Update: Higgs mass prediction in BSM models with FlexibleSUSY using an EFT calculation with M_h matching

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Higgs mass prediction in the THDM from high-scale SUSY

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   - Uncertainty estimation
4. M_h in the THDM
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FlexibleSUSY = spectrum generator generator

FlexibleSUSY

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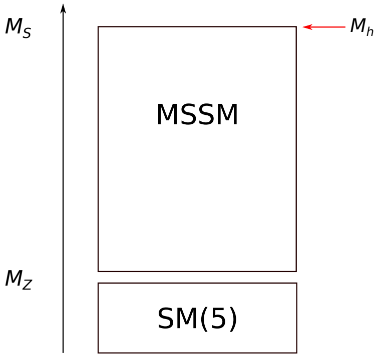
Full model approach



Idea: Calculate M_h in the MSSM at the scale $Q = M_S$ as a function of the $\overline{\text{DR}}$ parameters:

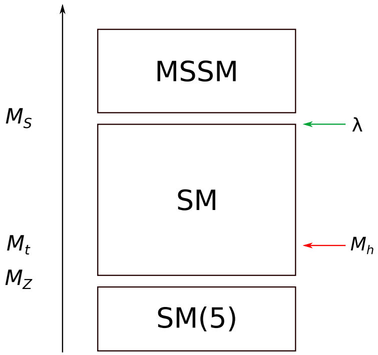
$$g_i,\ y_{ij}^f,\ v_i,\ \mu,\ B\mu,\ m_{H_i}^2,\ m_{\tilde{f},ij}^2,\ M_i,\ T_{ij}^f$$

Full model approach

$$(M_h^{\text{MSSM}})^2 = \text{smallest eigenvalue of}$$
$$\left[(m_h^{\text{MSSM}})^2 - \Sigma_h^{\text{MSSM}}((M_h^{\text{MSSM}})^2, M_S) + \frac{t_h^{\text{MSSM}}}{v}\right]_{ij}$$

Advantage: includes all 1L terms $O(p^2/M_S^2)$
Disadvantage: suffers from large logarithms $\propto \log(M_t/M_S)$ if $M_S \gg M_t$

EFT approach



Idea: Calculate M_h in the SM at the scale $Q = M_t$ as a function of the $\overline{\text{MS}}$ parameters:

$$g_i,\ y_{ij}^f,\ v,\ \mu^2,\ \lambda$$

EFT approach with Γ matching

Determine $\lambda(M_S)$ from mathching all $\Gamma^{(k)}_{\phi_1,\ldots,\phi_n}(p^2 = 0, Q = M_S)$:
$\Rightarrow$

$$\lambda(M_S) = \frac{1}{4}\left[g_Y^2 + g_2^2\right]\cos^2 2\beta + \Delta\lambda$$

RG running to $Q = M_t \Rightarrow$

$$(M_h^{\text{SM}})^2 = \lambda v^2 - \Sigma_h^{\text{SM}}((M_h^{\text{SM}})^2) + \frac{t_h^{\text{SM}}}{v}$$

Advantage: resums large logarithms $\propto \log(M_t/M_S)$
Disadvantage: difficult to automatize; neglects terms $O(p^2/M_S^2)$ from SUSY particles if performed at 1L-level only

EFT approach with M_h matching

$$M_h^{\text{SM}} \stackrel{!}{=} M_h^{\text{MSSM}} \quad \text{at} \quad Q = M_S, 1L$$

with

$$(M_h^{\text{SM}})^2 = \lambda(M_S) v^2 - \Sigma_h^{\text{SM}}(M_h^2) + \frac{t_h^{\text{SM}}}{v}$$

$$(M_h^{\text{MSSM}})^2 = (m_h^{\text{MSSM}})^2 - \Sigma_h^{\text{MSSM}}(M_h^2) + \frac{t_h^{\text{MSSM}}}{v}$$

$\Rightarrow$

$$\lambda(M_S) = \frac{1}{v^2}\left[(m_h^{\text{MSSM}})^2 - \Sigma_h^{\text{MSSM}} + \frac{t_h^{\text{MSSM}}}{v} + \Sigma_h^{\text{SM}} - \frac{t_h^{\text{SM}}}{v}\right]$$

EFT approach with M_h matching

Next step: RG running to $Q = M_t$

$\Rightarrow$

$$M_h^2 = \lambda(M_t)v^2 - \Sigma_h^{\text{SM}}(M_h^2) + \frac{t_h^{\text{SM}}}{v}$$

EFT approach with M_h matching

Advantages:

- easily automatizable
- resums large logarithms $\log(M_t/M_S)$ due to RG running
- includes all 1L terms $O(p^n/M_S^n, v^n/M_S^n)$

Disadvantage:

- large logs in matching cancel only in SM limit $\cos(\beta - \alpha) \to 0$
- only 1L calculation so far

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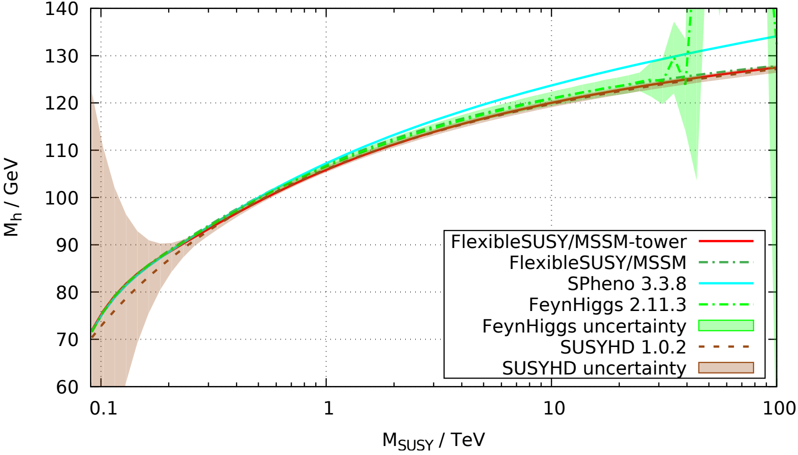
Comparison full model vs. EFT approach



$\tan\beta = 5,\ X_{t,b,\tau} = 0$

Comparison full model vs. EFT approach

Q: Why is FlexibleSUSY/MSSM so close to the EFT approaches and SPheno so far off?

Calculation of $y_t^{\text{MSSM}}(M_Z)$

A: Different treatment of 2-loop corrections to $y_t^{\text{MSSM}}(M_Z)$:

FlexibleSUSY:

$$m_t = M_t + \text{Re}\left[\widetilde{\Sigma}_t^{(1),S}(M_t)\right] + M_t\,\text{Re}\left[\widetilde{\Sigma}_t^{(1),L}(M_t) + \widetilde{\Sigma}_t^{(1),R}(M_t)\right] + M_t\left[\widetilde{\Sigma}_t^{(1),\text{qcd}}(m_t) + \left(\widetilde{\Sigma}_t^{(1),\text{qcd}}(m_t)\right)^2 + \widetilde{\Sigma}_t^{(2),\text{qcd}}(m_t)\right]$$

SPheno:

$$m_t = M_t + \text{Re}\left[\widetilde{\Sigma}_t^{(1),S}(m_t)\right] + m_t\,\text{Re}\left[\widetilde{\Sigma}_t^{(1),L}(m_t) + \widetilde{\Sigma}_t^{(1),R}(m_t)\right] + m_t\left[\widetilde{\Sigma}_t^{(1),\text{qcd}}(m_t) + \widetilde{\Sigma}_t^{(2),\text{qcd}}(m_t)\right]$$

Calculation of $y_t^{\text{MSSM}}(M_Z)$

$\Rightarrow$

$$\tilde{y}_t^{\text{FlexibleSUSY}} = y_t + t^2\kappa^2\left(\frac{184}{9}g_3^4 y_t - 24 g_3^2 y_t^3 + \frac{9}{8}y_t^5\right) + \dots$$
$$\tilde{y}_t^{\text{SPheno}} = y_t + t^2\kappa^2\left(\frac{248}{9}g_3^4 y_t - 16 g_3^2 y_t^3 + \frac{27}{8}y_t^5\right) + \dots$$

with

$$y_t \equiv y_t^{\text{SM}}(M_S), \qquad g_3 \equiv g_3^{\text{SM}}(M_S),$$
$$\tilde{y}_t \equiv y_t^{\text{MSSM}}(M_S), \qquad \tilde{g}_3 \equiv g_3^{\text{MSSM}}(M_S),$$
$$t \equiv \log\frac{M_S}{M_t}, \qquad \kappa \equiv \frac{1}{(4\pi)^2}$$

