Resummation of logarithmic contributions in MSSM Higgs-boson mass calculations

Henning Bahl

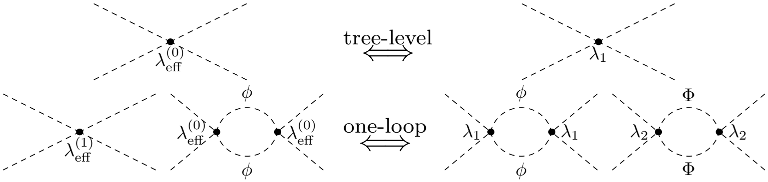
17.6.2015

$$\mathcal{L}_{\text{toy}} = \frac{1}{2}\partial_\mu\phi\partial^\mu\phi + \frac{1}{2}\partial_\mu\Phi\partial^\mu\Phi - m^2\phi^2 - M^2\Phi^2 - V(\phi,\Phi)$$
$$V(\phi,\Phi) = \frac{\lambda_1}{4!}\phi^4 + \frac{\lambda_2}{4}\phi^2\Phi^2 + \frac{\lambda_3}{4!}\Phi^4$$

Effective Langragian for $Q \sim m \ll M$

$$\mathcal{L}_{\text{eff}} = \frac{1}{2}\partial_\mu\phi\partial^\mu\phi - m^2\phi^2 - \frac{g_{\text{eff}}}{3!}\phi^3 - \frac{\lambda_{\text{eff}}}{4!}\phi^4$$

Determine $g_{\text{eff}}, \lambda_{\text{eff}}$ by matching with full theory



MSSM particles:

name	spin	gauge eigenstate	mass eigenstate
Higgs bosons	0	$\mathcal{H}_{1,2}$	$h,\ H,\ A,\ H^\pm$
Goldstone bosons	0	$\mathcal{H}_{1,2}$	$G,\ G^\pm$
squarks	0	$\tilde{q}_{L,R}$	$\tilde{q}_{1,2}$
sleptons	0	$\tilde{e}_{L,R}, \mu_{L,R}, \ldots$	$\tilde{e}_{1,2}, \tilde{\mu}_{1,2}, \ldots$
neutralinos	1/2	$\tilde{B},\ \tilde{\mathcal{H}}_{1,2},\ \tilde{W}^0$	$\tilde{\chi}^0_{1,2,3,4}$
charginos	1/2	$\tilde{\mathcal{H}}^\pm_{1,2},\ \tilde{W}^\pm$	$\tilde{\chi}^\pm_{1,2}$
gluino	1/2	$\tilde{g}$	$\tilde{g}$

- sleptons, squarks $\to$ mass scale $M_S \equiv \sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}}$
- heavy Higgs $(H, A, H^\pm)$ $\to$ mass scale M_A
- charginos, neutralinos $\to$ mass scale M_1, M_2, μ

$\mathcal{H}_{1,2}$ get vev's v_1, v_2:

$$\tan\beta \equiv \frac{v_2}{v_1}$$

Stop mass matrix:

$$\mathbf{M}_{\tilde{t}}^2 \simeq \begin{pmatrix} m_{\tilde{t}}^2 + m_t^2 & m_t X_t \\ m_t X_t & m_{\tilde{t}}^2 + m_t^2 \end{pmatrix}$$

- mass of the lightest Higgs can be calculated in the MSSM
- terms up to 3-loop level are known
- calculation yields terms $\propto \ln\left(\frac{M_S^2}{m_t^2}\right)$
- for large sparticles masses $M_S \gg m_t$ logarithms get large

Higher order logarithms are relevant

$\Rightarrow$ **resummation of logarithms needed**

Higgs mass

$M_h^2 = 2\lambda(Q = m_t)v^2$, how to get $\lambda(m_t)$?

