Resummation of logarithmic contributions in MSSM Higgs-boson mass calculations

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IMPRS workshop
at Max Planck Institute of Physics
29.6.2015

Minimal **S**upersymmetric **S**tandard **M**odel:

- one of the most common models of BSM physics
- Supersymmetry relates bosons to fermions
- each SM particle gets a superpartner (e.g. stops $\leftrightarrow$ tops)
- able to address:
  hierarchy problem, DM, gauge coupling unification,...

Distinct feature

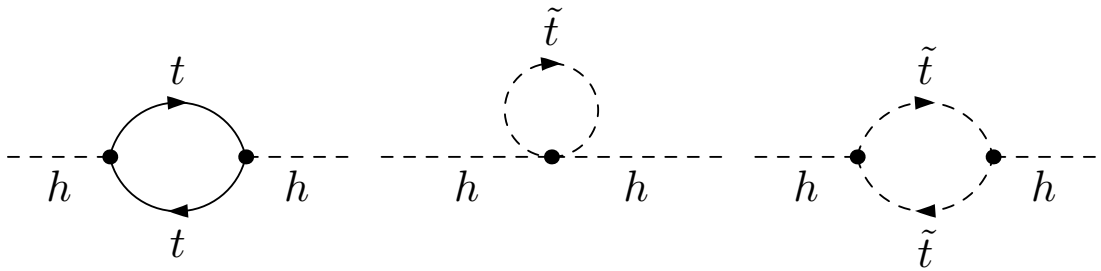
Mass of lightest Higgs boson is calculable in terms of model parameters .

- measured M_h can be used as a precision observable to constrain parameter space of the model
- at tree-level: $M_h \leq M_Z$
- large quantum correction shift M_h upwards

$\Rightarrow$ **Precision calculation needed to match experimental accuracy**

Simplest approach

Calculate corrections to Higgs self-energy diagrammatically



- calculation yields terms $\propto \ln\left(\frac{M_S^2}{m_t^2}\right)$ (M_S: stop mass scale)
- for large $M_S \gg m_t$ 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

- Match SM to MSSM at $Q = M_S$: $\lambda(M_S)$ fixed in MSSM
  $\lambda(M_S) = \lambda_{\text{tree}} + \Delta\lambda_{\text{threshold}}$
- In EFT (SM) all SUSY-particles are integrated out
  $\rightarrow$ no large logarithms

$\Rightarrow$ **large logarithms originate from RGE running:**

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

Solve system of RGEs ($dg_i/d\ln Q^2 = ...$) **numerically**:

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

Leading logarithms (LL) $\rightarrow$ 1-loop RGEs, tree-level matching
Subleading logarithms (NLL) $\rightarrow$ 2-loop RGEs, 1-loop matching

Non-logarithmic terms $\rightarrow$ combine with Feynman diagrammatic result:

- Avoid double-counting
- Take care of different renormalization schemes: OS $\leftrightarrow$ $\overline{\text{MS}}$

`FeynHiggs 2.10`:
Resummation of logarithms $\propto \alpha_t, \alpha_s$ already included

(Hahn et al.: arXiv:1312.4937)

