Hybrid calculation of the lightest CP-even Higgs mass in the MSSM in `FlexibleSUSY`

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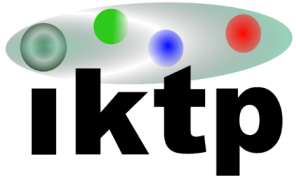
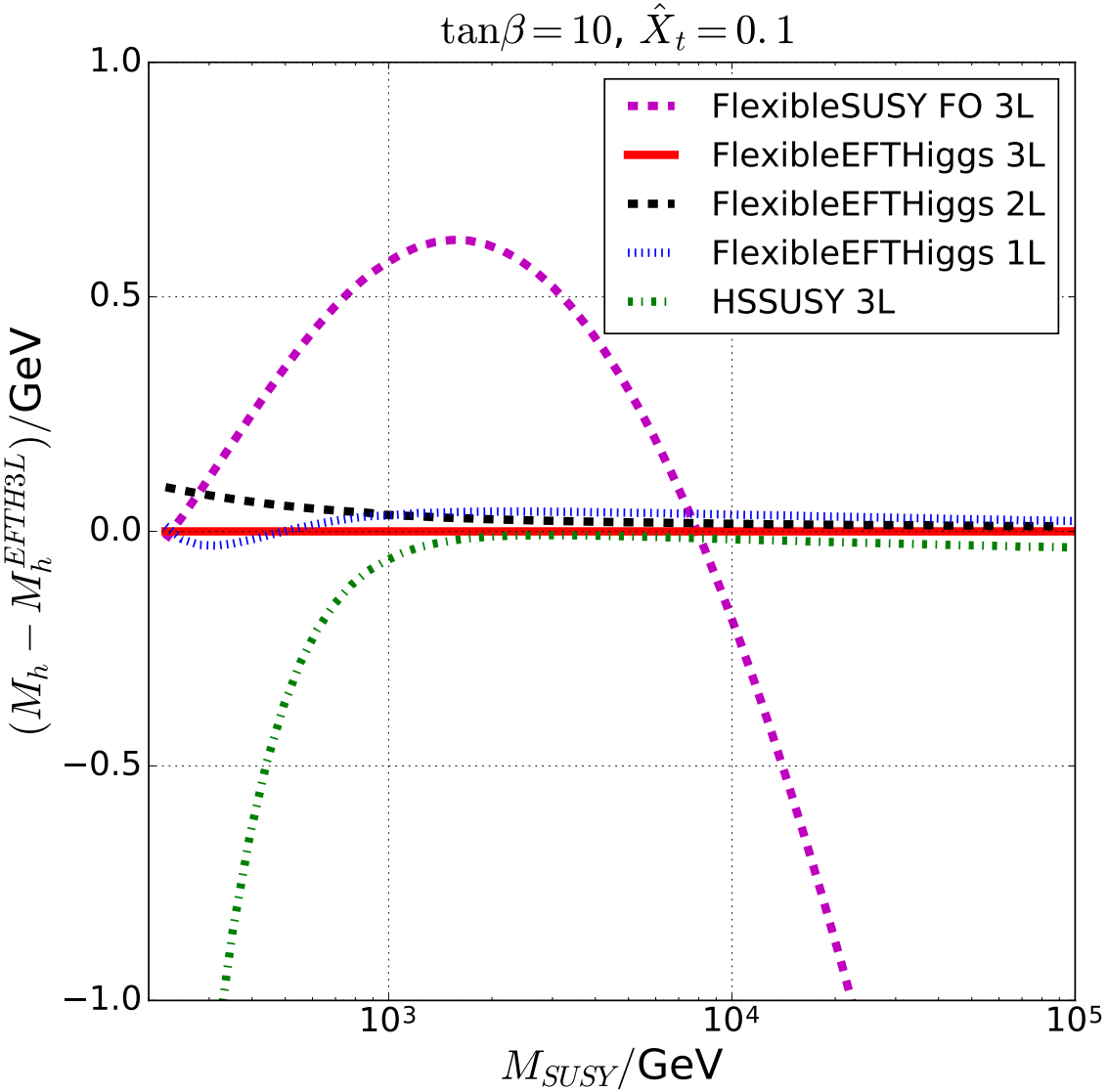
"Physics at the Terascale"



Contents


$\tan\beta = 10,\ \hat{X}_t = 0.1$
FlexibleSUSY FO 3L
FlexibleEFTHiggs 3L
FlexibleEFTHiggs 2L
FlexibleEFTHiggs 1L
HSSUSY 3L
1.0
0.5
0.0
−0.5
−1.0
10^3
10^4
10^5
M_{SUSY}/GeV
$(M_h - M_h^{EFTH3L})$/GeV