Idea: Effective field theory

M_S mass scale of SUSY-particles, above $\rightarrow$ MSSM, below $\rightarrow$ SM

- λ fixed in MSSM: $\lambda(M_S) = \frac{1}{4}(g^2 + g'^2)c_{2\beta}^2$ at tree-level

$\Rightarrow$ **use SM-RGEs to run λ down:**

$$\lambda(M_S) \overset{\beta_{\mathbf{SM}}}{\rightarrow} \lambda(m_t)$$

Notation: $t = \ln Q^2, k = 1/(16\pi^2), h_t = m_t/v$

$$\frac{d\lambda}{dt} = 6k\left(\lambda^2 + \lambda h_t^2 - h_t^4\right)$$

Solve iteratively:

$$\lambda(m_t) \approx \lambda(M_S) + \int_{M_S}^{m_t} \frac{d\lambda}{dt} dt \approx$$

$$\approx \lambda(M_S) - 6k\left(\lambda^2(M_S) + \lambda(M_S)h_t^2(m_t) - h_t^4(m_t)\right) \ln\left(\frac{M_S^2}{m_t^2}\right) \approx$$

$$\approx \lambda_{tree} + 6kh_t^4(m_t) \ln\left(\frac{M_S^2}{m_t^2}\right)$$

Solve **numerically**:

$\Rightarrow$ **Resummation of large logarithms to all orders**

(sub)leading logarithms

Use 1-loop RGEs → Resummation of leading logarithms $(k^n L^n)$
Use 2-loop RGEs → Also next-to-leading logarithms $(k^n L^{n-1})$

Additional complication:

Threshold corrections

$\lambda(M_S) = \frac{1}{4}(g^2 + g'^2)\, c_{2\beta}^2 + \Delta\lambda_{thres}$

- originate from integrating out heavy sparticles
- n-loop threshold corrections result in (next-to)^n-leading logarithms
- $\Delta\lambda_{thres} = 6kh_t^4\left(\hat{X}_t^2 - \frac{1}{12}\hat{X}_t^4\right) \qquad (\hat{X}_t = X_t/M_S)$

`FeynHiggs` already contains full 1-loop and partial 2-loop results

$$\Downarrow$$

Double counting has to be avoided:

$\Rightarrow$ Subtract logarithms from the diagrammatic result

$\Rightarrow$ Subtract non-logarithmic terms from the RGE result

RGEs derived in $\overline{\text{MS}}$, diagrammatic calculation in OS:

$\Rightarrow$ Conversion $\overline{\text{MS}} \leftrightarrow$ OS is mandatory: $A^{\text{OS}} = A^{\overline{\text{MS}}} + \delta A^{\text{OS}}_{\text{fin.}}$

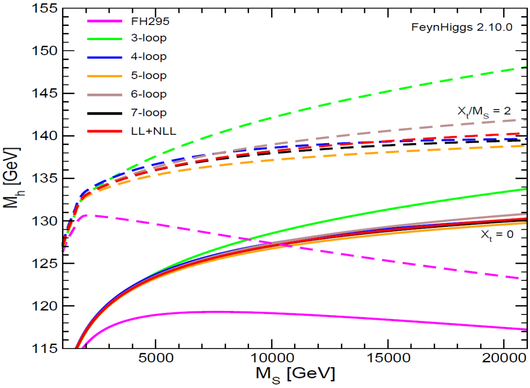
$$\Downarrow$$

$$\begin{aligned} M_h^2 =& (M_h^2)^{\text{FD}} + (\Delta M_h^2)^{\text{RGE}}(X_t^{\overline{\text{MS}}}) \\ & - (\Delta M_h^2)^{\text{RGE,non-log}}(X_t^{OS}) - (\Delta M_h^2)^{\text{FD,Logs}}(X_t^{OS}) \end{aligned}$$

FeynHiggs 2.10

Resummation of leading/next-to-leading logarithms $\propto \alpha_t, \alpha_s$

- weak gauge couplings are neglected ($g = g' = 0$)



