SUSY parameter determination with SFITTER

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Introduction

SFITTER is designed to be a tool to determine SUSY parameters from experimental measurements

Started in the GDR and as a project in Les Houches 2003

Languages used: C++, C and Fortran

Different approaches used:

- analytical calculations (J.-L. Kneur et al., J. Kalinowski et al.)
- calculating model sets and interpolating (G. Polesello)
- fitting: FITTINO (P. Bechtle and P. Wienemann)

Difficulties:

- many parameters, e.g. MSSM

$\rightarrow$ not so good for a GRID (CPU-time), slightly better for fit

- starting point dependence of fit

$\rightarrow$ fit by starting values could be confined to a "wrong" region or biased to the "right region", GRID is less biased

SFITTER uses both approaches and allows to combine them

Complete use:

1. GRID (subset of parameters with subset of measurements) others fixed
2. GRID parameters fixed and non-GRID parameters fit
3. fit of all parameters

Caveat: for the GRID separable subset of parameters and measurements, e.g. in the MSSM neutralino and chargino masses for M1, M2, μ, $\tan\beta$

SFITTER

Backbone of SFITTER are

- SUSPECT for the mass calculations
- MSMlib for branching ratios and e^+e^- cross sections
- Prospino2.0 NLO for pp cross sections
- MINUIT

Long term: be able to use different calculations/tools such a SDECAY, SoftSUSY, etc

In practice
driven by sfit_params.in

```
// Select model : MSUGRA GMSB AMSB pMSSM pMSSM-HighScale
MODEL = MSUGRA
// 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
M1/2 = 500. [G/M] STEP=50. LOW=0. HIGH=1000. GRID=10
TANB = 50. [G/M] STEP=20. LOW=0. HIGH=100. GRID=10
A0 = 0. [G/M] STEP=200. LOW=-1000. HIGH=1000. GRID=20
SGNMU = 1. [-/-] STEP=0 LOW=1. HIGH=1.
```

and sfit_data.in

```
// Automatically set data error to 0.5%
DATA_ERR = 0.005
// Automatically smear data measurements with a gaussian
SMEAR = 0
// Higgs masses
m_h = 111.6 +/- 11.16 [-/M]
// neutralino masses
m_chi+_1 = 182.3 +/- 18.23 [G/M]
m_chi0_1 = 97.03 +/- 97.03 [G/M]
// Correlations
//CORR(m_chi+_1,m_chi+_2) = 0.03
```

Data Sets SPS1a by G. Blair, G. Polesello et al.

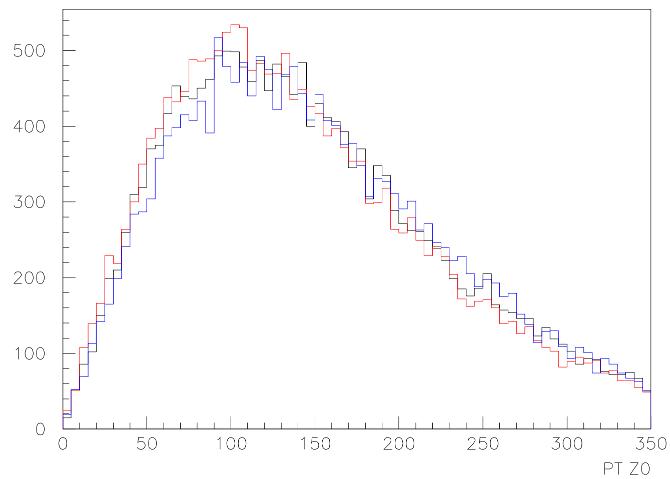
Scope of the analysis:
central value of all masses of SPS1a MSUGRA by SUSPECT
theoretical errors zero
no correlations between measurements

