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Theoretical uncertainties in sparticle mass predictions from computational tools

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in collaboration with

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OUTLINE

1. Introduction

- **Motivation and philosophy**
- **The codes: Isajet, Softsusy, Spheno, Suspect**

2. Tricky corners of SUSY parameter space

- **Large $\tan\beta$**
- **Large m_0 (focus point)**

$\Big\}$ **discussion**

3. Comparison of theoretical with experimental errors

- **Fits of mSUGRA to LHC data**
- **Linear Collider measurements**

4. Conclusions and outlook

⇒ Online comparison via web form

Motivation (2)

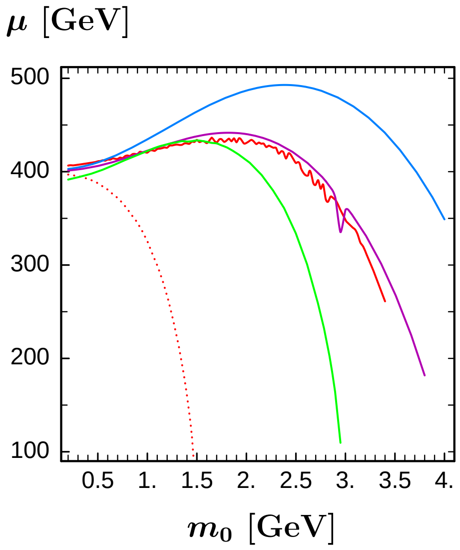
Different SUSY-RGE codes can give quite different results for the sparticle spectrum!

This has previously been addressed in:

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**

$\mathcal{Q}$: What is the current theoretical uncertainty ?
$\mathcal{Q}$: Which are its main sources ?
$\mathcal{Q}$: How does this compare with experimental accuracies ?

⇒ B. C. Allanach, S. K. and W. Porod, hep-ph/0302102



We compare the mass spectrum calculations of 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 2.0
by W. Porod, hep-ph/0301101,
`http://www-theorie.physik.unizh.ch/~porod/SPheno.html`

SuSpect 2.1
by A. Djouadi, J.-L. Kneur, G. Moultaka, hep-ph/0211331,
`http://www.lpm.univ-montp2.fr:6714/~kneur/Suspect/`

Pragmatic approach:

- We define the current theoretical uncertainty to be the variance of the results from these codes.
- After all, when fitting SUSY breaking models to experimental data, one must use (one of) the available computational tools.
- We expect that the differences in the results are due to differences in the implementation of the known higher-order corrections.

  At least to a large part, cannot rule out bugs ....

	Isajet 7.64	Suspect 2.101	Softsusy 1.71	Spheno 2.0
RGEs	2–loop	2–loop scalars at 1–loop	2–loop	2–loop
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
$\tilde{t}$	—	1–loop approx.	full 1–loop	full 1–loop
$\tilde{b}$	—	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, Zwirner, hep-ph/0105096; Brignole, Degrassi, Slavich, Zwirner, hep-ph/0112177.

Comparison
with experimental errors

Fitting
mSUGRA parameters
to LHC data

(c.f. ATLAS physics TDR)

Fitting mSUGRA parameters to LHC data

c.f. ATLAS Physics TDR, Vol.2, p. 855 ff

Analysis of LHC benchmark points 1 and 2:

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

$\tan\beta = 2$ (Point 1) and $\tan\beta = 10$ (Point 2)

$$\begin{array}{ll} \tilde{g} \to q\,\tilde{q}_{L,R} & \\ \quad\hookrightarrow & \tilde{q}_L \to \tilde{\chi}^0_2\, q \to \tilde{\chi}^0_1\, h\, q \\ \quad\hookrightarrow & \tilde{q}_R \to \tilde{\chi}^0_1\, q \end{array}$$

Possible measurements with $\mathcal{L} = 300$ fb^{-1}

Quantity	Point 1	Point 2
m_h	95.4 ± 1.0 GeV	115.3 ± 1.0 GeV
m_{hq}^{max}	758.3 ± 13 GeV	758.3 ± 13 GeV
$m_{\tilde{q}_R}$	959 ± 15 GeV	959 ± 15 GeV
$m_{\tilde{g}}$	1004 ± 12 GeV	1004 ± 12 GeV
$m_{\tilde{t}_1}$	647 ± 100 GeV	713 ± 100 GeV

