Comparison of SUSY mass spectrum calculations

Sabine Kraml
CERN, Theory Div.

in collaboration with

Benjamin Allanach / CERN
Werner Porod / Zürich

Motivation

Many SUSY studies
rely on computer codes
that calculate
the SUSY mass spectra,
branching ratios etc.

from given sets of model parameters

- **Precision measurements of masses and branching ratios**
- **Determination of SUSY parameters**
- **Extrapolation to the GUT scale**
- **Model destinction**

$\Rightarrow$ Experimental acurracies of $\mathcal{O}(1\%)$!

However, different programs
can give quite different results,
especially for
large $\tan\beta$ and large m_0

<u>Question:</u>

What are the differences
in the available programs?

We compare the mass spectrum calculations of the following programs:

Isajet 7.58 and 7.63

by H. Baer, F. E. Paige, S. D. Protopopescu and X. Tata, hep-ph/0001086, `http://paige.home.cern.ch/paige`

SuSpect 2.005

by A. Djouadi, J.-L. Kneur and G. Moultaka,
`http://www.lpm.univ-montp2.fr:6714/∼kneur/suspect.html`

SoftSusy 1.4 (to be released soon)

by B. C. Allanach, hep-ph/0104145,
`http://allanach.home.cern.ch/allanach/softsusy.html`

SPheno 1.0

by W. Porod, *to be published*

Many thanks to Jean–Loic Kneur for a very active discussion of SuSpect calculations!

	Isajet 7.63	SuSpect 2.005	SoftSusy 1.4	SPheno 1.0
RGE's				
gauge + Yuk.	2–loop	2–loop	2–loop	2–loop
gaugino par.	2–loop	2–loop	2–loop	2–loop
scalar par.	2–loop	1–loop	1–loop	2–loop
SUSY masses [1]				
$\tilde\chi^\pm, \tilde\chi^0$	some corr. for $\tilde\chi_1^\pm$	1–loop approx. for ΔM_1, ΔM_2, $\Delta\mu$		full 1–loop
$\tilde t$	—	$\tilde t g + t\tilde g$ + Yuk.	full 1–loop	full 1–loop
$\tilde b$	—	$\tilde b g + b\tilde g$	full 1–loop	full 1–loop
$\tilde g$	$g\tilde g + q\tilde q$ loops resummed			
Yukawa couplings				
h_t	full 1–loop resum.	$tg + \tilde t\tilde g$	full 1–loop	full 1–loop
h_b	full 1–loop resum.	$bg + \tilde b\tilde g + \tilde t\tilde\chi^\pm$ corr. resummed		full 1–loop resum.
Higgs sector				
tadpoles for $m^2_{H_{1,2}}$	3rd gen. (s)fermions	complete 1–loop corrections [1]		
h^0, H^0	1–loop eff. pot. [2]	1–loop eff. pot. [3]	FeynHiggsFast [4]	2–loop eff. pot. [5]

[1] Pierce, Bagger, Matchev, Zhang, NPB 491, 3 (1997) [hep-ph/9606211]

[2] M. Bisset, Ph.D.Thesis, Univ. Hawaii, 1995.

[3] Carena, Quiros, Wagner, hep-ph/9508343.

[4] Heinemeyer, Hollik, Weiglein, hep-ph/9903404.

[5] Brignole, Degrassi, Slavich, Zwirner, hep-ph/0112177.

Changes in recent Isajet versions

Version 7.51, May 2000

Several improvements in the SUSY RGE's have been made. All two-loop terms including both gauge and Yukawa couplings and the contributions from right-handed neutrinos are now included.

Version 7.58, August 2001

[....] $\overline{DR}$ masses are used consistently. Yukawa couplings in the SUGRA routine are now calculated in the $\overline{DR}$ regularization scheme to be consistent with two loop renormalization group evolution.

