M_h in FlexibleSUSY 2.0

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FlexibleSUSY – a spectrum generator generator

Contents

Building a spectrum generator with FlexibleSUSY

Building the spectrum generator:

```
$ ./createmodel --name=HSSUSY
$ ./configure --with-models=HSSUSY
$ make -j4
```

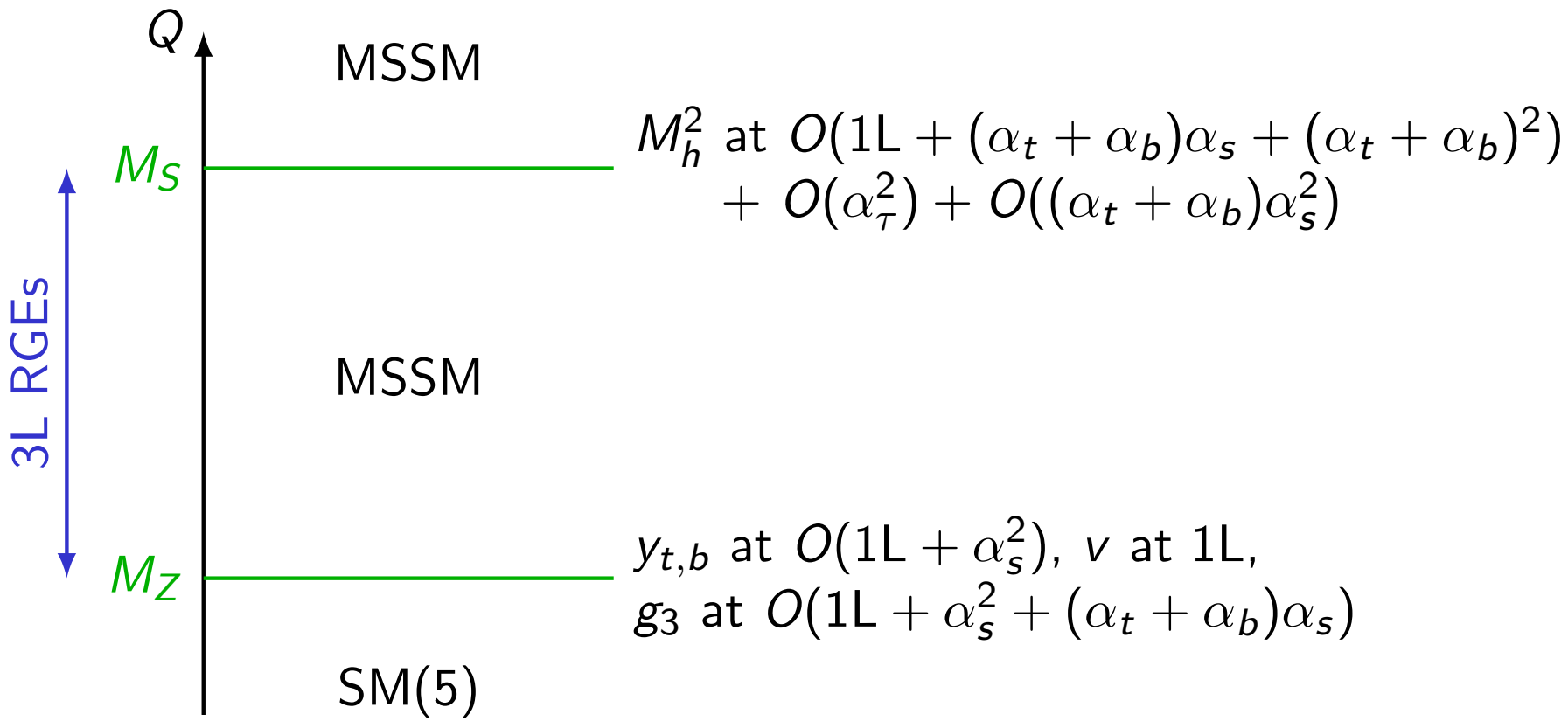
Run the spectrum generator from the command line:

```
$ cd models/HSSUSY/
$ ./run_HSSUSY.x \
    --slha-input-file=LesHouches.in.HSSUSY
```

