Determining SUSY models and their parameters with Fittino: Recent developments and future plans

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New physics at the LHC

- If Nature is gracious
  (from searchers' point of view),
  finding new physics might be the easy part
  (once detector is understood)

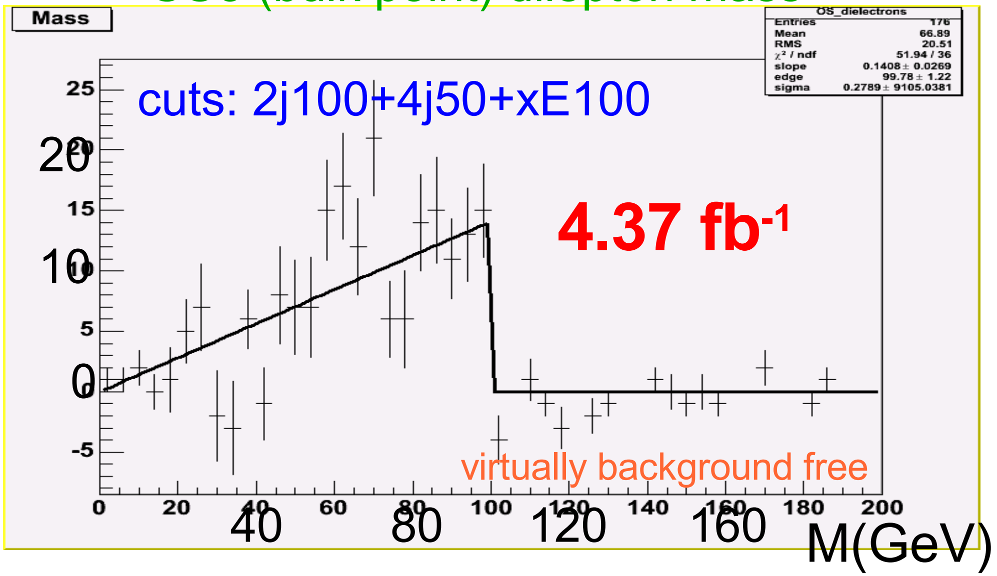
- Even if not so easy, it will be more challenging to determine underlying model of new physics
  (SUSY?, UED?, SUSY of which kind?)

- Moreover one would like to constrain parameters of the model

→ cf. efforts spent to determine SM parameters

In the following I will concentrate on SUSY

SU3 (bulk point) dilepton mass



The challenge

Even if model is "known": Lagrangian parameters ≠ observables

Need a procedure to connect observables to Lagrangian parameters within a certain theoretical framework

At tree level, some sectors (e. g. chargino, chargino+neutralino) can be treated separately.

At loop level, in principle every observable depends on every parameter.

Complicated mutual dependence of the various parameters.

Approximate picture:

$$\begin{bmatrix} P_1 \\ P_2 \\ \vdots \end{bmatrix} = \begin{bmatrix} \square & & 0 \\ & \square & \\ 0 & & \square \quad \ddots \end{bmatrix} \begin{bmatrix} O_1 \\ O_2 \\ \vdots \end{bmatrix}$$

Tree level

$$\begin{bmatrix} P_1 \\ P_2 \\ \vdots \end{bmatrix} = \begin{bmatrix} \square & & \neq 0 \\ & \square & \\ \neq 0 & & \square \quad \ddots \end{bmatrix} \begin{bmatrix} O_1 \\ O_2 \\ \vdots \end{bmatrix}$$

Loop level

Fittino

- C++ program to test different SUSY models and constrain their parameters (P. Bechtle, K. Desch, P. W., **`hep-ph/0412012`**)
- Code available at **`http://www-flc.desy.de/fittino`** (+ documentation, mailing list, etc.)
- Inputs specified using powerful input file syntax
- No *a priori* knowledge of parameters needed
- Alternative χ^2 minimisation techniques:
  - MINUIT
  - Simulated annealing
- Interface to SUSY spectrum calculator (SPheno, W. Porod) via SUSY Les Houches Accord
- Similar program: SFitter (R. Lafaye, T. Plehn, D. Zerwas, **`hep-ph/0404282`**)