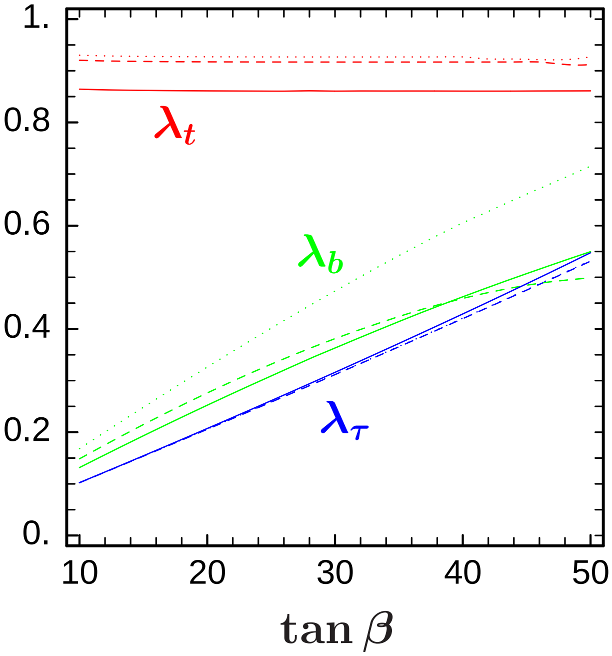
In solving the SUSY renormalization group equations, the requirement of good electroweak symmetry breaking is imposed only at the end. Previously a point could be rejected if there was no symmetry breaking even in the initial iteration with a truncated set of equations.

Version 7.63, April 2002

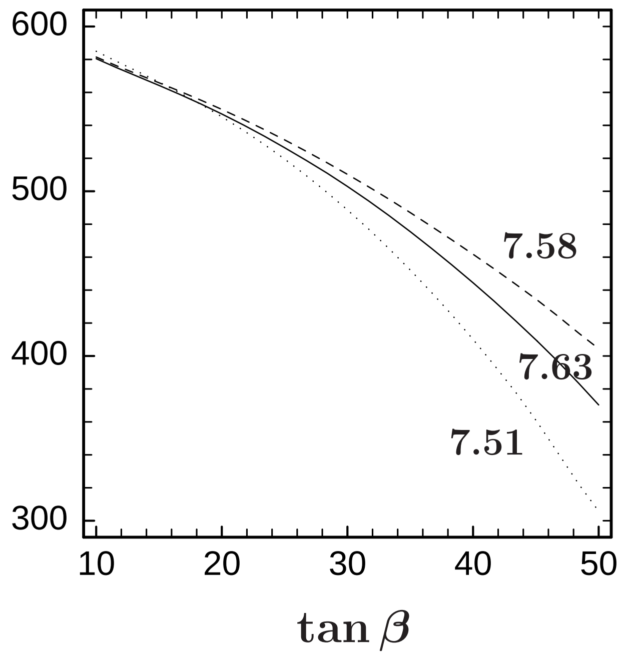
The SUSY mass calculations have been improved, especially for M_A in terms of other SUSY parameters, by using the MSSM Yukawa couplings from the renormalization group equations. The numerical precision of the solution to the SUSY renormalization group equations has also been improved; this should give better stability near the boundaries of the allowed regions. The complete 1-loop self-energies for the t, b, and τ have been included from Pierce, Bagger, Matchev, and Zhang, Nucl. Phys. B491, 3 (1997). Finally, a number of bugs have been fixed, including one in the τ decay of t quarks.

Yukawa couplings and m_A in recent Isajet versions

Yukawa couplings



m_A [GeV]