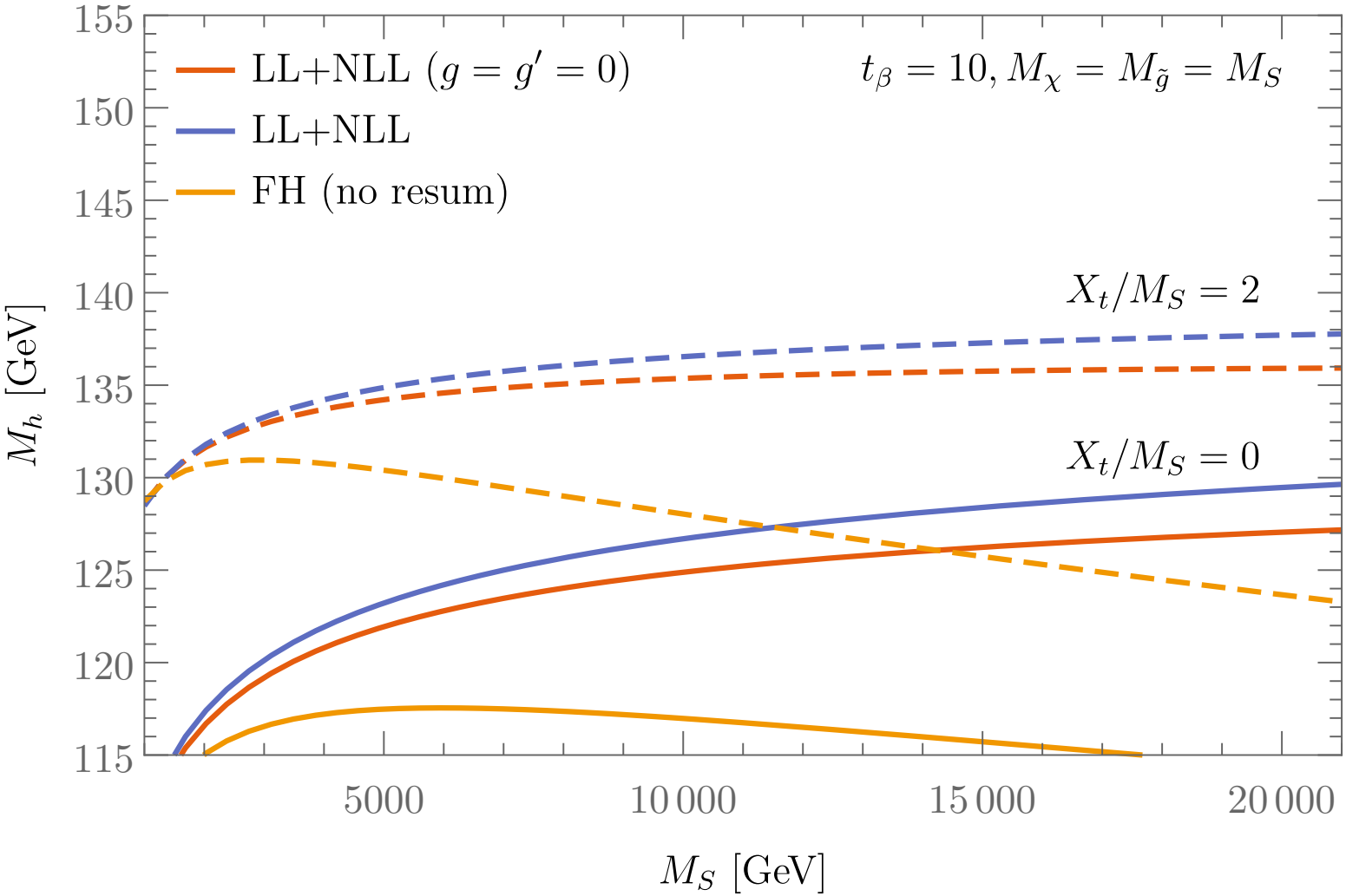
Extension I

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)

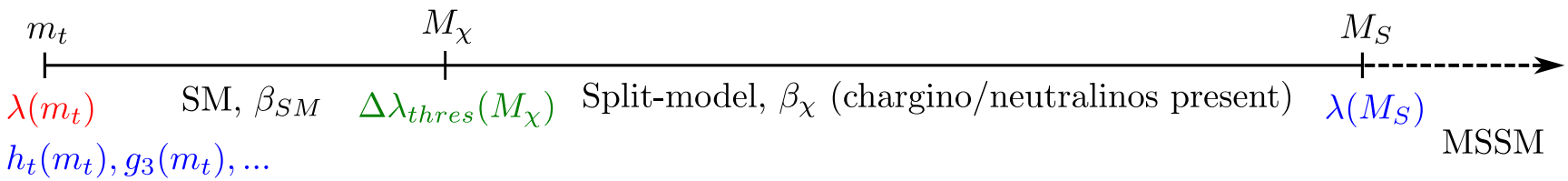
$$\lambda(M_S) = \lambda_{\text{tree}} + \Delta\lambda_{\text{stop}} + \Delta\lambda_{\text{heavy Higgs}} + \Delta\lambda_{\text{chargino/neutralino}} + \Delta\lambda_{\overline{\text{DR}}\to\overline{\text{MS}}}$$