Iterative approach

Experiment:

- Measured observables O_i^m
- Errors ΔO_i^m

Program output:

- SUSY parameters P_i
- Full error matrix V_{ij}

Compare

χ^2 fit: vary P_i

Tree level formulae:

Rough estimates for:

- Parameters P_i
- Errors ΔP_i

SUSY calculation package:

Calculated observables O_i^c

(including loop corrections)

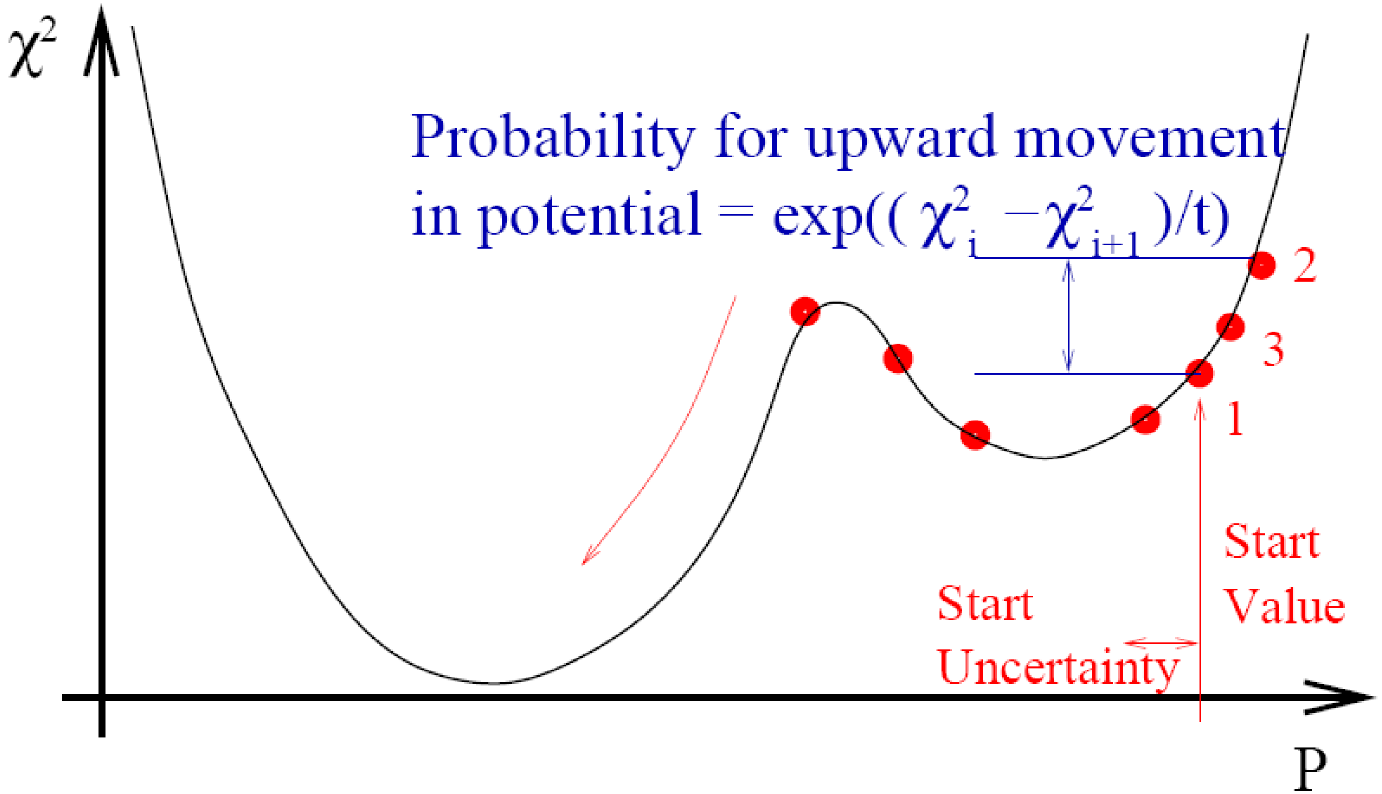
Fitting method

Fitting in high-dimensional space is a delicate business.