Run the spectrum generator from Mathematica:

```
$ math -run "<< \"models/HSSUSY/run_HSSUSY.m\""
```

Fixed-order calculation (NUHMSSMNoFVHimalaya)

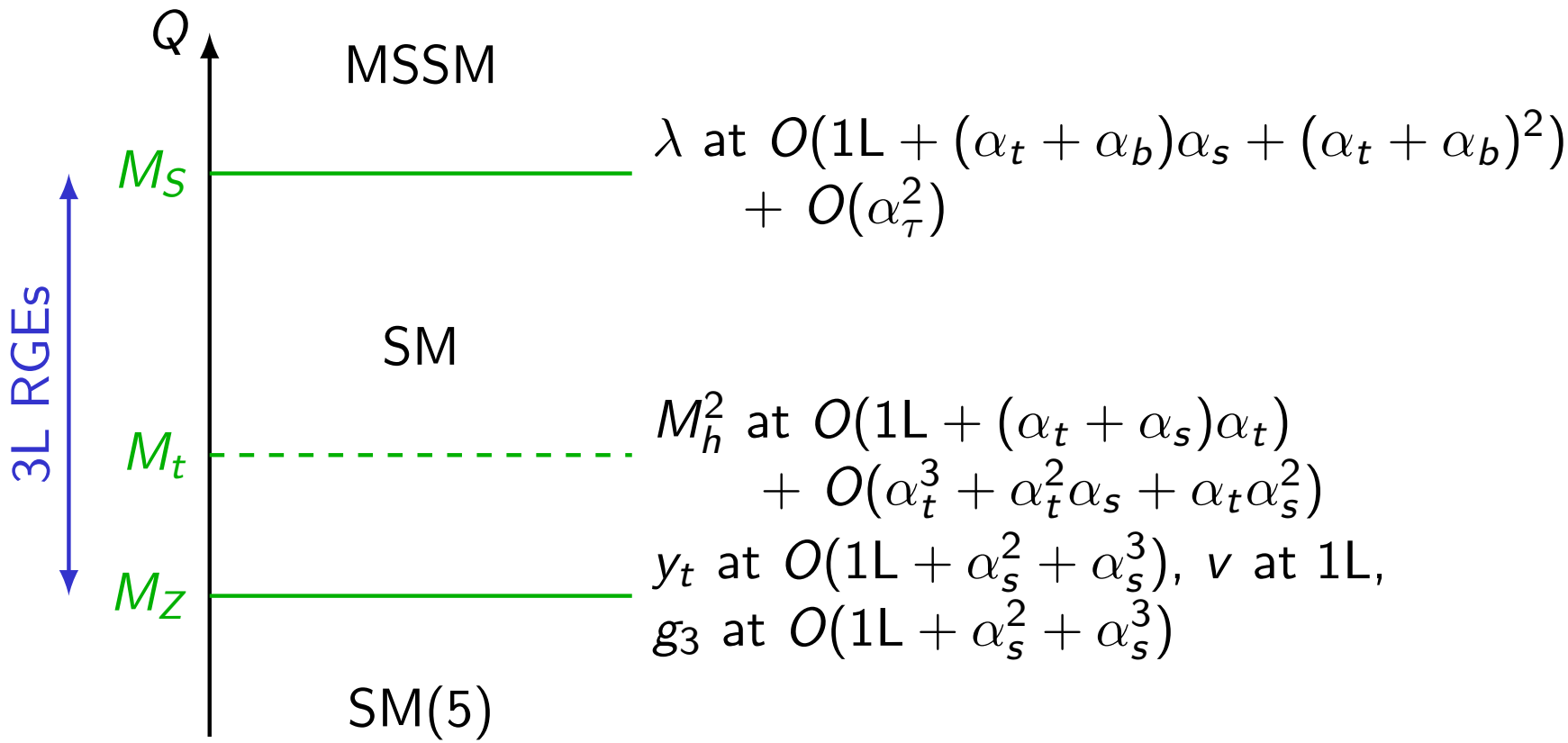


M_h^2: [0105096, 0112177, 0212132, 0206101, 0305127, 1708.05720]

$y_{t,b}$: [0210258, 0507139, 0707.0650, 0912.4652], g_3: [0509048, 0810.5101, 1009.5455]