Hahn et al.: arXiv:1312.4937

Extension I

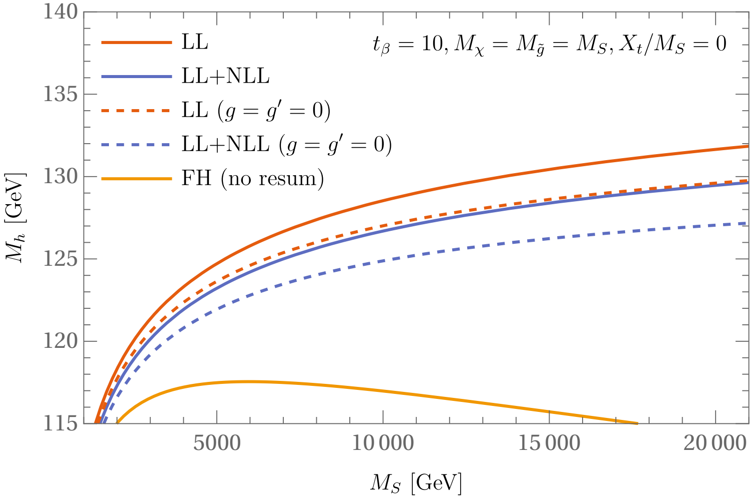
Use of full 2-loop SM-RGEs, including g, g' with all sparticles at scale M_S

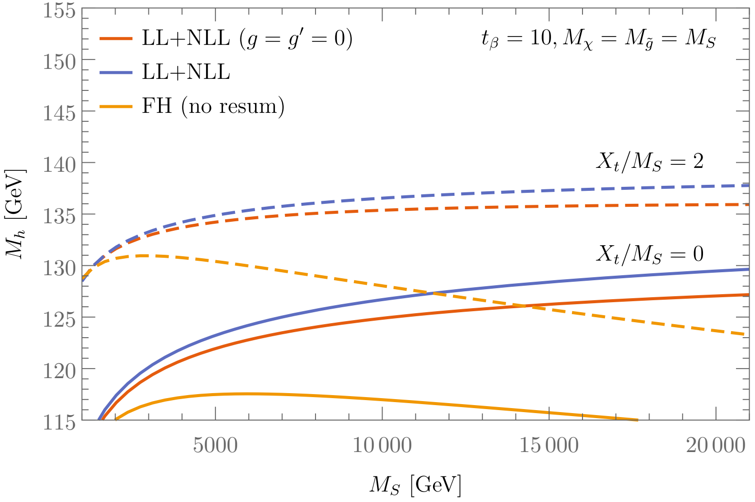
- avoid double-counting of electroweak logarithms at 1-loop
- new threshold corrections (e.g. Bagnaschi et al.: arXiv:1407.4081)

$$\lambda(M_S) = \lambda_{\text{tree}} + \Delta\lambda_{\text{stop}} + \Delta\lambda_{\text{heavy Higgs}} + \Delta\lambda_{\text{chargino/neutralino}} + \Delta\lambda_{\overline{\text{DR}}\to\overline{\text{MS}}}$$

- additional terms in $\overline{\text{MS}} \leftrightarrow$ OS conversion

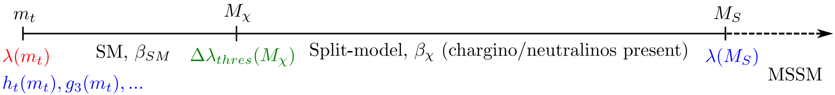
$$X_t^{\overline{\text{MS}}} = X_t^{\text{OS}} \left[1 + \left(\underbrace{\frac{\alpha_s}{\pi}}_{g,\tilde{g}} \underbrace{- \frac{3\alpha_t}{16\pi}\left(1 - \hat{X}_t^2\right)}_{\text{Higgs}} \underbrace{- \frac{\alpha}{96\pi}(1 - 26\,c_w^2)}_{\text{Z,W}^\pm} \right) \ln\left(\frac{M_S^2}{m_t^2}\right) \right]$$


LL
LL+NLL
LL ($g = g' = 0$)
LL+NLL ($g = g' = 0$)
FH (no resum)
$t_\beta = 10, M_\chi = M_{\tilde{g}} = M_S, X_t/M_S = 0$
M_h [GeV]
140
135
130
125
120
115
5000
10 000
15 000
20 000
M_S [GeV]


LL+NLL ($g = g' = 0$)
LL+NLL
FH (no resum)
$t_\beta = 10, M_\chi = M_{\tilde{g}} = M_S$
$X_t/M_S = 2$
$X_t/M_S = 0$
M_h [GeV]
M_S [GeV]
155
150
145
140
135
130
125
120
115
5000
10 000
15 000
20 000

Extension II

Additional threshold $M_\chi \equiv M_1 = M_2 = \mu$ ($m_t \ll M_\chi < M_S$), above which charginos/neutralinos contribute to RGE running



