Fittino: mapping measurements to SUSY theory parameters

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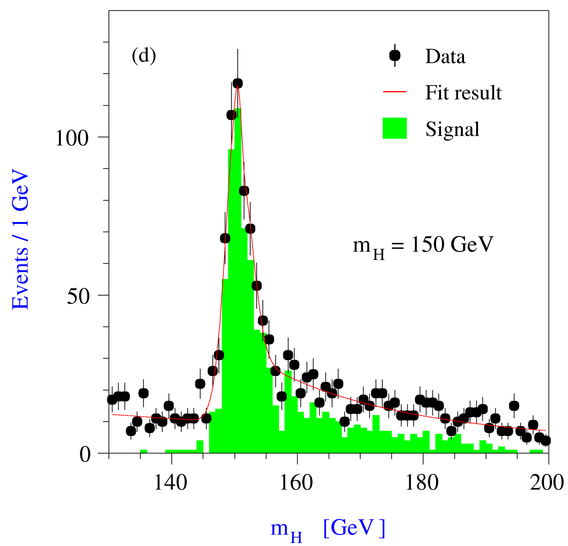
The task

Once SUSY has been established in experiments, Lagrangian parameters need to be extracted from measurements.

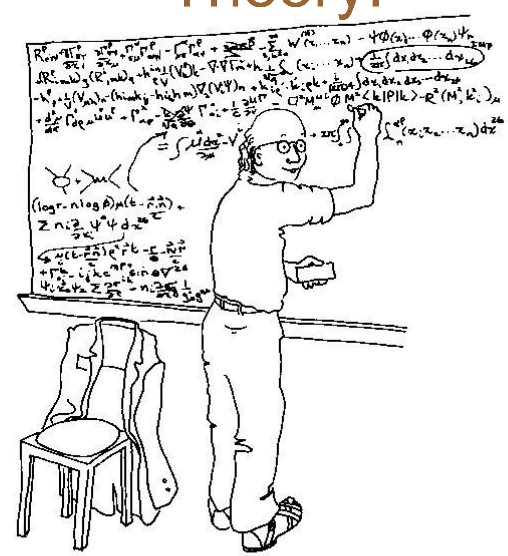
Stumbling block: Lagrangian parameters ≠ observables

Experiment:



Mapping

Theory:



Observables:

m(h)

BR(h→ gg)

$\sigma(e^+e^-\to\chi_1^+\chi_1^-)$ BR($\chi_1^+\to$Stau$_1$ ν) BR($\chi_1^-\to$Stau$_1$ ν)

etc.

Lagrangian parameters:

tan β

μ

M_1

etc.

The challenge

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 (not quite correct since non-linear mapping):

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

Tree level | Loop level

The solution: 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)

Fittino

- C++ program using described iterative method
- 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 minimization methods:
  - MINUIT
  - simulated annealing
- Interface to SUSY spectrum calculator (SPheno) via
  SUSY Les Houches Accord
- Similar program: SFitter $\rightarrow$ next talk

Fittino input file syntax

```
# 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
```

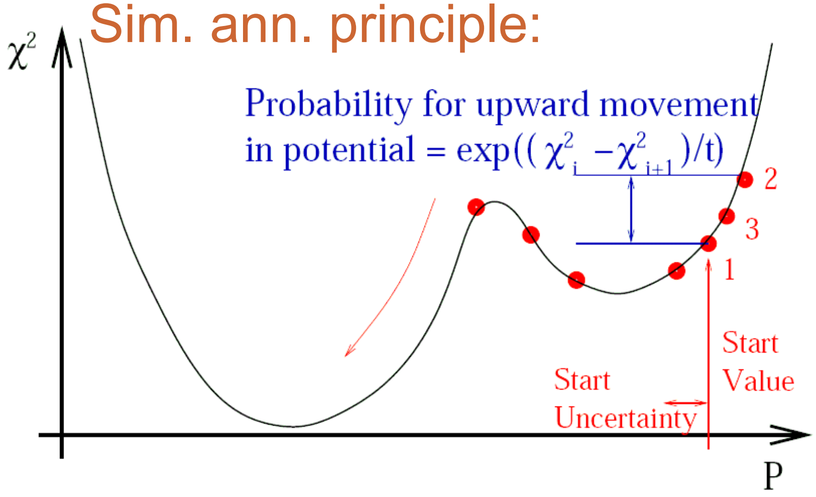
Simulated annealing

Fitting in high-dimensional space is a delicate business.

