dt} a_t = a_t \left(18 y_t^* y_t + y_b^* y_b + y_\nu^* y_\nu + \lambda_\nu^* \lambda_\nu - \frac{16}{3} g_3^2 - 3 g_2^2 - \frac{13}{15} g_1^2 \right) +$$

$$+ 2 y_t \left(a_b y_b^* + a_\nu y_\nu^* + a_{\not{R}\nu} \lambda_\nu^* + \frac{16}{3} g_3^2 M_3 + 3 g_2^2 M_2 + \frac{13}{15} g_1^2 M_1 \right)$$

$$16\pi^2 \frac{d}{dt} a_b = a_b \left(18 y_b^* y_b + y_t^* y_t + y_\tau^* y_\tau + \lambda_\nu^* \lambda_\nu - \frac{16}{3} g_3^2 - 3 g_2^2 - \frac{7}{15} g_1^2 \right) +$$

$$+ 2 y_b \left(a_t y_t^* + a_\tau y_\tau^* + a_{\not{R}\nu} \lambda_\nu^* + \frac{16}{3} g_3^2 M_3 + 3 g_2^2 M_2 + \frac{7}{15} g_1^2 M_1 \right)$$

$$16\pi^2 \frac{d}{dt} a_\tau = a_\tau \left(12 y_\tau^* y_\tau + 3 y_b^* y_b + y_\nu^* y_\nu + \lambda_\nu^* \lambda_\nu - 3 g_2^2 - \frac{9}{5} g_1^2 \right) +$$

$$+ 2 y_\tau \left(3 a_b y_b^* + a_\nu y_\nu^* + a_{\not{R}\nu} \lambda_\nu^* + 3 g_2^2 M_2 + \frac{9}{5} g_1^2 M_1 \right),$$

RG evolution of model parameters

RG equations for SUSY breaking parameters

$$16\pi^2 \frac{d}{dt} a_\nu = a_\nu \left(3y_t^* y_t + y_\tau^* y_\tau + 4y_\nu^* y_\nu + 4\lambda_\nu^* \lambda_\nu - 3g_2^2 - \frac{3}{5} g_1^2 \right) +$$
$$+ 2y_\nu \left(3a_t y_t^* + a_\tau y_\tau^* + 4a_\nu y_\nu^* + 4a_{\not{R}\nu} \lambda_\nu^* + 3g_2^2 M_2 + \frac{3}{5} g_1^2 M_1 \right)$$

$$16\pi^2 \frac{d}{dt} a_{\not{R}\nu} = a_{\not{R}\nu} \left(3y_t^* y_t + 3y_b^* y_b + 4y_\nu^* y_\nu + 4\lambda_\nu^* \lambda_\nu - 3g_2^2 - \frac{3}{5} g_1^2 \right) +$$
$$+ 2y_\tau \left(3a_t y_t^* + 3a_b y_b^* + 4a_\nu y_\nu^* + 4a_{\not{R}\nu} \lambda_\nu^* + 3g_2^2 M_2 + \frac{3}{5} g_1^2 M_1 \right),$$

$$16\pi^2 \frac{d}{dt} b = b \left(3y_t^* y_t + 3y_b^* y_b + y_\tau^* y_\tau + y_\nu^* y_\nu + 2\lambda_\nu^* \lambda_\nu - 3g_2^2 - \frac{3}{5} g_1^2 \right)$$
$$+ 2\mu \left(3a_t y_t^* + 3a_b y_b^* + a_\tau y_\tau^* + a_\nu y_\nu^* + 2a_{\not{R}\nu} \lambda_\nu^* + 3g_2^2 M_2 + \frac{3}{5} g_1^2 M_1 \right)$$