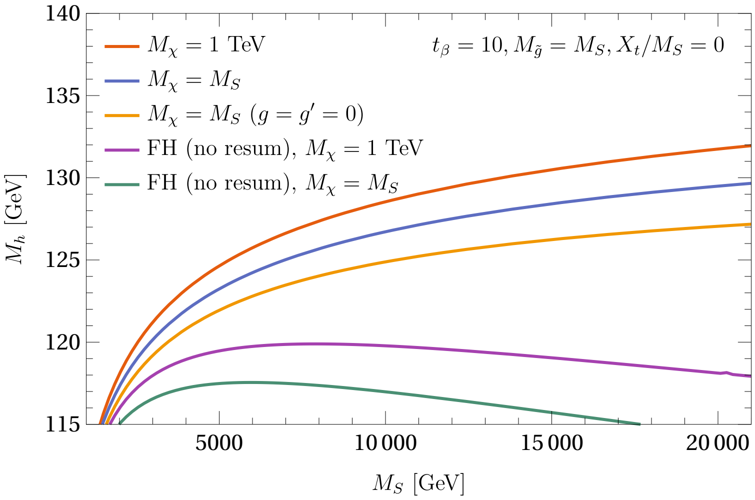
- gaugino-gaugino-Higgs couplings $\tilde{g}_{1u,1d,2u,2d}$ fixed at $Q = M_S$

  (e.g. Giudice et al. arXiv:1108.6077)

- threshold corrections at $Q = M_\chi$

  $\lambda_{\text{SM}}(M_\chi) = \lambda_\chi(M_\chi) + \Delta\lambda_{\text{chargino/neutralino}}$

  $h_{t,\text{SM}}(M_\chi) = h_{t,\chi}(M_\chi) + \Delta h_{t,\text{chargino/neutralino}}$

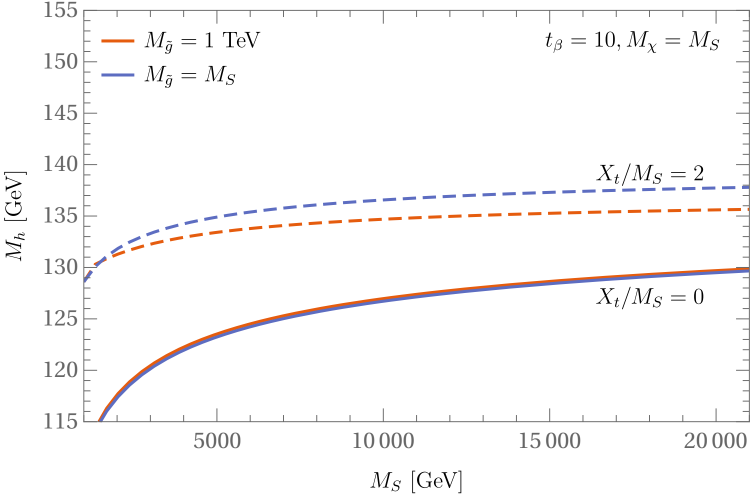

$M_\chi = 1$ TeV
$M_\chi = M_S$
$M_\chi = M_S$ $(g = g' = 0)$
FH (no resum), $M_\chi = 1$ TeV
FH (no resum), $M_\chi = M_S$
$t_\beta = 10, M_{\tilde{g}} = M_S, X_t/M_S = 0$
140
135
130
125
120
115
M_h [GeV]
5000
10 000
15 000
20 000
M_S [GeV]

