Review of SUSY Spectrum Codes

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based on
B.C. Allanach, S. K., W. Porod
JHEP03(2003)016 [hep-ph/0302102]

Motivation

- General SUSY phenomenology
  involves more than 100 new parameters

  → from the theoretical point of view: not satisfactory
  → from the practical point of view: too many possibilities

- Models of SUSY breaking provide relations between the SUSY breaking parameters at some high-energy scale, such as the GUT scale.

  Many schemes exist:

  SUGRA, AMSB, GMSB, gaugino mediation,
  string inspired models (dilaton/moduli) ......

- Calculation of the sparticle spectrum by renormalization group evolution

  → need sophisticated computational tools !

⇒ How accurate are these calculations?

⇒ Which accuracy do we actually need?

We compare the following programs

Isajet 7.64

by H. Baer, F. E. Paige, S. D. Protopopescu and X. Tata, hep-ph/0001086

`http://paige.home.cern.ch/paige`

SoftSusy 1.71

by B. C. Allanach, hep-ph/0104145

`http://allanach.home.cern.ch/allanach/softsusy.html`

SPheno 2.1

by W. Porod, hep-ph/0301101

`http://www-theorie.physik.unizh.ch/∼porod/SPheno.html`

SuSpect 2.101

by A. Djouadi, J.-L. Kneur, G. Moultaka, hep-ph/0211331

`http://www.lpm.univ-montp2.fr:6714/∼kneur/Suspect/`

NB: SPythia not on the same level of sophistication (1-loop RGEs only);
Susygen interfaces to Suspect; other codes (like SSARD) unfortunately not public.

	Isajet 7.64	Suspect 2.101	Softsusy 1.71	Spheno 2.1
RGEs	2–loop	2–loop scalars at 1–loop	2–loop	2–loop
thresholds	steps	steps	rad. corr.	rad. corr.
VEVs	not running	running (1–loop)		
Yukawa cpl.				
h_t	full 1–loop	full 1–loop	full 1–loop	full 1–loop
h_b	full 1–loop	$bg + \tilde{b}\tilde{g} + \tilde{t}\tilde{\chi}^\pm$ loops		full 1–loop
Higgs sector				
tadpoles	3rd gen. (s)fermions	complete 1–loop [1]		2–loop [1,4]
h^0, H^0	1–loop [2]	var. ops.	2–loop [3]	2–loop [5]
SUSY masses				
$\tilde{\chi}^\pm, \tilde{\chi}^0$	some corr. for $\tilde{\chi}_1^\pm$	1–loop aprox. for ΔM_1, ΔM_2, $\Delta\mu$		full 1–loop
$\tilde{t}$	logs from steps	1–loop approx.	full 1–loop	full 1–loop
$\tilde{b}$	logs from steps	1–loop approx.	full 1–loop	full 1–loop
$\tilde{g}$	all have 1-loop $g\tilde{g} + q\tilde{q}$ re-summed			

[1] Pierce, Bagger, Matchev, Zhang, NPB 491, 3 (1997) [hep-ph/9606211]
[2] M. Bisset, Ph.D. Thesis, Univ. Hawaii, 1995. [3] Heinemeyer, Hollik, Weiglein, hep-ph/9903404.
[4] Dedes, Slavich, hep-ph/0212132. [5] Degrassi, Slavich et. al., hep-ph/0105096, hep-ph/0112177, hep-ph/0305127.

NB: Isajet $\geq$ 7.66 also includes finite corrections to sparticle masses, runing VEVs etc.
Present version however still has bugs. Wait for Isajet 7.68 ....

Different SUSY-RGE codes can give quite different results for the sparticle spectrum!