Particle	mass	DATA SetLHC	DATA Set LC	DATA Set LHCLC
h	111.6	0.1	0.05	0.05
A	399.1		1.5	1.5
H	399.6		1.5	1.5
H+	407.1		1.5	1.5
χ_1	97.03	4.8	0.05	0.05
χ_2	182.9	4.7	1.2	0.08
χ_4	370.3	5.1		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		6.4
$\tilde{t}_1$	411.8		2.0	2.0
$\tilde{b}_1$	520.8	7.5		5.7
$\tilde{b}_2$	550.4	7.9		6.2
$\tilde{c}_1$	551.0	23.6		23.6
$\tilde{c}_2$	570.8	17.4		9.8
$\tilde{u}_1$	551.0	23.6		23.6
$\tilde{u}_2$	570.8	17.4		9.8
$\tilde{s}_1$	549.9	23.6		23.6
$\tilde{s}_2$	576.4	17.4		9.8
$\tilde{d}_1$	549.9	23.6		23.6
$\tilde{d}_2$	576.4	17.4		9.8
$\tilde{\tau}_1$	135.5	8.6	0.3	0.3
$\tilde{\tau}_2$	207.9		1.1	1.1
$\tilde{\mu}_1$	144.9	4.8	0.2	0.2
$\tilde{\mu}_2$	204.2	5.0	0.5	0.5
$\tilde{e}_1$	144.9	4.8	0.05	0.05
$\tilde{e}_2$	204.2	5.0	0.2	0.2
$\tilde{\nu}_e$	188.2		0.7	0.7

LC strong on Higgs and Sleptons plus stop
LHC strong on gluinos and squarks
B. Gjelsten et al: use of LC χ_1 mass in LHC analyses improves

Digression to Supersymmetric decays to Z^0

MIA: χ_3 (LHCLC), $\chi_2^{\pm}$ (LHC), $\tilde{t}_2$ (LHCLC)
e.g. $\chi_3 \to Z^0 + X$, but BR($\tilde{q}_L \to \chi_3 q$) $\sim 0.12\%$



Method		$m_{\chi_3}^{\text{SPS1a}} - 10\text{GeV}$	$m_{\chi_3}^{\text{SPS1a}}$	$m_{\chi_3}^{\text{SPS1a}} + 10\text{GeV}$	Comments
average	$(\ell\ell)^{\text{RECO}}$	151 GeV	157 GeV	162 GeV	RMS 80GeV

- infinite statistics and no background: doable

but need to calibrate average (or slope if fit)

$\to p_T$ of Z^0 depends on other SUSY masses.....

- 4 or more jets
- $p_{T,jet1} > 150\text{GeV}$, $p_{T,jet2} > 100\text{GeV}$, $p_{T,jet3} > 50\text{GeV}$
- M_{eff} (sum pt of 4 jets, E_T^{miss}) $> 600\text{GeV}$
- $E_T^{\text{miss}} > \max(100\text{GeV}, 0.2 M_{\text{eff}})$
- two and only two isolated OS-SF electrons or muons
- $89\text{GeV} < M_{\text{ee}}$ or $M_{\mu\mu} < 93\text{GeV}$
- $\tilde{q}_L \tilde{g} \to \chi_3 + Y \to Z^0 + X$, efficiency excluding branching ratios $\epsilon = 5\%$