χ^2 fit of m_0, $m_{1/2}$ and $\tan\beta$ to these data:

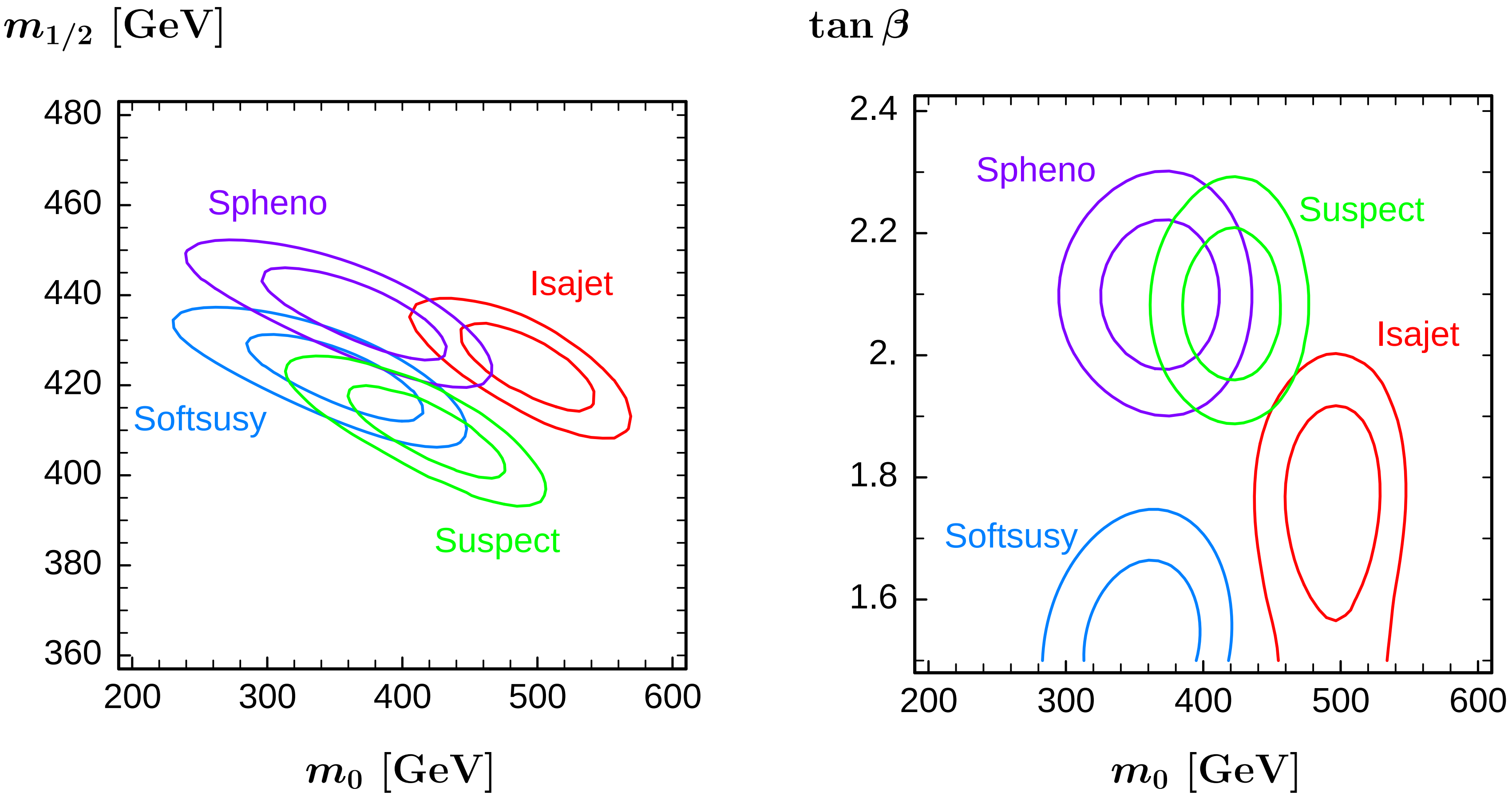
$$\Downarrow$$

$$\begin{array}{rcll} m_0 &=& 400 \pm 100 \text{ GeV} & \\ m_{1/2} &=& 400 \pm \quad 8 \text{ GeV} & \\ \tan\beta &=& 2 \pm 0.08 & \text{(Point 1)} \\ \tan\beta &=& 10 \pm 2 & \text{(Point 2)} \end{array}$$