β_i: [0308231, 0408128]

EFT calculation: MSSM – SM (HSSUSY)

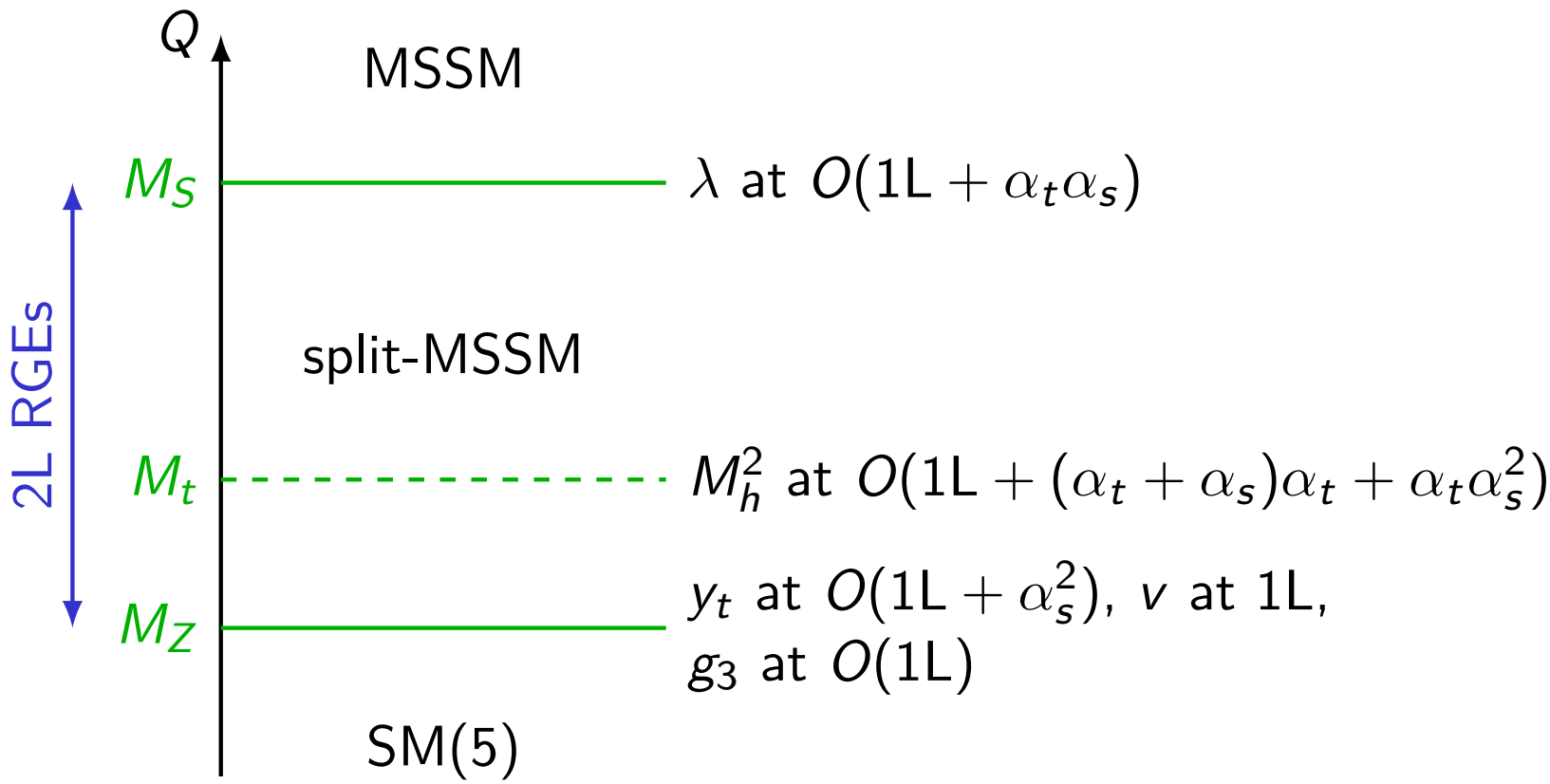


λ: [1407.4081, 1504.05200, 1703.08166] M_h^2: [1205.6497, 1504.05200, 1407.4336]

y_t: [9912391, 1205.2892], g_3: [9305305, 9707474, 9708255, 0004189]