Calculation of $y_t^{\text{MSSM}}(M_Z)$

$$
\begin{aligned}
(M_h^2)^{\text{EFT}} &= m_h^2 + v^2 y_t^4 \Big[12 t\kappa + 12 t^2 \kappa^2 \left(16 g_3^2 - 9 y_t^2\right) \\
&\quad + 4 t^3 \kappa^3 \left(736 g_3^4 - 672 g_3^2 y_t^2 + 90 y_t^4\right) + \ldots \Big], \\
(M_h^2)^{\text{FlexibleSUSY}} &= m_h^2 + v^2 y_t^4 \Big[12 t\kappa + 12 t^2 \kappa^2 \left(16 g_3^2 - 9 y_t^2\right) \\
&\quad + 4 t^3 \kappa^3 \left(\frac{736 g_3^4}{3} - 288 g_3^2 y_t^2 + \frac{27 y_t^4}{2}\right) + \ldots \Big], \\
(M_h^2)^{\text{SPheno}} &= m_h^2 + v^2 y_t^4 \Big[12 t\kappa + 12 t^2 \kappa^2 \left(16 g_3^2 - 9 y_t^2\right) \\
&\quad + 4 t^3 \kappa^3 \left(\frac{992 g_3^4}{3} - 192 g_3^2 y_t^2 + \frac{81 y_t^4}{2}\right) + \ldots \Big].
\end{aligned}
$$

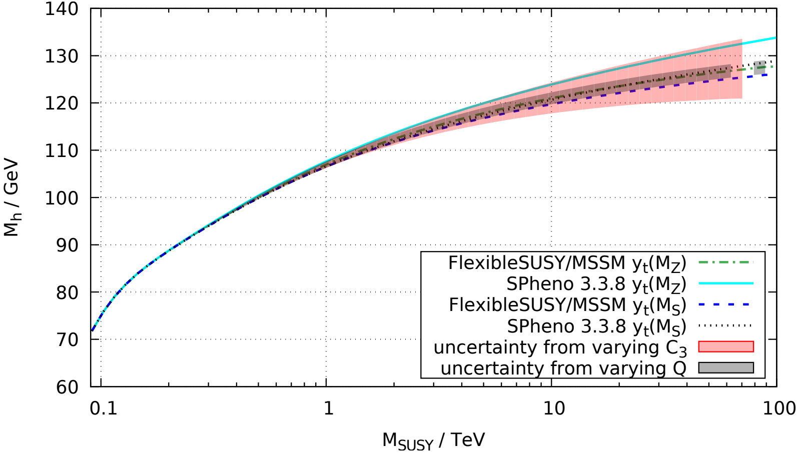
Uncertainty estimation in the full model approach

Parametrize difference between FlexibleSUSY and SPheno by adding

$$\Delta m_t = \frac{C_3 g_3^4 M_t}{(4\pi)^4} \log^2 \frac{M_S}{M_Z}$$

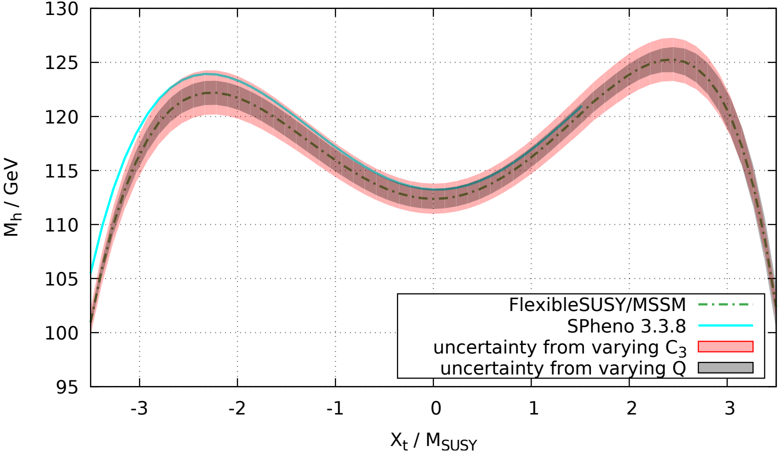
In the MSSM: $C_3 = -184/9 \approx 20$ [hep-ph/0210258]

Uncertainty estimation in the full model approach



$\tan\beta = 5$, $X_{t,b,\tau} = 0$

Uncertainty estimation in the full model approach



$\tan\beta = 5,\ M_S = 2\,\text{TeV},\ X_{b,\tau} = 0$

Uncertainty estimation in the EFT-M_h approach

Parametrize missing 2L threshold corrections by adding

$$\Delta\lambda^{(2)}_{(\alpha_t^2\alpha_s)} = \frac{g_3^2 (y_t^{\text{SM}})^4}{(4\pi)^4} \times C_1$$

$$\Delta\lambda^{(2)}_{(\alpha_t^4)} = \frac{(y_t^{\text{SM}})^6}{(4\pi)^4} \times C_2$$

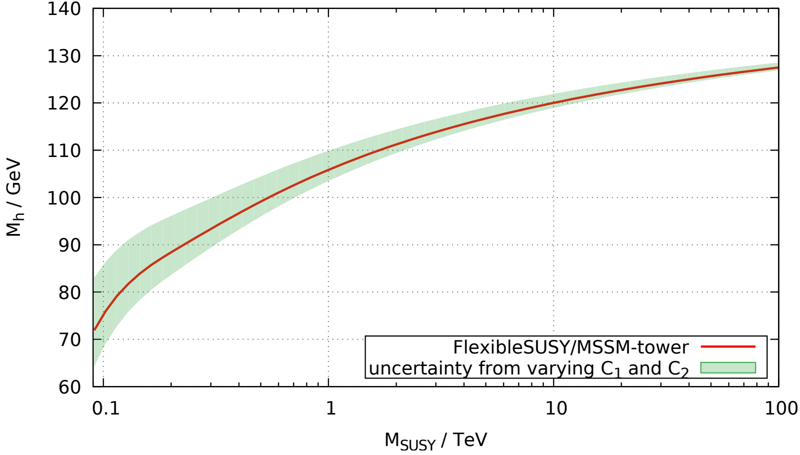
In the MSSM for $X_t \in [-3M_S, +3M_S]$, $\tan\beta \in [1, \infty]$ [1407.4081,1504.05200]:

$$C_1 \in [-314, 231]$$

$$C_2 \in [-6, 489]$$

Problem: This is most likely an over-estimate of the EFT uncertainty for small X_t, because for small X_t the 2L corrections to λ are small.

Uncertainty estimation in the EFT-M_h approach



$\tan\beta = 5,\ X_{t,b,\tau} = 0$

Uncertainty estimation in the EFT-M_h approach

Probably better: Change calculation of λ by higher-order terms:
For example, use $y_t^{\text{MSSM},(0)}$ vs. $y_t^{\text{MSSM},(1)}$ in

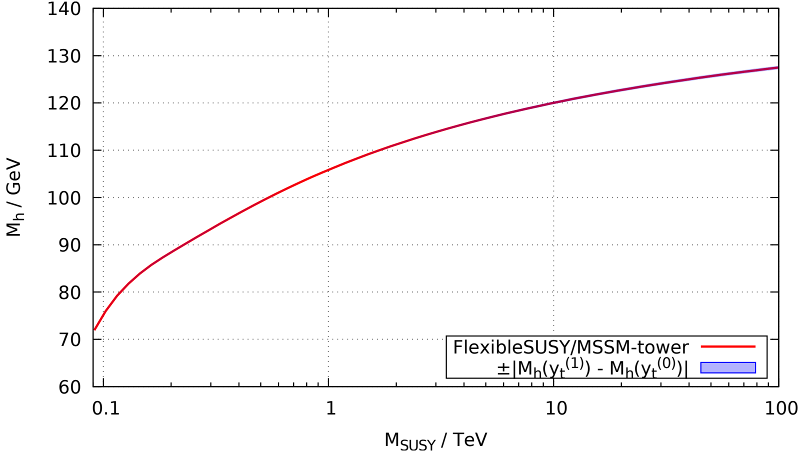
$$\lambda(M_S) = \frac{1}{v^2}\left[(m_h^{\text{MSSM}})^2 - \Sigma_h^{\text{MSSM}} + \frac{t_h^{\text{MSSM}}}{v} + \Sigma_h^{\text{SM}} - \frac{t_h^{\text{SM}}}{v}\right]$$

where

$$y_t^{\text{MSSM},(0)} = \frac{y_t^{\text{SM}}}{s_\beta}$$

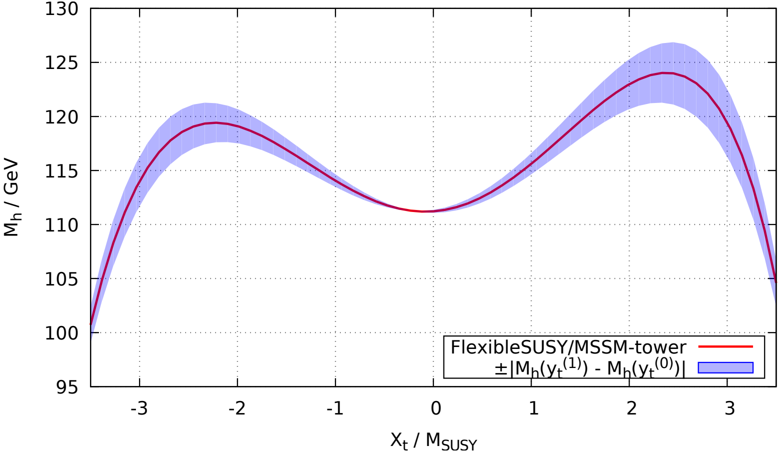
$$y_t^{\text{MSSM},(1)} = \frac{y_t^{\text{SM}}}{s_\beta} + \frac{\sqrt{2}}{s_\beta v}\left[\Sigma_t^{\text{MSSM}} - \Sigma_t^{\text{SM}}\right]$$