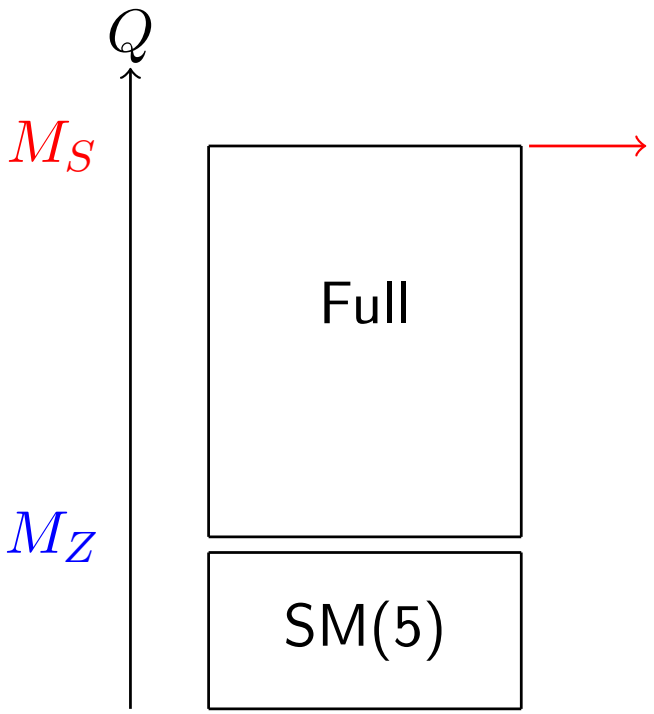
FlexibleSUSY

FlexibleSUSY = tool for generating spectrum generators

- Computation of observables for (non-)supersymmetric extensions of the Standard Model
  - mass spectrum
  - mixings of particles
  - decays (coming soon)
- Details of the models are specified in a SARAH model file, e.g. field content, gauge structure and (super)potential

Approaches to compute M_h

Fixed order calculation



$$\longrightarrow \quad M_h^2 = \mathsf{EV}[\mathcal{M}_{ij}^2 + \Pi_{ij}^{(n)}(p^2, Q = M_S)]$$

Approaches to compute M_h

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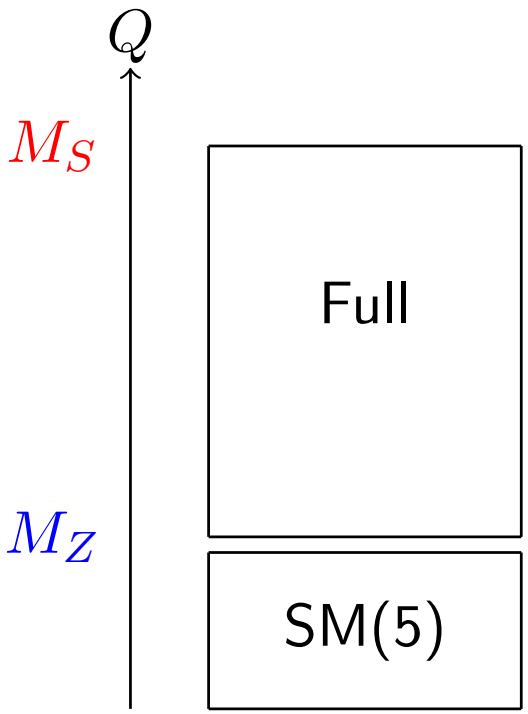


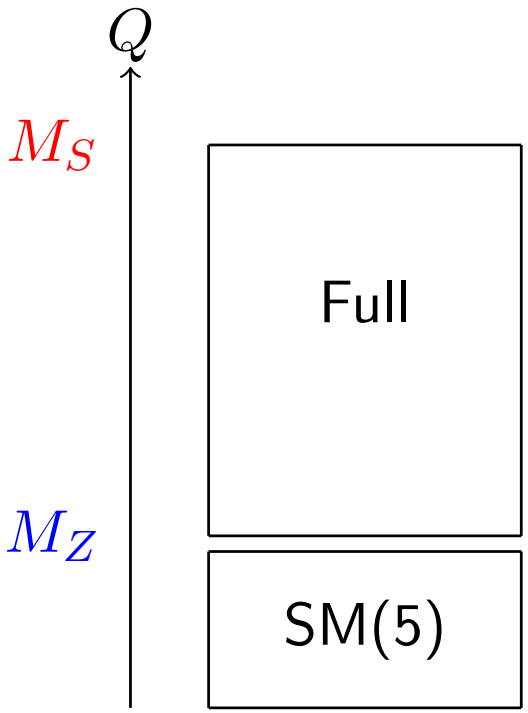
$$M_h^2 = \mathrm{EV}[\mathcal{M}_{ij}^2 + \Pi_{ij}^{(n)}(p^2, Q = M_S)]$$

$+$: includes terms $\mathcal{O}(\hbar^n v^2 / M_S^2)$

$-$: misses contributions $\mathcal{O}(\hbar^m \ln^m M_S / M_t)$ from higher orders, $m > n$