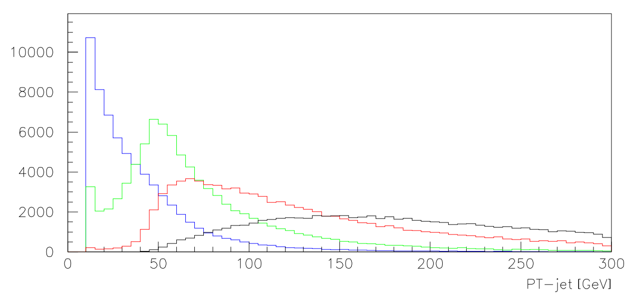
Standard Model background

Process	decay	events	σ	BR·σ	σ_B
fZ	$Z^0 \to \ell\ell$	1M	$3.8 \cdot 10^6$ fb	$2.2 \cdot 10^5$ fb	0
gZ	$Z^0 \to \ell\ell$	1M	$4 \cdot 10^6$ fb	$2.4 \cdot 10^5$ fb	0
ZZ		1M	$1.1 \cdot 10^4$ fb		0 (?)
ZW	$Z^0 \to \ell\ell, W \to \ell\nu$	1M	$2.7 \cdot 10^4$ fb	500 fb	0.002fb
ZW	$Z^0 \to \ell\ell, W \to$ had	1M	$2.7 \cdot 10^4$ fb	1100 fb	0

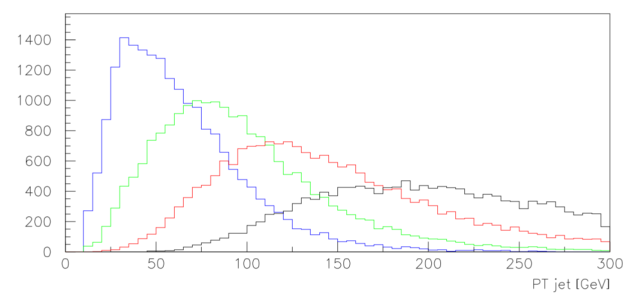
- E_T^{miss} ZW: $W \to \ell\nu$
- E_T^{miss} ZZ: $Z \to \nu\nu$
- but that's not enough: more hard jets

$\to$ ZZjjj with MadEvent and Pythia+ATLFAST

ZZjjj with p_T-jets$>$ 50 GeV



Signal



- hard jets from ZZjjj matrix element (PYTHIA not correct for jet-cuts)
- jet-p_T-shape above 50GeV identical for signal and background

Process	decay	events	σ	BR·σ	σ_B
ZZj	$Z^0 \to \ell\ell$, $Z^0 \to \nu\nu$	-	2500 fb	66 fb	
ZZjj	$Z^0 \to \ell\ell$, $Z^0 \to \nu\nu$	100 kEvts	1100 fb	30 fb	
ZZjjj	$Z^0 \to \ell\ell$, $Z^0 \to \nu\nu$	100 kEvts	560 fb	14.7 fb	$\sim$ 0.54fb

$p_{T,\text{jet}} > 50$GeV, No α_S series!

Supersymmetric decays to Z^0

σ^{NLO} from Prospino2.0 (http://pheno.physics.wisc.edu/ plehn)

	χ_3	χ_4	$\chi_2^\pm$	$\tilde{t}_2$
Production	$\tilde{q}_L\tilde{g}$	$\tilde{q}_L\tilde{g}$	$\tilde{q}_L\tilde{g}$	$\tilde{t}_2\tilde{t}_2$
σ	15.4 pb	15.4 pb	15.4 pb	275 fb
BR($\tilde{q}_L \to$ jet $+ \chi$)	0.12%	1.2%	2.6%	-
BR($\chi, \tilde{t} \to Z^0 + X$)	20%	3.8%	24%	22%
X-Decay			BR($\chi_1^\pm \to \tilde{\tau}\nu$) $= 98\%$	BR($\tilde{t}_1 \to \chi_1^\pm b$) $= 73\%$
BRs$\cdot\epsilon \cdot \sigma$	0.019fb	0.023fb	0.32fb	0.31fb
300fb^{-1}	5.9	6.9	95	90

- S/$\sqrt{\text{B}} \sim 15$

$\rightarrow$ Sum of MIAs $\chi_2^\pm$, χ_3, $\tilde{t}_2$ promising

- numbers indicative for one process, e.g. $\tilde{b}_2$ important for χ_3
- combinatorial background is a big worry......
- disentangling the relative contributions looks daunting......