This has been addressed in: **(list may be incomplete)**

1. **B.C. Allanach,** *Theoretical uncertainties in sparticle mass predictions.* **Snowmass 2001, hep-ph/0110227**
2. **M. Battaglia et. al.,** *Post-LEP cMSSM benchmarks for supersymmetry.* **hep-ph/0112013**
3. **N. Ghodbane and H.-U. Martyn,** *Compilation of SUSY particle spectra from Snowmass 2001 benchmark models.* **hep-ph/0201233**
4. **B.C. Allanach et. al.,** *The beyond the Standard Model working group: Summary report.* **Les Houches 2001, hep-ph/0204031**
5. **B.C. Allanach, S. K. and W. Porod,** *Comparison of SUSY mass spectrum calculations.* **SUSY 2002, hep-ph/0207314**
6. **G. Belanger, F. Boudjema, A. Pukhov and A. Semenov,** *micrOMEGAs: Recent developments.* **IDM 2002, hep-ph/0210327**
7. **B.C. Allanach, S. K. and W. Porod,** *Theoretical uncertainties in sparticle mass predictions from computational tools.* **JHEP03(2003)016, hep-ph/0302102**
8. **M. Battaglia, A. De Roeck, J. Ellis, F. Gianotti, K. A. Olive and L. Pape,** *Updated post-WMAP benchmarks for supersymmetry.* **hep-ph/0306219**
9. **B.C. Allanach, S. K. and W. Porod,** *Fits of mSUGRA to SPS1a.* **contribution to LHC/LC study**

Tricky Corners

- **Large $\tan\beta$: bottom Yukawa coupling important for calculation of m_A**

$$m_A^2 = \frac{1}{c_{2\beta}}\left(\overline{m}^2_{H_2} - \overline{m}^2_{H_1}\right) + s^2_\beta \frac{t_1}{v_1} + c^2_\beta \frac{t_2}{v_2} - M_Z^2 - \ldots$$

- **Large m_0: μ parameter becomes extremely sensitive to top Yukawa coupling**

$$\mu^2 = \frac{\overline{m}^2_{H_1} - \overline{m}^2_{H_2}\tan^2\beta}{\tan^2\beta - 1} - 0.5(M_Z^2 + \Re\Pi^T_{ZZ})$$

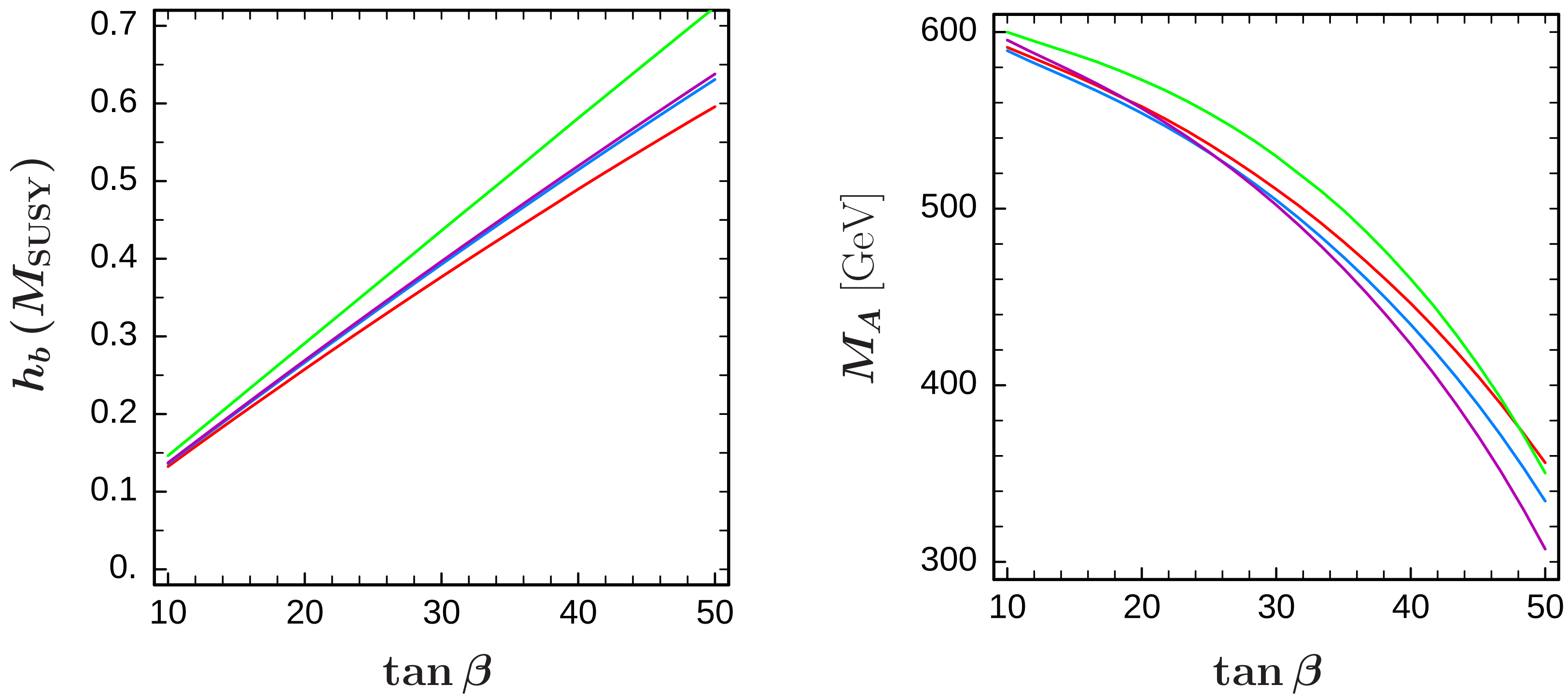
$$\overline{m}^2_{H_i} = m^2_{H_i} - t_i/v_i \quad (i = 1, 2)$$

