Update on the Standard Model Uncertainty

Harun Acaroglu, Alexander Voigt

KUTS-10 Dresden

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RWTHAACHEN UNIVERSITY

Contents

1. Motivation
2. Update on the Standard Model Uncertainty
   - EFT calculation in `FlexibleSUSY` (`HSSUSY`)
   - Adding $O(\alpha_t \alpha_s, \alpha_t^2)$ and $O(\alpha_s^4)$ corrections to m_t
   - Update of the SM uncertainty
3. When should the EFT be used?

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Motivation — SM uncertainty in SusyHD

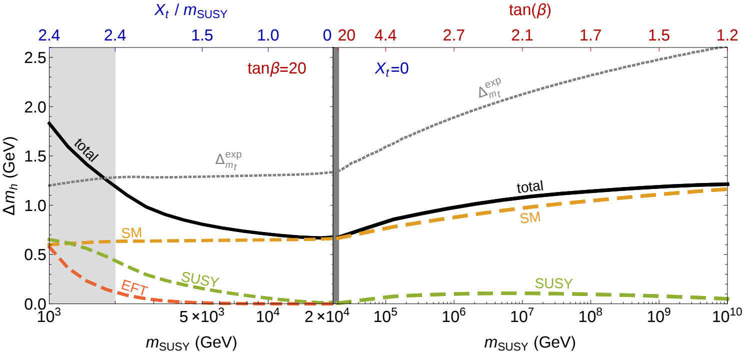

Image taken from [1504.05200]

Motivation — SM uncertainty in HSSUSY

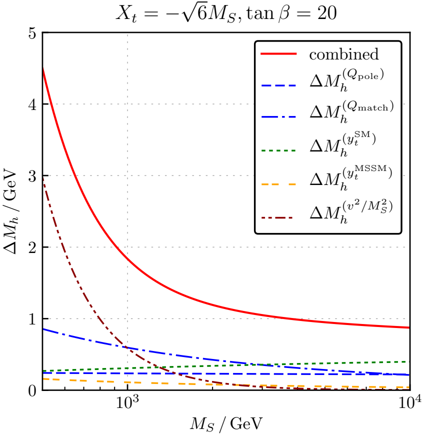

Image taken from [1804.09410]

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EFT calculation in FlexibleSUSY (HSSUSY)

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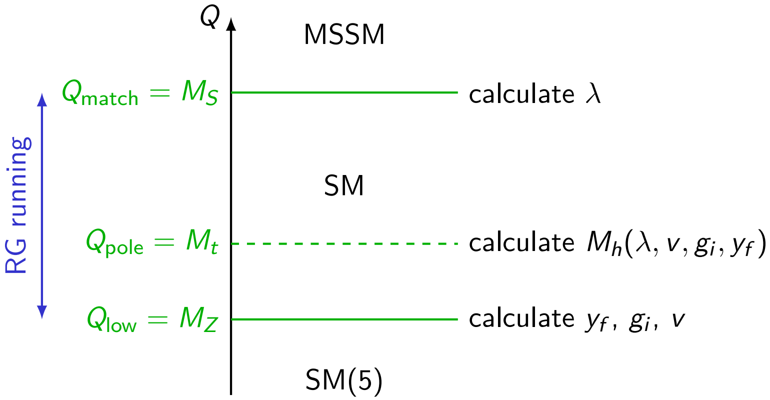


EFT calculation in FlexibleSUSY (HSSUSY)

	1ℓ	2ℓ	3ℓ	4ℓ	5ℓ
λ	full	$(\alpha_t+\alpha_b)\alpha_s$, $(\alpha_t+\alpha_b)^2$, $\alpha_b\alpha_\tau$, α_τ^2	$\alpha_t\alpha_s^2$	–	–
v	full	–	–	–	–
y_t	full	α_s^2, $\alpha_t\alpha_s$, α_t^2	α_s^3	α_s^4	–
$y_{b,\tau}$	full	–	–	–	–
g_3	full	α_s^2	α_s^3	–	–
$g_{1,2}$	full	–	–	–	–
β_λ	full	full	full	$\alpha_t^2\alpha_s^3$	–
β_{y_t}	full	full	full	$y_t\alpha_s^4$	–
β_{g_3}	full	full	full	$\alpha_s^{0<n\leq 4}$	α_s^5
$\beta_{\dots}$	full	full	full	–	–
M_h	full	$(\alpha_t+\alpha_b)\alpha_s$, $(\alpha_t+\alpha_b)^2$	$\alpha_t\alpha_s^2$, $\alpha_t^2\alpha_s$, α_t^3	$\alpha_t\alpha_s^3$	–