Uncertainty estimation in the EFT-M_h approach



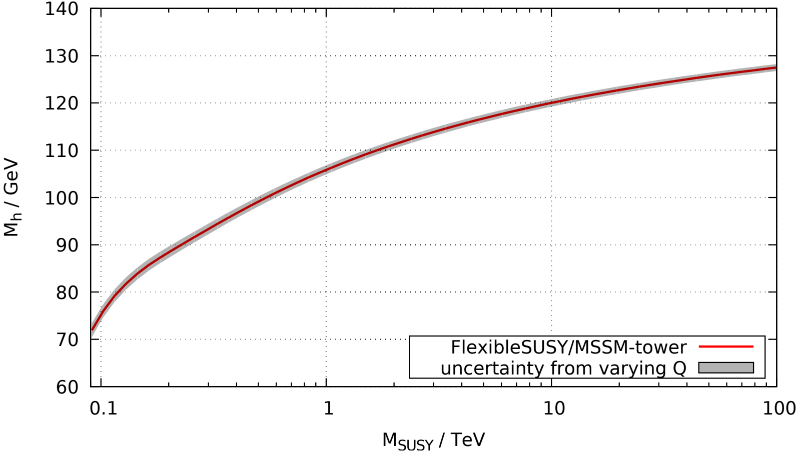
$\tan\beta = 5,\ X_{t,b,\tau} = 0$

Uncertainty estimation in the EFT-M_h approach



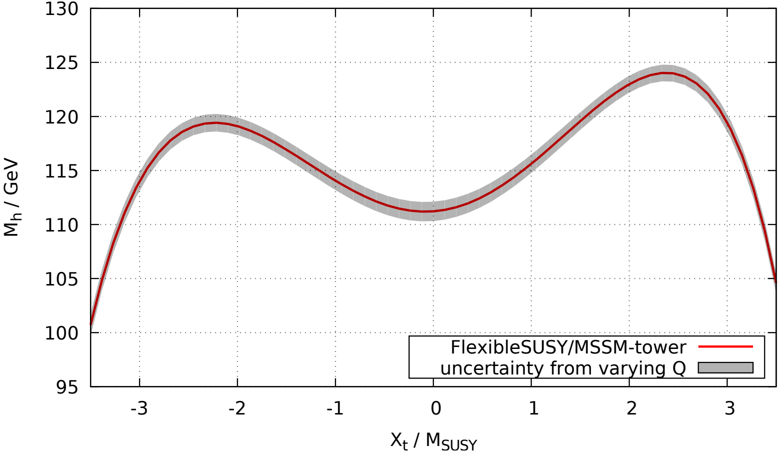
$\tan\beta = 5,\ M_S = 2\,\text{TeV},\ X_{b,\tau} = 0$

Uncertainty estimation in the EFT-M_h approach



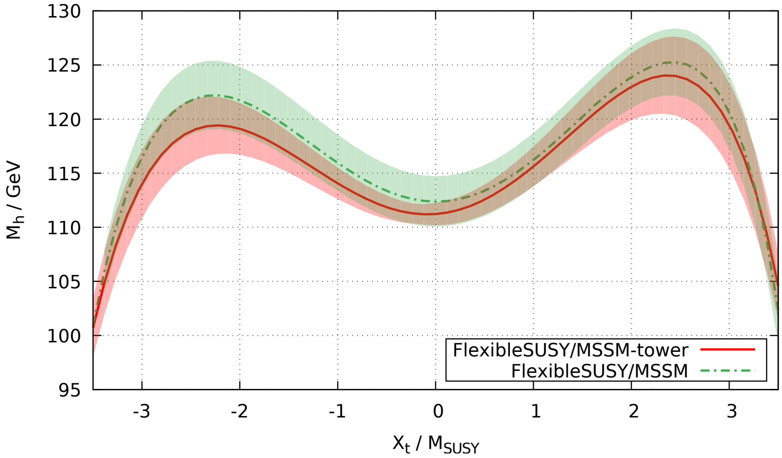
$\tan\beta = 5$, $X_{t,b,\tau} = 0$

Uncertainty estimation in the EFT-M_h approach



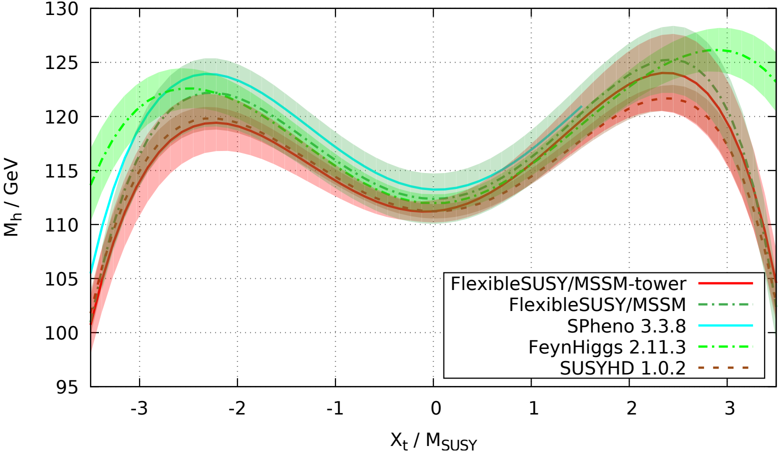
$\tan\beta = 5,\ M_S = 2\,\text{TeV},\ X_{b,\tau} = 0$

Comparison of full model and EFT-M_h approach



$\tan\beta = 5,\ M_S = 2\,\text{TeV},\ X_{b,\tau} = 0$

Comparison of full model and EFT-M_h approach



$\tan\beta = 5,\ M_S = 2\,\text{TeV},\ X_{b,\tau} = 0$

Conclusion of uncertainty estimations

Full model approach (2L):
(C_3 and Q uncertainties added linearly)

M_S/TeV	X_t/M_S	ΔM_h/GeV	X_t/M_S	ΔM_h/GeV
1	0	± 1.3	2	± 2.0
2	0	± 2.1	2	± 3.0
10	0	± 4.5	2	± 5.5

EFT-M_h approach (1L):
($y_t^{(i)}$ and Q uncertainties added linearly)

M_S/TeV	X_t/M_S	ΔM_h/GeV	X_t/M_S	ΔM_h/GeV
1	0	± 1.0	2	± 3.1
2	0	± 1.0	2	± 3.1
10	0	± 1.1	2	± 2.8

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M_h in the THDM

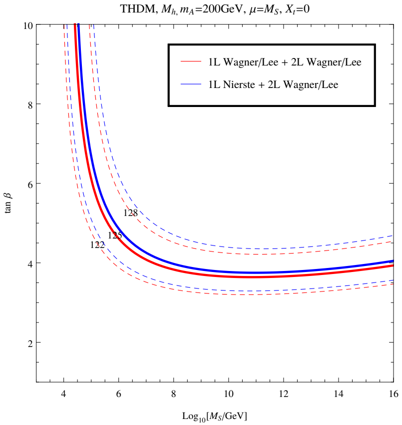
Wagner/Lee [1508.00576]:

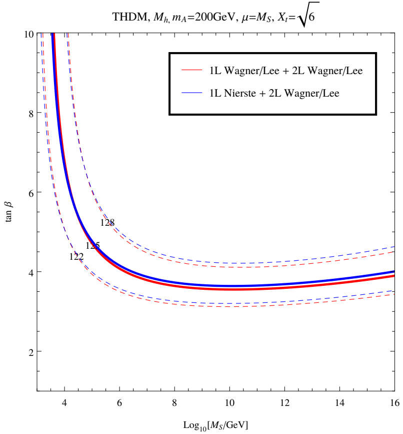
$$\lambda_i(M_S) = \kappa O(y^4_{t,b,\tau} + g_i^2 y^2_{t,b,\tau}) + \kappa^2 O(g_i^2 y^4_{t,b,\tau})$$

Nierste et.al.: [0901.2065]:

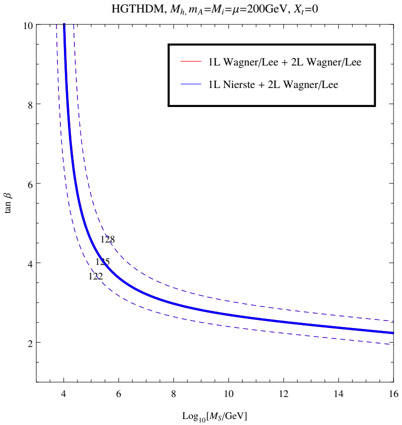
$$\lambda_i(M_S) = \kappa O(y^4_{jk} + g_i^2 y^2_{jk} + g_i^4)$$