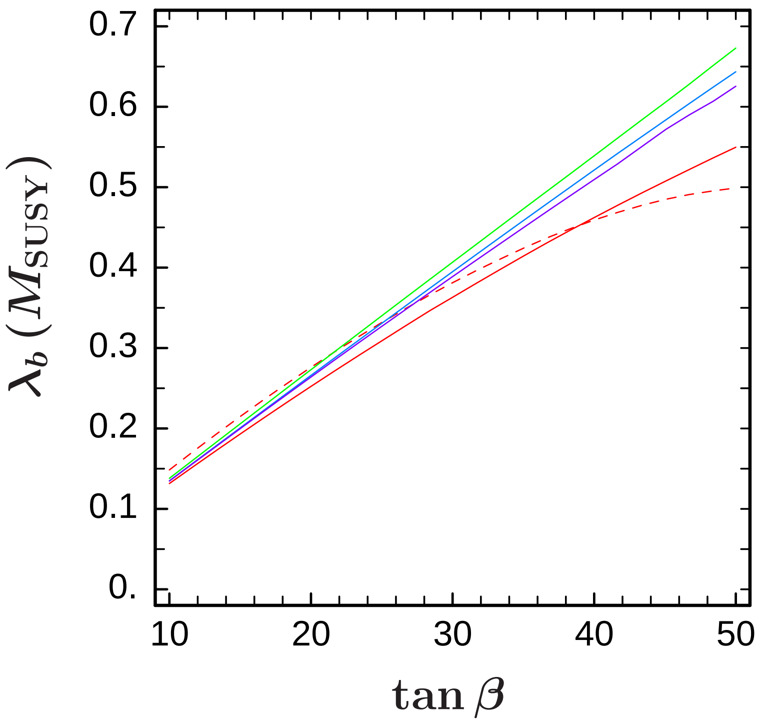


full lines .... Isajet 7.63
dashed .... Isajet 7.58
dotted .... Isajet 7.51

$$m_0 = 400 \text{ GeV}, \quad m_{1/2} = 300 \text{ GeV}, \quad A_0 = 0, \quad \mu > 0,$$

$$M_t = 175 \text{ GeV}, \quad M_b = 4.9 \text{ GeV}.$$

Bottom Yukawa coupling



red .... Isajet 7.63 (7.58) blue .... SoftSusy 1.4

