

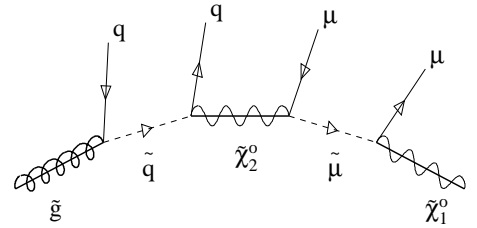
# MEASURING THE MSSM LAGRANGEAN

Tilman Plehn

CERN

- Jets in SUSY cascades: S**Mad**graph
- SUSY Parameter Studies: S**fitter**

# SUSY MEASUREMENTS AT LHC: 1



## SUSY spectra from cascade decays

- ★ decay  $\tilde{g} \rightarrow \tilde{q}\bar{q} \rightarrow \tilde{\chi}_2^0 q\bar{q} \rightarrow \mu^+ \mu^- q\bar{q} \tilde{\chi}_1^0$  [hopefully not via  $Z$ ]
  - ★ cross sections some 100 pb [more than  $3 \times 10^5$  events]
  - ★ thresholds & edges in spectra [Allanach, Lester, Parker, Webber]  
 classic example:  $m_{\ell\ell}^2 < (m_{\tilde{\chi}_2^0}^2 - m_{\tilde{\ell}}^2)(m_{\tilde{\ell}}^2 - m_{\tilde{\chi}_1^0}^2)/m_{\tilde{\ell}}^2$   
 critical: enough thresholds and edges for all masses?
- ⇒ detector resolution, calibration, systematic errors?

## Studies for SPS points

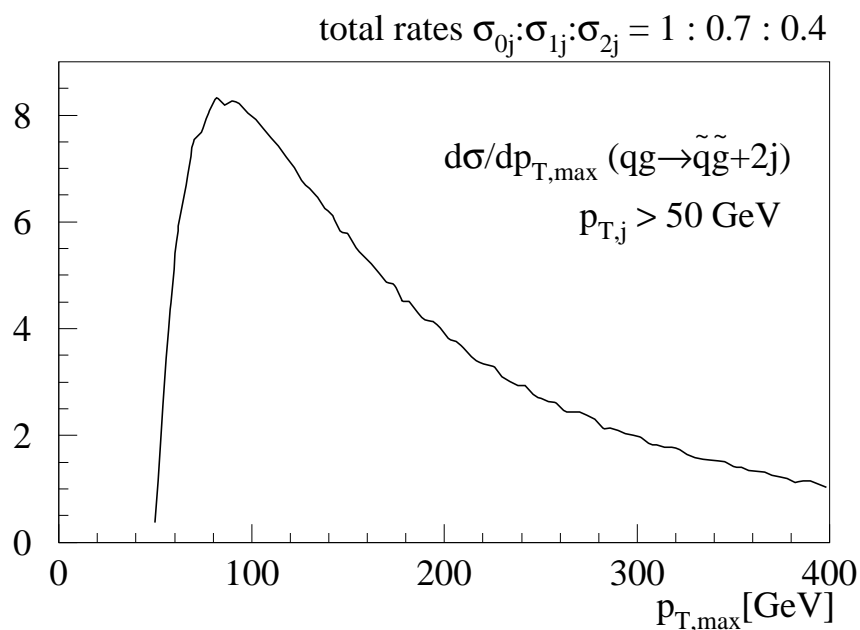
- ★ gluino mass in  $\tilde{g} \rightarrow \tilde{b}\bar{b}$
  - ★ higgsino masses in  $\tilde{q}_L \rightarrow q\tilde{\chi}_4^0, \tilde{q}_L \rightarrow \tilde{\chi}_2^\pm q$
  - ★ chargino mass in  $\tilde{q} \rightarrow q\tilde{\chi}_1^\pm \rightarrow qW_{\text{had}}^\pm \tilde{\chi}_1^0$  [Nojiri, Polesello, Tovey]
  - ★ slepton mass in  $\tilde{\ell} \rightarrow \ell\tilde{\chi}_1^0$
  - ★ ....
- ⇒ generic for small  $\tan\beta$   
 problems with  $b$ -jets und  $\tau$ -leptons for large  $\tan\beta$
- ⇒ **essentiel for SUSY parameters** [SFitter results 2 pages down]