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

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

$\Rightarrow$ want Yukawa couplings + tadpoles as precisely as possible (2–loops?) $\Leftarrow$

Large $\tan\beta$

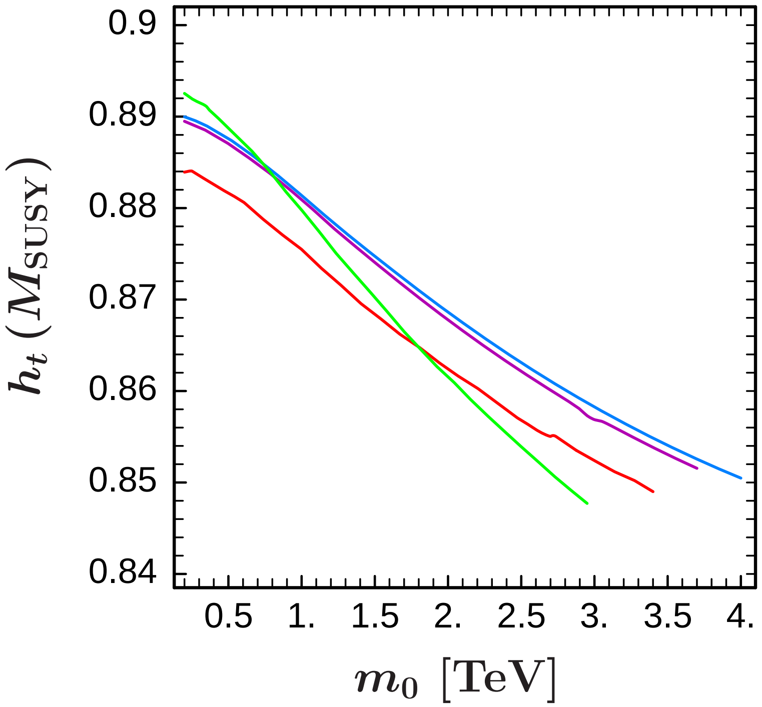


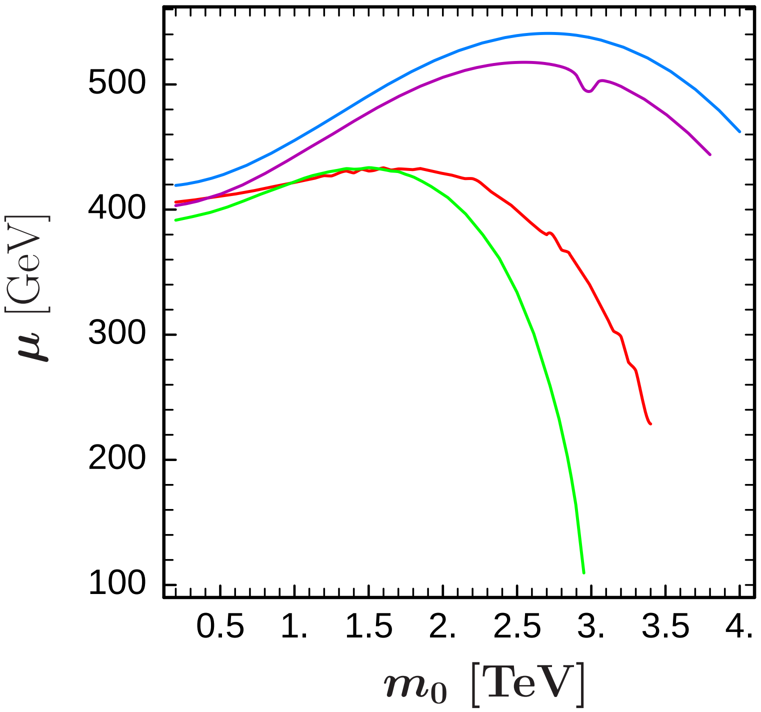
red .... Isajet 7.64   blue .... SoftSusy 1.71

green ..... SuSpect 2.101   purple ... SPheno 2.1

$$m_0 = 400\ \text{GeV}, \quad m_{1/2} = 300\ \text{GeV}, \quad A_0 = 0, \quad \mu > 0, \quad M_t = 175\ \text{GeV}.$$

Large m_0





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Computational Uncertainties

Pragmatic approach: we estimate the current computational uncertainty Δ_{co} in sparticle mass predictions as the variance of the results of the available state-of-the-art tools.

For example, for SPS1a (all values in GeV):

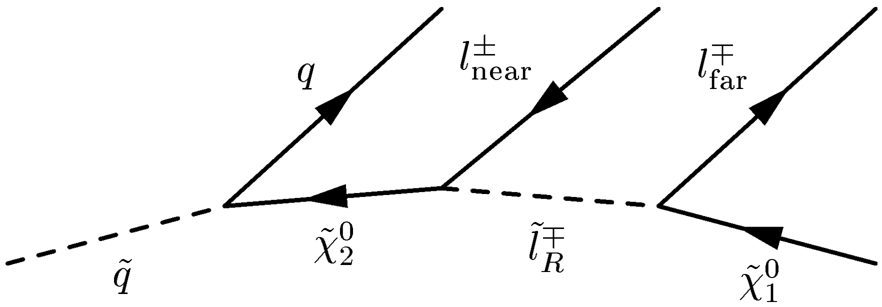
	$m_{\tilde{\chi}_1^0}$	$m_{\tilde{\chi}_2^0}$	$m_{\tilde{e}_L}$	$m_{\tilde{e}_R}$	$m_{\tilde{u}_L}$	$m_{\tilde{u}_R}$	$m_{\tilde{t}_1}$	$m_{\tilde{t}_2}$	$m_{\tilde{b}_1}$	$m_{\tilde{b}_2}$	$m_{\tilde{g}}$
Isajet 7.64	96.6	176.8	201.9	142.9	535.7	519.7	379.4	567.6	492.3	520.9	606.6
Softsusy 1.71	96.7	179.4	200.6	143.1	562.5	546.0	401.1	578.4	512.8	540.1	611.8
Spheno 2.1	97.7	183.2	206.6	143.9	564.9	547.8	398.8	589.1	516.2	547.5	594.3
Suspect 2.101	97.4	179.8	204.4	144.9	572.4	552.5	412.7	574.4	522.1	551.9	629.6
Δ_{co}	0.6	2.6	2.6	0.9	16.0	14.8	13.8	9.0	12.9	13.7	14.7