RG evolution of model parameters

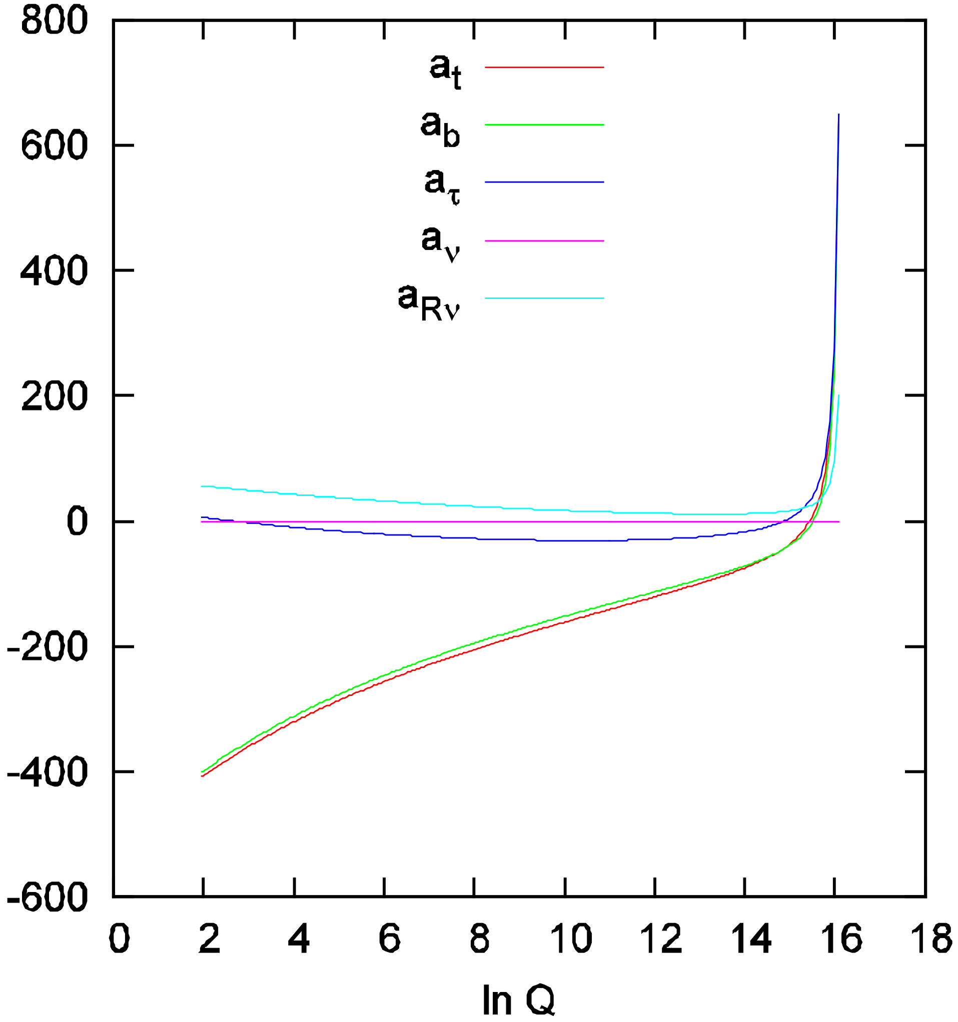
RG equations for SUSY breaking parameters

$$16\pi^2 \frac{d}{dt} a_\nu = a_\nu \left(3y_t^* y_t + y_\tau^* y_\tau + 4y_\nu^* y_\nu + 4\lambda_\nu^* \lambda_\nu - 3g_2^2 - \frac{3}{5} g_1^2 \right) + $$
$$ + 2y_\nu \left(3a_t y_t^* + a_\tau y_\tau^* + 4a_\nu y_\nu^* + 4a_{\not{R}\nu} \lambda_\nu^* + 3g_2^2 M_2 + \frac{3}{5} g_1^2 M_1 \right)$$

$$16\pi^2 \frac{d}{dt} a_{\not{R}\nu} = a_{\not{R}\nu} \left(3y_t^* y_t + 3y_b^* y_b + 4y_\nu^* y_\nu + 4\lambda_\nu^* \lambda_\nu - 3g_2^2 - \frac{3}{5} g_1^2 \right) + $$
$$ + 2y_\tau \left(3a_t y_t^* + 3a_b y_b^* + 4a_\nu y_\nu^* + 4a_{\not{R}\nu} \lambda_\nu^* + 3g_2^2 M_2 + \frac{3}{5} g_1^2 M_1 \right),$$