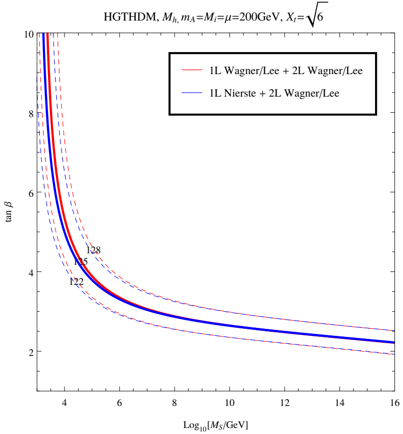
M_h in the THDM



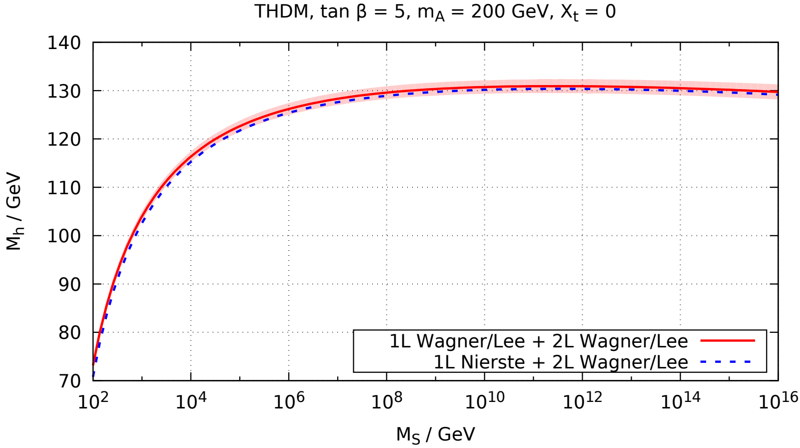


M_h in the THDM + Higgsinos + gauginos



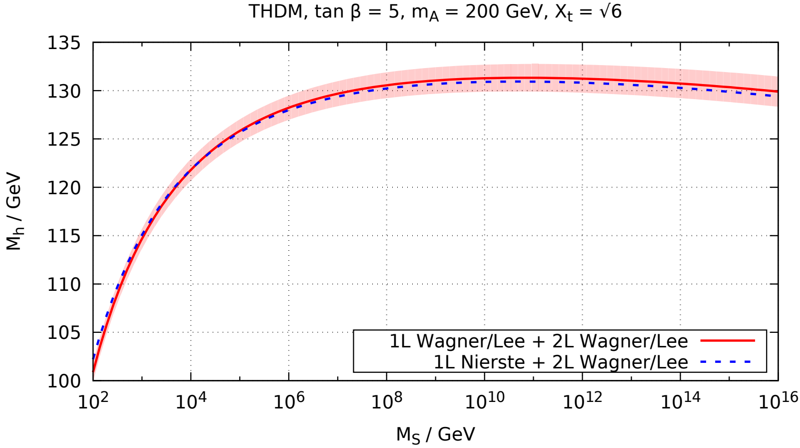


M_h in the THDM as function of M_S



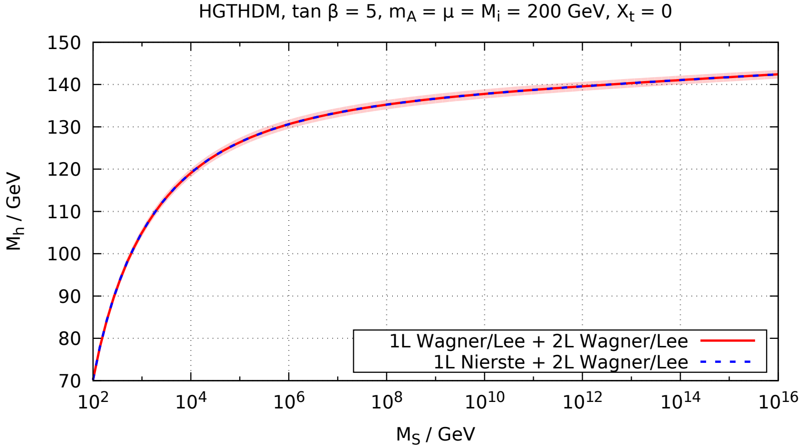
$\Delta\alpha_s(M_Z) = 0.0006$ [PDG], $\Delta M_t = 0.98\,\text{GeV}$ [arXiv:1403.4427], $Q \in [M_t/2, 2M_t]$

M_h in the THDM as function of M_S



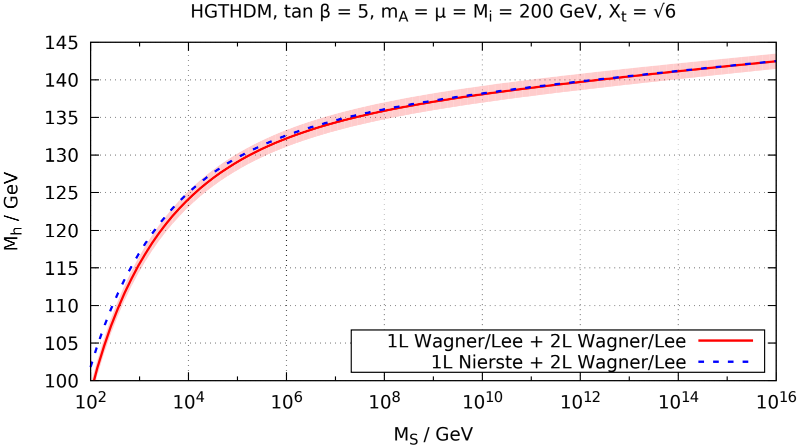
$\Delta\alpha_s(M_Z) = 0.0006$ [PDG], $\Delta M_t = 0.98\,\text{GeV}$ [arXiv:1403.4427],
$Q \in [M_t/2, 2M_t]$

M_h in the THDM + $\tilde{h}_i$ + $\tilde{g}_i$ as function of M_S



$\Delta\alpha_s(M_Z) = 0.0006$ [PDG], $\Delta M_t = 0.98\,\text{GeV}$ [arXiv:1403.4427],
$Q \in [M_t/2, 2M_t]$

M_h in the THDM + $\tilde{h}_i$ + $\tilde{g}_i$ as function of M_S



$\Delta\alpha_s(M_Z) = 0.0006$ [PDG], $\Delta M_t = 0.98\,\text{GeV}$ [arXiv:1403.4427], $Q \in [M_t/2, 2M_t]$

Summary

EFT-M_h approach

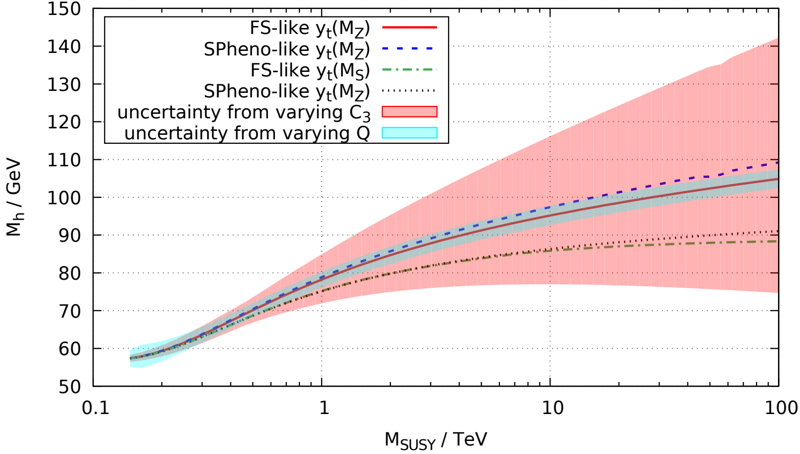
- full model approach suffers from large logs $\propto \log(M_t/M_S)$ if $M_S \gg M_t$
- EFT-λ approach resums large logs, but difficult to automatize (also misses 1L terms $O(p^2/M_S^2)$ if performed at 1L-level only)
- EFT-M_h approach
  - can be automatized easily $\rightarrow$ incorporation into FlexibleSUSY
  - resums large logs $\propto \log(M_t/M_S)$
  - includes all 1L terms $O(p^n/M_S^n, v^n/M_S^n)$
  - large logs cancel only in SM limit
  - more accurate than full model approach for $M_S \gtrsim 3\,\text{TeV}$
  - Todo: perform matching and calculation of M_h at 2-loop level

THDM (+ Higgsinos + Gauginos):

- Effect of threshold corrections $\kappa O(g_i^4)$ on M_h less than 1 GeV
- Uncertainty from variation of Q and M_t: max. $\pm 2\,\text{GeV}$

Backup

MRSSM



FS-like $y_t(M_Z)$
SPheno-like $y_t(M_Z)$
FS-like $y_t(M_S)$
SPheno-like $y_t(M_Z)$
uncertainty from varying C_3
uncertainty from varying Q
M_h / GeV
M_{SUSY} / TeV
150
140
130
120
110
100
90
80
70
60
50
0.1
1
10
100