In some cases, MINUIT turned out to be insufficient for minimization (local minima) and error estimation (too complex correlations).

Simulated annealing has proven to be a robust algorithm.

Sim. ann. principle:



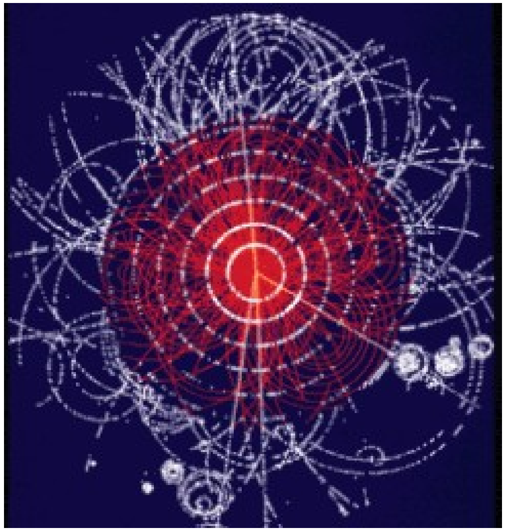
Fit strategy:

1. Sim. ann. minimization
2. MINUIT fit with start values from sim. ann.
3. Covariance matrix from many fits with smeared inputs

Disadvantage: CPU intensive

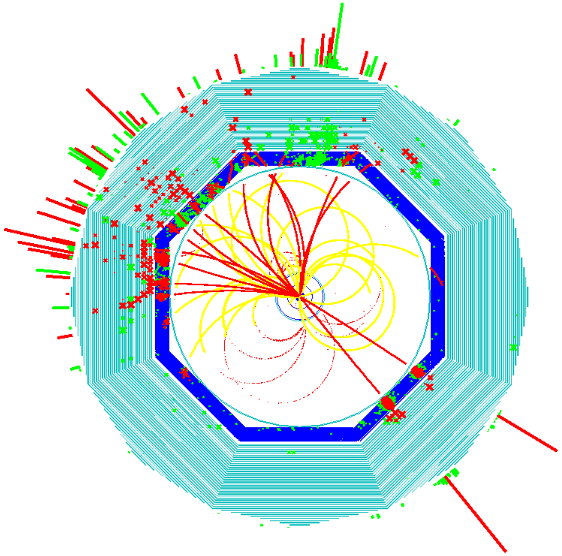
(but these days we have the grid!)

Colliders to explore SUSY



Large Hadron Collider (LHC):