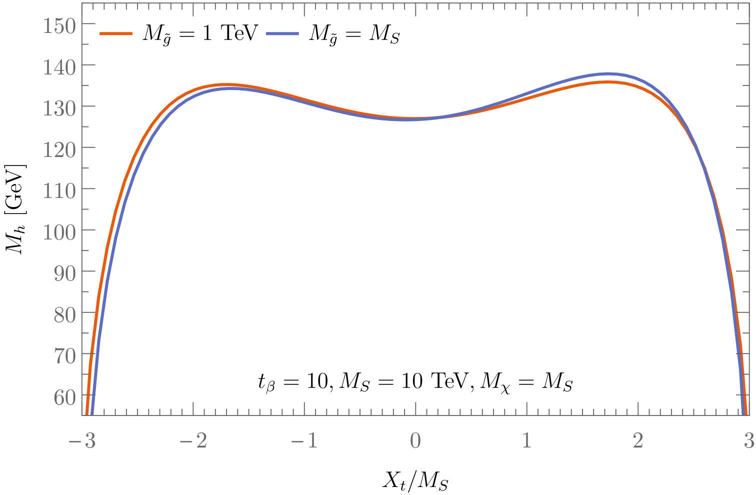
Extension III

Additional threshold $M_{\tilde{g}}$ ($m_t \ll M_{\tilde{g}} < M_S$), above which gluinos contribute to RGE running

- no additional threshold corrections at one-loop (gluino enters at two-loop level)
- only modifications of RGEs above $Q = M_{\tilde{g}}$ necessary, e.g.

$$\frac{dg_3}{dt} = \begin{cases} -\frac{7}{2} k g_3^3 & \text{for } Q < M_{\tilde{g}} \\ -\frac{5}{2} k g_3^3 & \text{for } Q > M_{\tilde{g}} \end{cases}$$


$M_{\tilde{g}} = 1$ TeV
$M_{\tilde{g}} = M_S$
$t_\beta = 10, M_\chi = M_S$
$X_t/M_S = 2$
$X_t/M_S = 0$
M_h [GeV]
M_S [GeV]
155
150
145
140
135
130
125
120
115
5000
10 000
15 000
20 000


$M_{\tilde{g}} = 1$ TeV
$M_{\tilde{g}} = M_S$
$t_\beta = 10, M_S = 10$ TeV$, M_\chi = M_S$
M_h [GeV]
X_t/M_S
150
140
130
120
110
100
90
80
70
60
−3
−2
−1
0
1
2
3

Scheme conversion

$\overline{\text{MS}} \leftrightarrow$ OS conversion: $X_t, M_S, M_\chi, M_{\tilde{g}}, m_t, M_W, M_Z$

- only logarithmic terms relevant
- definition of counterterms:
  - $M_S \equiv \sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}} \to \delta M_S^2 = \frac{1}{2}\left(\frac{m_{\tilde{t}_2}}{m_{\tilde{t}_1}}\delta M_{\tilde{t}_1}^2 + \frac{m_{\tilde{t}_1}}{m_{\tilde{t}_2}}\delta M_{\tilde{t}_2}^2\right)$
  - $M_\chi \equiv M_{\tilde{\chi}_2^0} \to$ use mass counterterm of $\tilde{\chi}_2^0$
  - $M_{\tilde{g}} \to$ use mass counterterm of $\tilde{g}$
- $m_t \to$ use running mass in Feynman diagrammatic result
- M_W, M_Z $(g, g') \to$ no logarithms (effective theory is SM)

Question

How to handle t_β?

- $\underbrace{\overline{\text{DR}}}_{\text{FeynHiggs}} \leftrightarrow \underbrace{\overline{\text{MS}}}_{\text{RGEs}}$ conversion
- running of t_β:
  - FeynHiggs takes $t_\beta(\mu = m_t)$ as input, $t_\beta(M_S)$ needed
  - definition of t_β in effective model below M_S?
- so far ($\tilde{h}_t = h_t/s_\beta$):

$$\frac{1}{t_\beta^2}\frac{dt_\beta^2}{dt} = -3k\tilde{h}_t^2$$

- Large SUSY-scale $\rightarrow$ large logarithms $\Rightarrow$ resummation necessary
- FeynHiggs 2.10: resummation of logarithms $\propto \alpha_t, \alpha_s$
- Extension I: resummation of logarithms $\propto \alpha_{em}$ up to ~ 3 GeV
- Extension II: intermediate chargino/neutralino threshold up to ~ 2 GeV
- Extension III: intermediate gluino threshold up to ~ 0.3 GeV ($\hat{X}_t = 0$), ~ 2 GeV ($\hat{X}_t = 2$) (mainly due to two-loop non-logarithmic terms)

- inclusion of (s)bottom contributions
- hierarchical stop spectrum $\rightarrow$ two stop thresholds
- heavy Higgs threshold
- next-to-next-to-leading logarithms using 3-loop RGEs