Isajet 7.34 or earlier

Fit of mSUGRA to LHC data for Point 1

Contours of 68% and 95% C.L.

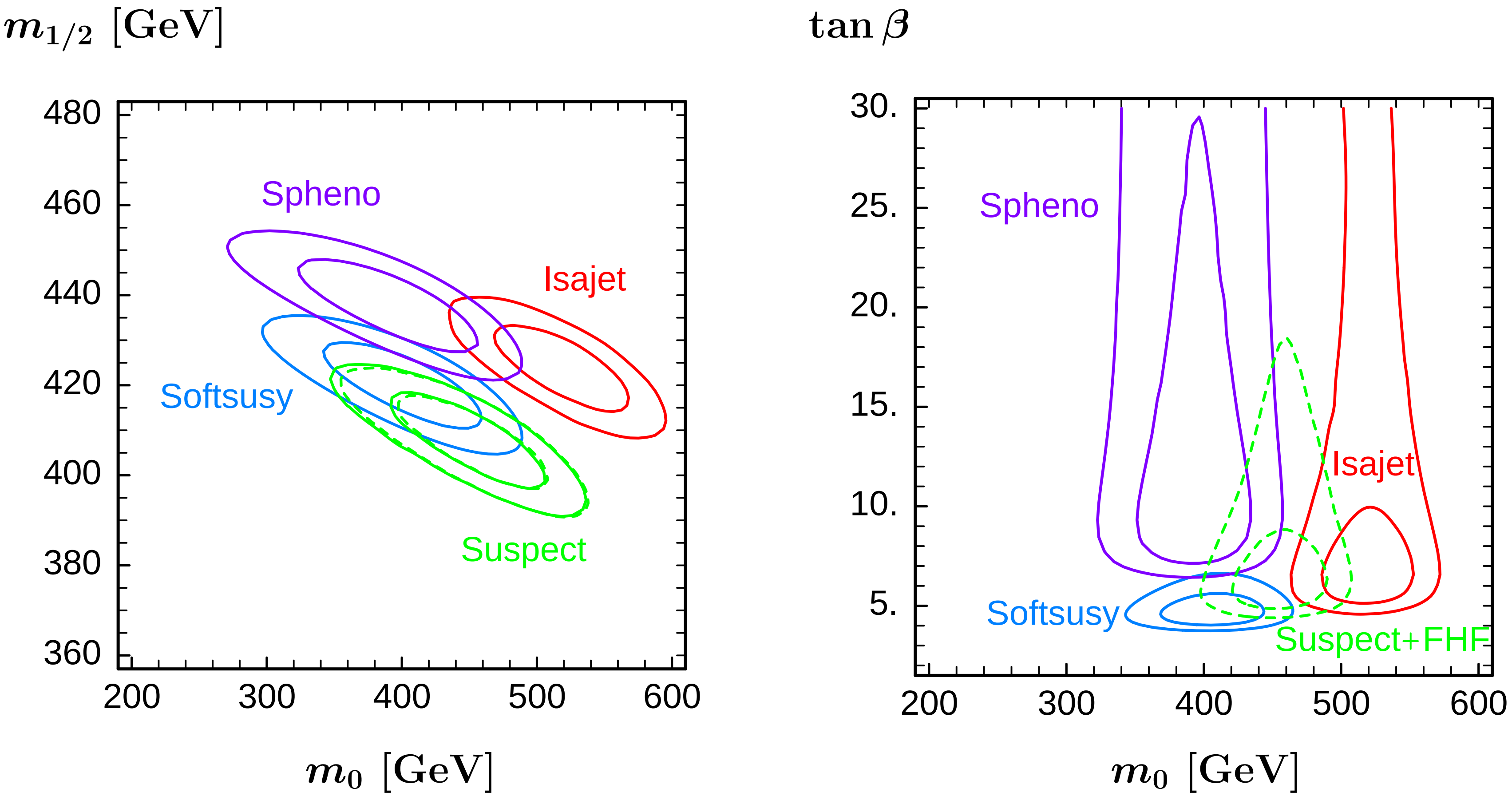


$$m_h = 95.4 \pm 1.0 \text{ GeV}, \quad m_{hq}^{max} = 758.3 \pm 25 \text{ GeV},$$

$$m_{\tilde{q}_R} = 959 \pm 15 \text{ GeV}, \quad m_{\tilde{g}} = 1004 \pm 12 \text{ GeV}, \quad m_{\tilde{t}_1} = 647 \pm 100 \text{ GeV}$$

Fit of mSUGRA to LHC data for Point 2

Contours of 68% and 95% C.L.



$$m_h = 115.3 \pm 1.0 \text{ GeV}, \quad m_{hq}^{max} = 758.3 \pm 25 \text{ GeV},$$

$$m_{\tilde{q}_R} = 959 \pm 15 \text{ GeV}, \quad m_{\tilde{g}} = 1004 \pm 12 \text{ GeV}, \quad m_{\tilde{t}_1} = 713 \pm 100 \text{ GeV}$$

Gluino and squark masses in GeV for the SPS points

Errors (in GeV) computed as the variance of the results

mass	code	1a	1b	2	3	4	5	6	7	8	9
$\tilde{g}$	ISAJET	607	936	794	932	732	719	718	944	835	1296
	SOFTSUSY	614	949	802	946	743	730	729	964	852	1306
	SPHENO	594	917	782	914	719	705	704	940	836	1232
	SUSPECT	626	964	870	959	761	730	742	986	902	1395