Approaches to compute M_h

Fixed order calculation



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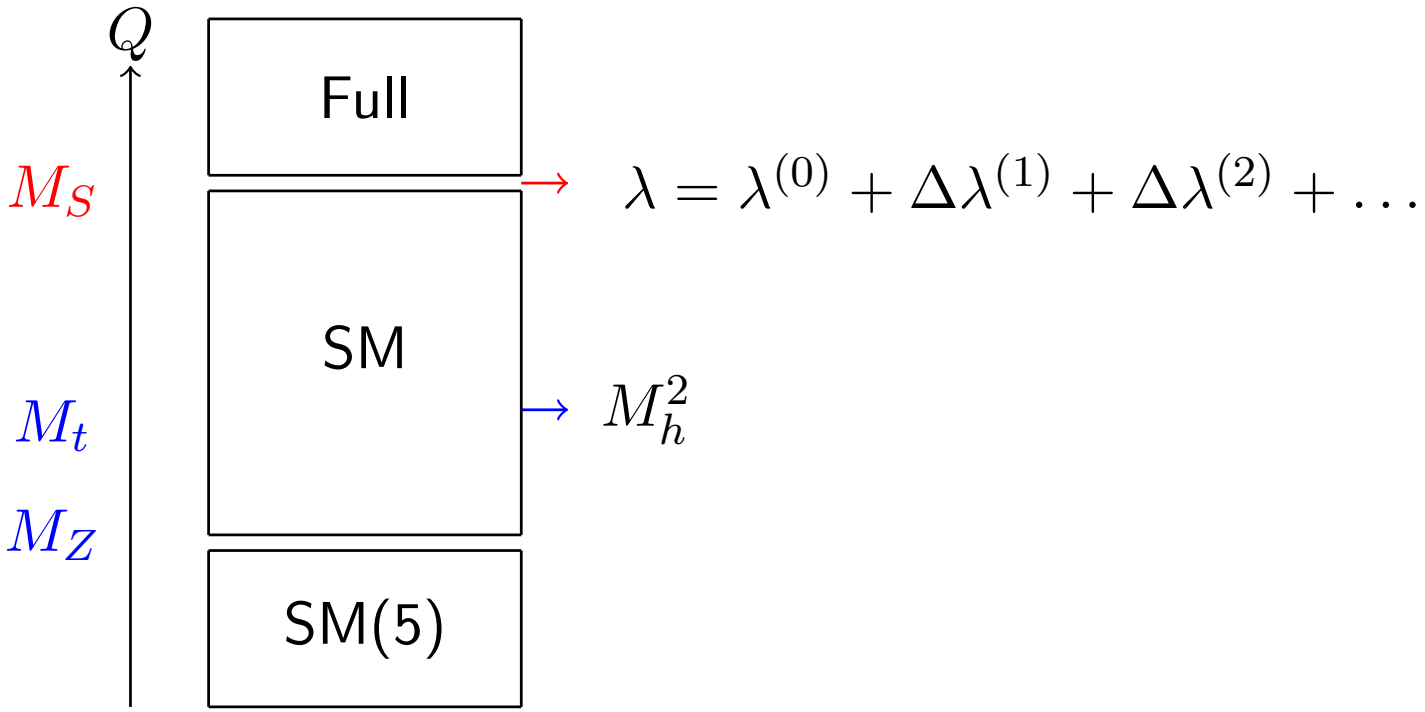
- **Difficulty:** automatize computation Π_{ij} at higher loops and model independent
- Gives reliable predictions if M_S and M_t are not too far apart

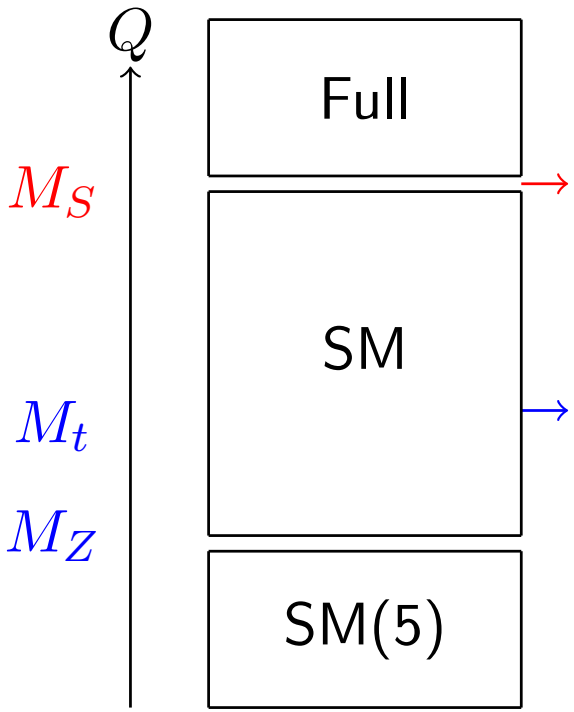
Approaches to compute M_h

Effective field theory approach



Approaches to compute M_h

Effective field theory approach



$\rightarrow \quad \lambda = \lambda^{(0)} + \Delta\lambda^{(1)} + \Delta\lambda^{(2)} + \ldots$