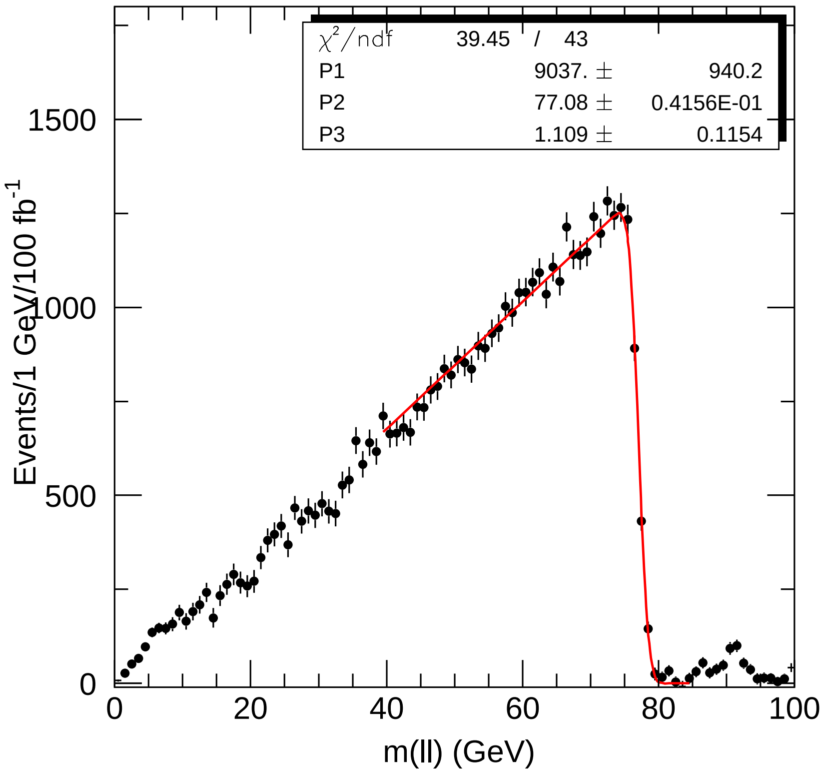
⇒ Typical relative uncertainties $\sim 1-3\,\%$
but may be larger dependent on parameter point or SUSY breaking scheme

⇒ Sufficient for LHC purposes ???

LHC Measurements

Kinematic endpoints (*ll*, *lq*, *llq* edges) can be measured quite precisely





[G. Polesello]

See e.g., ATLAS Physics TDR

B.C. Allanach, C.G. Lester, M.A. Parker and B.R. Webber, hep-ph/0007009.