# SUSY MEASUREMENTS AT LHC: 2

## Problem in decay studies

- ★ typical cuts:  $p_{T,j} > 150, 100, 50, 50$  GeV  
courageous analyses:  $p_{T,j} > 100, 100, 40, 20$  GeV
  - ★ (a) cuts on  $p_{T,j}$  hierarchy?  
⇒ background matrix elements e.g.  $pp \rightarrow ZZ + \text{hard jets}$
  - ★ (b) combinatorical background in cascades?  
⇒ matrix elements  $pp \rightarrow X_{\text{SUSY}} Y_{\text{SUSY}} + \text{hard jets}$
  - ★ good experience for Higgs+jets [Zeppenfeld, Rainwater, TP]
- ⇒ **SMadgraph** [Hagiwara, Kanzaki, TP, Rainwater, Stelzer]

## Additional jets from $\tilde{q}\tilde{g}$ matrix element [problem for decay cascade?]



# PARAMETER DETERMINATION AT LHC: 1

## Theorist's point of view

- ★ measured masses, cross sections, decays secondary
  - ★ parameters in SUSY Lagrangean from measurements
- ⇒ SUSY breaking parameters at scale  $M_{\text{TeV}}$

## Warmup exercise: Suga fit using SFitter

- ★ fit including theoretical errors on masses [ $h^0$ : 3 GeV, weak: 1%, strong: 3%]

	SPS1a	$\Delta_{\text{LHC}}^{\text{stat}}$	$\Delta_{\text{LHC}}^{\text{stat+theo}}$	$\Delta_{\text{LC}}^{\text{stat}}$	$\Delta_{\text{LC}}^{\text{stat+theo}}$	$\Delta_{\text{LHC+LC}}^{\text{stat}}$	$\Delta_{\text{LHC+LC}}^{\text{stat+theo}}$
$m_0$	100	4.0	4.7	0.09	0.6	0.08	0.6
$m_{1/2}$	250	1.8	2.6	0.13	0.6	0.11	0.5
$\tan \beta$	10	1.3	3.5	0.14	0.3	0.14	0.4
$A_0$	-100	31.8	32.4	4.43	8.5	4.23	12.6

- ★ spectrum from Suspect [Djouadi, Kneur]
- fit Suspect and Softsusy [Allanach]

LHC	Suspect	$\Delta$	Softsusy	$\Delta$
$m_0$	100.00	4.7	97.9	4.6
$m_{1/2}$	250.00	2.7	252.5	2.9
$\tan \beta$	10.00	3.5	11.6	3.6
$A_0$	-99.96	32.4	14.7	58.9
LC	Suspect	$\Delta$	Softsusy	$\Delta$
$m_0$	99.94	0.61	98.7	0.5
$m_{1/2}$	250.52	0.58	250.7	0.7
$\tan \beta$	10.26	0.35	10.1	0.5
$A_0$	-90.15	8.54	-45.2	15.1
LHC+LC	Suspect	$\Delta$	Softsusy	$\Delta$
$m_0$	100.0	0.59	98.4	0.7
$m_{1/2}$	249.99	0.49	254.3	0.8
$\tan \beta$	9.99	0.44	7.3	0.3
$A_0$	-100.1	12.6	902.0	18

⇒ best way to estimate theory errors?

## PARAMETER DETERMINATION AT LHC: 2

### Problem with SUGRA fit

- ★ example: gaugino mass unification major SUGRA feature
- ★ gluino missing at LC, only seen at LHC

	SPS1a	LHC	LC	LHC+LC		SPS1a	LHC	LC	LHC+LC
$\chi_1^0$	97.03	4.8	0.05	0.05	$\chi_2^0$	182.9	4.7	1.2	0.08
$\chi_3^0$	349.2		4.0	4.0	$\chi_4^0$	370.3	5.1	4.0	2.3
$\chi_1^\pm$	182.3		0.55	0.55	$\chi_2^\pm$	370.6		3.0	3.0
$\tilde{g}$	615.7	8.0		6.5					
$\tilde{t}_1$	411.8		2.0	2.0					
$\tilde{b}_1$	520.8	7.5		5.7	$\tilde{b}_2$	550.4	7.9		6.2
$\tilde{q}_R$	551.0	19.0		16.0	$\tilde{q}_L$	570.8	17.4		9.8
$\tilde{e}_1$	144.9	4.8	0.05	0.05	$\tilde{e}_2$	204.2	5.0	0.2	0.2
$\tilde{\mu}_1$	144.9	4.8	0.2	0.2	$\tilde{\mu}_2$	204.2	5.0	0.5	0.5
$\tilde{\tau}_1$	135.5	6.5	0.3	0.3	$\tilde{\tau}_2$	207.9		1.1	1.1
$\tilde{\nu}_e$	188.2		1.2	1.2					

⇒ SUGRA fit to LC  $\Delta m_{1/2} = 0.6 \text{ GeV}$

SUGRA fit to LHC+LC  $\Delta m_{1/2} = 0.5 \text{ GeV}$

⇒ **what is data and what are model assumptions?**

⇒ stick to honest weak-scale MSSM fits if possible

⇒ need a proper fitting tool...