$\rightarrow \quad M_h^2$

$+$: resummed logarithms of M_S/M_t

$-$: misses suppressed terms of $\mathcal{O}(v^2/M_S^2)$

Approaches to compute M_h

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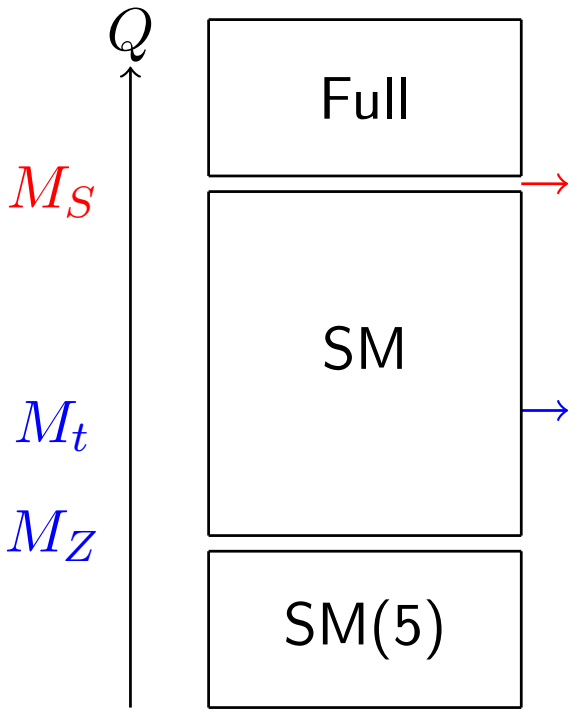

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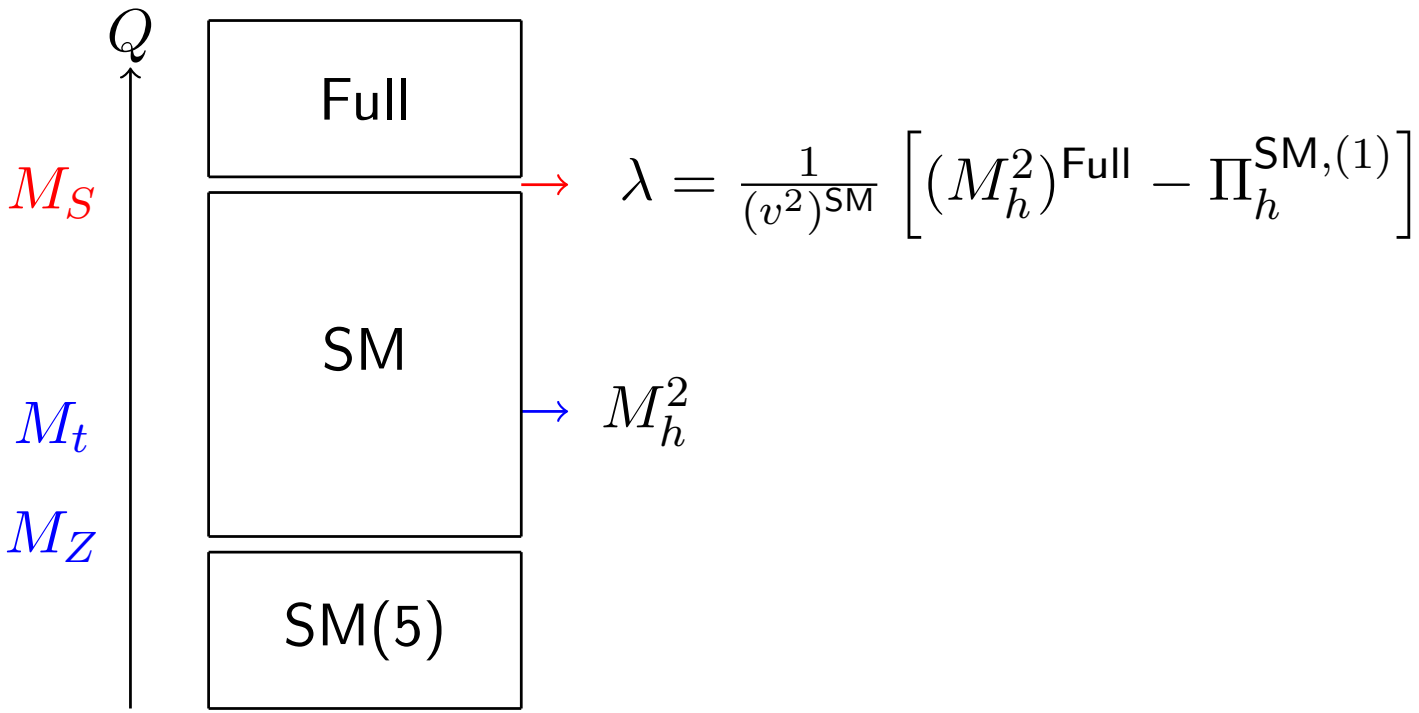
- Predicts Higgs mass reliably for large separation of M_t and M_S
- **Difficulty:** generalize computation of $\Delta\lambda^{(n)}$ in a model independent way for $n > 1$