Uncertainty estimate of the EFT calculation

[1804.09410] considered 5 sources of uncertainty:

$$\Delta M_h^{(Q_{\text{pole}})} = \max_{Q_{\text{pole}} \in [M_t/2, 2M_t]} \left| M_h(Q_{\text{pole}}) - M_h(M_t) \right|$$ [1609.00371]

$$\Delta M_h^{(Q_{\text{match}})} = \max_{Q_{\text{match}} \in [M_S/2, 2M_S]} \left| M_h(Q_{\text{match}}) - M_h(M_S) \right|$$ [1407.4081]

$$\Delta M_h^{(y_t^{\text{SM}})} = \left| M_h(y_t^{\text{SM},2\ell}(M_Z)) - M_h(y_t^{\text{SM},3\ell}(M_Z)) \right|$$ [1504.05200]

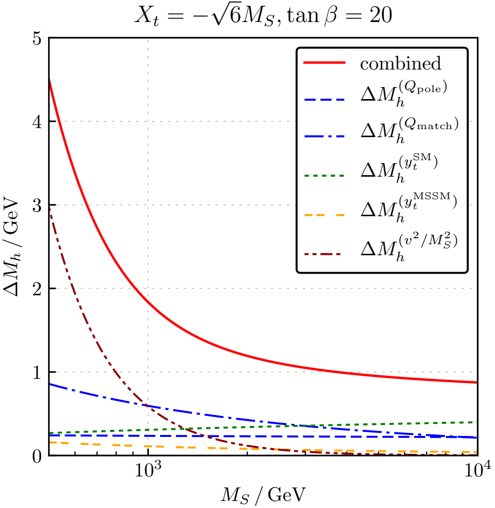
$$\Delta M_h^{(v^2/M_S^2)} = \left| M_h - M_h(v^2/M_S^2) \right|$$ [1504.05200]

$$\Delta M_h^{(y_t^{\text{MSSM}})} = \left| M_h - M_h(y_t^{\text{MSSM}}(M_S)) \right|$$ [Bagnaschi,AV,Weiglein]

Combination:

$$\Delta M_h^{(\texttt{HSSUSY})} = \Delta M_h^{(Q_{\text{pole}})} + \Delta M_h^{(Q_{\text{match}})} + \Delta M_h^{(y_t^{\text{SM}})} + \Delta M_h^{(y_t^{\text{MSSM}})} + \Delta M_h^{(v^2/M_S^2)}$$

Uncertainty estimate of the EFT calculation



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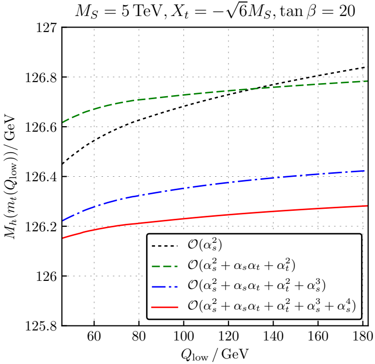
Adding $O(\alpha_t\alpha_s, \alpha_t^2)$ and $O(\alpha_s^4)$ corrections to m_t

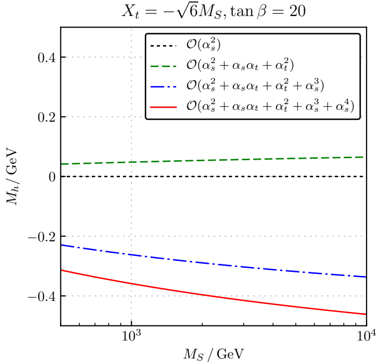
Adding 2-loop corrections of $O(\alpha_t\alpha_s, \alpha_t^2)$ [1604.01134] and $O(\alpha_s^4)$ [1508.00912]:

$$
\begin{aligned}
m_t = M_t &+ \Sigma^{(1\ell)}_{S,\text{non-QCD}} + \Sigma^{(2\ell)}_{S,\alpha_t\alpha_s} + \Sigma^{(2\ell)}_{S,\alpha_t^2} \\
&+ M_t \Big[\Sigma^{(1\ell)}_{L,\text{non-QCD}} + \Sigma^{(1\ell)}_{R,\text{non-QCD}} + \Delta m^{(1\ell)}_{\alpha_s} \\
&\quad + \Delta m^{(2\ell)}_{\alpha_s^2} + \Delta m^{(2\ell)}_{\alpha_t\alpha_s} + \Delta m^{(2\ell)}_{\alpha_t^2} \\
&\quad + \Delta m^{(3\ell)}_{\alpha_s^3} + \Delta m^{(4\ell)}_{\alpha_s^4} \Big]
\end{aligned}
$$

at $p^2 = M_t^2$ and $Q = M_Z$.

Effect of loop corrections to m_t on M_h





Intermediate conclusions for M_h

In the shown parameter region ($X_t = -\sqrt{6}M_S$, $\tan\beta = 20$)

- 2-loop $O(\alpha_t\alpha_s + \alpha_t^2)$ corrections to m_t: $\Delta M_h \lesssim 80\,\text{MeV}$
- 3-loop $O(\alpha_s^3)$ corrections to m_t: $\Delta M_h^{(y_t^{\text{SM}})} \lesssim 400\,\text{MeV}$
- 4-loop $O(\alpha_s^4)$ corrections to m_t: $\Delta M_h \lesssim 125\,\text{MeV}$
- 4-loop $\Delta M_h^{(Q_{\text{low}})} \sim 125\,\text{MeV}$

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- 4-loop $O(\alpha_s^4)$ corrections to m_t: $\Delta M_h \lesssim 125\,\text{MeV}$
- 4-loop $\Delta M_h^{(Q_{\text{low}})} \sim 125\,\text{MeV}$

Potential for improvement: The uncertainty estimate [1504.05200, 1804.09410]

$$\Delta M_h^{(y_t^{\text{SM}})} = \left| M_h(y_t^{\text{SM},2\ell}(M_Z)) - M_h(y_t^{\text{SM},3\ell}(M_Z)) \right|$$

is appropriate if 4-loop corrections to M_h are unknown.
But they are known by [1508.00912].

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Update of SM uncertainty

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λ	full	$(\alpha_t+\alpha_b)\alpha_s$, $(\alpha_t+\alpha_b)^2$, $\alpha_b\alpha_\tau$, α_τ^2	$\alpha_t\alpha_s^2$	–	–
v	full	–	–	–	–
y_t	full	α_s^2, $\alpha_t\alpha_s$, α_t^2	α_s^3	α_s^4	–
$y_{b,\tau}$	full	–	–	–	–
g_3	full	α_s^2	α_s^3	–	–
$g_{1,2}$	full	–	–	–	–
β_λ	full	full	full	$\alpha_t^2\alpha_s^3$	–
β_{y_t}	full	full	full	$y_t\alpha_s^4$	–
β_{g_3}	full	full	full	$\alpha_s^{0<n\leq 4}$	α_s^5
$\beta_{\dots}$	full	full	full	–	–
M_h	full	$(\alpha_t+\alpha_b)\alpha_s$, $(\alpha_t+\alpha_b)^2$	$\alpha_t\alpha_s^2$, $\alpha_t^2\alpha_s$, α_t^3	$\alpha_t\alpha_s^3$	–

Update of SM uncertainty

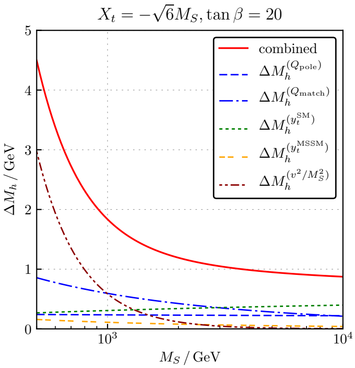
Updated SM uncertainty:

$$\Delta M_h^{(Q_{\text{pole}})} = \max_{Q_{\text{pole}} \in [M_t/2, 2M_t]} |M_h(Q_{\text{pole}}) - M_h(M_t)|$$

$$\Delta M_h^{(y_t^{\text{SM}})} = \left| M_h(y_t^{\text{SM},3\ell}(M_Z)) - M_h(y_t^{\text{SM},4\ell}(M_Z)) \right|$$