green ..... SuSpect 2.005 violet ..... SPheno 1.0

$$m_0 = 400 \text{ GeV}, \quad m_{1/2} = 300 \text{ GeV}, \quad A_0 = 0, \quad \mu > 0,$$

$$M_t = 175 \text{ GeV}, \quad M_b = 4.9 \text{ GeV}.$$

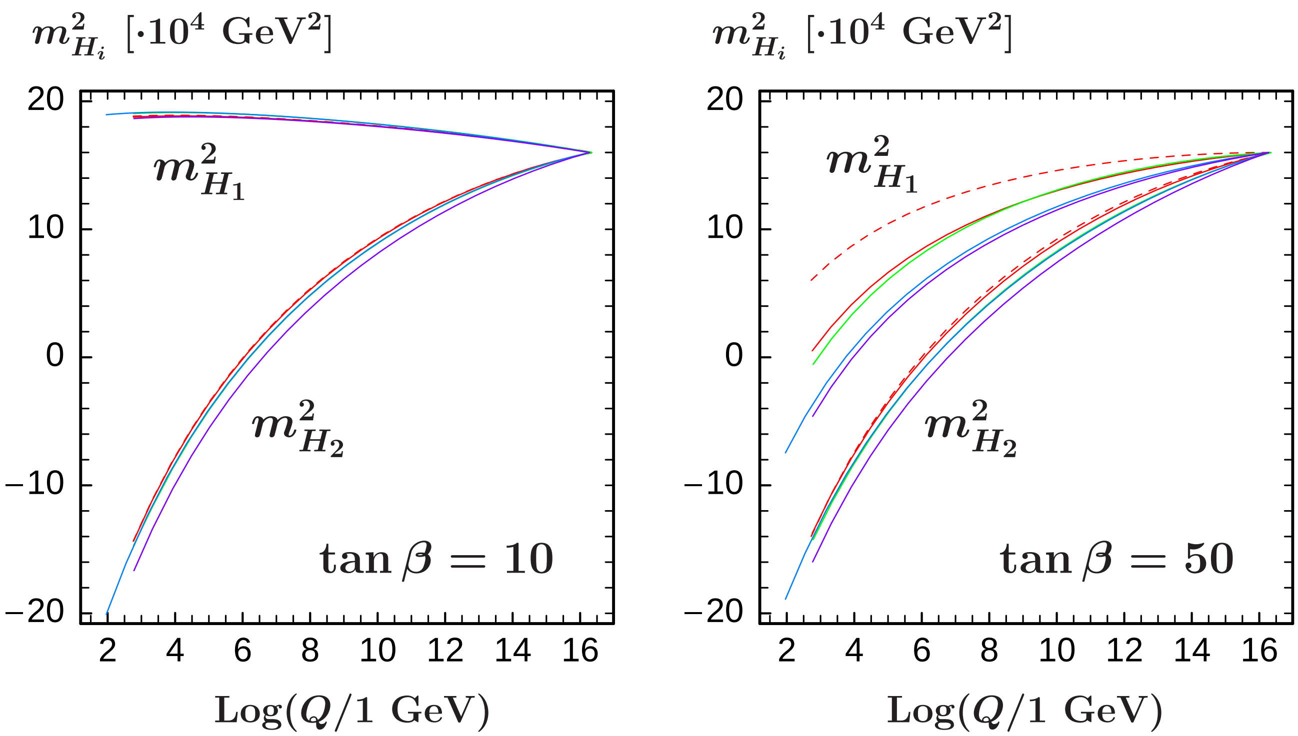
$$\overline{m}_b^{\rm MSSM}(M_Z) = \frac{\overline{m}_b^{\rm SM}(M_Z)}{1 - \left(\frac{\Delta m_b}{m_b}\right)^{\rm SUSY}} \quad ^*$$