β_i: [1201.5868, 1210.6873, 1212.6829, 1205.2892, 1303.4364]

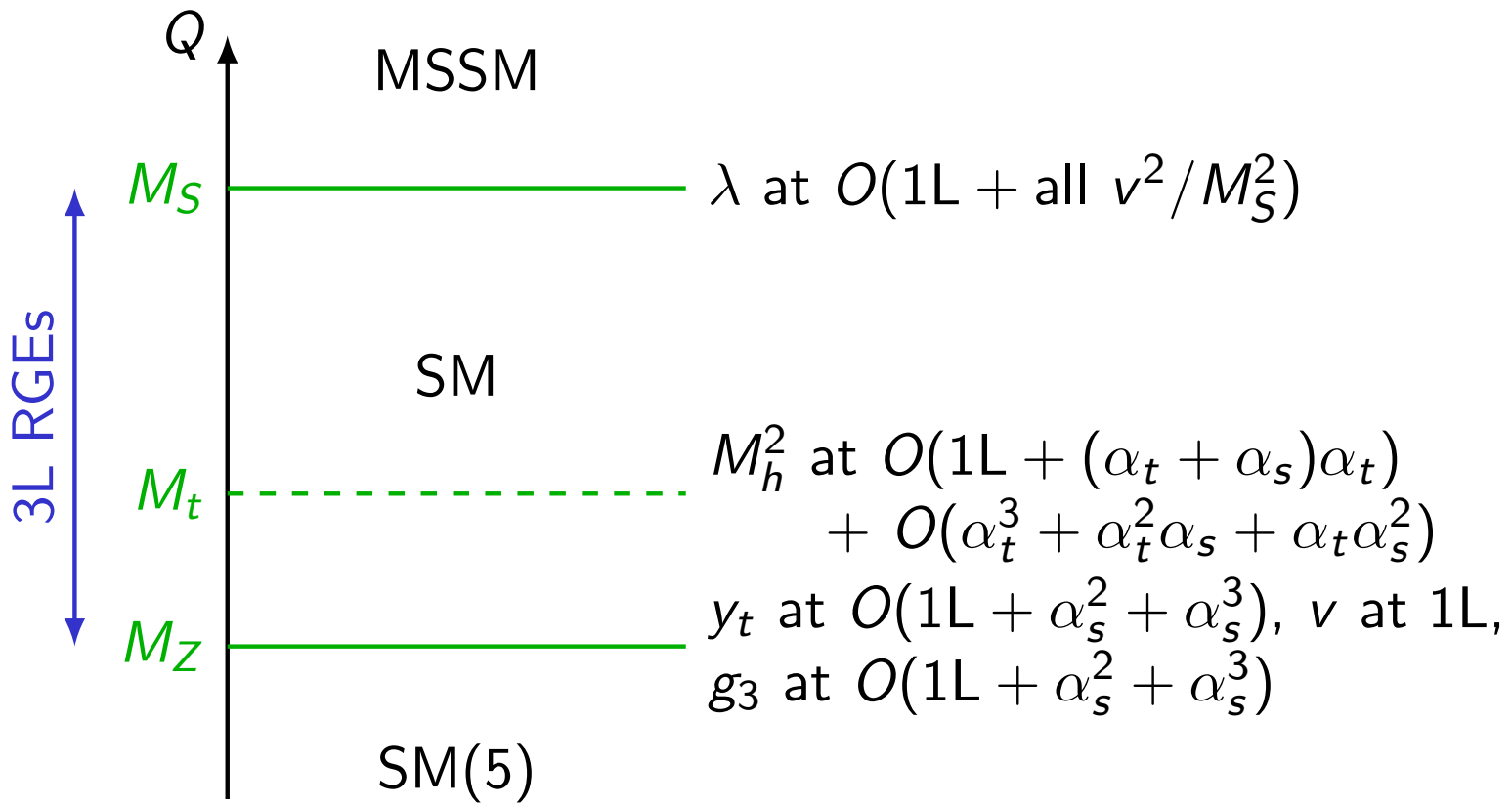
EFT calculation: MSSM – split-MSSM (`SplitMSSM`)