# PARAMETER DETERMINATION AT LHC: 3

## SUSY parameters from observables

- ★ **parameters:** weak-scale MSSM Lagrangean
- ★ **measurements:** masses [Suspect, Softsusy, FeynHiggs...]  
branching fractions [MSMlib, Sdecay]  
cross sections [Prospino, MSMlib]  
edges & thresholds  
additional measurements trivial to add
- ★ **errors:** general correlation, statistics & systematics & theory
- ★ problem in grid: huge phase space, local minimum?  
problem in fit: domain walls, starting values, global minimum?

## Sfitter [Lafaye, TP, D. Zerwas, also Fittino]

### (1) sfit\_model.h

```
// Select model : MSUGRA GMSB AMSB pMSSM pMSSM-HighScale
MODEL = MSUGRA
SUSY = SUSPECT
// pre-fit/SCAN
GRID = 0
//Parameters for MSUGRA - Only sign of MU matters
M0 = 500. [G/M] STEP=20. LOW=0. HIGH=1000. GRID=10
```

### (2) sfit\_data.h

```
#include "../inc/sfitter_msmcom.h"
#include "../inc/sfitter_prospino.h"
// Automatically smear data measurements with a gaussian
SMEAR = 1
// Higgs masses
MASS(m_h,IMH01) = 111.6 +/- 3.50 [-/M]
// Correlations
//CORR(m_chi+_1,m_chi+_2) = 0.03
```

⇒ **general fitting tool, completely modular**

⇒ soon public: <http://sfitter.web.cern.ch>

# PARAMETER DETERMINATION AT LHC: 4

## Fit of weak-scale MSSM

- (1) **grid** for part of measurements and parameters [neutralino/chargino sector]
- (2) **fit** of all other parameters to all measurements
- (3) **fit** of complete system with these starting values

## Results without theoretical errors

	LHC	LC	LHC+LC	SPS1a
$\tan \beta$	10.22±9.1	10.26±0.3	10.06±0.2	10
$M_1$	102.45±5.3	102.32±0.1	102.23±0.1	102.2
$M_2$	191.8±7.3	192.52±0.7	191.79±0.2	191.8
$M_3$	578.67±15	<b style="color: red;">fix 500</b>	588.05±11	589.4
$m_A$	<b style="color: red;">fix 500</b>	399.1±0.9	399.1±0.8	399.1
$\mu$	345.21±7.3	344.34±2.3	344.36±1.0	344.3
$M_{\tilde{\tau}_L}$	<b style="color: red;">fix 500</b>	197.68±1.2	199.25±1.1	197.8
$M_{\tilde{\tau}_R}$	129.03±6.9	135.66±0.3	133.35±0.6	135.5
$M_{\tilde{\mu}_L}$	198.7±5.1	198.7±0.5	198.7±0.5	198.7
$M_{\tilde{\mu}_R}$	138.2±5.0	138.2±0.2	138.2±0.2	138.2
$M_{\tilde{q}_{3L}}$	498.3±110	497.6±4.4	521.9±39	501.3
$M_{\tilde{t}_R}$	<b style="color: red;">fix 500</b>	420±2.1	411.73±12	420.2
$M_{\tilde{b}_R}$	522.26±113	<b style="color: red;">fix 500</b>	504.35±61	525.6
$A_\tau$	<b style="color: red;">fix 0</b>	-202.4±89.5	<b style="color: red;">352.1±171</b>	-253.5
$A_t$	-507.8±91	-501.95±2.7	<b style="color: red;">-505.24±3.3</b>	-504.9
$A_b$	-784.7±35603	<b style="color: red;">fix 0</b>	<b style="color: red;">-977±12467</b>	-799.4

⇒ **all but LHC+LC not without model assumptions** [additional measurements?]

# OUTLOOK

## SUSY signals at LHC [talk by Michael Spira]

- ★ measurement of rates and decays first step
- ★ NLO cross sections using public code **Prospino2.0**

## SUSY measurements at LHC

- ★ final state with jets essential [Higgs at LHC]
- ★ hard matrix elements using **SMadgraph**
- ★ analysis of cascade decays promising strategy

## SUSY parameters at LHC

- ★ SUSY observables secondary for theorists
- ★ determination of SUSY parameters using **Sfitter**
- ★ combination of experiments vital