$$\lambda_b(M_Z) = \frac{\overline{m}_b(M_Z)}{v_1}, \quad M_Z \to M_{\rm SUSY} = \sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}}$$

*) Carena et al., hep-ph/9912516

Running of $m^2_{H_{1,2}}$

$X_b = m^2_{\tilde{Q}_L} + m^2_{\tilde{b}_R} + m^2_{H_1} + A_b^2$



red .... Isajet 7.63 (7.58) blue .... SoftSusy 1.4

green ..... SuSpect 2.005 violet ..... SPheno 1.0

$m_0 = 400$ GeV, $m_{1/2} = 300$ GeV, $A_0 = 0$, $\mu > 0$,

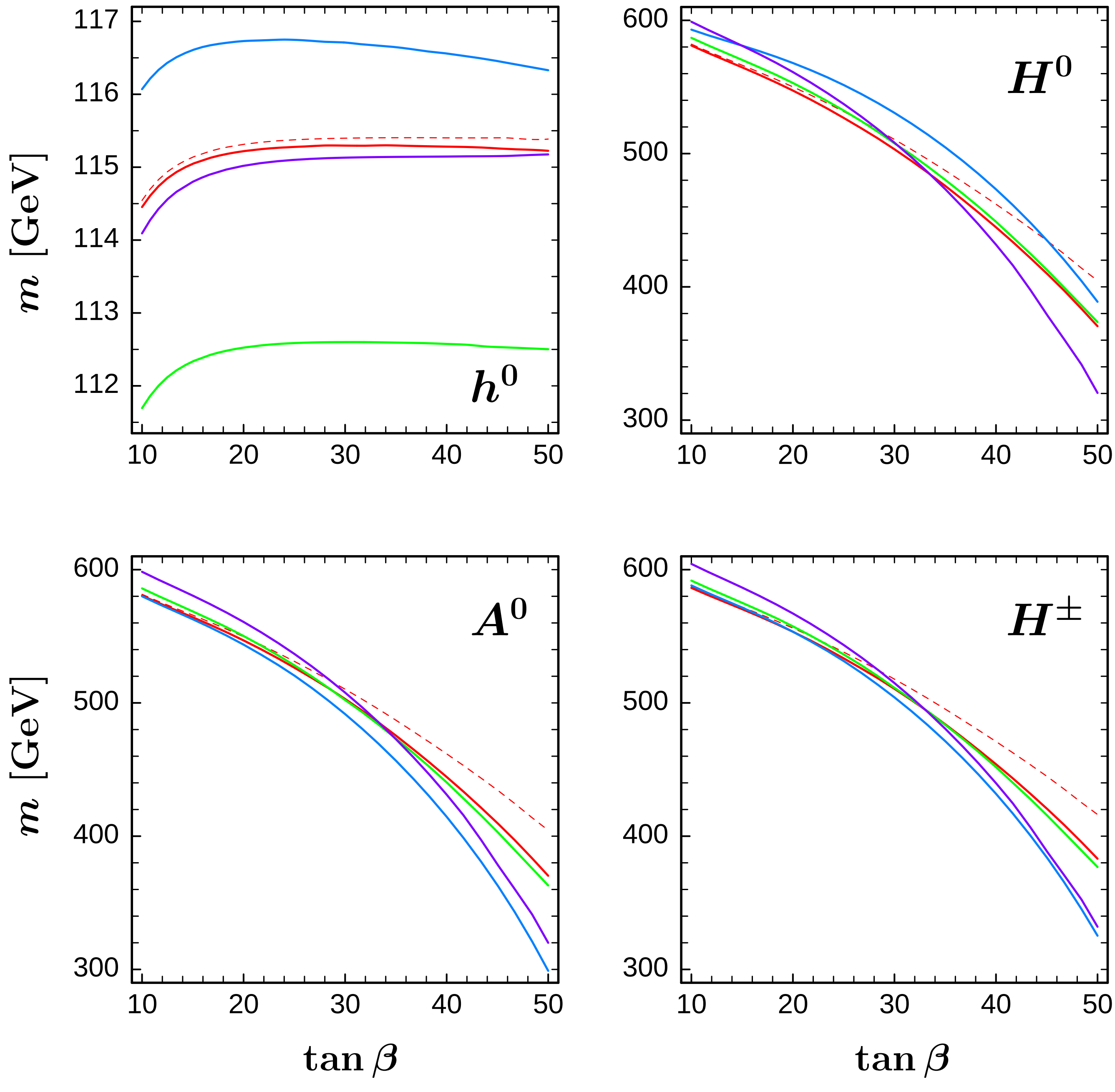
$M_t = 175$ GeV, $M_b = 4.9$ GeV.