Equivalence of EFT-λ and EFT-M_h approach

Equivalence EFT-λ and EFT-M_h approach $O(\hbar y_t^4)$

$$M_h^{\mathrm{SM}} \stackrel{!}{=} M_h^{\mathrm{MSSM}} \quad \text{at} \quad Q = M_S, 1L$$

where

$$(M_h^{\mathrm{SM}})^2 = \lambda v^2 - \Sigma_h^{\mathrm{SM}} + t_h^{\mathrm{SM}}/v$$
$$t_h^{\mathrm{SM}}/v = -6(y_t^{\mathrm{SM}})^2 A_0(m_t)/(4\pi)^2$$

and [neglecting stop mass mixing $O(m_t X_t/M_S^2)$]

$$(M_h^{\mathrm{MSSM}})^2 = \frac{1}{4}(g_Y^2 + g_2^2)(v_u^2 + v_d^2)c_{2\beta}^2 - \Sigma_h^{\mathrm{MSSM}} + t_h^{\mathrm{MSSM}}/v$$
$$\Sigma_h^{\mathrm{MSSM}} = \Sigma_h^{\mathrm{SM}}\frac{c_\alpha^2}{s_\beta^2} + 3\frac{(y_t^{\mathrm{SM}})^2}{(4\pi)^2}\frac{c_\alpha^2}{s_\beta^2}\Big\{A_0(m_{Q_3}) + A_0(m_{U_3})$$
$$+ 2m_t\big[B_0(m_{Q_3}, m_{Q_3}) + B_0(m_{U_3}, m_{U_3})\big]\Big\}$$
$$t_h^{\mathrm{MSSM}}/v = -3\frac{(y_t^{\mathrm{SM}})^2}{(4\pi)^2}\frac{c_\alpha^2}{s_\beta^2}\Big[2A_0(m_t) - A_0(m_{Q_3}) - A_0(m_{U_3})\Big]$$

Equivalence EFT-λ and EFT-M_h approach $O(\hbar y_t^4)$

in SM limit $\frac{c_\alpha^2}{s_\beta^2} \to 1$
$\Rightarrow$

$$
\begin{aligned}
\lambda &= \frac{1}{4}(g_Y^2 + g_2^2)c_{2\beta}^2 \\
&\quad - 3\frac{(y_t^{\text{SM}})^4}{(4\pi)^2}\Big[B_0(p^2, m_{Q_3}, m_{Q_3}) + B_0(p^2, m_{U_3}, m_{U_3})\Big] \\
&= \frac{1}{4}(g_Y^2 + g_2^2)c_{2\beta}^2 \\
&\quad - 3\frac{(y_t^{\text{SM}})^4}{(4\pi)^2}\Big[-\log\frac{m_{Q_3}^2}{Q^2} + \frac{p^2}{6m_{Q_3}^2} + O\Big(\frac{p^4}{m_{Q_3}^4}\Big) \\
&\qquad\qquad\qquad -\log\frac{m_{U_3}^2}{Q^2} + \frac{p^2}{6m_{U_3}^2} + O\Big(\frac{p^4}{m_{U_3}^4}\Big)\Big] \\
&= [\text{Bagnaschi et. al. 2014}] + O\Big(\frac{p^2}{m_{Q_3}^2}\Big) + O\Big(\frac{p^2}{m_{U_3}^2}\Big)
\end{aligned}
$$

Determination of MSSM parameters

Determination of MSSM parameters

Fixed by observables:

Input				Output
$\alpha_{\text{em}}^{\text{SM(5)}}(M_Z)$	$\to$	$\alpha_{\text{em}}^{\text{MSSM}}(M_Z)$	$\to$	$g_1^{\text{MSSM}}(M_Z)$
G_F	$\to$	$\sin\theta_W^{\text{MSSM}}(M_Z)$	$\to$	$g_2^{\text{MSSM}}(M_Z)$
$\alpha_{\text{s}}^{\text{SM(5)}}(M_Z)$			$\to$	$g_3^{\text{MSSM}}(M_Z)$
M_Z	$\to$	$m_Z^{\text{MSSM}}(M_Z)$	$\to$	$v^{\text{MSSM}}(M_Z)$
M_t	$\to$	$m_t^{\text{MSSM}}(M_Z)$	$\to$	$y_t^{\text{MSSM}}(M_Z)$
$m_b^{\text{SM(5)}}(m_b)$	$\to$	$m_b^{\text{MSSM}}(M_Z)$	$\to$	$y_b^{\text{MSSM}}(M_Z)$
M_τ	$\to$	$m_\tau^{\text{MSSM}}(M_Z)$	$\to$	$y_\tau^{\text{MSSM}}(M_Z)$

Fixed by 2 EWSB conditions: $m_{H_u}^2$, $m_{H_d}^2$

Free parameters: $\tan\beta$, μ, $B\mu$, $m_{\tilde{f},ij}^2$, M_i, T_{ij}^f

Determination of SM parameters

Fixed by observables:

Input				Output
$\alpha_{\text{em}}^{\text{SM(5)}}(M_Z)$	$\rightarrow$	$\alpha_{\text{em}}^{\text{SM}}(M_Z)$	$\rightarrow$	$g_1^{\text{SM}}(M_Z)$
G_F	$\rightarrow$	$\sin\theta_W^{\text{SM}}(M_Z)$	$\rightarrow$	$g_2^{\text{SM}}(M_Z)$
$\alpha_{\text{s}}^{\text{SM(5)}}(M_Z)$			$\rightarrow$	$g_3^{\text{SM}}(M_Z)$
M_Z	$\rightarrow$	$m_Z^{\text{SM}}(M_Z)$	$\rightarrow$	$v^{\text{SM}}(M_Z)$
M_t	$\rightarrow$	$m_t^{\text{SM}}(M_Z)$	$\rightarrow$	$y_t^{\text{SM}}(M_Z)$
$m_b^{\text{SM(5)}}(m_b)$	$\rightarrow$	$m_b^{\text{SM}}(M_Z)$	$\rightarrow$	$y_b^{\text{SM}}(M_Z)$
M_τ	$\rightarrow$	$m_\tau^{\text{SM}}(M_Z)$	$\rightarrow$	$y_\tau^{\text{SM}}(M_Z)$

Fixed by 1 EWSB condition: μ^2

Free parameter: λ

Determination of $g_3^{\mathsf{MSSM}}(M_S)$

$$\alpha_s^{\mathsf{MSSM}}(M_S) = \frac{\alpha_s^{\mathsf{SM}}(M_S)}{1 - \Delta\alpha_s(M_S)}$$

with

$$\Delta\alpha_s(Q) = \frac{\alpha_s}{2\pi}\left[\frac{1}{2} - \sum_{\text{SUSY particle } f} T_f \log\frac{m_f}{Q}\right]$$

$\Rightarrow$

$$g_3^{\mathsf{MSSM}}(M_S) = \sqrt{4\pi\alpha_s^{\mathsf{MSSM}}(M_S)}$$

Determination of $v_i^{\mathrm{MSSM}}(M_S)$

$$M_Z^{\mathrm{SM}} = M_Z^{\mathrm{MSSM}}$$

$\Rightarrow$

$$(m_Z^{\mathrm{MSSM}}(M_S))^2 = (M_Z^{\mathrm{SM}})^2 + \Pi_Z^{\mathrm{MSSM},1L}(Q = M_S)$$
$$(M_Z^{\mathrm{SM}})^2 = \frac{1}{4}\left[(g_Y^{\mathrm{SM}})^2 + (g_2^{\mathrm{SM}})^2\right](v^{\mathrm{SM}})^2 - \Pi_Z^{\mathrm{SM},1L}(Q = M_S)$$

$\Rightarrow$

$$v^{\mathrm{MSSM}}(M_S) = \frac{2m_Z^{\mathrm{MSSM}}(M_S)}{\sqrt{(g_Y^{\mathrm{MSSM}})^2 + (g_2^{\mathrm{MSSM}})^2}}$$

$\Rightarrow$

$$v_u^{\mathrm{MSSM}}(M_S) = v^{\mathrm{MSSM}}(M_S)\sin\beta(M_S)$$
$$v_d^{\mathrm{MSSM}}(M_S) = v^{\mathrm{MSSM}}(M_S)\cos\beta(M_S)$$

Determination of $y_i^{\text{MSSM}}(M_S)$

$$M_f^{\text{SM}} = M_f^{\text{MSSM}}$$

$\Rightarrow$

$$m_f^{\text{MSSM}}(M_S) = M_f^{\text{SM}} + \Sigma_f^{\text{MSSM},1L}(Q = M_S)$$
$$M_f^{\text{SM}} = \frac{\sqrt{2} m_f^{\text{SM}}}{v_i^{\text{SM}}} - \Sigma_f^{\text{SM},1L}(Q = M_S)$$

$\Rightarrow$

$$y_f^{\text{MSSM}}(M_S) = \frac{\sqrt{2} m_f^{\text{MSSM}}(M_S)}{v_i^{\text{MSSM}}(M_S)}$$

Determination of SM parameters

Determination of $g_3^{\mathsf{SM}}(M_Z)$

Input: $\alpha_s^{\mathsf{SM}(5)}(M_Z) = 0.1185$

$\rightarrow$

$$\alpha_s^{\mathsf{SM}}(M_Z) = \frac{\alpha_s^{\mathsf{SM}(5)}(M_Z)}{1 - \Delta\alpha_s(M_Z)}$$

with

$$\Delta\alpha_s(Q) = \frac{\alpha_s}{2\pi}\left[-\frac{2}{3}\log\frac{m_t}{Q}\right]$$