Standard Model RGEs (1 loop):

$$\frac{d\lambda}{dt} = k\left[6\left(\lambda^2 + \lambda h_t^2 - h_t^4\right) - \lambda\left(\frac{9}{2}g^2 + \frac{3}{2}g'^2\right) + \frac{9}{8}g^4 + \frac{3}{8}g'^4 + \frac{3}{4}g^2 g'^2\right]$$

$$\frac{dh_t}{dt} = \frac{1}{2}h_t k\left(\frac{9}{2}h_t^2 - 8g_3^2 - \frac{9}{4}g^2 - \frac{17}{12}g'^2\right)$$

$$\frac{dg_3}{dt} = -\langle\frac{7}{2};\frac{5}{2}\rangle k g_3^3$$

$$\frac{dg'}{dt} = \frac{41}{12}g'^3$$

$$\frac{dg}{dt} = -\frac{19}{12}g^3$$

Split Model Langrangian:

$$\begin{aligned}\mathcal{L}_{\text{split}} =& \langle 0; -\frac{1}{2} M_3 \tilde{g}^a \tilde{g}^a \rangle - \frac{1}{2} M_\chi \tilde{W}^a \tilde{W}^a - \frac{1}{2} M_\chi \tilde{B}^a \tilde{B}^a - M_\chi \tilde{H}_u^T \epsilon \tilde{H}_d \\ & - \frac{1}{\sqrt{2}} H^\dagger \left(\tilde{g}_{2u} \sigma^a \tilde{W}^a + \tilde{g}_{1u} \tilde{B} \right) \tilde{H}_u \\ & - \frac{1}{\sqrt{2}} H^T \epsilon \left(-\tilde{g}_{2d} \sigma^a \tilde{W}^a + \tilde{g}_{1d} \tilde{B} \right) \tilde{H}_d \\ & + h.c. + ...\end{aligned}$$

Split Model RGEs (1 loop):

$$
\begin{aligned}
\frac{dg'}{dt} =& \frac{15}{4} k g'^3 \\
\frac{dg}{dt} =& -\frac{7}{12} k g^3 \\
\frac{dg_3}{dt} =& -\langle \frac{7}{2}; \frac{5}{2} \rangle k g_3^3 \\
\frac{dh_t}{dt} =& \frac{1}{2} k h_t \left[-\frac{9}{4} g^2 - 8 g_3^2 - \frac{17}{12} g'^2 + \frac{9}{2} h_t^2 + \frac{1}{2} (\tilde{g}_{1d}^2 + \tilde{g}_{1u}^2 + 3\tilde{g}_{2d}^2 + 3\tilde{g}_{2u}^2) \right] \\
\frac{d\lambda}{dt} =& \frac{1}{2} k \left[-\tilde{g}_{1d}^4 - \tilde{g}_{1u}^4 + \frac{9}{4} g^4 - 5\tilde{g}_{2d}^4 - 4\tilde{g}_{1d}\tilde{g}_{1u}\tilde{g}_{2d}\tilde{g}_{2u} - 5\tilde{g}_{2u}^4 \right. \\
& -2(\tilde{g}_{1u}^2 + \tilde{g}_{2d}^2)(\tilde{g}_{1d}^2 + \tilde{g}_{2u}^2) \\
& + \frac{3}{2} g^2 g'^2 + \frac{3}{4} g'^4 - 12 h_t^4 + 2(\tilde{g}_{1d}^2 + \tilde{g}_{1u}^2 + 3\tilde{g}_{2d}^2 + 3\tilde{g}_{2u}^2)\lambda \\
& \left. -9 \left(g^2 + \frac{1}{3} g'^2 \right) \lambda + 12 h_t^2 \lambda + 12 \lambda^2 \right]
\end{aligned}
$$