MINUIT turned out to be insufficient for minimisation (local minima) and error estimation (too complex correlations) for complicated fits, e. g. general (N)MSSM fits.

Simulated annealing has proven to be a robust algorithm.

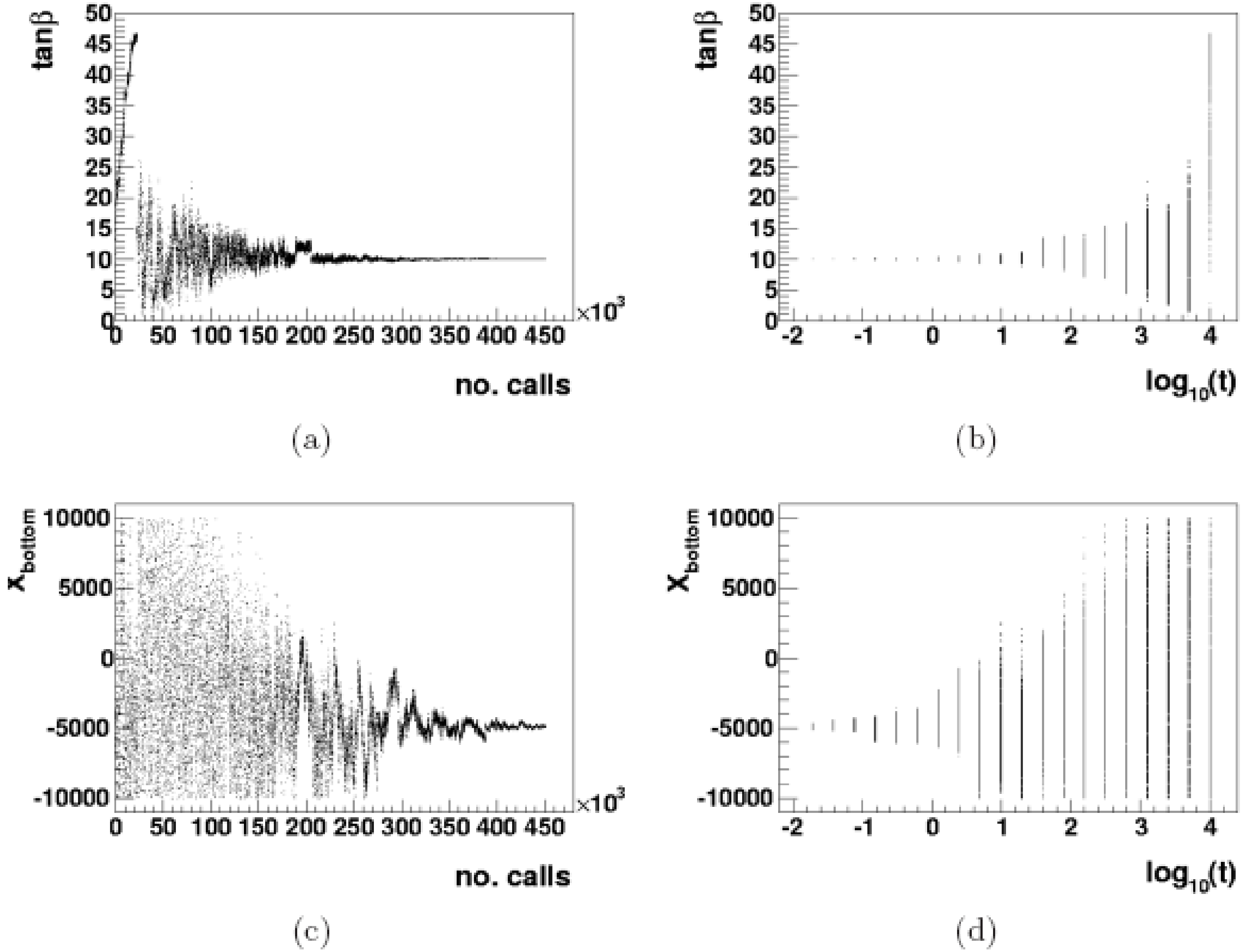
Simulated annealing



Fit strategy:

1. Simulated annealing minimization
2. MINUIT fit with start values from simulated annealing
3. Covariance matrix from many fits with smeared inputs

Simulated annealing in action



(a) (b)

(c) (d)

Possible fit models

Fittino fit models include:

- mSUGRA
- GMSB
- AMSB
- MSSM*
- NMSSM* (only in repository so far) NEW!