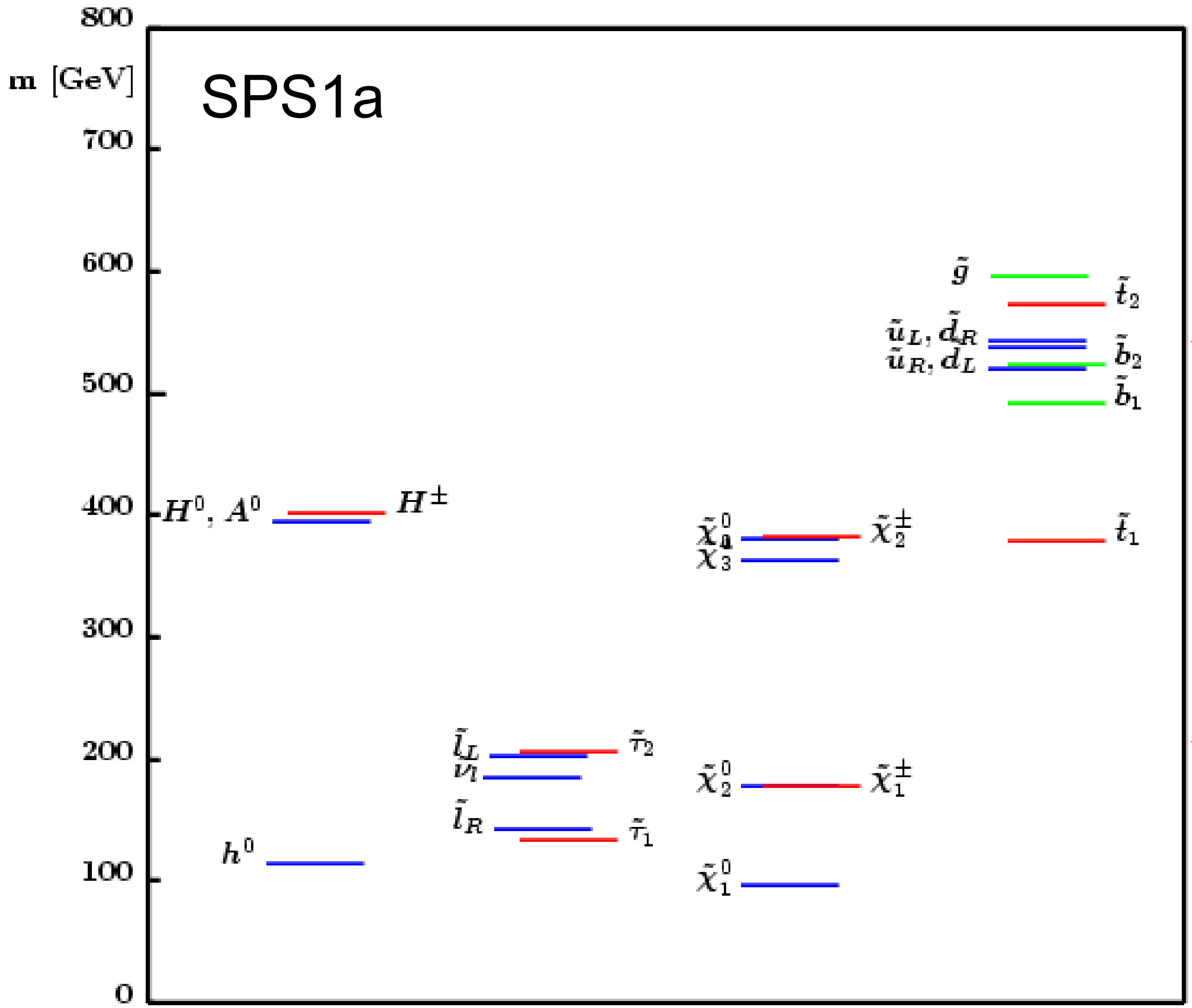
- high mass reach (several TeV) for squarks+gluinos
- colorless sparticles mainly through cascades
- modest accurary on masses 1-10 %
- rates subject to QCD/PDF uncertainties



International Linear Collider (ILC):

- precise spectroscopy: masses 0.1-1 % up to $\sum m = 1$ TeV
- polarized cross-sections usable: ~ 1 %

An example spectrum



well measurable at LHC

precise spectroscopy at ILC

Some Fittino results

Used Fittino to determine precision of SUSY Lagrangian parameters from LHC and ILC measurements

Input observables:

- masses from LHC (edges) and ILC
- polarized σ_{e+e-} at 400, 500 and 1000 GeV
- polarized σ_{e+e-} x BR at 400, 500 and 1000 GeV
- BR

All the details concerning the following results can be found in:

P. Bechtle, K. Desch, W. Porod, P. W.
hep-ph/0511006

Fit assumptions

Without assuming a certain SUSY breaking scenario, the MSSM contains 105 parameters (masses, phases, mixing angles)

$\rightarrow$ infeasible to determine all of them
(technical difficulties, lack of sensitive observables)

Simplifying assumptions:

- no CP violation (all phases = 0)
- no mixing between generations
- no mixing within first two generations
- universality of same type sfermion mass parameters in first two generations