$\Rightarrow$

$$g_3^{\mathsf{SM}}(M_Z) = \sqrt{4\pi\alpha_s^{\mathsf{SM}}(M_Z)}$$

Determination of $y_t^{\text{SM}}(M_Z)$

$$y_t^{\text{SM}}(M_Z) = \frac{\sqrt{2}\, m_t^{\text{SM}}(M_Z)}{v(M_Z)}$$

where

$$\begin{aligned} m_t^{\text{SM}}(Q) &= M_t + \text{Re}\,\Sigma_t^S(M_Z) + M_t \Big[\text{Re}\,\Sigma_t^L(M_Z) \\ &\quad + \text{Re}\,\Sigma_t^R(M_Z) + \Delta m_t^{1L,\text{gluon}} + \Delta m_t^{2L,\text{gluon}} \Big] \\ \Delta m_t^{1L,\text{gluon}} &= -\frac{g_3^2}{12\pi^2}\left[4 - 3\log\left(\frac{m_t^2}{Q^2}\right)\right] \\ \Delta m_t^{2L,\text{gluon}} &= \left(\Delta m_t^{1L,\text{gluon}}\right)^2 \\ &\quad - \frac{g_3^4}{4608\pi^4}\left[396\log^2\left(\frac{m_t^2}{Q^2}\right) - 2028\log\left(\frac{m_t^2}{Q^2}\right)\right. \\ &\qquad \left. - 48\zeta(3) + 2821 + 16\pi^2(1+\log 4)\right] \end{aligned}$$

Determination of v^{SM}

The VEV v^{SM} is calculated from the running Z mass at $Q = M_Z$:

$$v^{\mathrm{SM}}(M_Z) = \frac{2m_Z^{\mathrm{SM}}(M_Z)}{\sqrt{g_Y^2 + g_2^2}}$$

$$m_Z^{\mathrm{SM}}(M_Z) = \sqrt{M_Z^2 + \Pi_Z^{1L}(p^2 = M_Z^2, Q = M_Z)}$$

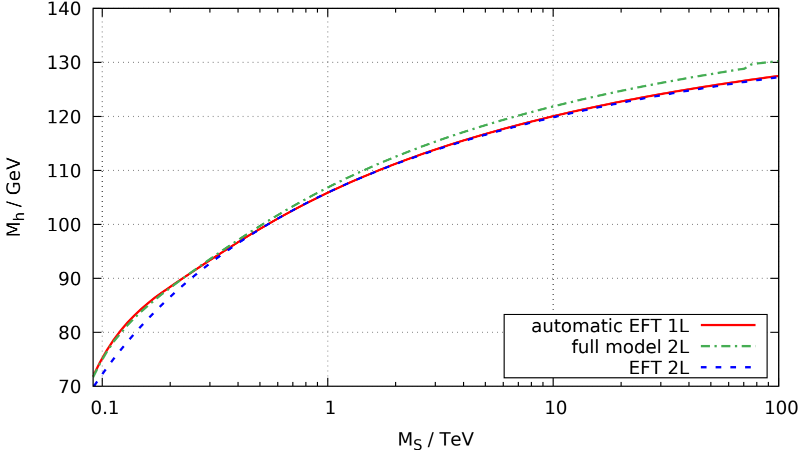
v^{SM} evolves under RG running according to
[Sperling, Stöckinger, AV, 2013, 2014]

X_t dependence

(default algorithm: $1L$ matching SM $\rightarrow$ MSSM)

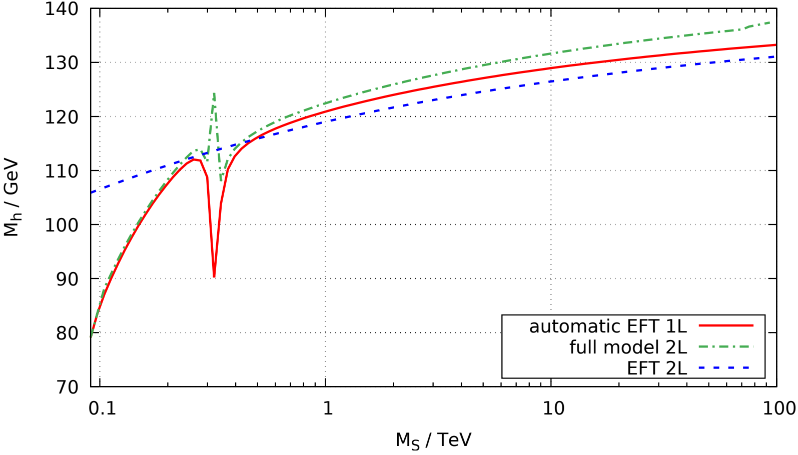
$\tan\beta = 5$

Comparison full vs. EFT-λ vs. EFT-M_h approach



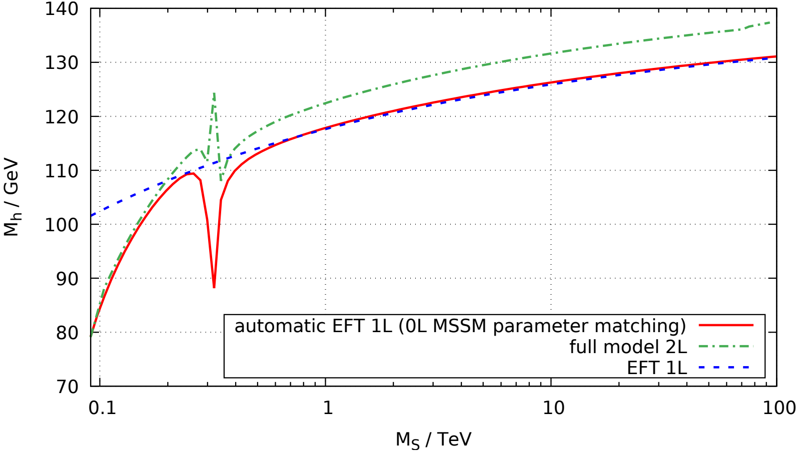
$\tan\beta = 5,\ X_{t,b,\tau} = 0$

Comparison full vs. EFT-λ vs. EFT-M_h approach



$\tan\beta = 5,\ X_t = \sqrt{6},\ X_{b,\tau} = 0$

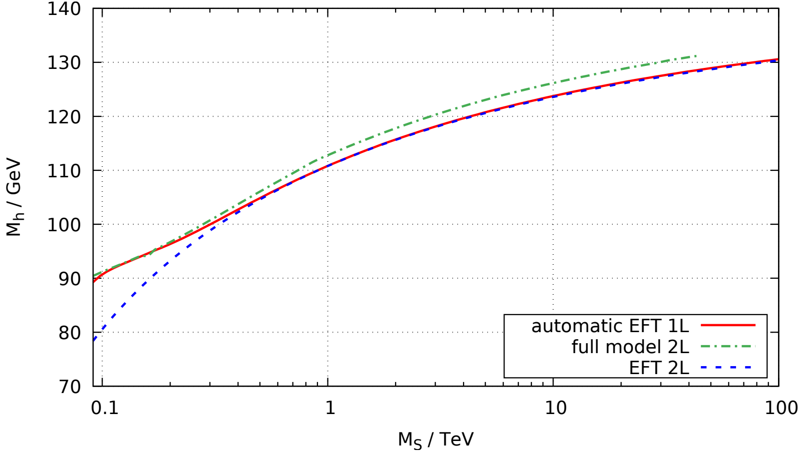
Comparison full vs. EFT-λ vs. EFT-M_h approach



$\tan\beta = 5$, $X_t = \sqrt{6}$, $X_{b,\tau} = 0$ ($0L$ matching SM $\to$ MSSM)