	error	13	20	40	19	18	12	16	22	31	67
$\tilde{u}_L$	ISAJET	536	835	1532	817	730	642	640	858	1079	1233
	SOFTSUSY	549	851	1582	831	753	657	662	876	1083	1291
	SPHENO	565	876	1563	859	764	676	674	910	1127	1314
	SUSPECT	570	886	1595	867	775	681	680	910	1138	1502
	error	15	23	27	23	19	18	18	26	30	116
$\tilde{u}_R$	ISAJET	520	807	1529	788	714	622	626	830	1033	1242
	SOFTSUSY	569	884	1592	866	774	681	679	914	1142	1297
	SPHENO	548	847	1552	828	746	655	659	880	1080	1266
	SUSPECT	550	852	1585	832	754	656	662	880	1092	1492
	error	20	32	29	32	25	24	22	35	45	114
$\tilde{t}_1$	ISAJET	379	633	947	621	523	236	476	774	951	998
	SOFTSUSY	398	658	974	645	544	232	497	813	987	951
	SPHENO	398	658	964	646	545	248	497	813	982	986
	SUSPECT	410	676	1004	663	560	243	513	831	1015	1140
	error	13	18	24	17	16	7	15	24	26	83

e^+e^- Linear Collider

$\Downarrow$

experimental accuracies
of ${}^{o}/_{o}$ or even ${}^{o}/_{oo}$ level

Kinematically accessible sparticles at a 500 GeV LC: differences in predicted masses in GeV for the SPS points 1a – 3