Approaches to compute M_h

Hybrid calculation `FlexibleEFTHiggs`

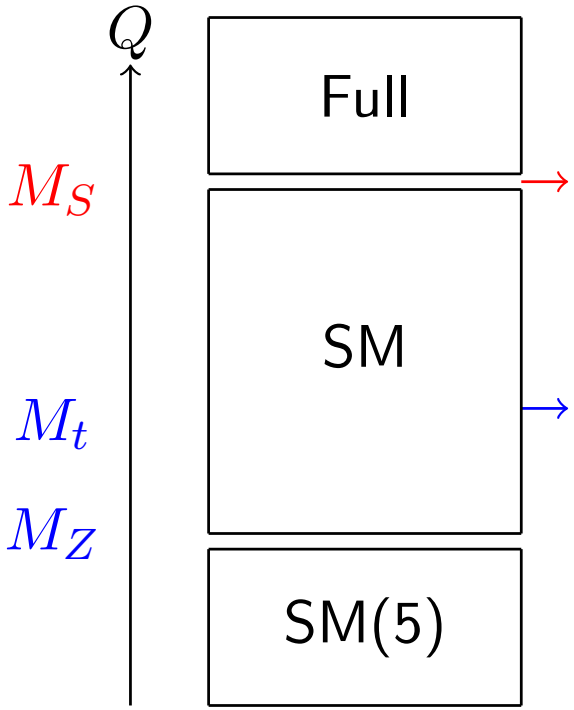


- Obtain λ from pole mass matching at one loop

$$(M_h^2)^{\mathsf{SM}} = (M_h^2)^{\mathsf{Full}}, \qquad Q = M_S$$

Approaches to compute M_h

Hybrid calculation `FlexibleEFTHiggs`



$\rightarrow \quad \lambda = \frac{1}{(v^2)^{\mathsf{SM}}} \left[(M_h^2)^{\mathsf{Full}} - \Pi_h^{\mathsf{SM},(1)} \right]$

$\rightarrow \quad M_h^2$

$+$: resummed logarithms of M_S/M_t at second order (NLL)

$+$: includes contributions of $\mathcal{O}(\hbar v^2/M_S^2)$ (NLO)

- Obtain λ from pole mass matching at one loop

$$(M_h^2)^{\mathsf{SM}} = (M_h^2)^{\mathsf{Full}}, \qquad Q = M_S$$

- Automatized derivation of $\Delta\lambda$ from self energies and tadpoles

FlexibleEFTHiggs beyond NLO and NLL

Goal: find threshold correction $\Delta\lambda^{(2,3)}$:

$$\lambda = \frac{1}{(v^2)^{\mathsf{SM}}} \left[(M_h^2)^{\mathsf{Full}} - \Pi_h^{\mathsf{SM}} \right] \Big|_{\mathsf{3L}}$$

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- **Explicit contributions**: $\Pi_h^{(2,3)}$ in SM and full model
- **Implicit contributions**: from double loop expansion of SM parameters $P \in \{y_f, v, g_i, p^2\}$ in SM self energies $(\Pi_h^{(1,2)})^{\mathsf{SM}}$

$$P^{\mathsf{SM}} = P^{(0)} + \Delta P^{(1)} + \Delta P^{(2)}$$

$$\Pi_h^{\mathsf{SM}} = \cdots + \left[\frac{\partial}{\partial P} (\Pi_h^{(1,2)})^{\mathsf{SM}} \right] (\Delta P^{(1,2)}) + \cdots$$

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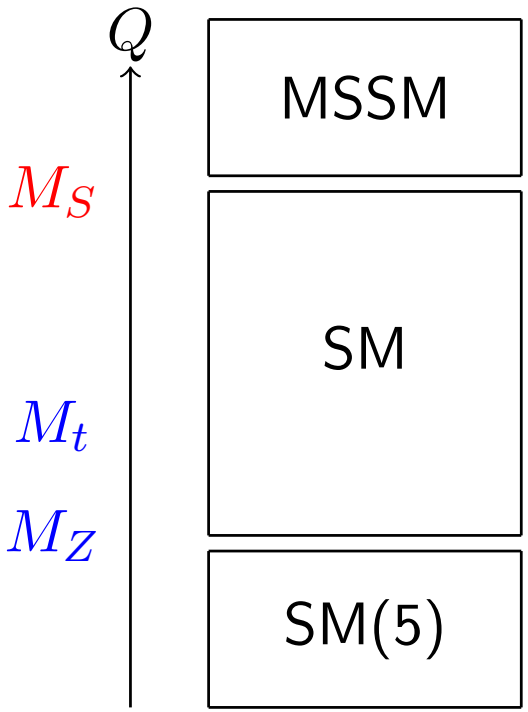
- Implementation of $\frac{\partial^i}{\partial P^i}(\Pi_h^{(j)})^{\mathsf{SM}}$ independent of full model

M_h in the MSSM at N^{3}LO and N^{3}LL



M_h^2 at 3L

$\mathcal{O}((\alpha_t+\alpha_b)\alpha_s+(\alpha_t+\alpha_b+\alpha_\tau)^2+\alpha_s^2\alpha_t)$

[0105096, 0112177, 0212132, 0206101, 0305127, 1205.6497, 1407.4336, 1708.05720]

RGE at 4L [1201.5868, 1205.2892, 1212.6829, 1303.4364, 1604.00853]