LHC Measurements at SPS1a:
Computational vs. Experimental Errors

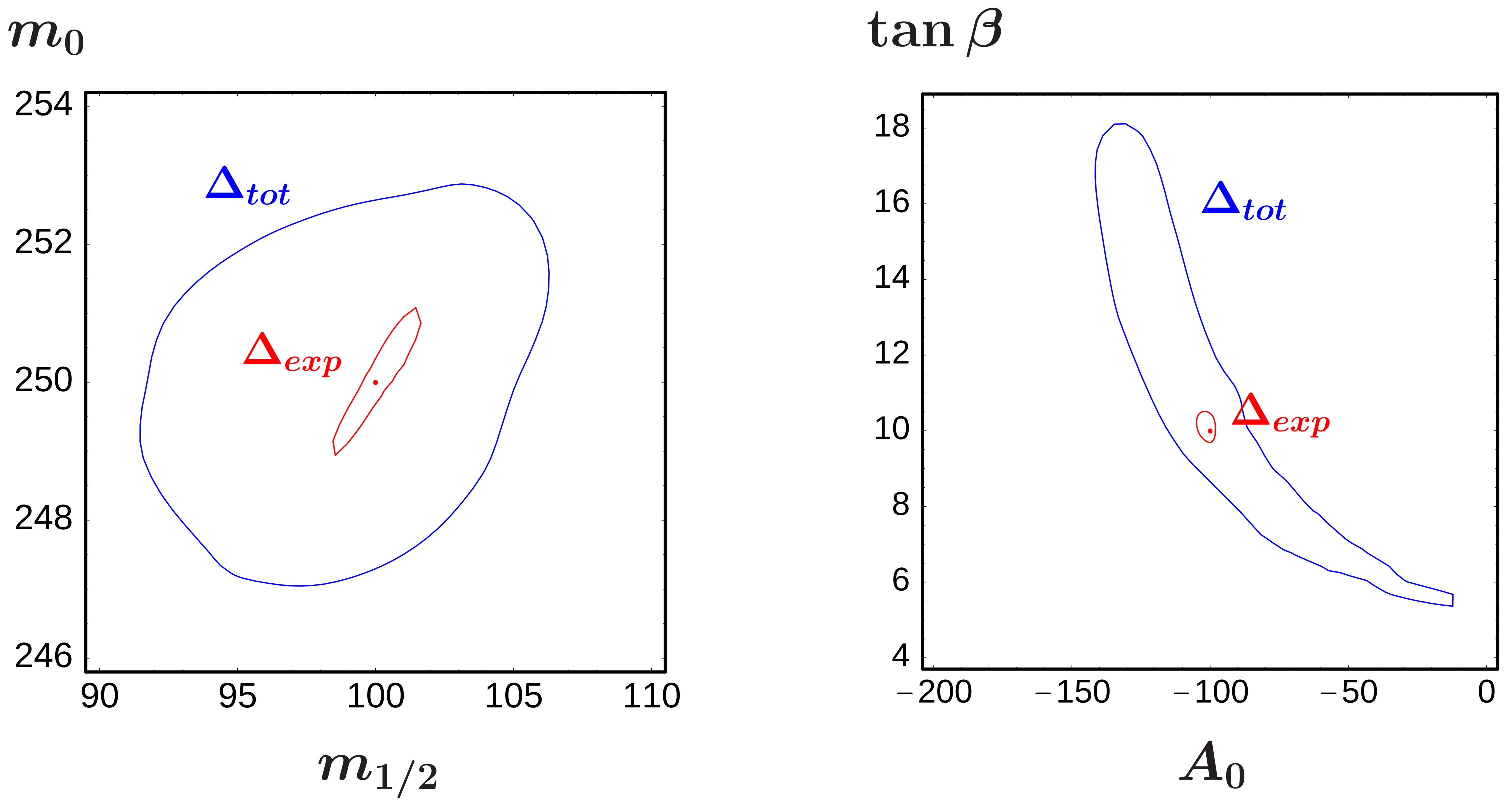
	m_{ll}^{max}	m_{llq}^{max}	m_{llq}^{min}	m_{lq}^{high}	m_{lq}^{low}	$m_{\tau\tau}^{max}$	$m_{ll}^{max}(\tilde{\chi}_4^0)$	m_{llb}^{min}
Isajet 7.64	76.70	426.1	200.9	375.0	299.4	80.0	282.1	182.9
Δ_{exp}	0.08	4.5	2.6	3.9	3.1	5.1	2.3	4.0
Δ_{co}	3.3	15.5	9.9	11.3	10.7	2.7	1.0	8.4

	$m_{\tilde{q}_R} - m_{\tilde{\chi}_1^0}$	$m_{\tilde{l}_L} - m_{\tilde{\chi}_1^0}$	$m_{\tilde{g}} - m_{\tilde{b}_1}$	$m_{\tilde{g}} - m_{\tilde{b}_2}$	$m_{\tilde{g}} - 0.99\, m_{\tilde{\chi}_1^0}$	m_{h^0}
Isajet 7.64	423.2	105.3	114.3	85.7	511.0	113.6
Δ_{exp}	10.0	1.4	1.9	2.6	5.6	1.0
Δ_{co}	14.7	2.6	18.2	19.7	9.6	1.4

Δ_{exp} from B. K. Gjelste, E. Lytken, D. Miller, P. Osland and G. Polesello [contribution to LHC/LC study]

Δ_{co} calculated as the variance of the results of Isajet 7.64, Softsusy 1.71 and Spheno 2.1