λ: [1407.4081] M_h^2: [1205.6497, 1312.5220]

y_t: [1312.5220]

Hybrid calculation: FlexibleEFTHiggs (`MSSMEFTHiggs`)

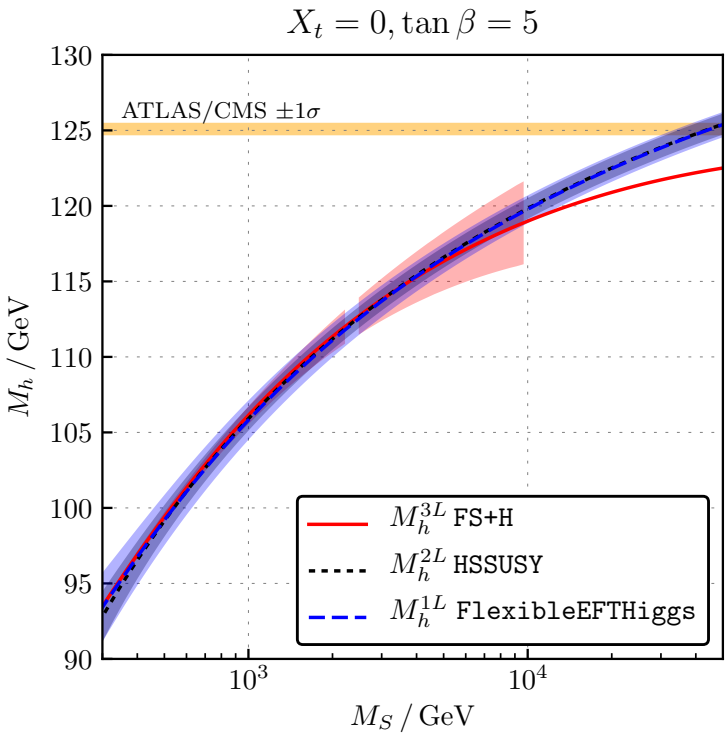


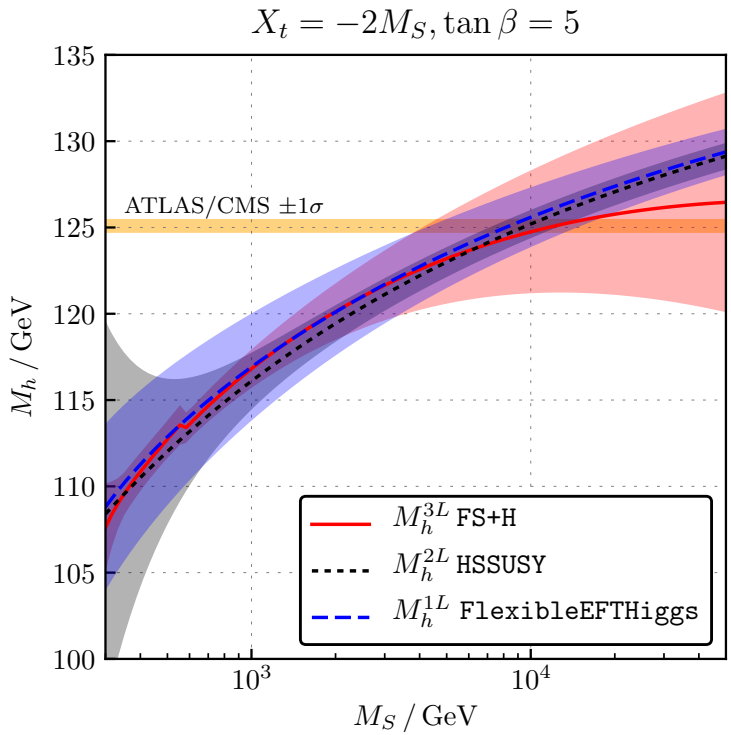
M_h^2: [1205.6497, 1504.05200, 1407.4336]

y_t: [9912391, 1205.2892], g_3: [9305305, 9707474, 9708255, 0004189]

β_i: [1201.5868, 1210.6873, 1212.6829, 1205.2892, 1303.4364]