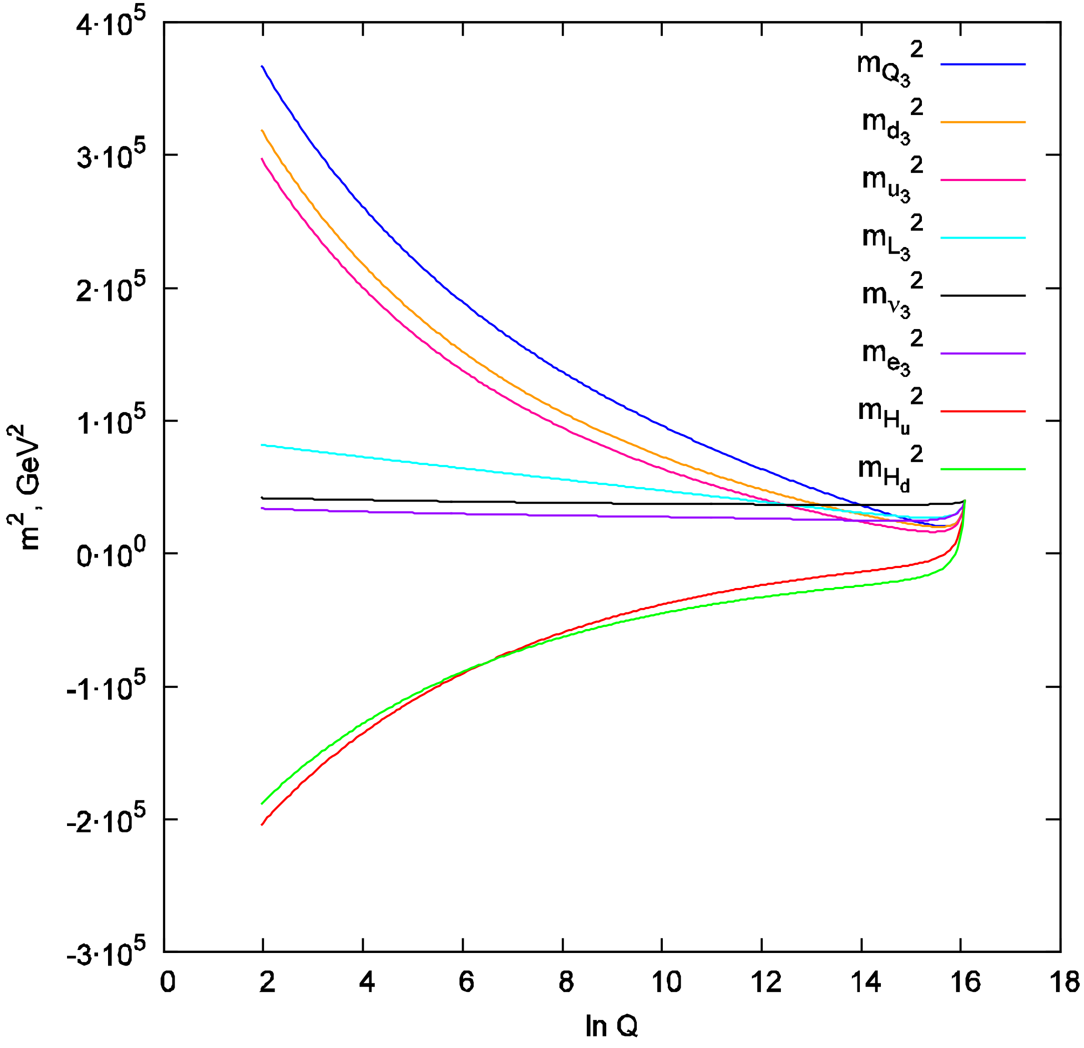
$$16\pi^2 \frac{d}{dt} b = b \left(3y_t^* y_t + 3y_b^* y_b + y_\tau^* y_\tau + y_\nu^* y_\nu + 2\lambda_\nu^* \lambda_\nu - 3g_2^2 - \frac{3}{5} g_1^2 \right)$$
$$ + 2\mu \left(3a_t y_t^* + 3a_b y_b^* + a_\tau y_\tau^* + a_\nu y_\nu^* + 2a_{\not{R}\nu} \lambda_\nu^* + 3g_2^2 M_2 + \frac{3}{5} g_1^2 M_1 \right)$$