point	code	$M_{\chi_1^0}$	$M_{\chi_2^0}$	$M_{\chi_1^\pm}$	$M_{\tilde{\nu}_e}$	$M_{\tilde{\nu}_\tau}$	$M_{\tilde{e}_R}$	$M_{\tilde{e}_L}$	$M_{\tilde{\tau}_1}$	$M_{\tilde{\tau}_2}$
1a	ISAJET	96.6	176.8	176.4	185.8	184.9	142.9	201.9	133.3	206.0
	SOFTSUSY	96.4	178.2	177.6	188.7	187.9	144.9	204.3	136.3	207.8
	SPHENO	97.6	182.9	181.3	190.5	189.6	143.9	206.6	134.6	210.3
	SUSPECT	97.4	179.8	179.1	188.5	187.5	144.9	204.4	135.7	208.1
	error	0.3	1.5	1.2	1.1	1.1	0.6	1.1	0.8	1.0
1b	ISAJET	161.2	299.2	–	–	–	–	–	195.2	–
	SOFTSUSY	161.3	303.5	–	–	–	–	–	204.6	–
	SPHENO	163.7	310.2	–	–	–	–	–	195.1	–
	SUSPECT	162.6	305.5	–	–	–	–	–	199.7	–
	error	0.7	2.6	–	–	–	–	–	2.6	–
2	ISAJET	120.2	221.7	221.5	–	–	–	–	–	–
	SOFTSUSY	118.6	232.0	231.8	–	–	–	–	–	–
	SPHENO	123.8	233.6	232.1	–	–	–	–	–	–
	SUSPECT	123.1	233.0	232.6	–	–	–	–	–	–
	error	1.4	3.2	3.1	–	–	–	–	–	–
3	ISAJET	160.5	297.0	–	–	–	178.3	–	170.6	–
	SOFTSUSY	160.8	300.4	–	–	–	182.0	290.4	175.3	292.3
	SPHENO	162.7	307.2	–	–	–	180.2	290.3	172.4	292.4
	SUSPECT	161.7	302.4	–	–	–	182.1	290.7	174.8	292.6
	error	0.6	2.5	–	–	–	1.0	0.1	1.3	0.1

Kinematically accessible sparticles at a 500 GeV LC: differences in predicted masses in GeV for the SPS points 4–5

point	code	$M_{\chi_1^0}$	$M_{\chi_2^0}$	$M_{\chi_1^\pm}$	$M_{\tilde{\nu}_e}$	$M_{\tilde{\nu}_\tau}$	$M_{\tilde{e}_R}$	$M_{\tilde{e}_L}$	$M_{\tilde{\tau}_1}$	$M_{\tilde{\tau}_2}$
4	ISAJET	119.3	219.6	219.6	–	–	–	–	–	–
	SOFTSUSY	118.6	223.6	223.4	–	–	–	–	–	–
	SPHENO	121.4	228.9	227.4	–	–	–	–	–	–
	SUSPECT	121.1	225.9	225.7	–	–	–	–	–	–
	error	0.8	2.3	1.9	–	–	–	–	–	–
5	ISAJET	119.8	225.9	225.9	244.3	242.3	191.5	256.3	180.9	257.7
	SOFTSUSY	118.7	229.4	229.2	248.2	246.1	193.5	259.4	183.7	260.7
	SPHENO	121.1	230.0	229.8	248.0	245.9	192.0	259.4	181.7	260.9
	SUSPECT	120.7	230.6	230.4	247.8	245.5	193.5	259.5	182.8	260.6
	error	0.6	1.2	1.2	1.1	1.0	0.6	0.9	0.7	0.9

Kinematically accessible sparticles at a 500 GeV LC: differences in predicted masses in GeV for the SPS points 6–9