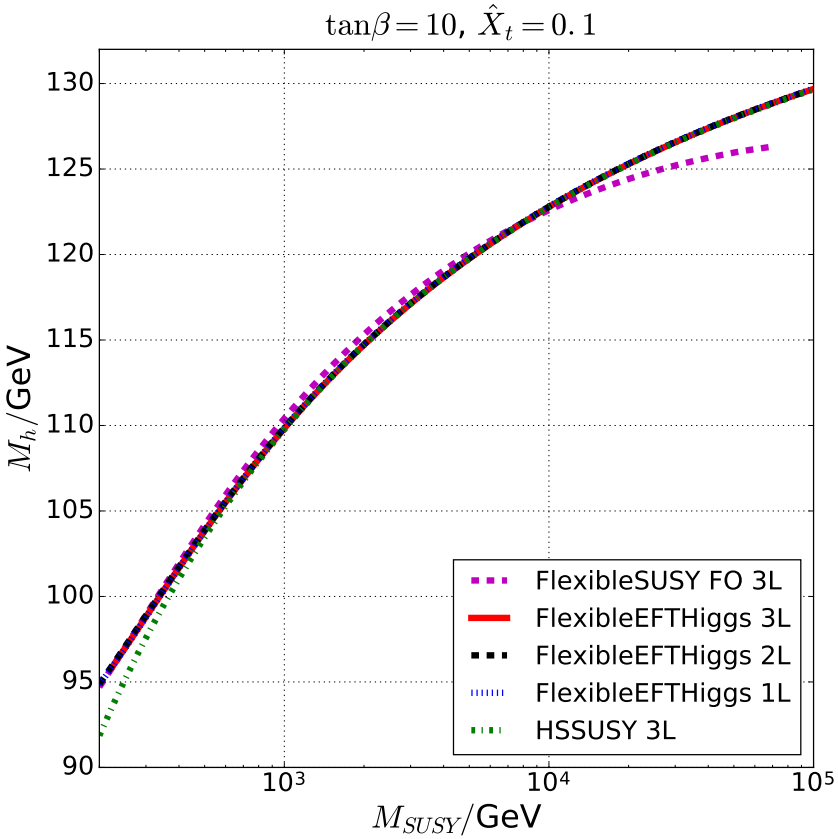
$\alpha_s^{\text{SM}(5)}$ at 2L [9305305, 9707474]

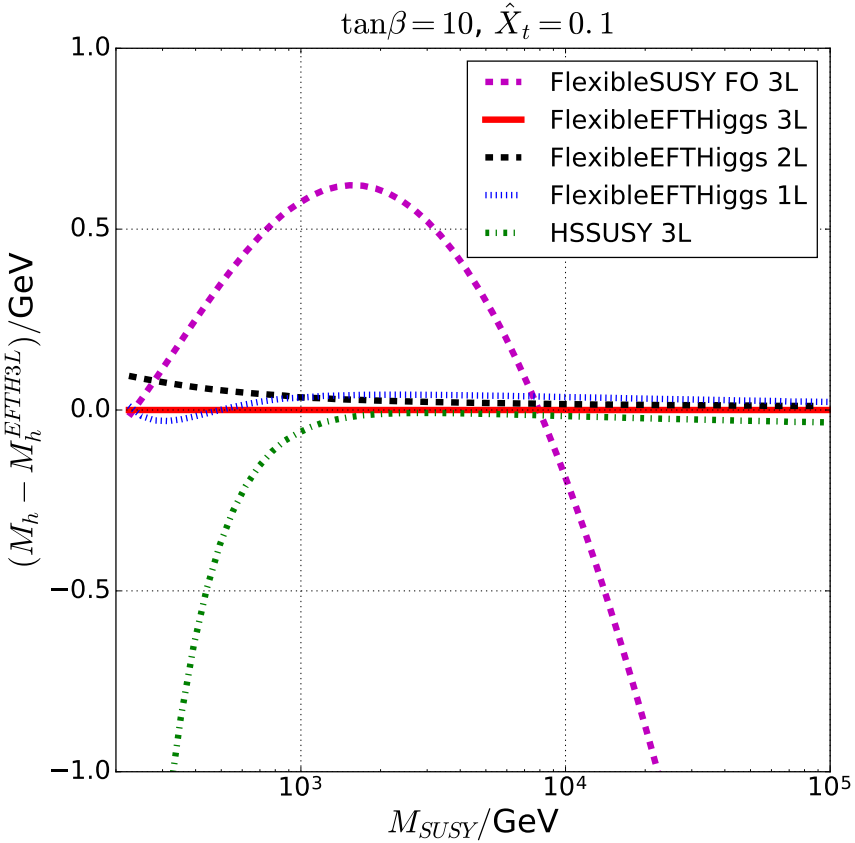
M_t at 2L $\mathcal{O}(\alpha_s^2)$ [9912391, 0507139]

Note:

- Explicit 2L and 3L corrections are obtained in the limit $g_Y = g_2 = 0$ $\rightarrow$ implicit contributions respect the same limit
- 3L self energy from `FlexibleSUSY+Himalaya` obtained without terms of $\mathcal{O}(\hbar^3 v^2/M_S^2)$