Split Model RGEs (1 loop), cont.:

$$\begin{aligned}
\frac{d\tilde{g}_{1u}}{dt} &= \frac{1}{2}k\left[3\tilde{g}_{1d}\tilde{g}_{2d}\tilde{g}_{2u} + \tilde{g}_{1u}\left(\frac{5}{4}\tilde{g}_{1u}^2 + 2\tilde{g}_{1d}^2 + \frac{9}{4}\tilde{g}_{2u}^2 + \frac{3}{2}\tilde{g}_{2d}^2 - \frac{9}{4}g^2 - \frac{3}{4}g'^2 + 3h_t^2\right)\right] \\
\frac{d\tilde{g}_{1d}}{dt} &= \frac{1}{2}k\left[3\tilde{g}_{1u}\tilde{g}_{2d}\tilde{g}_{2u} + \tilde{g}_{1d}\left(\frac{5}{4}\tilde{g}_{1d}^2 + 2\tilde{g}_{1u}^2 + \frac{9}{4}\tilde{g}_{2d}^2 + \frac{3}{2}\tilde{g}_{2u}^2 - \frac{9}{4}g^2 - \frac{3}{4}g'^2 + 3h_t^2\right)\right] \\
\frac{d\tilde{g}_{2u}}{dt} &= \frac{1}{2}k\left[\tilde{g}_{1d}\tilde{g}_{1u}\tilde{g}_{2d} + \tilde{g}_{2u}\left(\frac{1}{2}\tilde{g}_{1d}^2 + \frac{3}{4}\tilde{g}_{1u}^2 + \tilde{g}_{2d}^2 + \frac{11}{4}\tilde{g}_{2u}^2 - \frac{33}{4}g^2 - \frac{3}{4}g'^2 + 3h_t^2\right)\right] \\
\frac{d\tilde{g}_{2d}}{dt} &= \frac{1}{2}k\left[\tilde{g}_{1d}\tilde{g}_{1u}\tilde{g}_{2u} + \tilde{g}_{2d}\left(\frac{1}{2}\tilde{g}_{1u}^2 + \frac{3}{4}\tilde{g}_{1d}^2 + \tilde{g}_{2u}^2 + \frac{11}{4}\tilde{g}_{2d}^2 - \frac{33}{4}g^2 - \frac{3}{4}g'^2 + 3h_t^2\right)\right]
\end{aligned}$$

$$\lambda(M_S) = \underbrace{\frac{1}{4}\cos^2(2\beta)\left(g^2 + g'^2\right)}_{\text{tree level}}$$

$$\underbrace{-k\left[\left(\frac{3}{4} - \frac{1}{6}c_{2\beta}^2\right)g^4 + \frac{1}{2}g^2 g'^2 + \frac{1}{4}g'^4\right]}_{\text{tree-level term } \overline{\mathrm{DR}} \to \overline{\mathrm{MS}}}$$

$$\underbrace{+6h_t^2 k\left\{\left[h_t^2 + \frac{1}{8}\left(g^2 + g'^2\right)c_{2\beta}\right]\hat{X}_t^2 - \frac{1}{12}h_t^2\hat{X}_t^4\right\}}_{\text{stop-threshold corr.}}$$

$$\underbrace{-\frac{1}{4}kh_t^2(g^2 + g'^2)c_{2\beta}^2\hat{X}_t^2}_{\text{stop-threshold corr.}}$$

$$\underbrace{-\frac{3}{16}k(g'^2 + g^2)^2 s_{4\beta}^2}_{\text{heavy Higgs threshold corr.}}$$

$$\tilde{g}_{1u}(M_S) = g s_\beta \left\{1 + k\left[\frac{3}{16} g^2\left(-2 + 7c_\beta^2\right) + \frac{1}{20} g'^2\left(-44 + 7c_\beta^2\right) + \frac{9}{4s_\beta^2} h_t^2\right]\right\}$$

$$\tilde{g}_{1d}(M_S) = g c_\beta \left\{1 + k\left[\frac{3}{16} g^2\left(-2 + 7s_\beta^2\right) + \frac{1}{20} g'^2\left(-44 + 7s_\beta^2\right)\right]\right\}$$

$$\tilde{g}_{2u}(M_S) = g' s_\beta \left\{1 + k\left[-g^2\left(\frac{2}{3} + \frac{11}{16} c_\beta^2\right) + \frac{1}{20} g'^2\left(-2 + 7c_\beta^2\right) + \frac{9}{4s_\beta^2} h_t^2\right]\right\}$$

