The Higgs masses in the NMSSM at one- and two-loop level

Florian Staub (University of Würzburg)

in collaboration with:
W. Porod (Uni. Würzburg), B. Herrmann (DESY)
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Outline

Introduction

Motivation

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$$W_{\text{MSSM}} = -\hat{H}_u \hat{q} Y_u \hat{u} + \hat{H}_d \hat{q} Y_d \hat{d} + \hat{H}_d \hat{l} Y_e \hat{e} + \mu \hat{H}_u \hat{H}_d$$

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New soft-breaking terms:

$$V_{SB,NMSSM} = m_S^2 |S|^2 + T_\lambda H_u H_d S + \frac{1}{3} T_\kappa SSS$$

Higgs sector of the NMSSM

Scalar gauge singlet S receives a VEV v_s after SUSY breaking

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The Higgs sector of the NMSSM consists in total of

- Three CP-even scalar Higgs h_i
- Two physical CP-odd pseudo scalar Higgs A_i^0
- Two physical charged Higgs $H^\pm$ with $H^+ = (H^-)^*$

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- 1-loop tadpoles/self-energies calculated ($\overline{DR}$,'t Hooft-gauge)
- 1-loop mass matrix given by

$$m_{1L}^{2,h}(p^2) = \tilde{m}_T^{2,h} - \Pi_{hh}(p^2)$$

- 1-loop masses: real part of poles of propagator matrix

$$\text{Det}\left[p_i^2 \mathbf{1} - m_{1L}^{2,h}(p^2)\right] = 0,$$

$\rightarrow$ iterative solution for external masses on-shell

Two-loop contributions

Dominant two-loop contributions known in literature

G. Degrassi, P. Slavich, Nucl.Phys.B825:119-150,2010,
arXiv: 0907.4682

Includes the contributions of (s)top/(s)bottom

Authors calculated also the one-loop corrections:

- Neglected Yukawa couplings of 1. and 2. generation: differences in the per-mille range to our results
- Complete agreement between both calculations in the limit they used

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  - Two-loop RGEs with complete flavor structure
  - SUSY thresholds at EW scale are included
  - All one-loop masses with external momenta on-shell calculated
  - Calculations of two- and three body decays of SUSY particles
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- Fortran routines for two-loop Higgs masses provided by Slavich & Degrassi were included

Constraint NMSSM

Constraint NMSSM (soft version)

Free parameters

$$m_0, M_{1/2}, A_0, \tan\beta = \frac{v_u}{v_d}, \lambda, \kappa, A_\lambda, A_\kappa, v_s$$

Relations at the GUT Scale:

$$M_1 = M_2 = M_3 \equiv M_{1/2},$$
$$m^2_{\tilde{D}} = m^2_{\tilde{U}} = m^2_{\tilde{Q}} = m^2_{\tilde{E}} = m^2_{\tilde{L}} \equiv m^2_0\, \mathbf{1}_3.$$
$$T_u = A_0 Y_u, \quad T_d = A_0 Y_d, \quad T_e = A_0 Y_e,$$
$$T_\lambda = A_\lambda \lambda, \quad \text{and} \quad T_\kappa = A_\kappa \kappa.$$

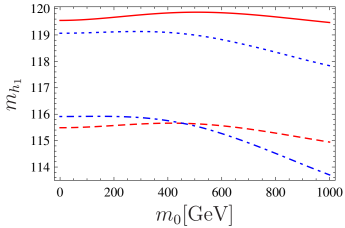
$m^2_{H_d}, m^2_{H_u}, m^2_s$ fixed by tadpole equations at EW scale.

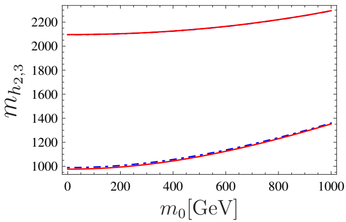
Numerical example

Particle	m_T [GeV]	m_{1L} [GeV]	Δ [%]	m_{2L} [GeV]	Δ [%]
h_1	86.7	113.3	23.5	119.6	5.2
h_2	863.1	934.2	7.6	937.3	0.3
h_3	2073.9	2073.9	< 0.1	2073.9	< 0.1
A_1^0	76.4	69.3	10.2	69.5	0.3
A_2^0	865.2	937.2	7.7	940.4	0.3

Comparison with literature

$$A_0 = -1500\,\text{GeV}, \;\; \tan\beta = 10, \lambda^{\text{SUSY}} = 0.1, \;\; A_\kappa^{\text{GUT}} = -33.45, \;\; \mu_{\text{eff}} > 0$$





SPheno 2-loop (plain), dominant 1-loop (dashed)