Numerical results MSSM





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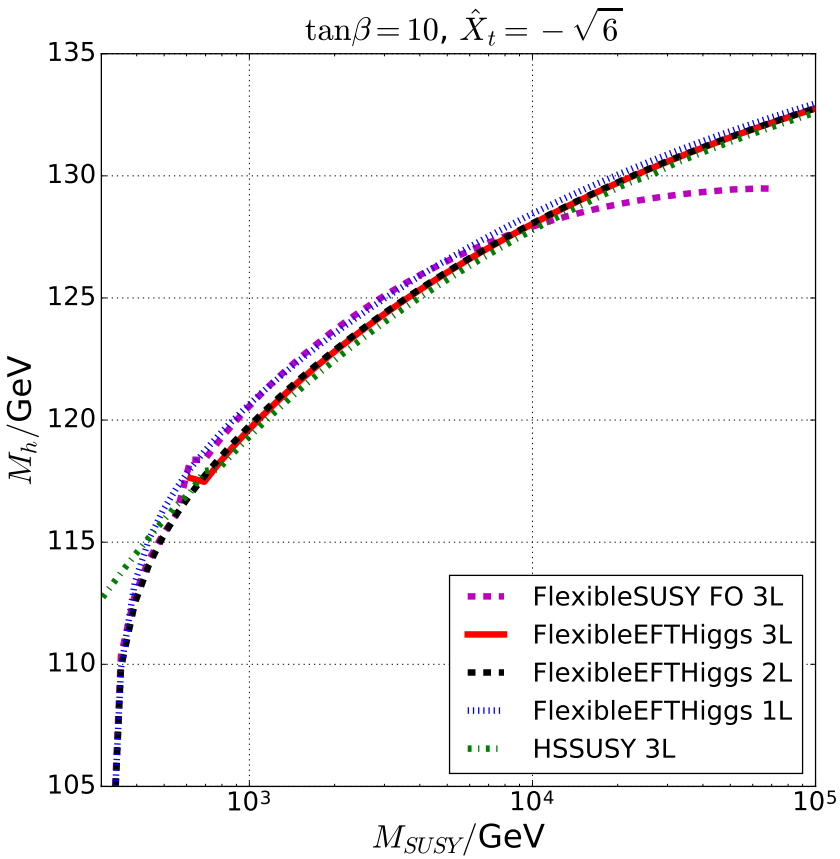
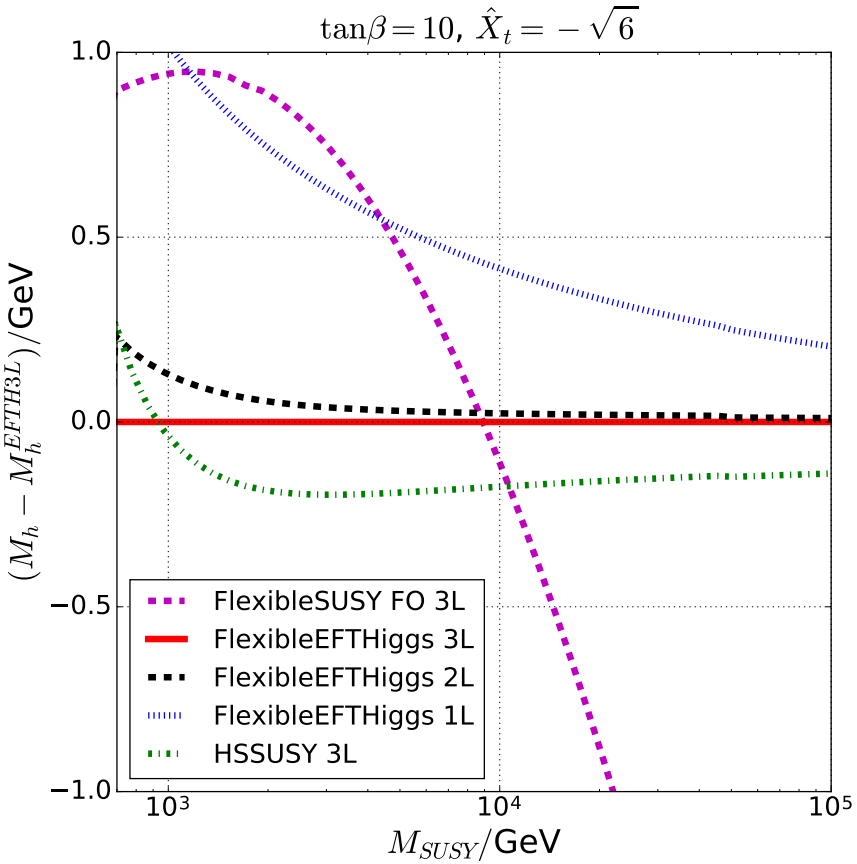
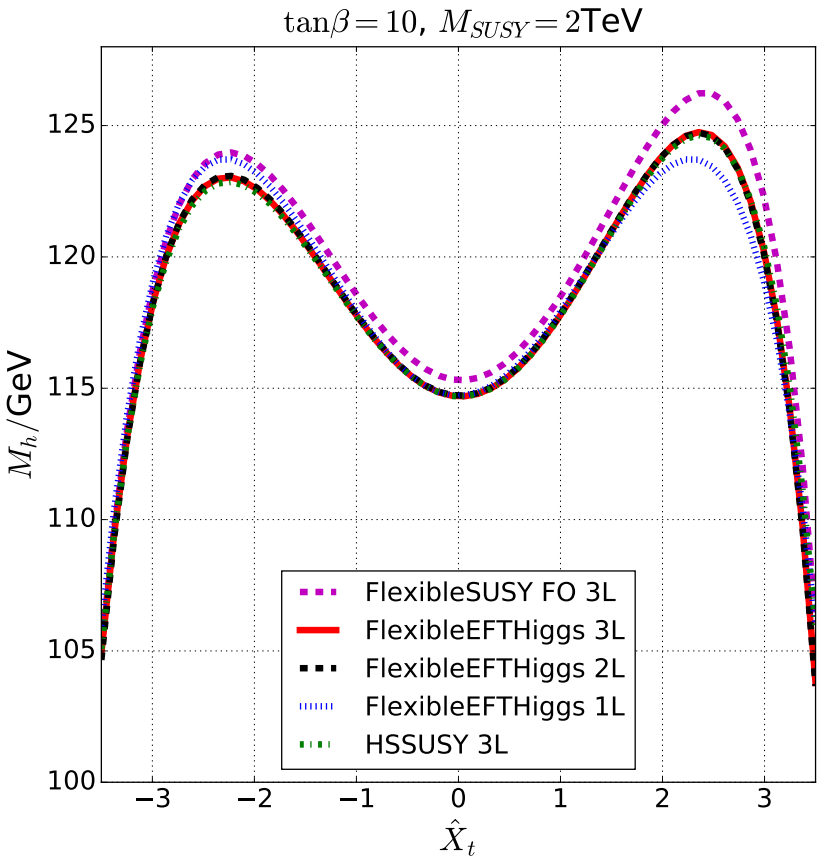
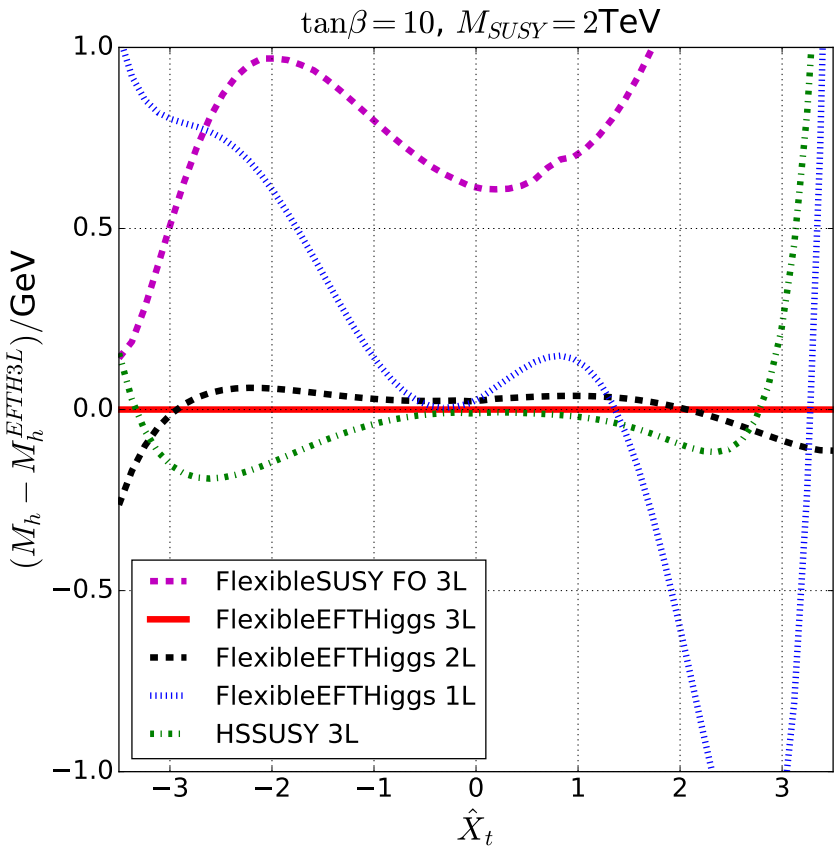