RG evolution of model parameters



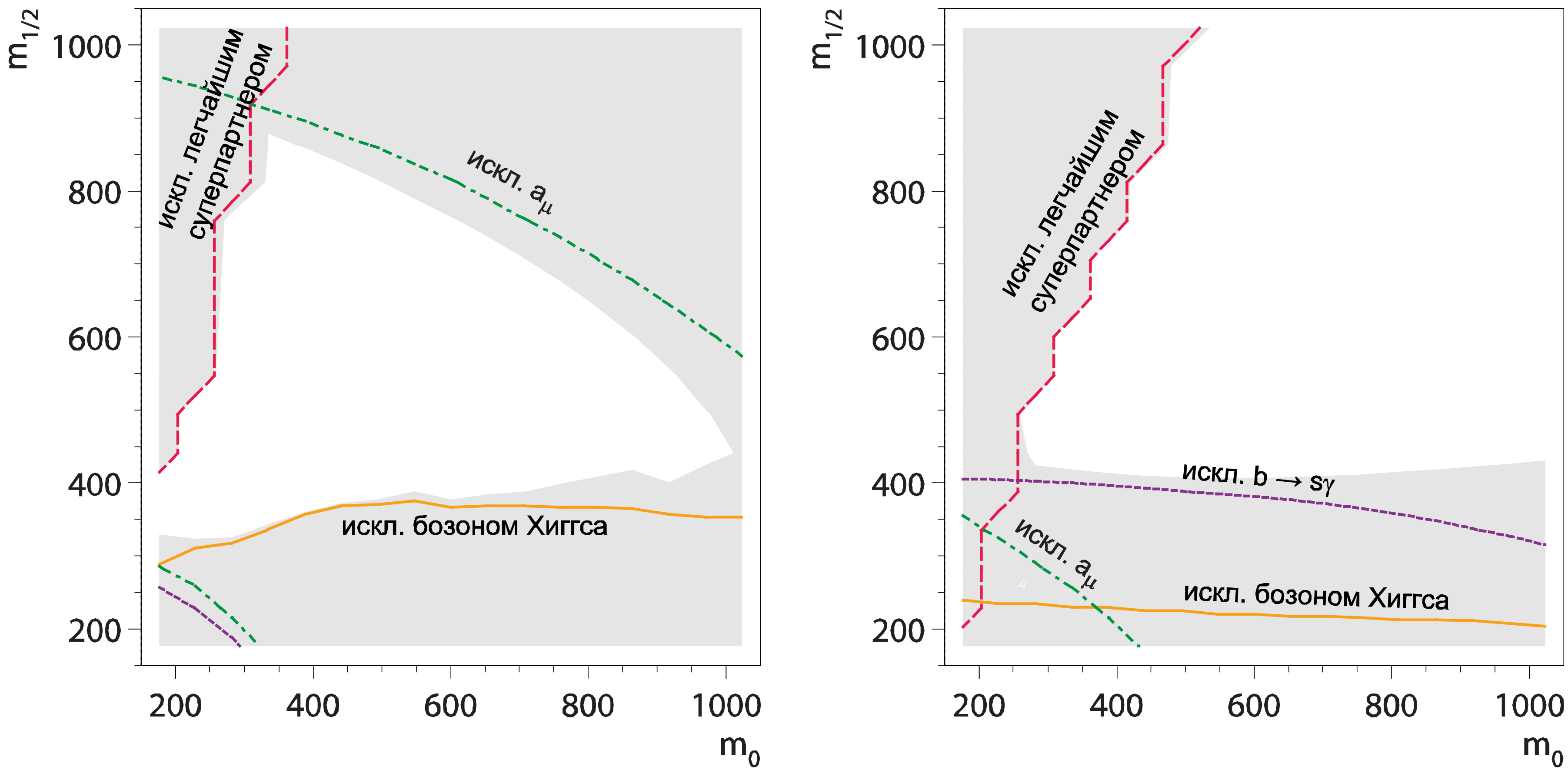
RG evolution of trilinear soft SUSY breaking parameters