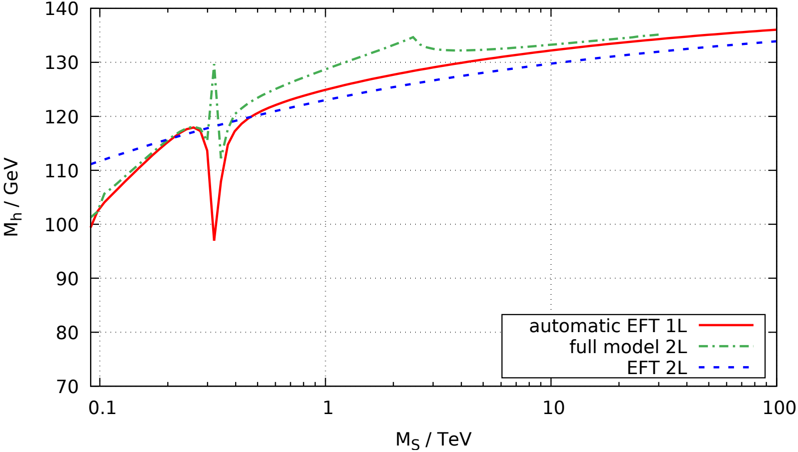
$\tan\beta = 20$

Comparison full vs. EFT-λ vs. EFT-M_h approach



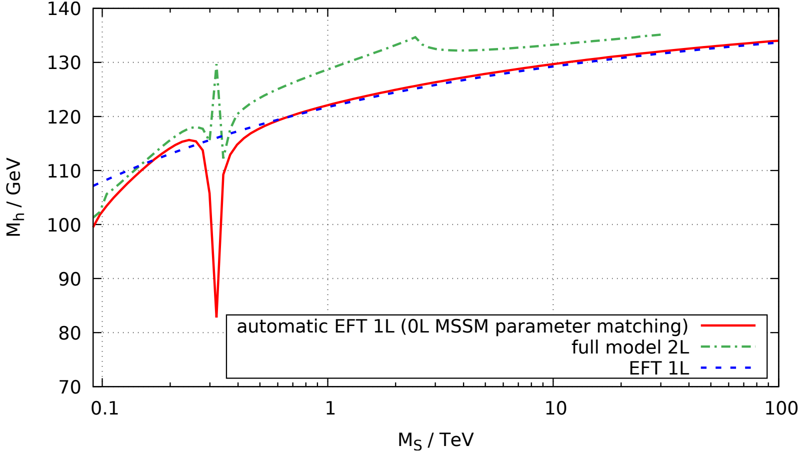
$\tan\beta = 20,\ X_{t,b,\tau} = 0$

Comparison full vs. EFT-λ vs. EFT-M_h approach



$\tan\beta = 20,\ X_t = \sqrt{6},\ X_{b,\tau} = 0$

Comparison full vs. EFT-λ vs. EFT-M_h approach

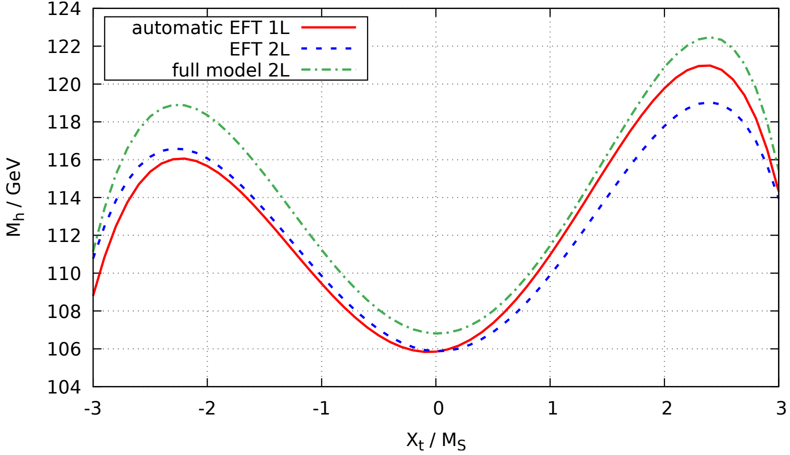


$\tan\beta = 20$, $X_t = \sqrt{6}$, $X_{b,\tau} = 0$ ($0L$ matching SM $\rightarrow$ MSSM)

X_t dependence

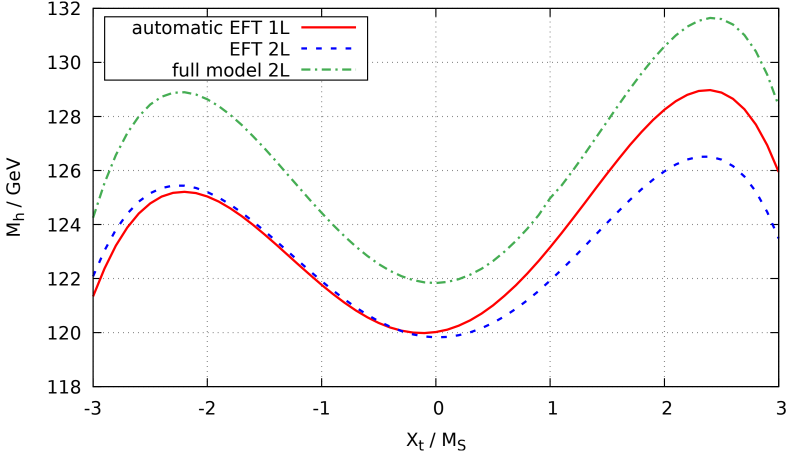
(default algorithm: $1L$ matching SM $\to$ MSSM)

Comparison full vs. EFT-λ vs. EFT-M_h approach



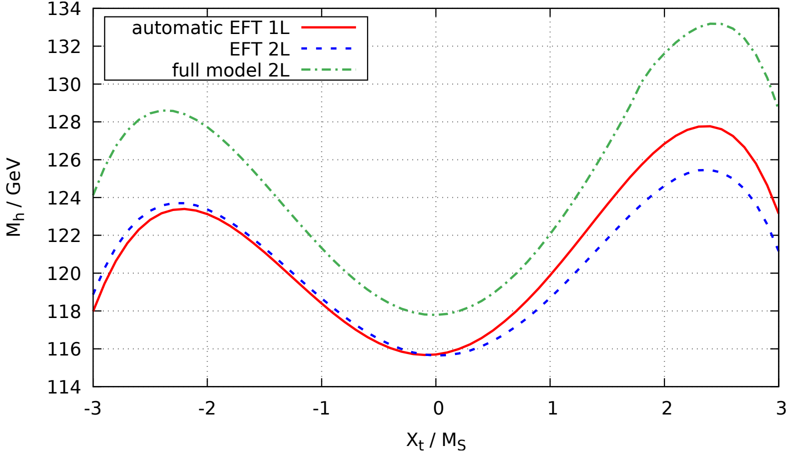
$\tan\beta = 5,\ X_{b,\tau} = 0,\ M_S = 1\,\text{TeV}$

Comparison full vs. EFT-λ vs. EFT-M_h approach



$\tan\beta = 5,\ X_{b,\tau} = 0,\ M_S = 10\,\text{TeV}$

Comparison full vs. EFT-λ vs. EFT-M_h approach

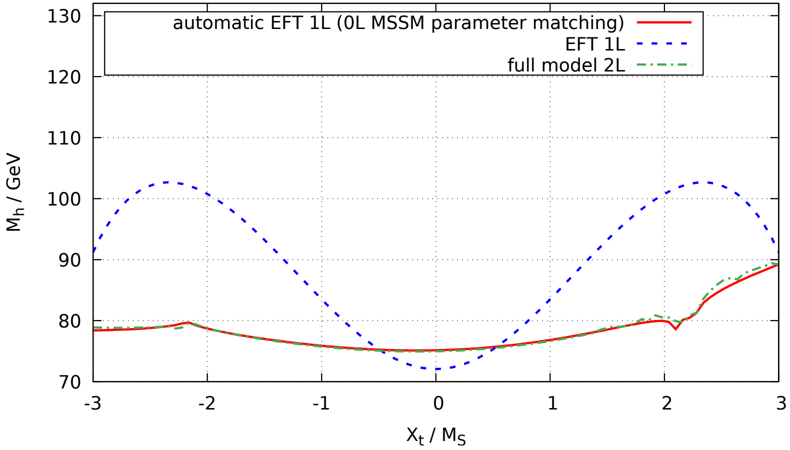


$\tan\beta = 20,\ X_{b,\tau} = 0,\ M_S = 2\,\text{TeV}$

X_t dependence

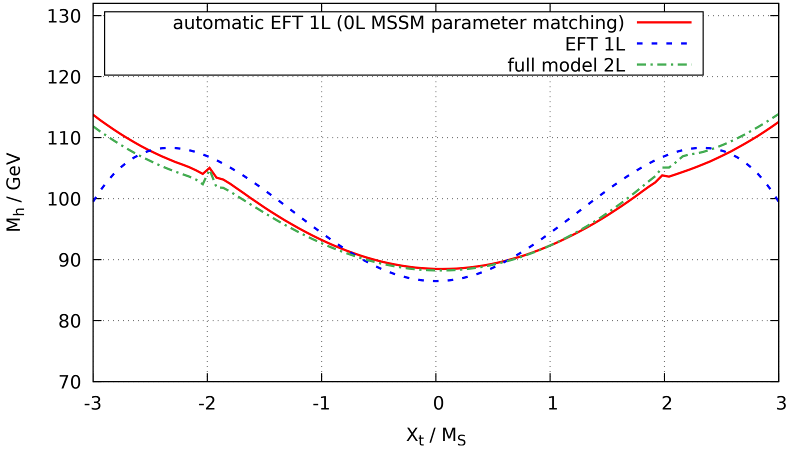
($0L$ matching SM $\rightarrow$ MSSM)

Comparison full vs. EFT-λ vs. EFT-M_h approach



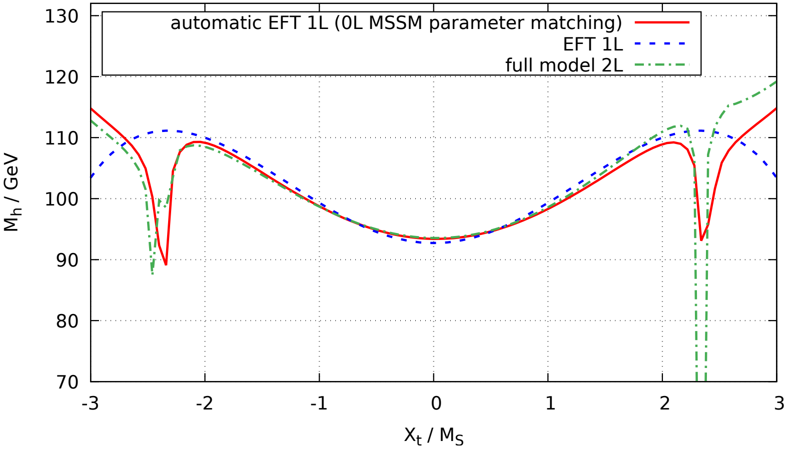
$\tan\beta = 5$, $X_{b,\tau} = 0$, $M_S = 100\,\text{GeV}$ ($0L$ matching SM $\rightarrow$ MSSM)