$$m_A^2 = \frac{1}{c_{2\beta}}\left(\overline{m}^2_{H_2} - \overline{m}^2_{H_1}\right) - M_Z^2 - \Re\Pi_{ZZ} - \Re\Pi_{AA} + b_A\,,$$

$$\overline{m}^2_{H_i} = m^2_{H_i} - t_i/v_i\,, \quad b_A = s_\beta^2\, t_1/v_1 + c_\beta^2\, t_2/v_2$$

$$16\pi^2\,\frac{t_1}{v_1} = -\sum_{f_d} 2N_c^f \lambda_d^2\, A_0(m_d) + \sum_f \sum_{i=1}^{2} N_c^f\, \frac{g\lambda_{s_1 \tilde{f}_i \tilde{f}_i}}{2m_W c_\beta} + \ldots.$$

Higgs boson masses

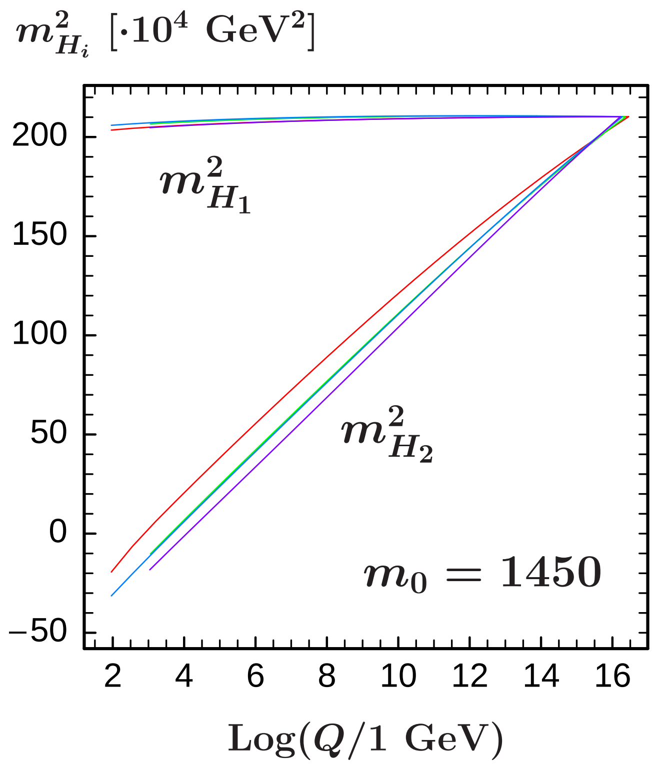


red: Isajet 7.63 (7.58) blue: SoftSusy 1.4

green: SuSpect 2.005 violet: SPheno 1.0

$$m_0 = 400 \text{ GeV}, \quad m_{1/2} = 300 \text{ GeV}, \quad A_0 = 0, \quad \mu > 0$$

Large $m_0 \longrightarrow$ focus point ?



red .... Isajet 7.63 (7.58) blue .... SoftSusy 1.4

green ..... SuSpect 2.005 violet ..... SPheno 1.0

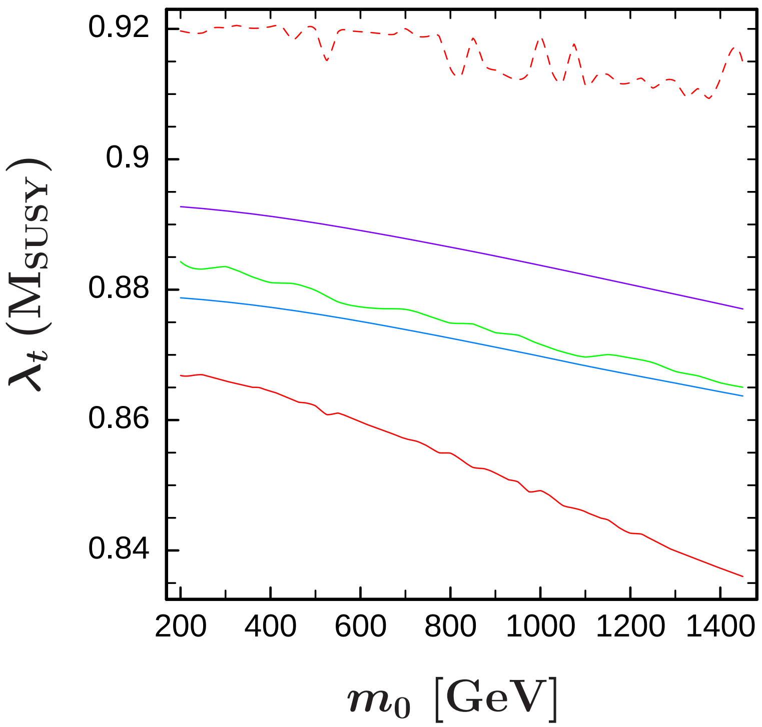
$$m_{1/2} = 300 \text{ GeV}, \quad A_0 = 0, \quad \tan\beta = 10, \quad \mu > 0,$$

$$M_t = 175 \text{ GeV}, \quad M_b = 4.9 \text{ GeV}.$$

$$\frac{d\,m^2_{H_2}}{dt} \sim \frac{1}{8\pi^2}\left(-\frac{3}{5}\,g_1^2 M_1^2 - 3\,g_2^2 M_2^2 + 3\,\lambda_t^2 X_t\right)$$

$$X_t = m^2_{\tilde{Q}_L} + m^2_{\tilde{t}_R} + m^2_{H_2} + A_t^2$$

Top Yukawa coupling for large m_0



red .... Isajet 7.63 (7.58) blue .... SoftSusy 1.4

green ..... SuSpect 2.005 violet ..... SPheno 1.0

$$m_{1/2} = 300 \text{ GeV}, \quad A_0 = 0, \quad \tan\beta = 10, \quad \mu > 0,$$