RG evolution of model parameters



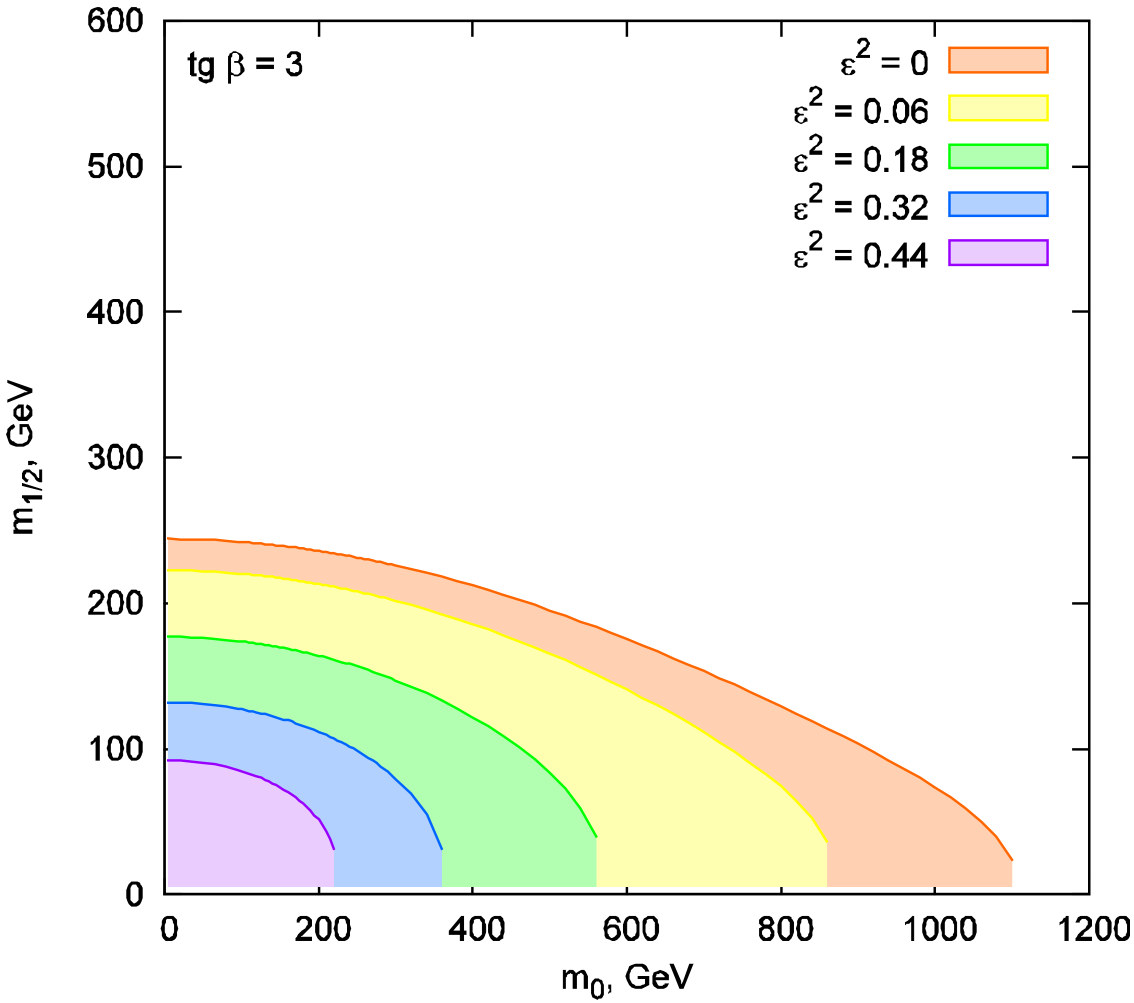
RG evolution of soft SUSY breaking mass terms