* without CP violation (phases = 0), no mixing between generations and no mixing within first two generations

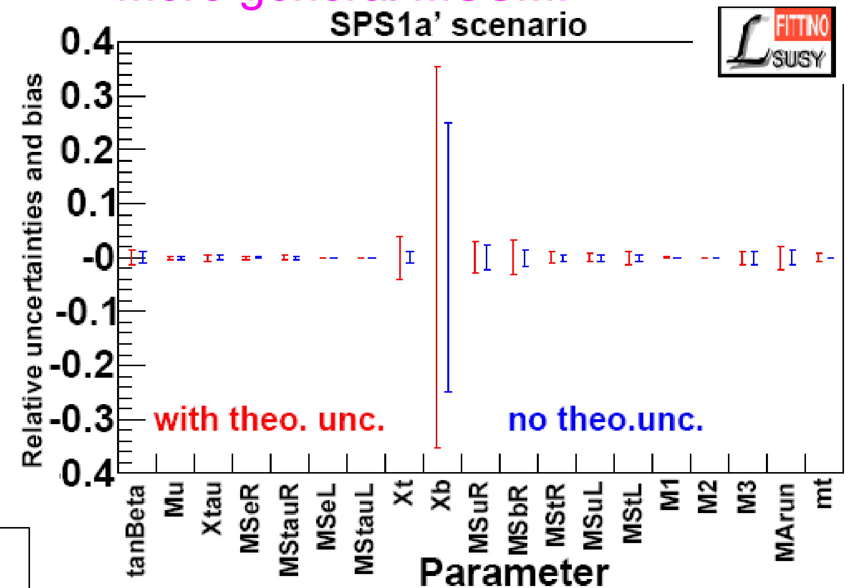
Past studies

Rather detailed analysis of what can be learned from combined LHC and ILC measurements
(P. Bechtle, K. Desch, W. Porod, P. W., **hep-ph/0511006**)

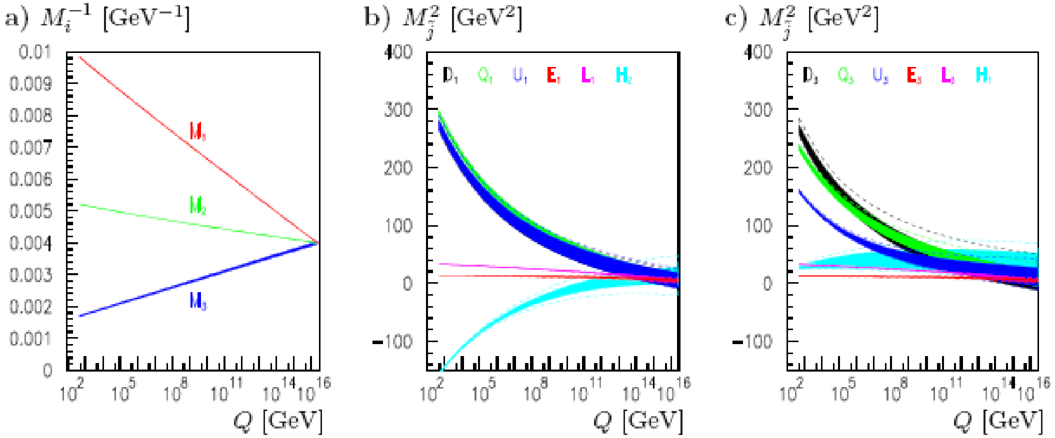
Imposing mSUGRA:

	SPS1a' value	Fitted value	$\Delta_{\text{LHC+ILC}}$	$\Delta_{\text{LHC only}}$
$\tan\beta$	10.000	10.000	0.036	1.3
M_0 (GeV)	70.000	70.000	0.070	1.4
$M_{1/2}$ (GeV)	250.000	250.000	0.065	1.0
A_0 (GeV)	−300.0	−300.0	2.5	16.6

More general MSSM:



Extrapolation of MSSM parameters at the electroweak scale to high scale ("bottom-up approach"):



and more ...