point	code	$M_{\chi_1^0}$	$M_{\chi_2^0}$	$M_{\chi_1^\pm}$	$M_{\tilde{\nu}_e}$	$M_{\tilde{\nu}_\tau}$	$M_{\tilde{e}_R}$	$M_{\tilde{e}_L}$	$M_{\tilde{\tau}_1}$	$M_{\tilde{\tau}_2}$
6	ISAJET	190.0	218.1	215.7	–	–	236.8	–	227.8	–
	SOFTSUSY	190.2	220.6	217.9	–	–	240.9	–	232.8	–
	SPHENO	191.2	225.3	222.3	–	–	237.6	–	229.1	–
	SUSPECT	190.2	222.2	219.6	–	–	240.9	–	232.2	–
	error	0.3	1.7	1.6	–	–	1.3	–	1.4	–
7	ISAJET	162.4	268.0	–	248.7	248.3	127.3	261.1	119.9	263.3
	SOFTSUSY	163.6	263.5	–	247.2	246.9	126.4	259.3	120.5	261.2
	SPHENO	163.4	271.1	–	251.6	251.3	131.0	265.3	123.8	267.3
	SUSPECT	163.6	262.2	–	246.9	246.6	127.8	259.4	121.6	261.4
	error	0.3	2.4	–	1.2	1.2	1.2	1.6	1.0	1.6
8	ISAJET	137.4	254.6	–	–	–	175.7	–	168.9	–
	SOFTSUSY	138.4	261.2	–	–	–	175.4	–	169.9	–
	SPHENO	139.2	266.1	–	–	–	180.3	–	173.5	–
	SUSPECT	140.0	263.5	–	–	–	177.6	–	171.8	–
	error	0.6	2.8	–	–	–	1.3	–	1.2	–
9	ISAJET	174.8	–	175.0	–	–	–	–	–	–
	SOFTSUSY	196.7	–	196.7	–	–	–	–	–	–
	SPHENO	168.0	–	168.4	–	–	–	–	–	–
	SUSPECT	167.3	–	167.3	–	–	–	–	–	–
	error	7.9	–	7.9	–	–	–	–	–	–

LC measurements for SPS1a

Take SPS mSUGRA point 1a for illustration:

$$m_0 = 200\ \text{GeV}, \quad m_{1/2} = 250\ \text{GeV}, \quad A_0 = -100,$$
$$\tan\beta = 10, \quad \mu > 0, \quad M_t = 175\ \text{GeV}.$$

Δ_{th}: Gaussian error in sparticle masses from Isajet 7.64, Softsusy 1.71, Spheno 2.0 and Suspect 2.101.

Δ_{exp}: estimated statistical error for a 500 GeV e^+e^- LC with $\mathcal{L} = 1\ \text{ab}^{-1}$.

G. Blair, W. Porod, P.M. Zerwas, hep-ph/0210058

[GeV]	$m_{\chi_1^0}$	$m_{\chi_2^0}$	$m_{\chi_1^\pm}$	$m_{\tilde{e}_R}$	$m_{\tilde{e}_L}$
Δ_{exp}	0.2	0.3	0.1	0.1	0.3
Δ_{th}	0.3	1.5	1.2	0.6	1.1

[GeV]	$m_{\tilde{\nu}_e}$	$m_{\tilde{\nu}_\tau}$	$m_{\tilde{\tau}_1}$	$m_{\tilde{\tau}_2}$
Δ_{exp}	0.9	1.1	1.0	0.9
Δ_{th}	1.1	1.1	0.8	1.0

Conclusions

We have analysed the current uncertainty in sparticle mass predictions by comparing 4 state-of-the-art codes: Isajet 7.64, Softsusy 1.71, Spheno 2.0 and Suspect 2.101.

Owing to

- **details in the calculation of the top and bottom Yukawa couplings**
- **w/o threshold corrections to sparticle masses**

we find uncertainties of the per-cent level in predicted sparticle masses.

⇒ dependent on the point in SUSY parameter space
⇒ particularly difficult: large $\tan\beta$ and/or large m_0

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'Theory uncertainty' estimated as the variance of the results (or from fits) is

- **comparable to LHC statistical errors**
- **$\sim$ or larger than LC errors (up to an order of magnitude!)**