$\Rightarrow$ 18 SUSY parameters remain

MSSM fit

General MSSM fit:
No assumption on SUSY breaking in the fit

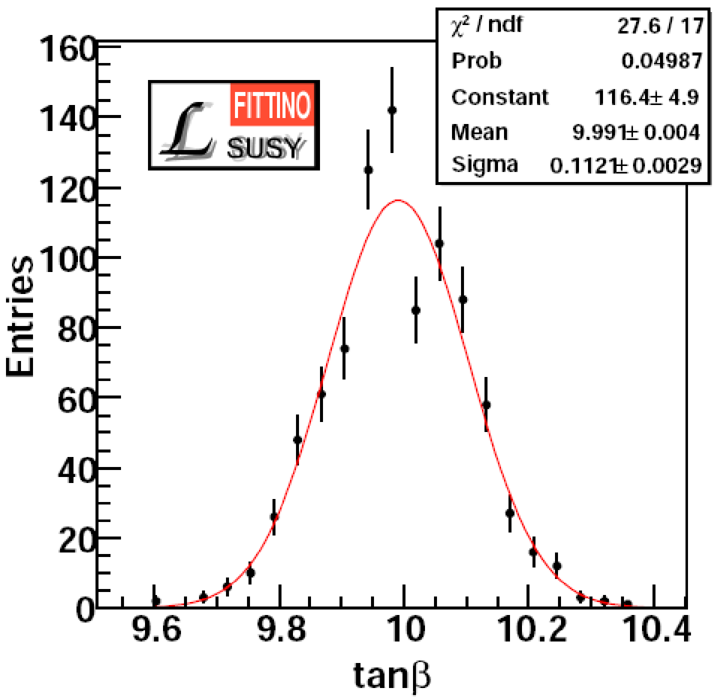
Fit LE parameters to data and learn about SUSY breaking from extrapolation to high scale ("bottom-up approach")

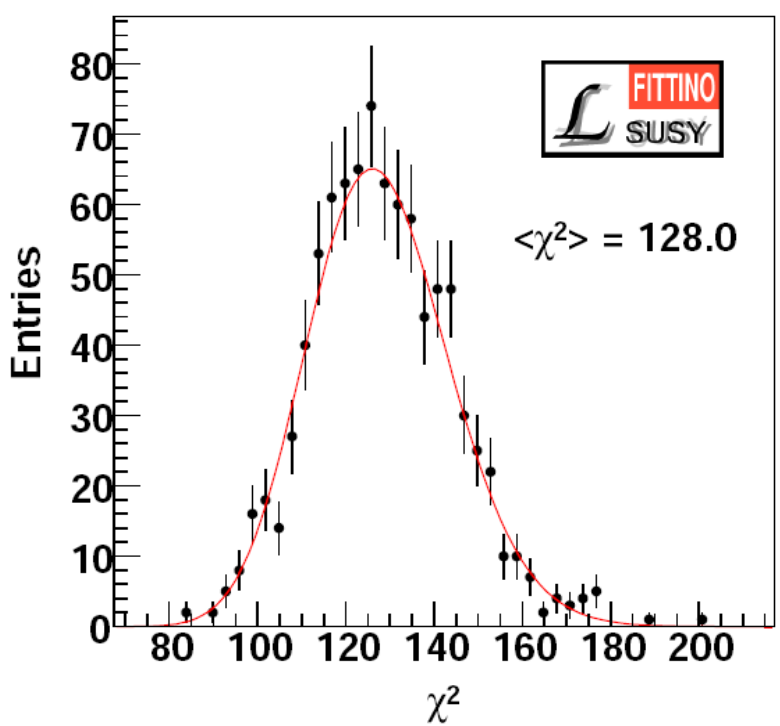
Requires many precision measurements. Only possible with combined LHC and ILC inputs.

18 SUSY parameters ($\rightarrow$ previous slide) + m_{top} fit performed for SPS1a' inspired scenario (Definition: `http://spa.desy.de/spa`)

MSSM fit uncertainties

Due to occasionally unreliable MINOS behavior, fit uncertainties are determined from ~ 1000 individual fits with smeared input values