Constraints on model parameters



Constraints on the parameter space in the MSSM for large tan beta

Constraints on model parameters



Region excluded by non-observation of the light Higgs boson

$$\varepsilon^2 = \frac{|\lambda|^2}{g^2 + g'^2}.$$

Neutrino-neutralino mixing

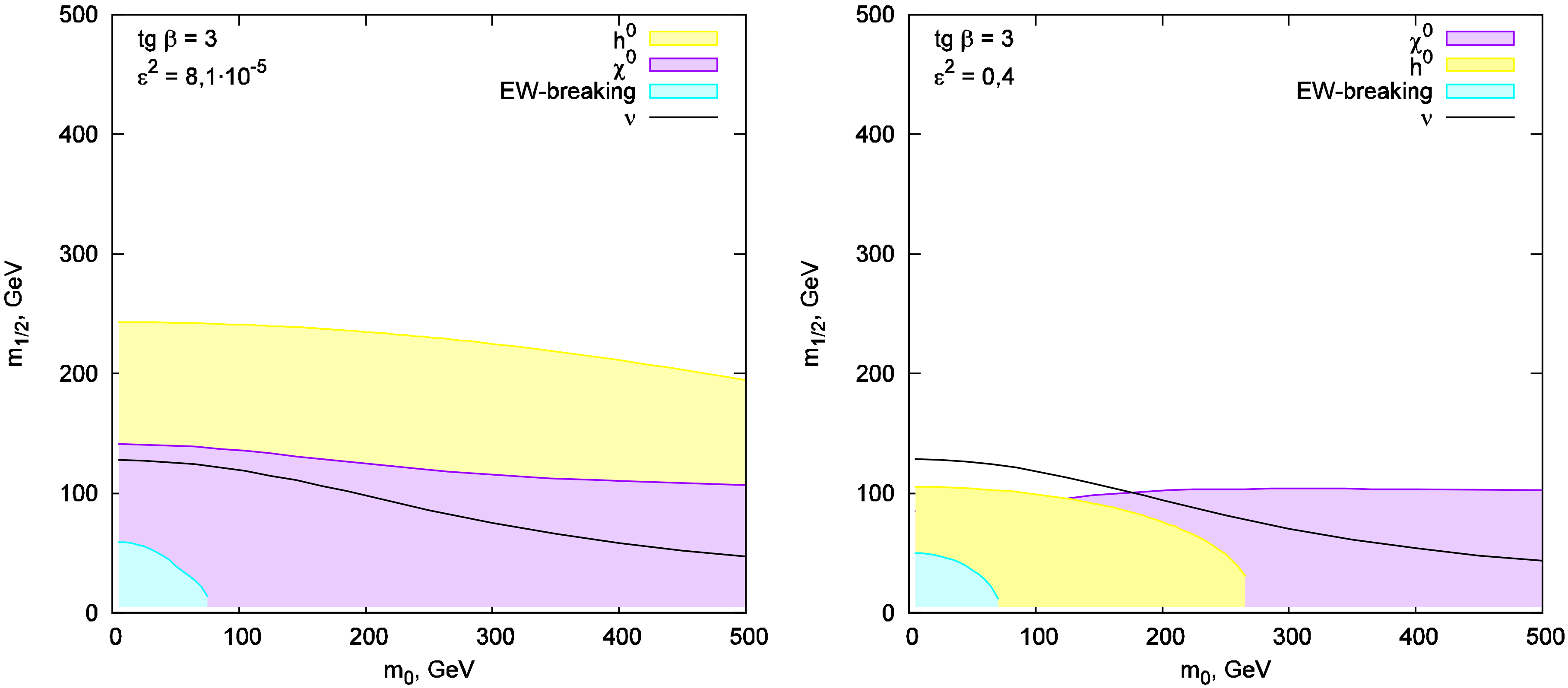
$$-\frac{1}{2}\left((-\lambda_\nu^i)H_\mathrm{u}^0(\bar{\nu}_i\tilde{H}_\mathrm{d}^0+\tilde{H}_\mathrm{d}^0\bar{\nu}_i)+(-\lambda_\nu^i)H_\mathrm{d}^0(\bar{\nu}_i\tilde{H}_\mathrm{u}^0+\tilde{H}_\mathrm{u}^0\bar{\nu}_i)\right)$$

Neutrino-neutralino mass matrix

$$-\frac{1}{2}(\tilde{G}^{0\mathrm{T}}\bar{N}^\mathrm{T}N^\mathrm{T})\begin{pmatrix}\mathrm{M}_{\tilde{G}^0} & \mathrm{M}_{\tilde{G}^0\bar{N}} & 0\\ \mathrm{M}_{\tilde{G}^0\bar{N}}^\mathrm{T} & \mathrm{M}_{\bar{N}} & \mathrm{M}_D\\ 0 & \mathrm{M}_D^\mathrm{T} & 0\end{pmatrix}\begin{pmatrix}\tilde{G}^0\\ \bar{N}\\ N\end{pmatrix}+\mathrm{h.c.},$$