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


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



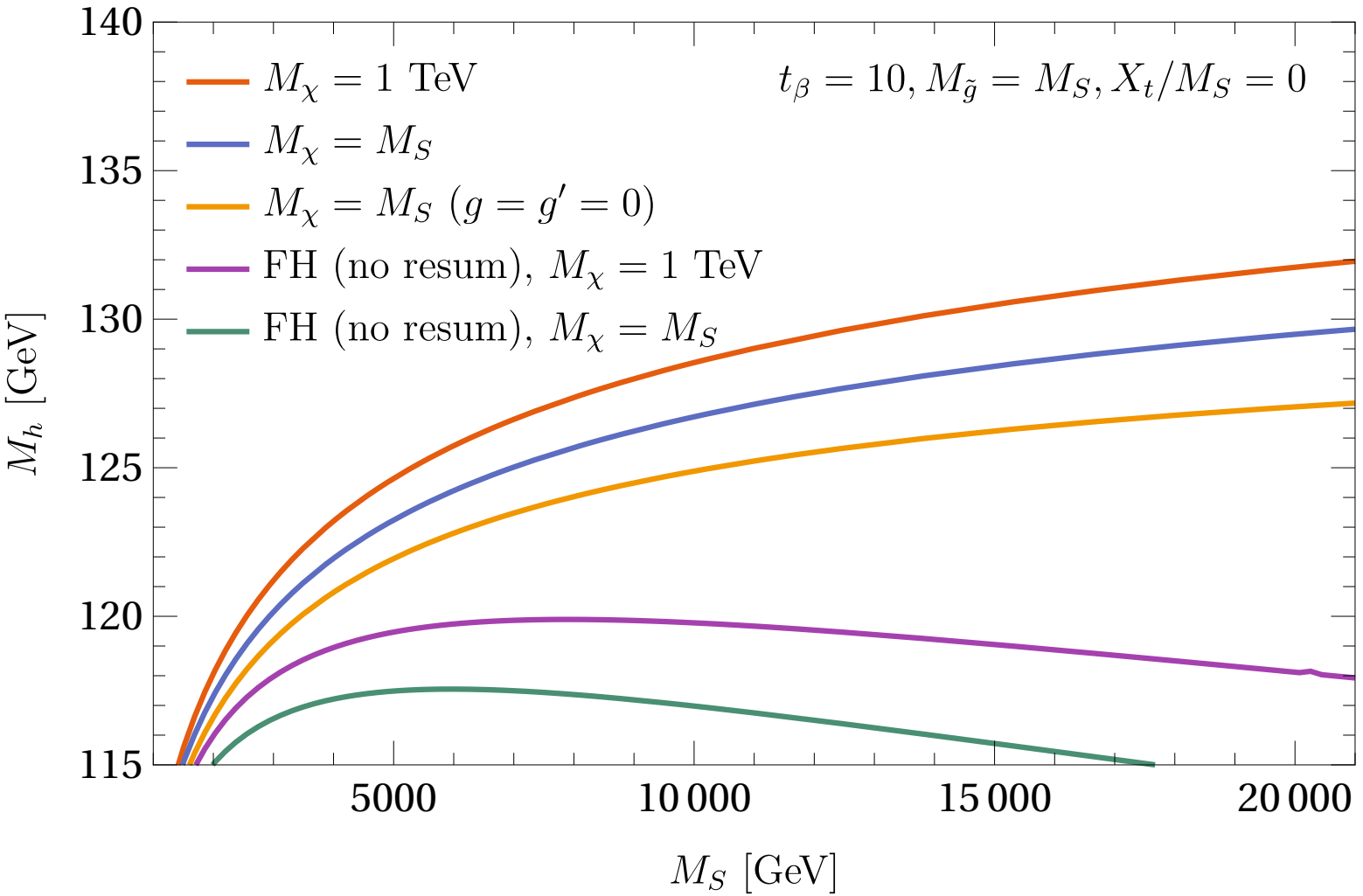
- gaugino-gaugino-Higgs couplings $\tilde{g}_{1u,1d,2u,2d}$ fixed at $Q = M_S$

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

- threshold corrections at $Q = M_\chi$

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

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


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

Conclusion:

- Higgs mass calculable in MSSM → large quantum corrections
- Large SUSY-scale → large logarithms ⇒ resummation necessary
- `FeynHiggs 2.10`: resummation of logarithms $\propto \alpha_t, \alpha_s$
- Extension I: resummation of electroweak logarithms up to ~ 3 GeV
- Extension II: intermediate chargino/neutralino threshold up to ~ 2 GeV

Outlook:

- (s)bottom contributions
- additional thresholds
- next-to-next-to-leading logarithms using 3-loop RGEs