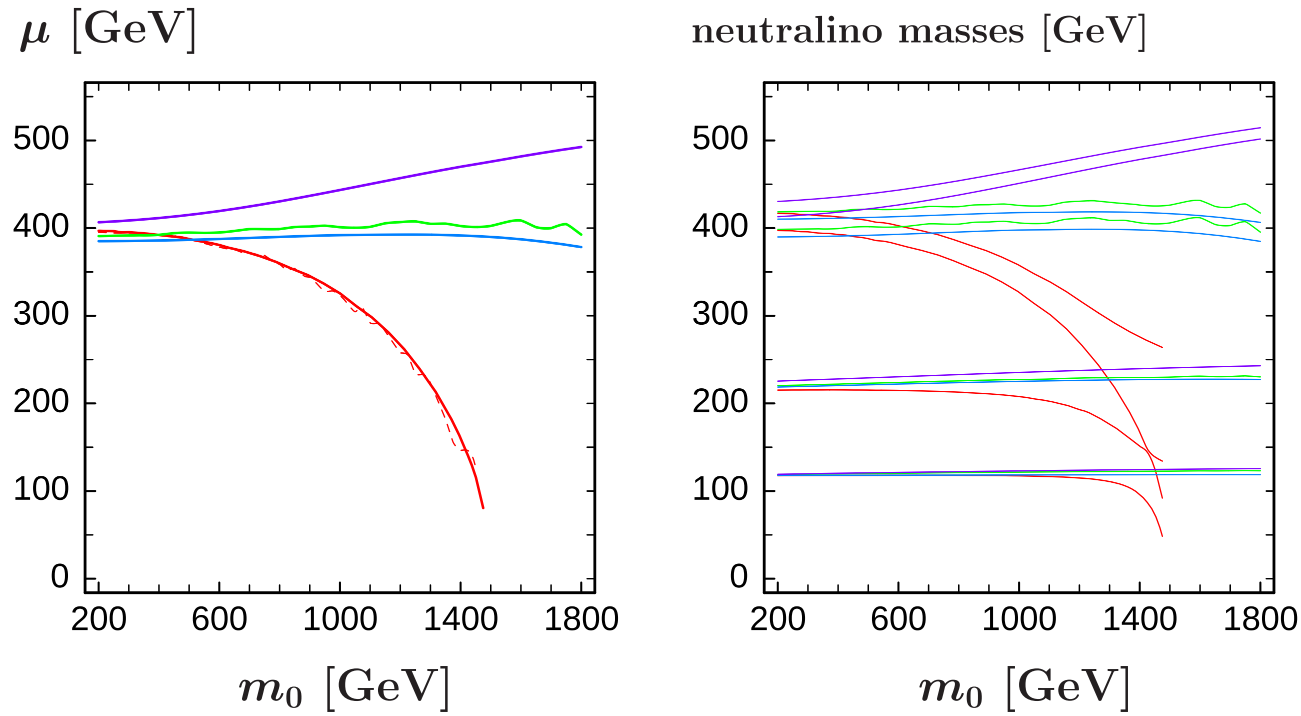
$$M_t = 175 \text{ GeV}, \quad M_b = 4.9 \text{ GeV}.$$

$$M_{SUSY} = \sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}}$$

M_{SUSY} for $m_0 = 1450$ GeV:

Isajet	→	1084 GeV
SuSpect	→	1139 GeV
SoftSusy	→	1166 GeV
SPheno	→	1080 GeV

Problem with large m_0



red .... Isajet 7.63 (7.58) **blue .... SoftSusy 1.4**

green ..... SuSpect 2.005 **violet ..... SPheno 1.0**

$$m_{1/2} = 300 \text{ GeV}, \quad A_0 = 0, \quad \tan\beta = 10, \quad \mu > 0,$$