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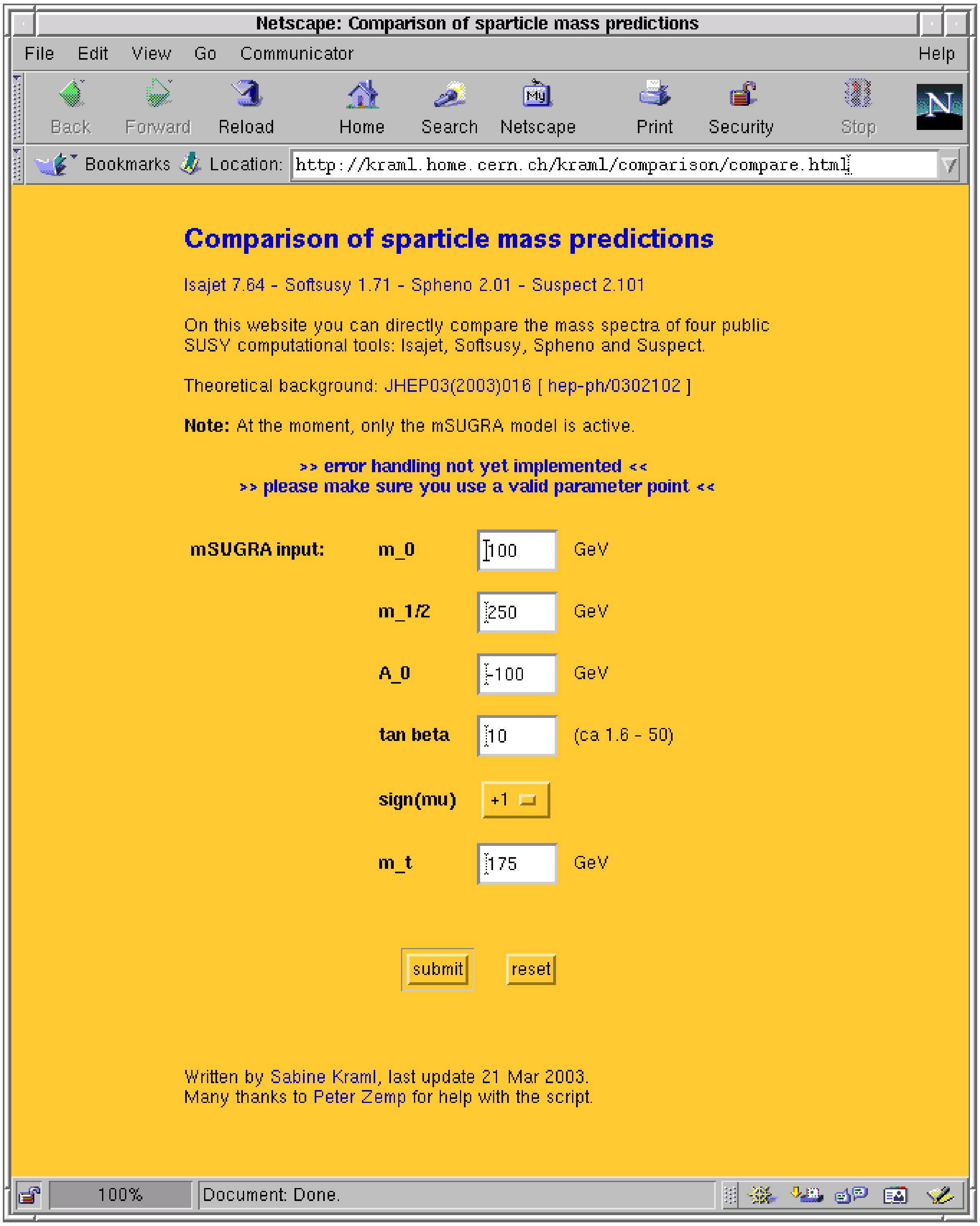
No problem for simulations of particular scenarios, measurements of masses, mixing angles etc.

However, when interpreting experimental data in terms of SUSY breaking parameters at the high scale, theoretical uncertainties must be taken into account.

Outlook: Online comparison via web form



Comparison of sparticle mass predictions

Isajet 7.64 - Softsusy 1.71 - Spheno 2.01 - Suspect 2.101

On this website you can directly compare the mass spectra of four public SUSY computational tools: Isajet, Softsusy, Spheno and Suspect.

Theoretical background: JHEP03(2003)016 [hep-ph/0302102]

Note: At the moment, only the mSUGRA model is active.

>> error handling not yet implemented <<
>> please make sure you use a valid parameter point <<

mSUGRA input:	**m_0**	100	GeV
	m_1/2	250	GeV
	A_0	-100	GeV
	tan beta	10	(ca 1.6 - 50)
	sign(mu)	+1	
	m_t	175	GeV

Written by Sabine Kraml, last update 21 Mar 2003.
Many thanks to Peter Zemp for help with the script.