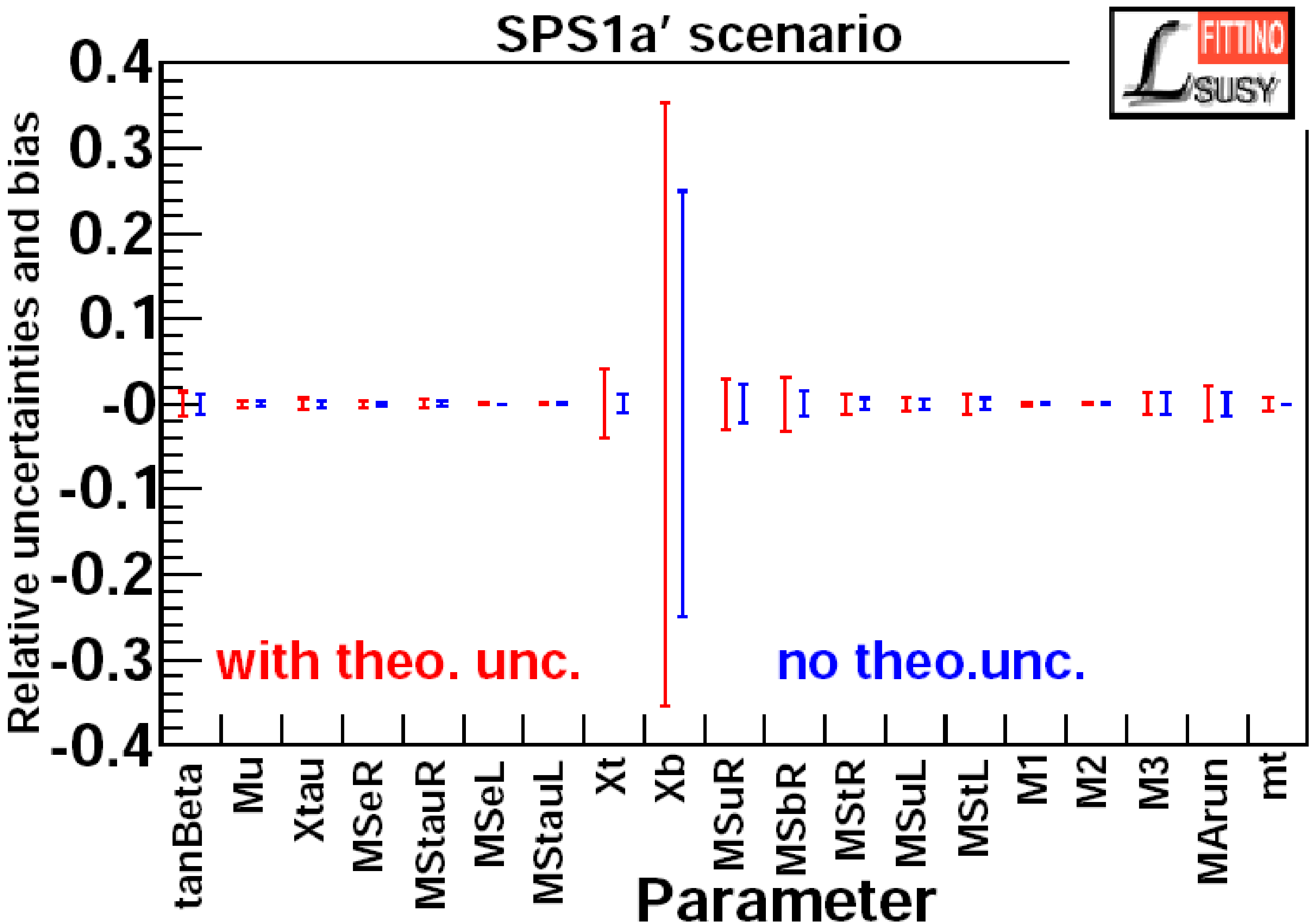




χ^2 distribution of the ~ 1000 fits

expectation: 129.0 ± 0.7

MSSM fit


SPS1a′ scenario
FITTINO
SUSY
Relative uncertainties and bias
0.4
0.3
0.2
0.1
-0
-0.1
-0.2
-0.3
-0.4
with theo. unc.
no theo.unc.
tanBeta
Mu
Xtau
MSeR
MStauR
MSeL
MStauL
Xt
Xb
MSuR
MSbR
MStR
MSuL
MStL
M1
M2
M3
MArun
mt
Parameter

MSSM fit

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
$m_{\mathrm{A_{run}}}$	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}				

< 2 %

$$X_{\mathrm{t}} = A_{\mathrm{t}} - \mu/\tan\beta$$
$$X_{\mathrm{b}} = A_{\mathrm{b}} - \mu\tan\beta$$
$$X_\tau = A_\tau - \mu\tan\beta$$