$$\tilde{g}_{2u}(M_S) = g' c_\beta \left\{1 + k\left[-g^2\left(\frac{2}{3} + \frac{11}{16} s_\beta^2\right) + \frac{1}{20} g'^2\left(-2 + 7s_\beta^2\right)\right]\right\}$$

$$
\begin{aligned}
\lambda_{\rm SM}(M_\chi) &= \lambda_\chi(M_\chi) \\
&+ k\left\{ -\frac{7}{12}(\tilde{g}_{1d}^4 + \tilde{g}_{1d}^4) - \frac{9}{4}(\tilde{g}_{2d}^4 + \tilde{g}_{1u}^4) - \frac{3}{2}\tilde{g}_{1d}^2 g_{1u}^2 - \frac{7}{2} g_{2d}^2 g_{2u}^2 \right. \\
&- \frac{8}{3}\tilde{g}_{1d}\tilde{g}_{1u}\tilde{g}_{2d}\tilde{g}_{2u} - \frac{7}{6}(\tilde{g}_{1d}^2\tilde{g}_{2d}^2 + \tilde{g}_{1u}^2\tilde{g}_{2u}^2) - \frac{1}{6}(\tilde{g}_{1d}^2\tilde{g}_{2u}^2 + \tilde{g}_{1u}^2\tilde{g}_{2d}^2) \\
&- \frac{4}{3}(\tilde{g}_{1d}\tilde{g}_{2u}^2 + \tilde{g}_{1u}\tilde{g}_{2d})(\tilde{g}_{1d}\tilde{g}_{2d} + \tilde{g}_{1u}\tilde{g}_{2u}) \\
&+ \frac{2}{3}\tilde{g}_{1d}\tilde{g}_{1u}(\lambda_\chi - 2\tilde{g}_{1d}^2 - 2\tilde{g}_{1u}^2) + 2\tilde{g}_{2d}\tilde{g}_{2u}(\lambda_\chi - 2\tilde{g}_{2d}^2 - 2\tilde{g}_{2u}^2) \\
&\left. + \frac{1}{3}\lambda_\chi(\tilde{g}_{1d}^2 + \tilde{g}_{1u}^2) + \lambda_\chi(\tilde{g}_{2d}^2 + \tilde{g}_{2u}^2) \right\}
\end{aligned}
$$

$$
\begin{aligned}
g_{\chi}(M_{\chi}) &= g_{\mathrm{SM}}(M_{\chi}) \\
g'_{\chi}(M_{\chi}) &= g'_{\mathrm{SM}}(M_{\chi}) \\
g_{3,\chi}(M_{\chi}) &= g_{3,\mathrm{SM}}(M_{\chi}) \\
h_{t,\chi}(M_{\chi}) &= h_{t,\mathrm{SM}}(M_{\chi}) \left\{ 1 - k \left[\frac{1}{6}\tilde{g}_{1u}\tilde{g}_{1d} + \frac{1}{12}(\tilde{g}_{1u}^2 + \tilde{g}_{1d}^2) \right.\right. \\
&\qquad \left.\left. + \ \frac{1}{2}\tilde{g}_{2u}\tilde{g}_{2d} + \frac{1}{4}(\tilde{g}_{2u}^2 + \tilde{g}_{2d}^2) \right] \right\}
\end{aligned}
$$

one-loop logarithms ($M_\chi = M_{Susy}$):

$$M_h^{\mathrm{LL}} = -\frac{\alpha}{192\pi M_W^2 s_w^2}\Big\{288 M_t^4 + 144 m_t^2 M_Z^2 c_{2\beta} + 4c_{4\beta}\left(22M_W^4 - 64M_W^2 M_Z^2 + 41M_Z^4\right) - 9M_Z^4 c_{8\beta} - 56M_W^4 - 256M_W^2 M_Z^2 + 101M_Z^4\Big\}\ln\left(\frac{M_s^2}{m_t^2}\right)$$

chargino/neutralino contribution:

$$\frac{\alpha M_Z^2}{24\pi c_w^4}\Big[(10c_w^2(2c_w^2-1)-1)c_{4\beta} + 2c_w^2(22c_w^2-5)+11\Big]\ln\left(\frac{M_\chi^2}{m_t^2}\right)$$