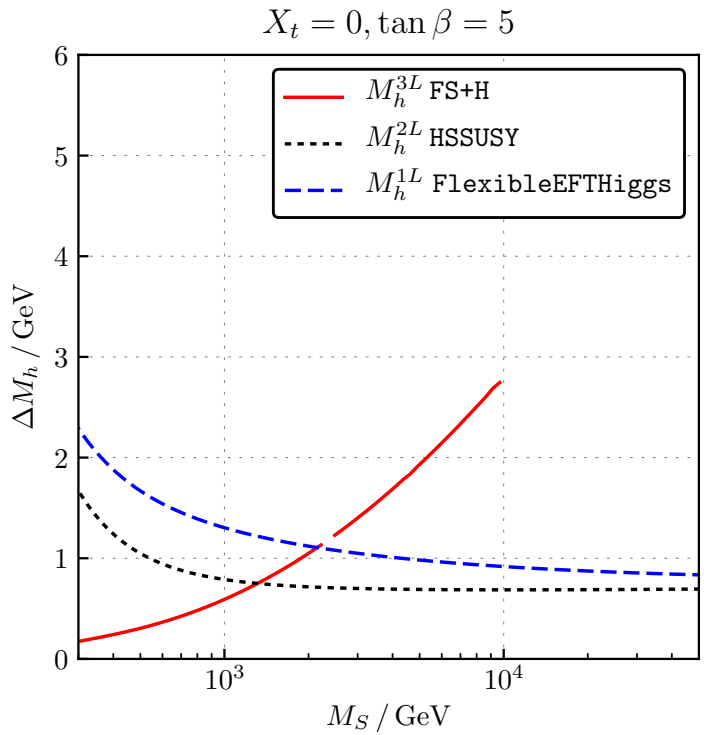
Results

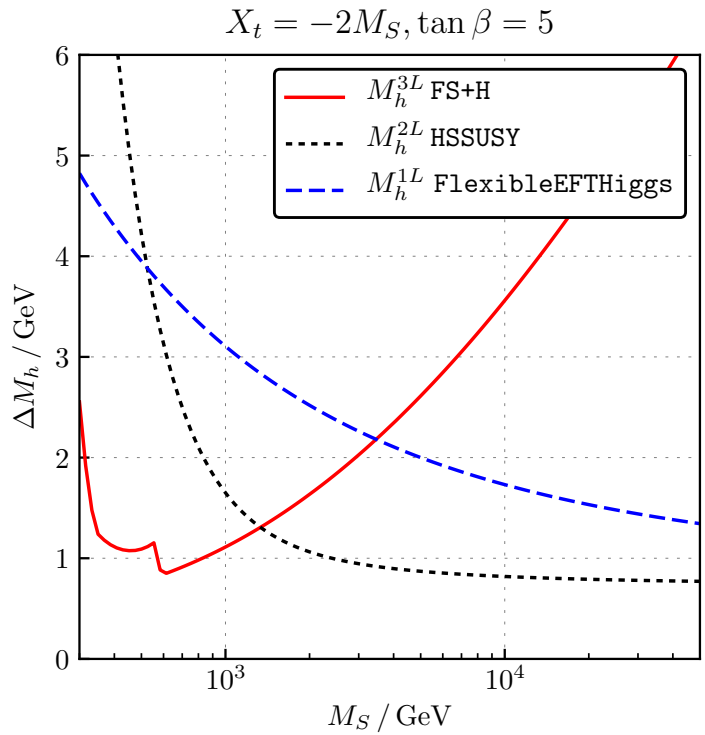

$X_t = 0, \tan\beta = 5$
ATLAS/CMS $\pm 1\sigma$
M_h^{3L} FS+H
M_h^{2L} HSSUSY
M_h^{1L} FlexibleEFTHiggs
M_h / GeV
M_S / GeV


$X_t = -2M_S, \tan\beta = 5$
ATLAS/CMS $\pm 1\sigma$
M_h^{3L} FS+H
M_h^{2L} HSSUSY
M_h^{1L} FlexibleEFTHiggs
M_h / GeV
M_S / GeV

Backup

Uncertainty estimate





Uncertainty estimate

Fixed-order calculation (`FS+H`):