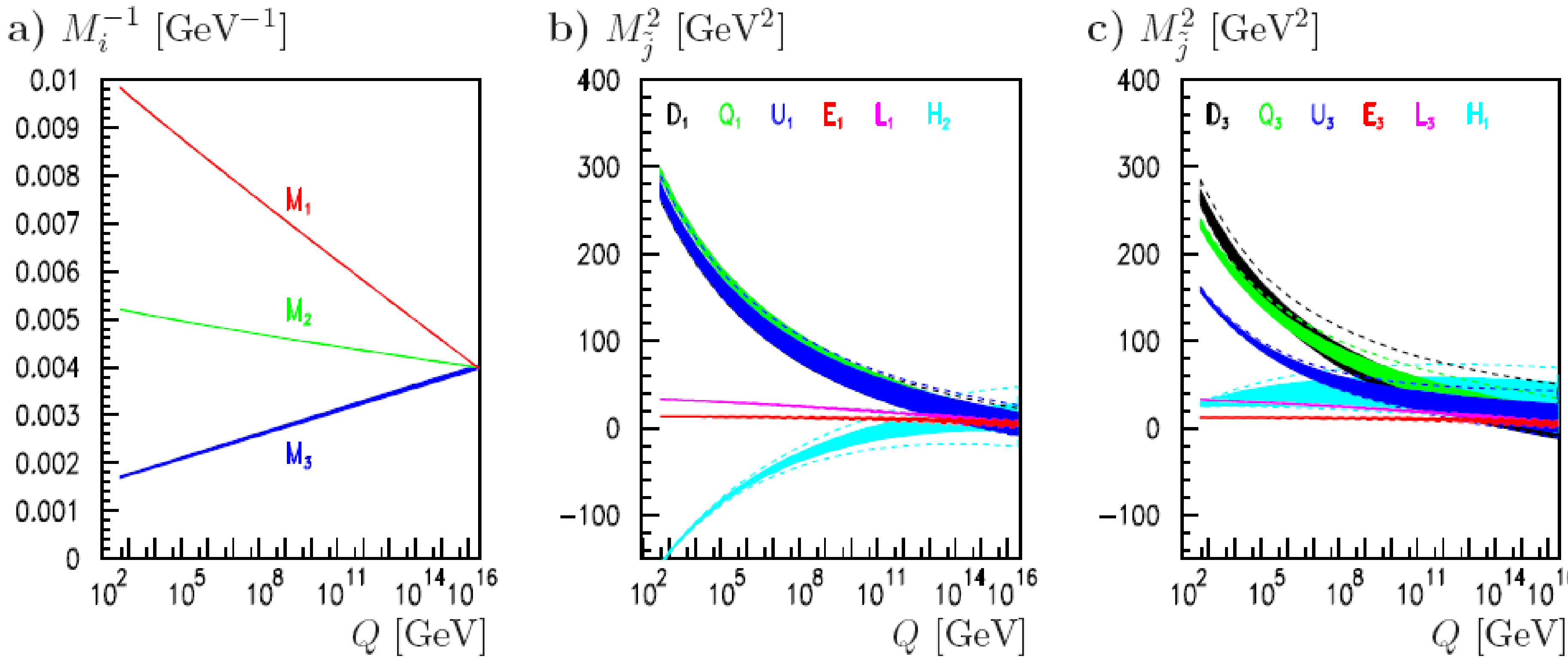
significant impact
of theory uncertainties

< 0.1 %

> 125 %

Extrapolation to high scale

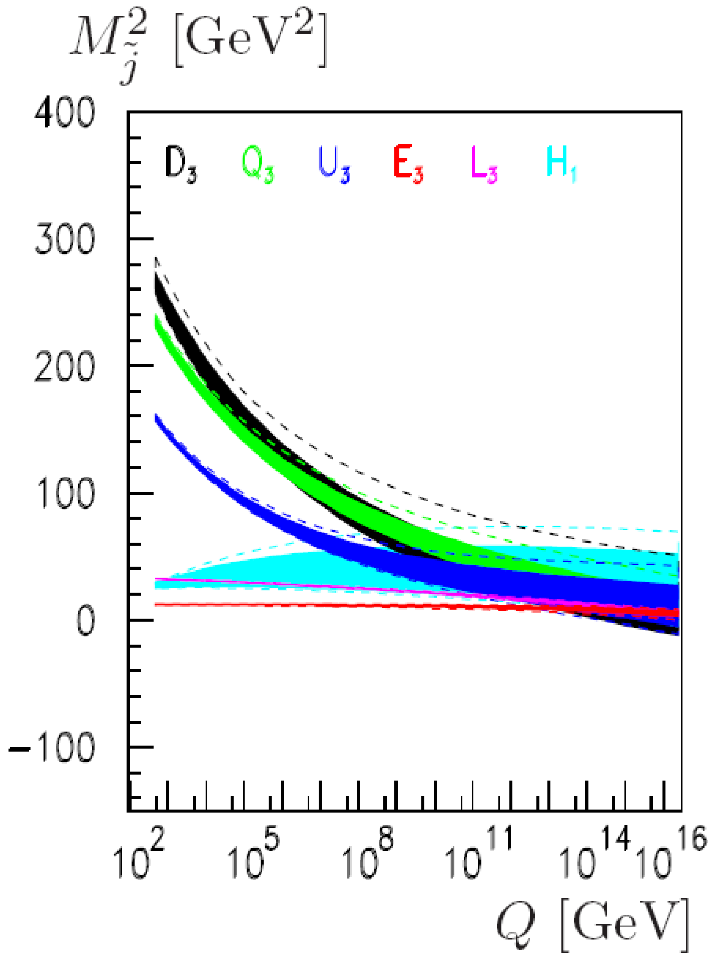
Use fitted LE parameters and extrapolate to the high scale using RGE:



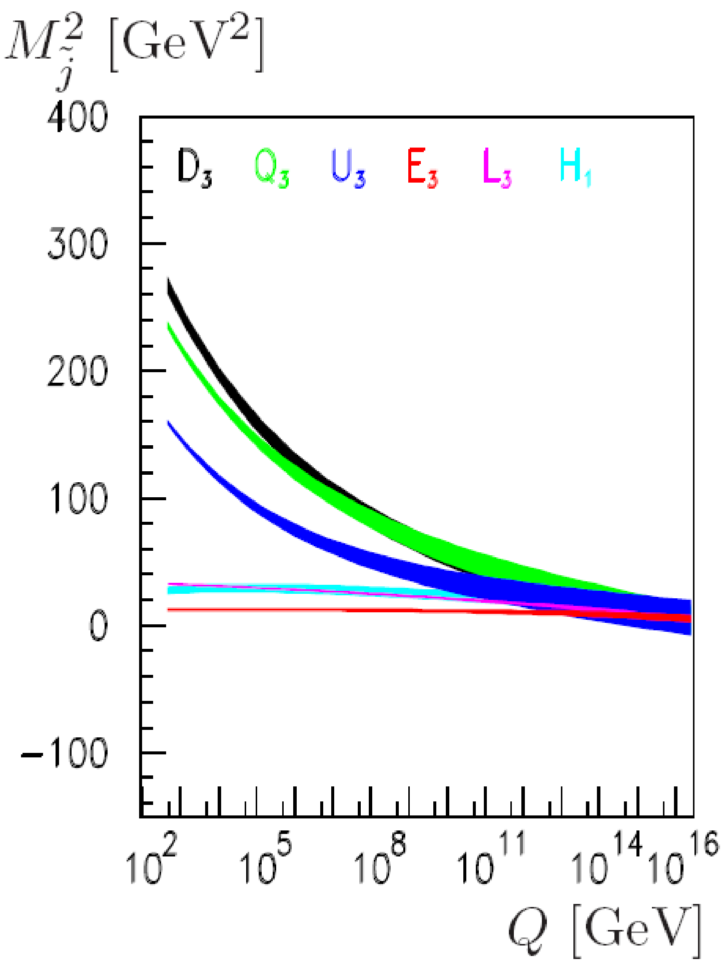
Compare behavior with expectations from SUSY breaking models

Extrapolation to high scale

130 % / 180 % A_b precision:



50 % A_b precision:



A_b sensitive observables are needed

mSUGRA fit

If results from bottom-up approach point to an mSUGRA SUSY breaking mechanism, mSUGRA parameters can be fitted directly to the LE data.

Only 4½ parameters: tan β, m_0, $m_{½}$, A_0, sign(μ)

	SPS1a' value	Fitted value	$\Delta_{LHC+ILC}$	$\Delta_{LHC\ only}$
$\tan\beta$	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

sign(μ) fixed

Summary

- With Fittino a powerful tool is available to extract SUSY parameters from collider observables.
- LHC and ILC nicely complement one another to pin down the SUSY model. Stringent checks rely on inputs from both machines.
- Most parameters can be determined to the percent level, some can be measured even more precisely.
- In order to fully benefit from ILC precision, theoretical uncertainties need to be reduced.
- A_b sensitive observables are needed to improve precision.
- We are eagerly awaiting data from LHC and ILC.

Outlook

- Comparison study SFitter - Fittino:
  Run both programs with exactly the same inputs and compare output.
- Enhance Fittino functionality to enable NMSSM parameter fits.