Fit to mSUGRA at SPS1a



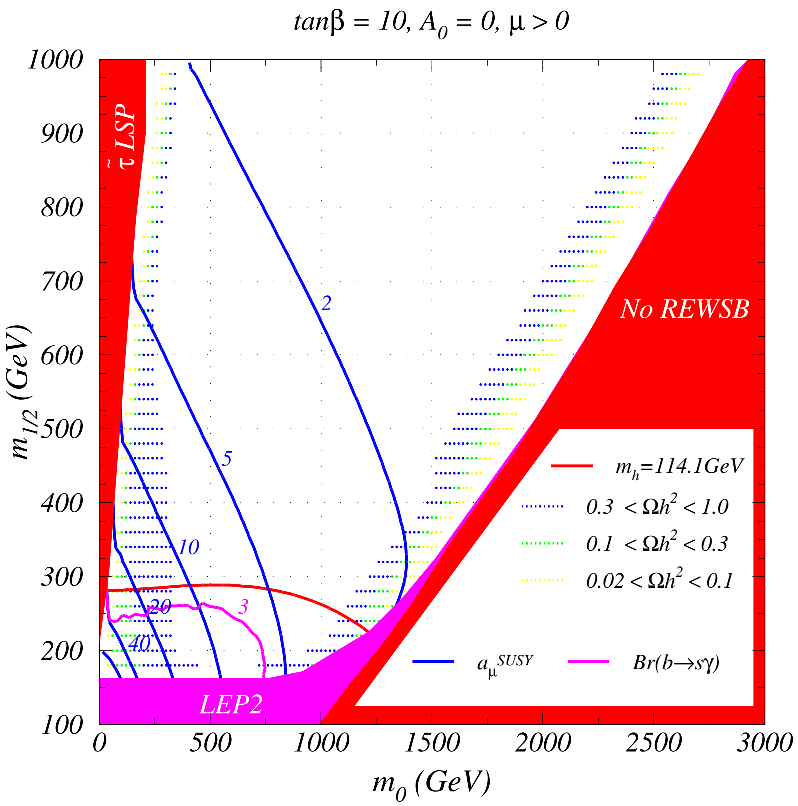
$$\Delta_{tot} = \sqrt{\Delta_{exp}^2 + \Delta_{co}^2}$$