Numerical results: MSSM





Summary

- FlexibleEFTHiggs extension in MSSM:
  combined resummation of N^{3}LL and inclusion of terms of $\mathcal{O}(\hbar^2 v^2/M_S^2)$
- Hybrid calculation interpolates between EFT and FO approach at 3L
- **Outlook**:
  - Estimation of uncertainties
  - Computation of threshold corrections is kept general
    $\Rightarrow$ method applicable for general models
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Thanks for your attention!

Backup

New matching procedure in MSSM

$$
\begin{aligned}
M_f^{\mathsf{SM}} &= M_f^{\mathsf{MSSM}} && && y_f^{\mathsf{SM}} \\
(M_V^{\mathsf{SM}})^2 &= (M_V^{\mathsf{MSSM}})^2,\ (V = W, Z) && \rightarrow && g_{1,2}^{\mathsf{SM}} \\
\alpha_e^{\mathsf{SM}} &= \alpha_e^{\mathsf{MSSM}}(1 - \Delta\alpha_e) && && v^{\mathsf{SM}} \\
\alpha_s^{\mathsf{SM}} &= \alpha_s^{\mathsf{MSSM}}(1 - \Delta\alpha_s) && \rightarrow && g_s^{\mathsf{SM}} \\
(M_h^{\mathsf{Full}})^2 &= (M_h^{\mathsf{SM}})^2 && \rightarrow && \lambda
\end{aligned}
$$

1)SM 0L parameters obtained from 0L matching
2)SM 1L parameters obtained from 1L matching
repeat 1) and 2) for $g_Y^{\mathsf{MSSM}} = g_2^{\mathsf{MSSM}} = 0$

- obtain λ at 2L and 3L