Next steps:

- complete SM model background study
- complete signal and background estimate
- all production channels
- all decay channels

End of Digression: Back to SFITTER

MSUGRA in SPS1a

all parameters correlated in MSUGRA
→ fit from an unbiased starting point (GRID would be full set of parameters)

Parameter	SPS1a	Starting point
m_0	100	500
$m_{1/2}$	250	500
$\tan\beta$	10	50
A_0	-100	0
μ	+	+

Results:

Parameter	LHC	ΔLHC	LC	ΔLC	LHCLC	ΔLHCLC
M0	100.08	4.1	100.03	0.08	100.04	0.08
M1/2	249.95	1.8	250.02	0.13	250.01	0.10
$\tan\beta$	9.87	1.0	9.98	0.15	9.98	0.14
A0	-99.00	30.8	-98.24	4.56	-98.21	4.23
χ^2/dof	0.00291/16		0.68719/12		0.71148/24	

- central values ok → good chi2 for all fits
- LC is more precise by a least a factor 10 on all parameters
- the errors for LHCLC are improved slightly over LC alone
- the errors for LHCLC are improved significantly over LHC

Correlation Matrix for the LHC measurement

	M0	M1/2	$\tan\beta$	A0
M0	1.00000	-0.40043	-0.02132	-0.14219
M1/2	-0.40043	1.00000	0.16614	0.43014
$\tan\beta$	-0.02132	0.16614	1.00000	0.88300
A0	-0.14219	0.43014	0.88300	1.00000

To be added: correlations in measurements
LC: error on m_h 10 times worse A_0 and $\tan\beta$ wrong with bad χ^2

MSSM

- using all sparticle and Higgs masses with 0.5% precision on all masses
- GRID in μ, $\tan\beta$, M1, M2 (GRID 100GeV, 10, 100GeV, 100GeV)
- GRID for chargino and neutralino masses
- other starting points: “SOLUTION”

$\rightarrow$ unbiased in first approx only for μ, $\tan\beta$, M_1, M_2

	AfterGrid	AfterFit	SPS1a		AfterGrid	AfterFit	SPS1a
$\tan\beta$	100	10.02±3.4	10	$M_{\tilde{u}_R}$	532.1	532.1±2.8	532.1
M_1	100	102.2±0.74	102.2	$M_{\tilde{d}_R}$	529.3	529.3±2.8	529.3
M_2	200	191.79±1.9	191.8	$M_{\tilde{c}_R}$	532.1	532.1±2.8	532.1
M_3	589.4	589.4±7.0	589.4	$M_{\tilde{s}_R}$	529.3	529.3±2.8	529.3
μ	300	344.3±1.3	344.3	$M_{\tilde{t}_R}$	420.2	420.08±13.3	420.2
m_A	399.35	399.1±1.2	399.1	$M_{\tilde{b}_R}$	525.6	525.5±10.1	525.6
$M_{\tilde{e}_R}$	138.2	138.2±0.76	138.2	$M_{\tilde{q}1_L}$	553.7	553.7±2.1	553.7
$M_{\tilde{\mu}_R}$	138.2	138.2±0.76	138.2	$M_{\tilde{q}2_L}$	553.7	553.7±2.1	553.7
$M_{\tilde{\tau}_R}$	135.5	135.48±2.3	135.5	$M_{\tilde{q}3_L}$	501.3	501.42±10.	501.3
$M_{\tilde{e}_L}$	198.7	198.7±0.68	198.7	$A_{\tilde{\tau}}$	-253.5	-244.7±1428	-253.5
$M_{\tilde{\mu}_L}$	198.7	198.7±0.68	198.7	$A_{\tilde{t}}$	-504.9	-504.62±27.	-504.9
$M_{\tilde{\tau}_L}$	197.8	197.81±0.92	197.8	$A_{\tilde{b}}$	-797.99	-825.2±2494	-799.4

- GRID: ok for μ, M_1, M_2, not ok for $\tan\beta$ (secondary minimum)

$\rightarrow$ but Higgs masses undefined in this point (info needs to be added)