Comparison full vs. EFT-λ vs. EFT-M_h approach



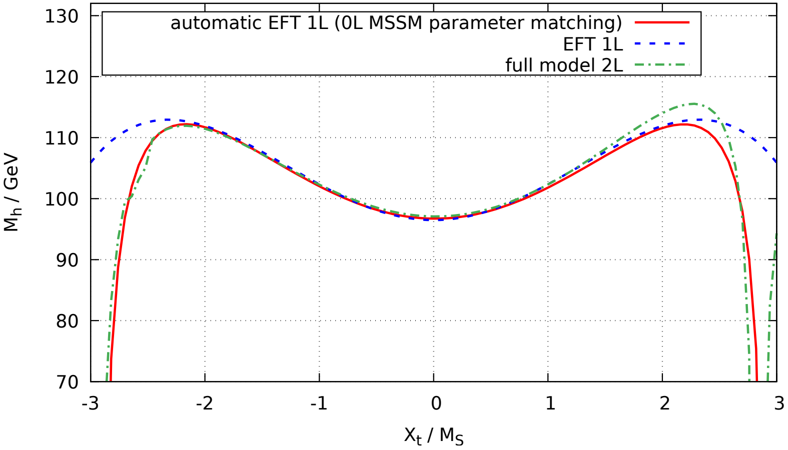
$\tan\beta = 5,\ X_{b,\tau} = 0,\ M_S = 200\,\text{GeV}$ ($0L$ matching SM $\to$ MSSM)

Comparison full vs. EFT-λ vs. EFT-M_h approach



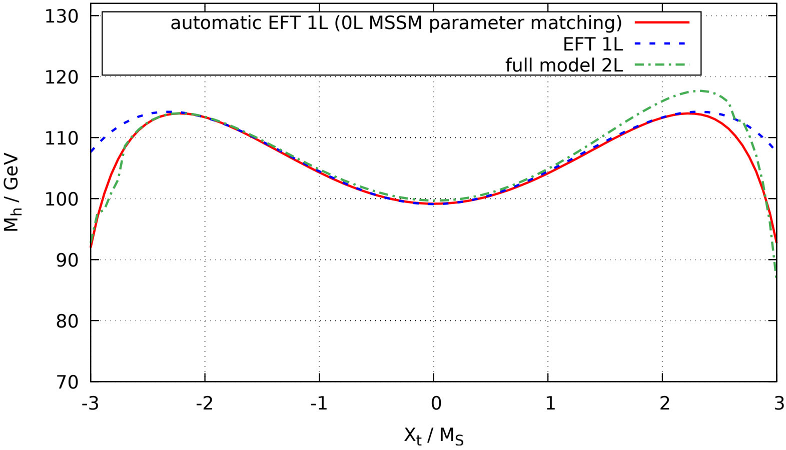
$\tan\beta = 5,\ X_{b,\tau} = 0,\ M_S = 300\,\text{GeV}$ ($0L$ matching SM $\to$ MSSM)

Comparison full vs. EFT-λ vs. EFT-M_h approach



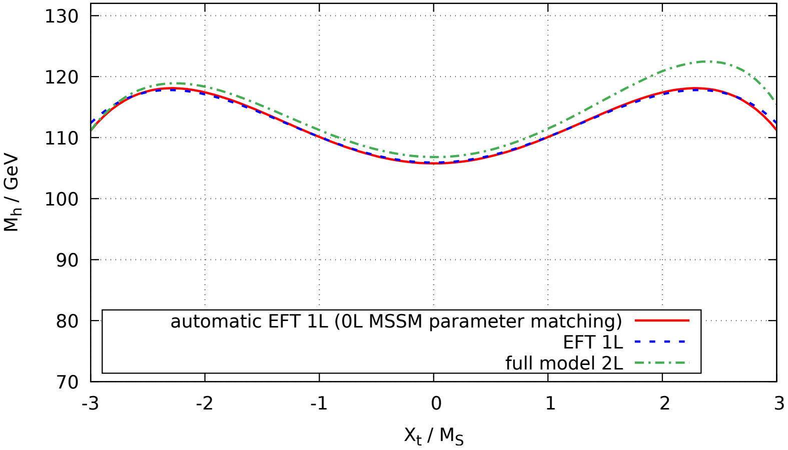
$\tan\beta = 5,\ X_{b,\tau} = 0,\ M_S = 400\,\text{GeV}$ ($0L$ matching SM $\to$ MSSM)

Comparison full vs. EFT-λ vs. EFT-M_h approach



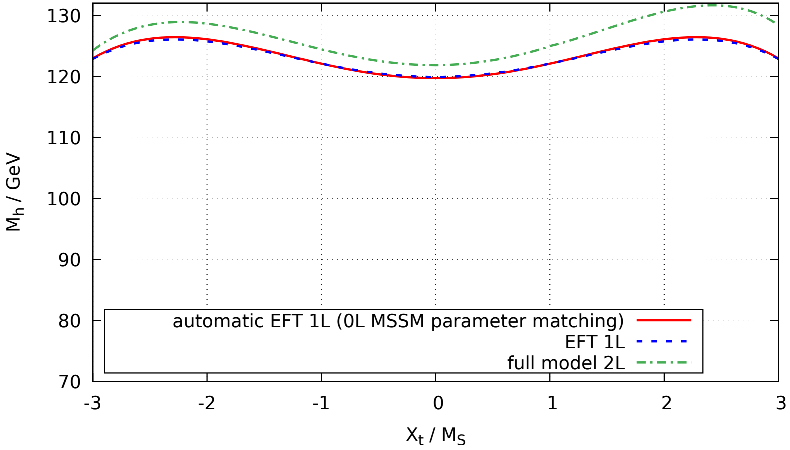
$\tan\beta = 5,\ X_{b,\tau} = 0,\ M_S = 500\,\text{GeV}$ ($0L$ matching SM $\to$ MSSM)

Comparison full vs. EFT-λ vs. EFT-M_h approach



$\tan\beta = 5$, $X_{b,\tau} = 0$, $M_S = 1\,\text{TeV}$ ($0L$ matching SM $\rightarrow$ MSSM)

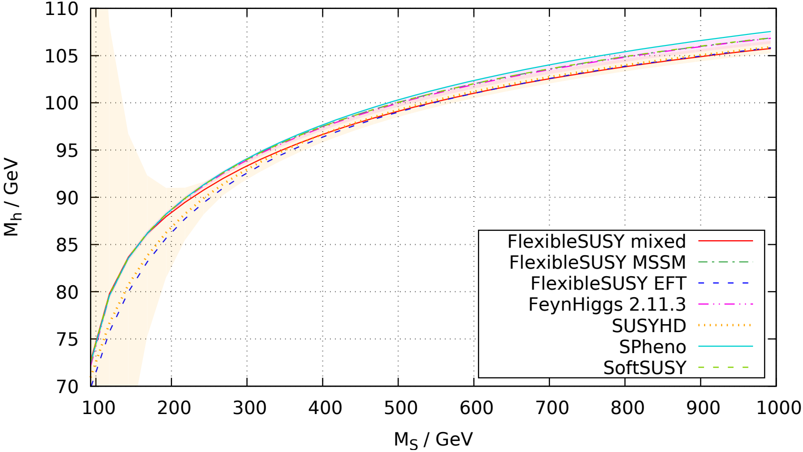
Comparison full vs. EFT-λ vs. EFT-M_h approach



$\tan\beta = 5,\ X_{b,\tau} = 0,\ M_S = 10\,\text{TeV}$ (0L matching SM $\to$ MSSM)

Comparison with other spectrum generators

Comparison full vs. EFT-λ vs. EFT-M_h approach

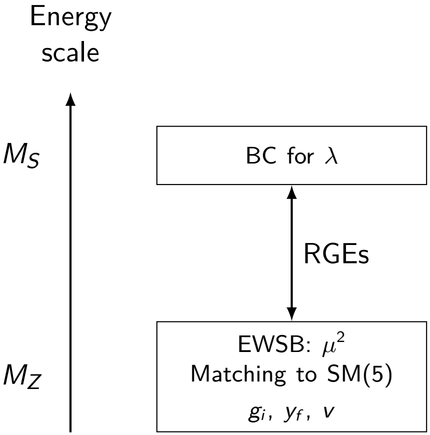


$\tan\beta = 5,\ X_{t,b,\tau} = 0$

FlexibleSUSY's Weltanschauung

- Model is defined in terms of Lagrangian parameters: g_i, y_{ij}, v_i, ... in the $\overline{\text{MS}}/\overline{\text{DR}}$ scheme
- Input parameters: $\alpha_{\text{em,SM}}^{(5),\overline{\text{MS}}}(M_Z)$, $\alpha_{\text{s,SM}}^{(5),\overline{\text{MS}}}(M_Z)$, M_Z, M_t, G_F, ...
- Output parameters: m_h, M_h, ...

Physical problem statement for the SM



Algorithm to calculate the model parameters consistent with all BCs