Ongoing studies

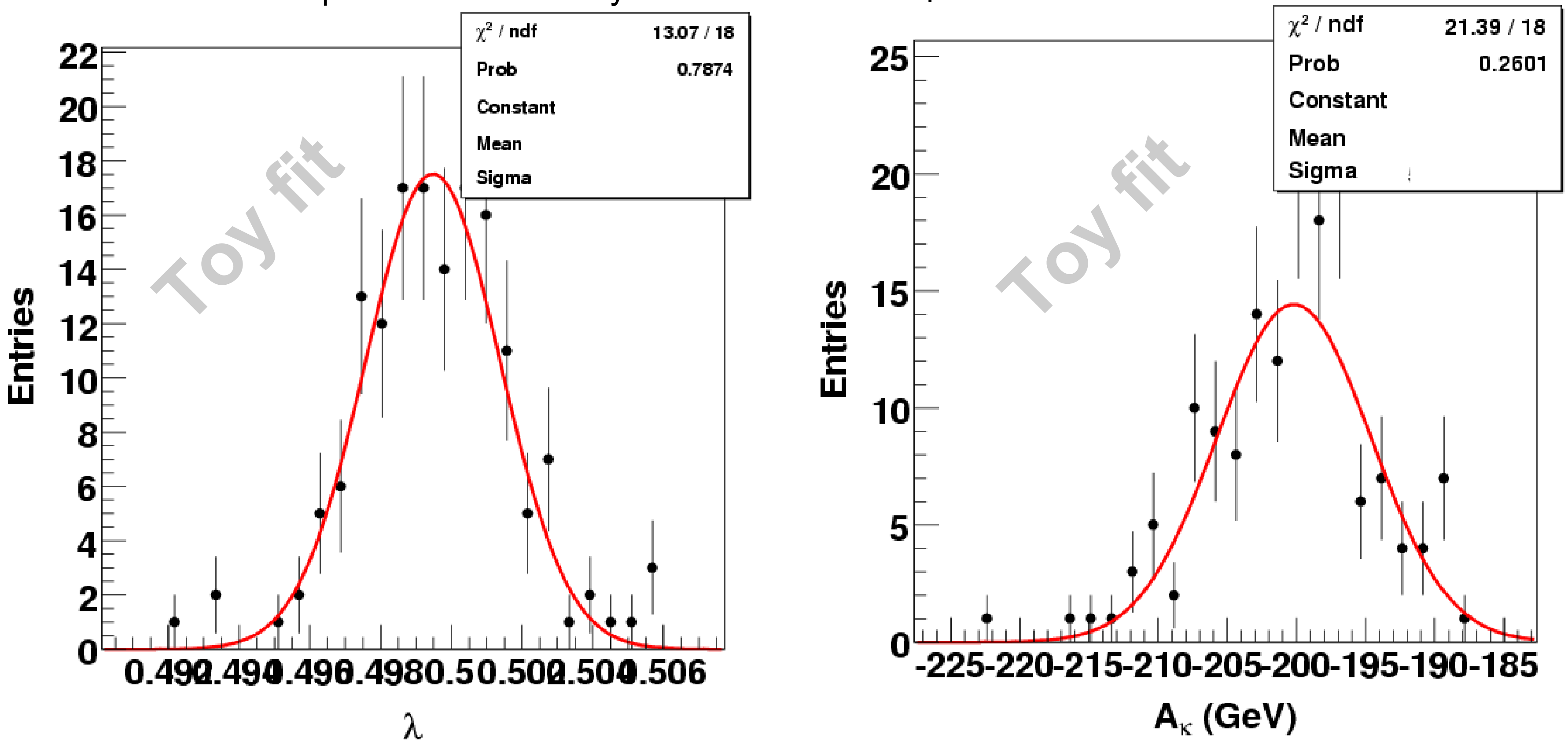
NMSSM vs. MSSM study:

- Recently extended Fittino to include NMSSM fit model
- Goal: Investigate discriminating power of LHC (and ILC) measurements to distinguish between NMSSM and MSSM (with S. Hesselbach and W. Porod)
- Chosen NMSSM scenario from **`hep-ph/0502036`**(has AMSB-like particle spectrum)
- Difficulties:
  - So far no experimental studies for such a scenario (to my knowledge)
  - Transferability of results from other studied parameter points unclear (more edges on top of each other, different neutralino couplings, danger of wrong assignments in Higgs and neutralino sector)

First results

Started with very few input observables, mostly guesses from **hep-ph/0502036**, and a small parameter set to test the fit machinery (do not draw any conclusions from the numerical results obtained with these inputs):

Distribution of fitted parameters for many individual fits with input observables smeared within uncertainties:



NMSSM fits work in Fittino

Next step: improve and extend list of input observables

Additional new features

- Included option to consider bounds on relic density in fits (interface to MicrOMEGAs)
- Inclusion of more low energy observables (like g-2, $b \to s\gamma$, ...) possible
- Ongoing work to take direct Higgs search limits into account in fits

Plans

Study bulk region scenario with more comprehensive and "realistic" LHC inputs:

- Better treatment of correlations between inputs (so far systematic uncertainties were treated as completely uncorrelated)
- Include more than the five "favourite" edges (e. g. add mass information about $\tilde{\chi}_1^{\pm}$,$\tilde{\chi}_2^{\pm}$, $\tilde{\chi}_4^0$, $\tilde{\ell}_L$, $\tilde{\tau}_1$ and $\tilde{\nu}$)
- Add information about (relative) rates, like e. g. $BR(\tilde{\chi}_2^0 \rightarrow \tilde{\ell}_R \ell)/BR(\tilde{\chi}_2^0 \rightarrow \tilde{\tau}_1 \tau)$