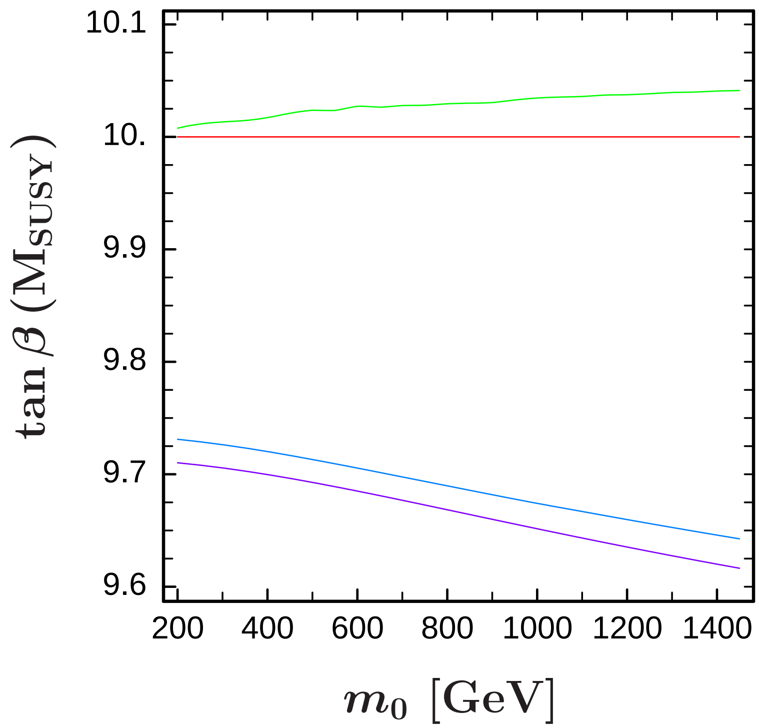
$$M_t = 175 \text{ GeV}, \quad M_b = 4.9 \text{ GeV}.$$

$$\mu^2 = \frac{1}{2}\left[\left(\overline{m}^2_{H_2}\tan\beta - \overline{m}^2_{H_1}\cot\beta\right)\tan 2\beta - M_Z^2 - \Re\Pi^T_{ZZ}\right]$$

$$\overline{m}^2_{H_i} = m^2_{H_i} - t_i/v_i \quad (i = 1, 2)$$

$$16\pi^2\,\frac{t_2}{v_2} = -\sum_{f_u} 2N_c^f \lambda_u^2\, A_0(m_u) + \sum_f \sum_{i=1}^{2} N_c^f\, \frac{g\lambda_{s_2 \tilde{f}_i \tilde{f}_i}}{2m_W c_\beta} + \ldots.$$

Running of $\tan\beta$



red .... Isajet 7.63 (7.58)

green ..... SuSpect 2.005

blue .... SoftSusy 1.4

violet ..... SPheno 1.0

$$m_{1/2} = 300 \text{ GeV}, \quad A_0 = 0, \quad \tan\beta = 10, \quad \mu > 0,$$

$$M_t = 175 \text{ GeV}, \quad M_b = 4.9 \text{ GeV}.$$

$$\mathrm{M_{SUSY}} = \sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}}$$

Conclusions

We have compared the mass spectrum calculations in Isajet 7.63, SuSpect 2005, SoftSusy 1.4, and Spheno 1.0.

Due to (non)inclusion of SUSY radiative corrections, differences of a few (up to ~ 10) per cent are expected.

Critical cases:

Large $\tan\beta$ $\quad\longrightarrow$ bottom Yukawa coupling

$\overline{\rm DR}$ scheme, resummation of corrections to m_b

$$\overline{m}_b^{\rm MSSM}(M_Z) = \frac{\overline{m}_b^{\rm SM}(M_Z)}{1 - \left(\frac{\Delta m_b}{m_b}\right)^{\rm SUSY}}$$

Considerable improvement:

$$\Delta m_A/m_A \lesssim 10\% \text{ for } \tan\beta \lesssim 40\,!$$

Large m_0 $\quad\longrightarrow$ top Yukawa coupling

- **Still very large differences**
- **Focus point + EWSB limit very sensitive to λ_t**
- **Isajet has lowest, SPheno highest λ_t**
  $\longrightarrow$ in Isajet μ drops off very fast, in SPheno it rises
- **For $m_{1/2} = 300$, $A_0 = 0$, $\tan\beta = 10$, $\mu > 0$, $m_t = 175$**
  $\longrightarrow$ Isajet has EWSB limit at $m_0 \sim 1.5$ TeV
  $\longrightarrow$ SuSpect and SoftSusy around $m_0 \sim 2.5$ TeV
  $\longrightarrow$ SPheno has none at all

needs to be clarified !