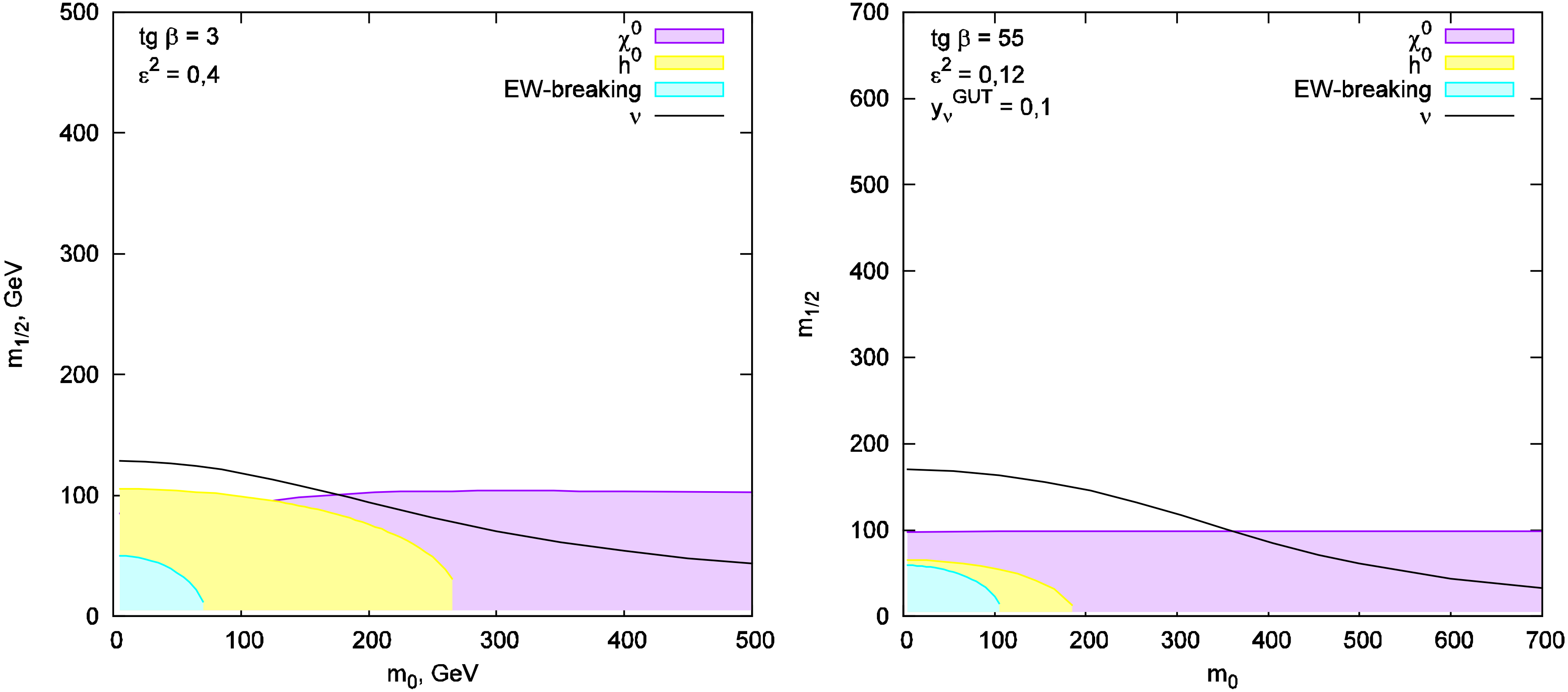
$$\mathrm{M}_{\tilde{G}^0\bar{N}}=\begin{pmatrix}0 & 0 & 0\\ 0 & 0 & 0\\ -\lambda_\nu^1 v_\mathrm{u} & -\lambda_\nu^2 v_\mathrm{u} & -\lambda_\nu^3 v_\mathrm{u}\\ -\lambda_\nu^1 v_\mathrm{d} & -\lambda_\nu^2 v_\mathrm{d} & -\lambda_\nu^3 v_\mathrm{d}\end{pmatrix}=m_\mathrm{Z}\sqrt{\frac{2}{g^2+g'^2}}\begin{pmatrix}0\\ 0\\ -\lambda_\nu^i\sin\beta\\ -\lambda_\nu^i\cos\beta\end{pmatrix}$$

Constraints on model parameters



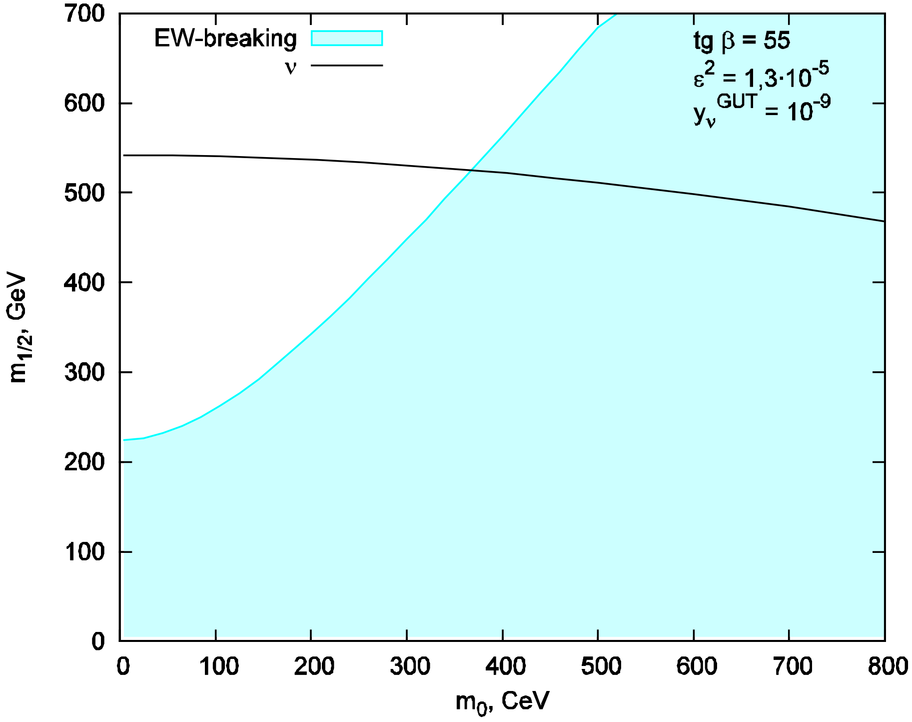
Regions excluded by electroweak symmetry breaking constraint, Higgs and neutralino mass limits