- Fit after Grid converging correctly in spite of $\tan\beta$ problem
- precision of 0.5% is insufficient for $A_{\tilde{\tau}}$ and $A_{\tilde{b}}$

- Datasets LC, LHC with all starting points: “SOLUTION” and FIT only
- Dataset LHCLC with all starting points: “SOLUTION”

→ except GRID μ, M_1, M_2, $\tan\beta$ with chargino and neutralino masses

Parameter	LHC	LC	LHCLC	SPS1a
$\tan\beta$	10.23±4.3	10.26±1.6	10.16±1.4	10
M_1	102.45±5.1	102.32±0.3	102.17±0.2	102.2
M_2	191.8±6.0	192.52±1.2	191.71±0.8	191.8
M_3	578.68±15.	FIXED 500	589.51±15.	589.4
$M_{\tilde{\tau}_L}$	FIXED 500	197.68±3.3	198.62±2.9	197.8
$M_{\tilde{\tau}_R}$	129.03±9.0	135.66±4.4	134.28±4.0	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
$M_{\tilde{e}_L}$	198.7±5.1	198.7±0.2	198.7±0.2	198.7
$M_{\tilde{e}_R}$	138.2±5.0	138.2±0.06	138.2±0.06	138.2
$M_{\tilde{q}3_L}$	498.1±108	497.6±51.	499.97±32.	501.3
$M_{\tilde{t}_R}$	FIXED 500	420±24.	420.25±15.	420.2
$M_{\tilde{b}_R}$	522.38±112	FIXED 500	526.93±32.	525.6
$M_{\tilde{q}2_L}$	550.73±13.	FIXED 500	553.74±7.0	553.7
$M_{\tilde{c}_R}$	529.02±24.	FIXED 500	532.14±24.	532.1
$M_{\tilde{s}_R}$	526.21±24.	FIXED 500	529.34±24.	529.3
$M_{\tilde{q}1_L}$	550.73±13.	FIXED 500	553.74±7.1	553.7
$M_{\tilde{u}_R}$	529.02±24.	FIXED 500	532.14±24.	532.1
$M_{\tilde{d}_R}$	526.2±24.	FIXED 500	529.34±24.	529.3
$A_{\tilde{\tau}}$	FIXED 0	-202.7±1007	118.32±1100	-253.5
$A_{\tilde{t}}$	-507.7±54.	-501.95±15.	-503.11±13.	-504.9
$A_{\tilde{b}}$	-741.55±35228	FIXED 0	-250.7±13513	-799.4
m_A	FIXED 500	399.1±0.9	399.1±0.9	399.1
μ	345.21±6.4	344.34±3.5	344.36±2.1	344.3
χ^2/dof	0 / 0	0.00097 / 1	0.00058 / 4	

- the MSSM results show better the complementarity of LHC and LC than MSUGRA
- use of cross sections and branching ratios should improve A_τ, A_b
- LC and LHC with GRID as LHCLC converge on a secondary minimum with a GOOD χ^2

→ compatibility of secondary minimum to be investigated, GRID size etc

Conclusions and Perspectives

SFITTER

- MSUGRA in SPS1a
  - LHC, LC and LHCLC datasets converge correctly
  - LC may be sensitive to error on Higgs mass
  - improvement of LHC by adding LC seen in parameter errors
  - improvement of LC by LHC not obvious....
- MSSM in SPS1a
  - GRID use for subset of parameters and measurements with good convergence
  - system underdetermined for LC and LHC, but ok for LHCLC
  - A_τ and A_b undetermined
  - many parameters show the superiority LHCLC with respect to LHC and LC alone
- SUSY decays to Z^0 in SPS1a
  - looking for χ_3, $\chi_2^\pm$, $\tilde{t}_2$
  - the sum of them may be detectable

Future:

- unbias MSSM-SPS1a further
- use correlations in measurements
- implement edge measurements
- implement the new version of SUSPECT