performed with Isajet 7.64, $\Delta\chi^2 = 4.72$

Different program versions sometimes have huge differences

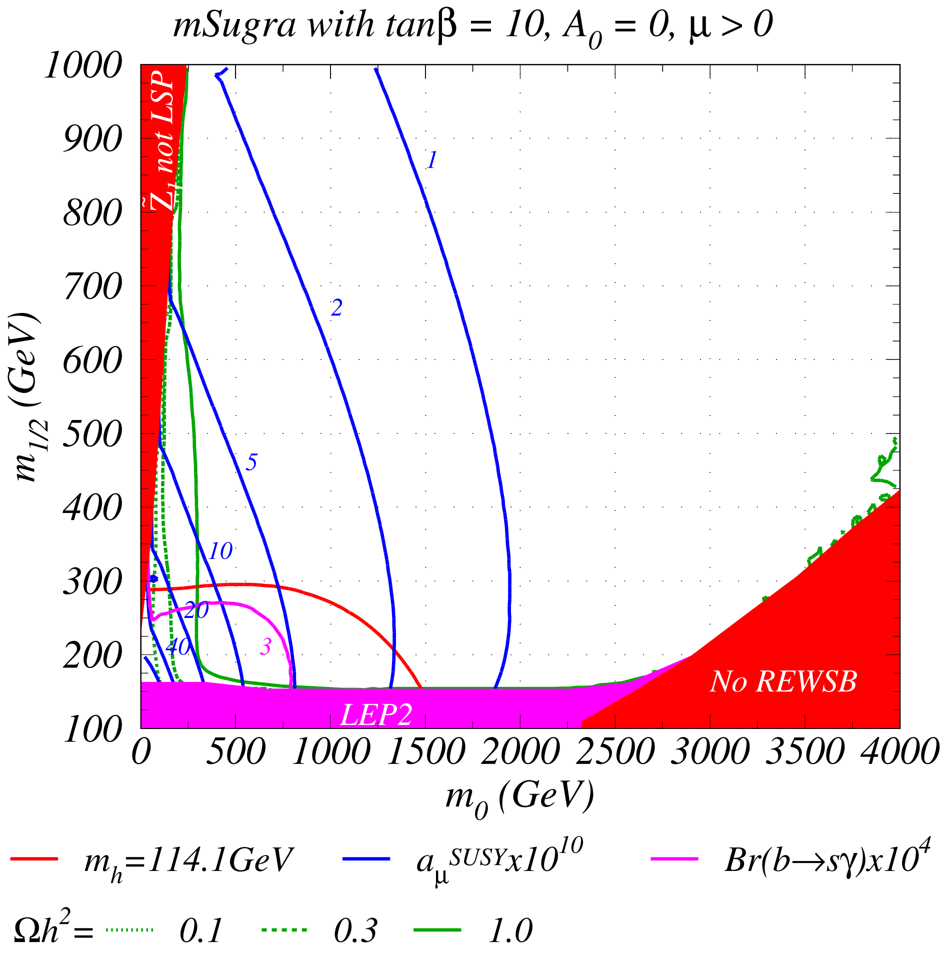
Isajet 7.63

Baer et al., hep-ph/0205325



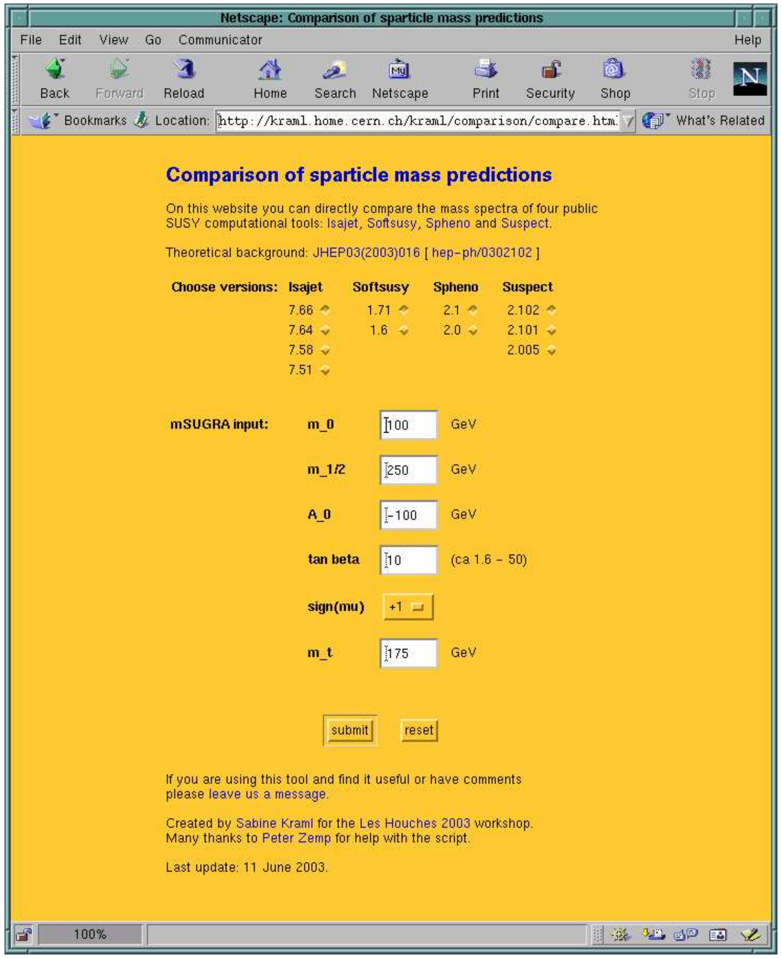
Isajet 7.64

Baer et al., hep-ph/0210441



Online Comparison Tool

http://cern.ch/kraml/comparison/compare.html



→ input a mSUGRA point
→ choose program versions to compare
→ press the submit button

→ you get the spectra of the different programs together with the mean and $min - max$ values and the variance of the results.

Conclusions

- **Present computational uncertainties from SUSY spectrum codes are comparable or larger than expected LHC experimental accuracies**

- **Errors are not static – authors of the existing tools are constantly improving their programs**

- **Differences from one version to the next can be huge (sometimes also due to bugs)**

- **Wanted: RGEs, Higgs potential, Yukawa couplings, $\overline{\mathrm{MS}} \rightarrow \overline{\mathrm{DR}}$ at 2-loop**
  all the rest at 1-loop (at least)

- **Need to further analyse existing uncertainties**
  $\rightarrow$ scale dependences, iteration accuracy, non-SUGRA models, etc

- **Much work to be done — hope to address some issues during this workshop, especially wishes/questions from experimental side**