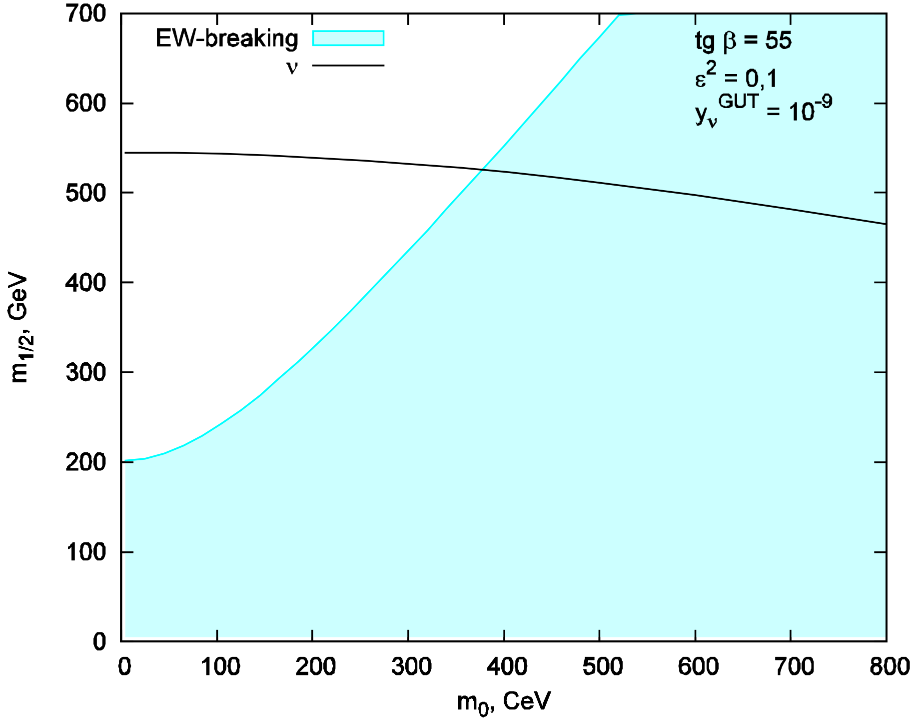
Constraints on model parameters



Regions excluded by electroweak symmetry breaking constraint, Higgs and neutralino mass limits

Constraints on model parameters





Region excluded by electroweak symmetry breaking constraint

Conclusions

The R-parity broken supersymmetric model with right handed singlet neutrino superfield has been considered

It is shown that Higgs masses are modified due to new couplings

$$m^2_{\mathrm{H}^0,\mathrm{h}^0} = \frac{1}{2}\left(m^2_{\mathrm{A}^0} + m^2_{\mathrm{Z}} \pm \sqrt{(m^2_{\mathrm{A}^0} + m^2_{\mathrm{Z}})^2 - 4m^2_{\mathrm{A}^0} m^2_{\mathrm{Z}} \cos^2 2\beta + \Delta_\varepsilon}\right)$$

$$m^2_{\mathrm{H}^\pm} = m^2_{\mathrm{A}^0} + m^2_{\mathrm{W}} - 2\varepsilon^2 m^2_{\mathrm{Z}}. \qquad \varepsilon^2 = \frac{|\bar{\lambda}|^2}{g^2 + g'^2}.$$

RG equations in the model have been obtained

The parameter space of the model is analyzed

Conclusions

The famous MSSM inequality for the lightest Higgs mass is modified

$$m_{h^0}^2 < m_Z^2 \cos^2 2\beta. \qquad \mathrm{tg}\,\beta \equiv \frac{v_u}{v_d},$$

$$\boxed{m_{h^0}^2 < m_Z^2 \left(\cos^2 2\beta + 2\varepsilon^2 \sin^2 2\beta\right)} \qquad \varepsilon^2 = \frac{|\lambda|^2}{g^2 + g'^2}.$$

The new contribution could be as large as loop corrections

The low tan beta regime is saved.