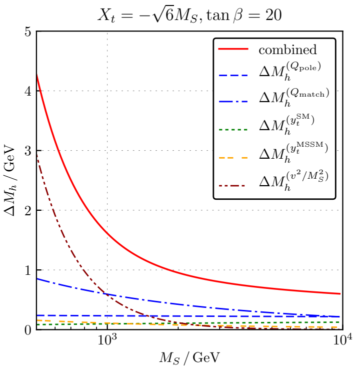
Update of SM uncertainty

[1804.09410]



$M_S(M_h^{\text{exp}}) \approx 3.45\,\text{TeV}$
$\Delta M_h \approx 1.0\,\text{GeV}$

This talk



$M_S(M_h^{\text{exp}}) \approx 3.50\,\text{TeV}$
$\Delta M_h \approx 0.75\,\text{GeV}$

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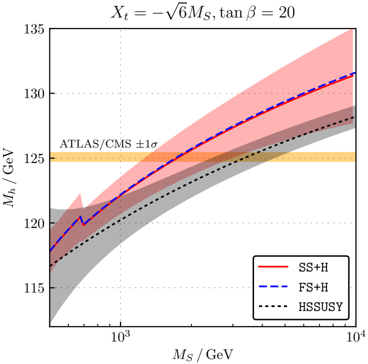
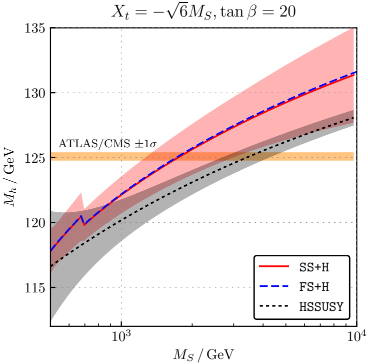
[1804.09410]



$$\Delta M_h^{(\texttt{SS+H})} \overset{!}{=} \Delta M_h^{(\texttt{HSSUSY})}$$

$$\Rightarrow M_S^{\text{equal}} = 1.0\text{–}1.3\,\text{TeV}$$

This talk



$$\Delta M_h^{(\texttt{SS+H})} \overset{!}{=} \Delta M_h^{(\texttt{HSSUSY})}$$

$$\Rightarrow M_S^{\text{equal}} = 1.0\text{–}1.2\,\text{TeV}$$

Backup

References for loop corrections used in HSSUSY

λ: [1407.4081, 1504.05200, 1703.08166, 1807.03509]

M_h: [1205.6497, 1504.05200, 1407.4336, 1508.00912]

y_t: [9911434, 9912391, 1604.01134]

g_3: [9305305, 9707474, 9708255, 0004189]

β_i:

[1201.5868, 1210.6873, 1212.6829, 1205.2892, 1303.4364, 1508.00912, 1508.02680, 1604.00853, 1606.08659]

Uncertainty estimate of the fixed-order calculation

[1804.09410] considered 5 sources of uncertainty:

$$\Delta M_h^{(Q_{\text{pole}})} = \max_{Q_{\text{pole}}\in[M_S/2,2M_S]} \left|M_h(Q_{\text{pole}}) - M_h(M_S)\right| \qquad \text{[1609.00371]}$$

$$\Delta M_h^{(Q_{\text{match}})} = \max_{Q_{\text{match}}\in[M_Z/2,2M_Z]} \left|M_h(Q_{\text{match}}) - M_h(M_Z)\right| \qquad \text{[1804.09410]}$$

$$\Delta M_h^{(m_t)} = \left|M_h(m_t^{(1)}) - M_h(m_t^{(2)})\right| \qquad \text{[1609.00371]}$$

$$\Delta M_h^{(\alpha_s)} = \left|M_h(\alpha_s^{(1)}) - M_h(\alpha_s^{(2)})\right| \qquad \text{[1804.09410]}$$

$$\Delta M_h^{(\alpha_{\text{em}})} = \left|M_h(\alpha_{\text{em}}^{(1)}) - M_h(\alpha_{\text{em}}^{(2)})\right| \qquad \text{[1804.09410]}$$

Combination:

$$\Delta M_h^{(\texttt{SS+H})} = \Delta M_h^{(Q_{\text{pole}})} + \Delta M_h^{(Q_{\text{match}})} + \Delta M_h^{(m_t)} + \Delta M_h^{(\alpha_s)} + \Delta M_h^{(\alpha_{\text{em}})}$$