Conclusions

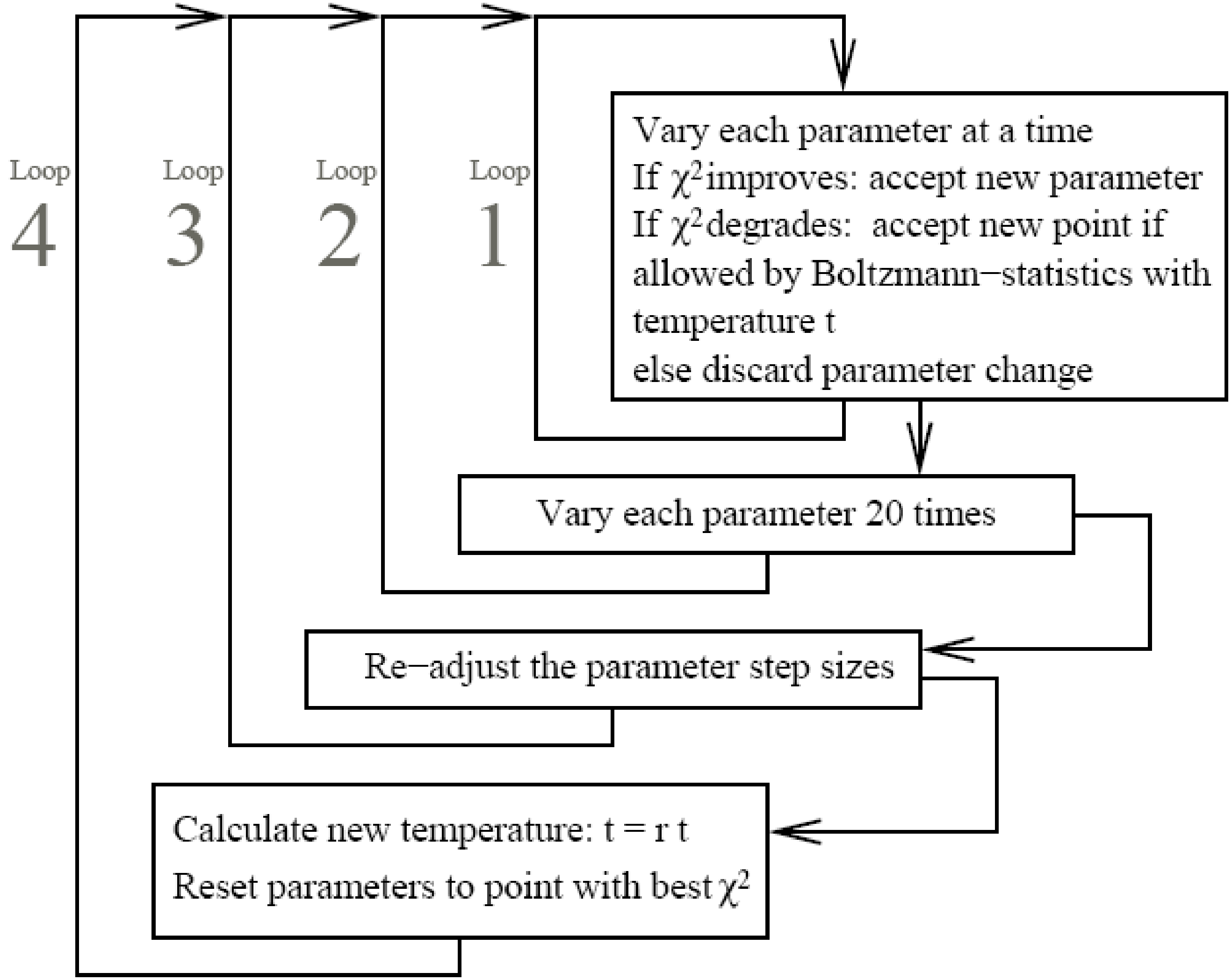
- Fittino provides a tool to test different SUSY models on a given set of measurements and to constrain the corresponding theory parameters from the available data
- It comprises already a rather broad spectrum of functions. Nevertheless its functionality is constantly being improved.
- Ongoing work to study discriminating power between different SUSY models and to use more realistic and comprehensive inputs for fits.
- We are eagerly awaiting to use Fittino with real data! :-)

BACKUP SLIDES

Fittino input file

```
# masses
massh0                   112.888 GeV +- 0.05 GeV +- 1.3 GeV
massNeutralino1          97.7662 GeV +- 0.05 GeV +- 0.4 GeV
massNeutralino2          184.345 GeV +- 0.08 GeV +- 1.2 GeV

# edges
edge 3 massNeutralino1 massSupL massNeutralino2   449.679 GeV +- 4.9 GeV +- 4.5 GeV alias 1

# cross sections
sigma ( ee -> Z h0, 500 GeV, -0.8, -0.6 )                  13.6286 fb +- 0.27 fb   alias  1
sigma ( ee -> Chargino1 Chargino1~, 500 GeV, -0.8, -0.6 )                          alias  2
sigma ( ee -> Neutralino1 Neutralino2, 500 GeV, -0.8, -0.6 )                       alias  3

# branching ratios
BR ( h0 -> Bottom Bottom~ )            0.7621 +- 0.019      alias 1
BR ( Chargino1 -> Stau1 Nutau )                             alias 2
BR ( Neutralino2 -> Stau1~ Tau )                            alias 3
BR ( Neutralino2 -> Stau1 Tau~ )                            alias 4

# sum of branching ratios
brsum ( br_3 br_4 )                                         alias 1

# topological cross sections
xsbr ( sigma_2 br_2 br_2 )         34.9838 fb +- 0.70 fb    alias 1
xsbr ( sigma_3 brsum_1 )           28.8158 fb +- 0.56 fb    alias 2

# many further options to provide inputs and steer fitting behavior
```