- vary $Q_{\text{pole}} \in [M_S/2, 2M_S]$
- $\alpha_s^{1L}(M_Z)$ vs. $\alpha_s^{2L}(M_Z)$

EFT calculation (`HSSUSY`):

- vary $Q_{\text{pole}} \in [M_t/2, 2M_t]$ [SM uncertainty]
- $y_t^{2L}(M_Z)$ vs. $y_t^{3L}(M_Z)$ [SM uncertainty]
- $\lambda(M_S)$ vs. $\lambda(M_S) + v^2/M_S^2$ [EFT uncertainty]
- vary $Q_{\text{match}} \in [M_S/2, 2M_S]$ [SUSY uncertainty]
- $y_t^{\text{SM}}(M_S)$ vs. $y_t^{\text{MSSM}}(M_S)$ [SUSY uncertainty]

Hybrid calculation (`FlexibleEFTHiggs`):

- vary $Q_{\text{pole}} \in [M_t/2, 2M_t]$ [SM uncertainty]
- $y_t^{2L}(M_Z)$ vs. $y_t^{3L}(M_Z)$ [SM uncertainty]
- vary $Q_{\text{match}} \in [M_S/2, 2M_S]$ [SUSY uncertainty]

Determination of $g_3(M_Z)$

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

$\rightarrow$

$$\alpha_s(M_Z) = \frac{\alpha_s^{\mathrm{SM}(5)}(M_Z)}{1 - \Delta\alpha_s^{1L}(M_Z) - \Delta\alpha_s^{2L}(M_Z) - \Delta\alpha_s^{3L}(M_Z)}$$

SM: $O(\alpha_s + \alpha_s^2 + \alpha_s^3)$ [9305305, 9707474, 9708255, 0004189]
split-MSSM: $O(\alpha_s)$ [9305305, 9707474, 9708255, 0004189]
MSSM: $O(\alpha_s + \alpha_s^2 + (\alpha_t + \alpha_b)\alpha_s)$ [0509048, 0810.5101, 1009.5455]

Determination of $m_t(M_Z)$

Input: $M_t = 173.34\,\text{GeV}$

$\rightarrow$

$$m_t(M_Z) = M_t + \text{Re}\,\Sigma_t^S(M_Z) + M_t\Big[\text{Re}\,\Sigma_t^L(M_Z) + \text{Re}\,\Sigma_t^R(M_Z) + \Delta m_t^{1L} + \Delta m_t^{2L} + \Delta m_t^{3L}\Big]$$

SM: $O(1\text{L} + \alpha_s^2 + \alpha_s^3)$ [9912391, 1205.2892]
split-MSSM: $O(1\text{L} + \alpha_s^2)$ [1312.5220]
MSSM: $O(1\text{L} + \alpha_s^2)$ [0210258, 0507139]

Determination of $m_b^{\rm MSSM}(M_Z)$

Input: $m_b^{\rm SM(5),\overline{MS}}(m_b) = 4.18\,\text{GeV}$

$\rightarrow$ running to $m_b^{\rm SM(5),\overline{MS}}(M_Z)$ at $O(\alpha_{\rm em} + \alpha_s^3)$

$\rightarrow$ convert to $m_b^{\rm SM(5),\overline{DR}}(M_Z)$ at $O(\alpha_{\rm em} + \alpha_s)$

$\rightarrow$

$$m_b(M_Z) = \frac{m_b^{\rm SM(5),\overline{DR}}(M_Z)}{1 - \Delta m_b^{1L} - \Delta m_b^{2L}}\,,$$

$$\Delta m_b^{1L} = \Sigma_b^S(p^2 = (m_b^{\rm SM(5)})^2, M_Z)/m_b + \Sigma_b^L(p^2 = (m_b^{\rm SM(5)})^2, M_Z) + \Sigma_b^R(p^2 = (m_b^{\rm SM(5)})^2, M_Z)$$

$$\Delta m_b^{2L} = \Delta m_b^{2L,\rm dec} - \frac{\alpha_s}{3\pi}\Delta m_b^{1L}$$

with $\Delta m_b^{2L,\rm dec}$ at $O(\alpha_s^2)$ from [0707.0650, 0810.5101]