NMSSM-Tools [Ellwanger,Hygonie (hep-ph/0612134)]: 2-loop (dotted), 1-loop (dotdashed)

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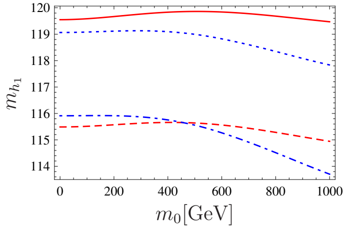

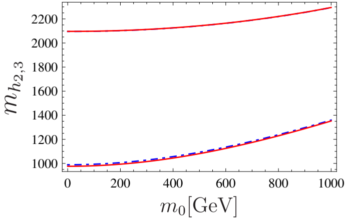

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Differences stemming from:

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2. Electroweak corrections

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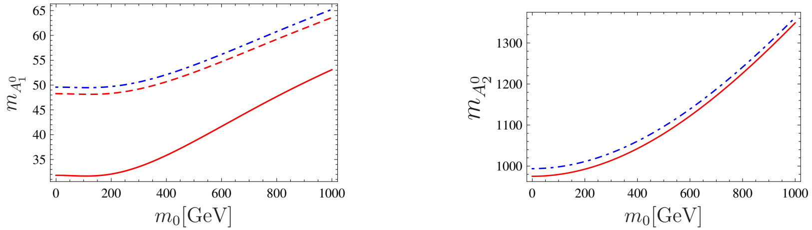

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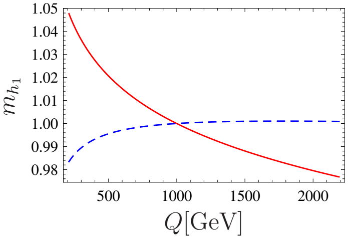
Scale dependence

$$m_0 = 180 \text{ GeV}, m_{1/2} = 500 \text{ GeV}, \ A_0 = A_\lambda^{GUT} = -1500 \text{ GeV}, \ A_\kappa^{GUT} = -36 \text{ GeV}, \ \tan\beta = 10,$$
$$\kappa^{GUT} = 0.11, \ \lambda^{GUT} = 0.1, \ v_s = 13689 \text{ GeV} .$$



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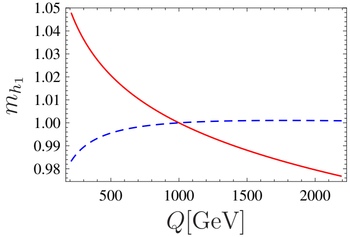

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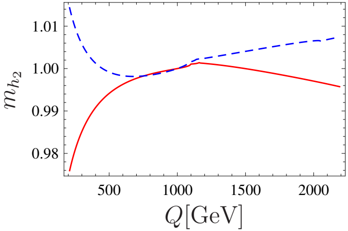

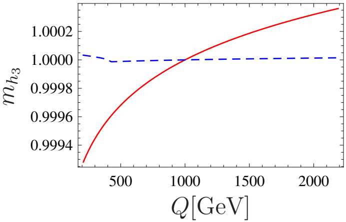

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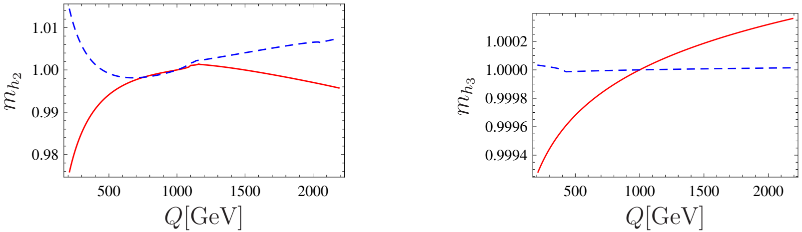

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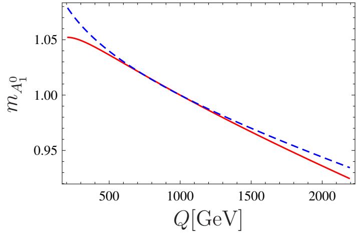

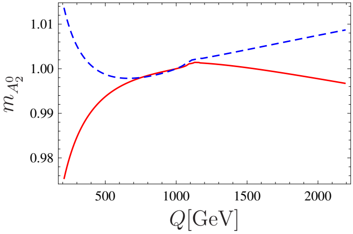

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Summary

- The NMSSM is an attractive extension of the MSSM
- The loop-corrections in the Higgs sector of the NMSSM are important as in case of the MSSM
- We performed a complete one-loop calculation of all masses without any approximation
- Implementation of a constraint GUT version in SPheno including dominant two-loop corrections
- Our results are consistent with literature
- Scale dependences improves significantly on 2-loop level for non-singlet states