Simulated annealing scheme



SPS1a' fit

"General" MSSM fit using combined LHC and ILC inputs (see **hep-ph/0511006**):

Parameter	"True" value	Fit value	Uncertainty (exp.)	Uncertainty (exp.+theor.)
$\tan\beta$	10.00	10.00	0.11	0.15
μ	400.4 GeV	400.4 GeV	1.2 GeV	1.3 GeV
X_τ	−4449. GeV	−4449. GeV	20. GeV	29. GeV
$M_{\tilde{e}_R}$	115.60 GeV	115.60 GeV	0.13 GeV	0.43 GeV
$M_{\tilde{\tau}_R}$	109.89 GeV	109.89 GeV	0.32 GeV	0.56 GeV
$M_{\tilde{e}_L}$	181.30 GeV	181.30 GeV	0.06 GeV	0.09 GeV
$M_{\tilde{\tau}_L}$	179.54 GeV	179.54 GeV	0.12 GeV	0.17 GeV
X_t	−565.7 GeV	−565.7 GeV	6.3 GeV	15.8 GeV
X_b	−4935. GeV	−4935. GeV	1207. GeV	1713. GeV
$M_{\tilde{q}_R}$	503. GeV	504. GeV	12. GeV	16. GeV
$M_{\tilde{b}_R}$	497. GeV	497. GeV	8. GeV	16. GeV
$M_{\tilde{t}_R}$	380.9 GeV	380.9 GeV	2.5 GeV	3.7 GeV
$M_{\tilde{q}_L}$	523. GeV	523. GeV	3.2 GeV	4.3 GeV
$M_{\tilde{t}_L}$	467.7 GeV	467.7 GeV	3.1 GeV	5.1 GeV
M_1	103.27 GeV	103.27 GeV	0.06 GeV	0.14 GeV
M_2	193.45 GeV	193.45 GeV	0.08 GeV	0.13 GeV
M_3	569. GeV	569. GeV	7. GeV	7.4 GeV
$m_{A_{run}}$	312.0 GeV	311.9 GeV	4.3 GeV	6.5 GeV
m_t	178.00 GeV	178.00 GeV	0.05 GeV	0.12 GeV
Corresponding values for the trilinear couplings:				
A_τ	−445. GeV	−445. GeV	40. GeV	52. GeV
A_t	−526. GeV	−526. GeV	6. GeV	16. GeV
A_b	−931. GeV	−931. GeV	1184. GeV	1676. GeV
χ^2 for unsmeared observables: 2.1×10^{-5}				

NMSSM

Peccei-Quinn (PQ) symmetry breaking term
(to prevent unobserved massless Nambu-Goldstone boson)

NMSSM Superpotential:

$$W_{\text{NMSSM}} = \hat{Q}\hat{H}_u \mathbf{h_u} \hat{U}^C + \hat{H}_d \hat{Q} \mathbf{h_d} \hat{D}^C + \hat{H}_d \hat{L} \mathbf{h_e} \hat{E}^C + \lambda \hat{S}(\hat{H}_u \hat{H}_d) + \frac{1}{3}\kappa \hat{S}^3$$

extra scalar Higgs superfield (singlet)

Soft SUSY breaking Higgs sector described by

$$V_{\text{NMSSM}} = m_{H_u}^2 |H_u|^2 + m_{H_d}^2 |H_d|^2 + m_S^2 |S|^2 + \left(\lambda A_\lambda S H_u H_d + \frac{1}{3}\kappa A_\kappa S^3 + \text{h.c.} \right)$$

MSSM μ term replaced by interaction term ~ $\hat{S}\hat{H}_u\hat{H}_d$
Soft MSSM term ~ $B\mu H_u H_d$ replaced by term ~ $A_\lambda S H_u H_d$

Additional parameters in NMSSM:

Higgs couplings λ and κ, their associated soft SUSY breaking parameters A_λ and A_κ and $\mu_{eff} = \lambda \langle S \rangle$

Additional particles in NMSSM:

1 neutral scalar Higgs, 1 neutral pseudoscalar Higgs, 1 neutralino