Determination of $v(M_Z)$

Input: $M_Z = 91.1876\,\text{GeV}$

$\rightarrow$

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

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

Determination of g_1 and g_2 as in BPMZ [9606211]

Input: $\alpha_{\rm em}^{\rm SM(5)}(M_Z) = 1/127.916,\ G_F = 1.1663787 \cdot 10^{-5}{\rm GeV}^2$

$\rightarrow$

$$\alpha_{\rm em}(M_Z) = \frac{\alpha_{\rm em}^{\rm SM(5)}(M_Z)}{1 - \Delta\alpha_{\rm em}^{1L}(M_Z)}$$

$$g_1(M_Z) = \sqrt{\frac{5}{3}}\frac{\sqrt{4\pi\alpha_{\rm em}(M_Z)}}{\cos\theta_w(M_Z)}, \qquad g_2(M_Z) = \frac{\sqrt{4\pi\alpha_{\rm em}(M_Z)}}{\sin\theta_w(M_Z)}$$

$$\sin^2\theta_w \cos^2\theta_w = \frac{\pi\,\alpha_{\rm em}}{\sqrt{2}M_Z^2 G_F(1-\delta_r)}$$

$$\delta_r = \hat{\rho}\frac{{\rm Re}\,\Sigma_{W,T}(0)}{M_W^2} - \frac{{\rm Re}\,\Sigma_{Z,T}(M_Z^2)}{M_Z^2} + \delta_{\rm VB} + \delta_r^{(2)}$$

$$\hat{\rho} = \frac{1}{1-\Delta\hat{\rho}}, \qquad \Delta\hat{\rho} = {\rm Re}\left[\frac{\Sigma_{Z,T}(M_Z^2)}{\hat{\rho}\,M_Z^2} - \frac{\Sigma_{W,T}(M_W^2)}{M_W^2}\right] + \Delta\hat{\rho}^{(2)}$$

Determination of M_h^2 in the SM and split-MSSM

SM: Iterate until $p^2 = M_h^2$:

$$M_h^2 = m_h^2 + (\Delta m_h^2)_{1L}(p^2) + (\Delta m_h^2)_{2L}(p^2) + (\Delta m_h^2)_{3L}$$

$O(1\text{L} + (\alpha_t + \alpha_s)\alpha_t + (\alpha_t^2 + \alpha_t\alpha_s + \alpha_s^2)\alpha_t)$

[1205.6497, 1504.05200, 1407.4336]

Note: $O(\alpha_t^3)$ incomplete due to missing p^2-dependence of $O(\alpha_t^2)$

split-MSSM: Iterate until $p^2 = M_h^2$:

$$M_h^2 = m_h^2 + (\Delta m_h^2)_{1L}(p^2) + (\Delta m_h^2)_{2L} + (\Delta m_h^2)_{3L}$$

split-MSSM: $O(1\text{L} + (\alpha_t + \alpha_s)\alpha_t + \alpha_t\alpha_s^2)$ [1205.6497, 1312.5220]

Determination of M_h^2 in the MSSM

Iterate until $p^2 = M_h^2$:

$$M_h^2 = \text{Eigenvalue}\left[m_h^2 + (\Delta m_h^2)_{1L}(p^2) + (\Delta m_h^2)_{2L} + (\Delta m_h^2)_{3L}\right]$$

MSSM: $O(1\text{L} + (\alpha_t + \alpha_b)\alpha_s + (\alpha_t + \alpha_b)^2 + \alpha_\tau^2 + (\alpha_t + \alpha_b)\alpha_s^2)$

[0105096, 0112177, 0212132, 0206101, 0305127, 1708.05720]

Determination of λ in the FlexibleEFTHiggs

[1609.00371, 1703.03267, 1710.03760]

Matching condition:

$$(M_h^2)_{\text{SM}} \stackrel{!}{=} (M_h^2)_{\text{MSSM}} \qquad \text{at 1L at } Q = M_S$$

With $(M_h^2)_{\text{SM}} = \lambda v^2 + (\Delta m_h^2)_{\text{SM}}$
$\Rightarrow$

$$\lambda(M_S) = \frac{1}{v^2}\left[(M_h^2)_{\text{MSSM}} - (\Delta m_h^2)_{\text{SM}}\right]$$