Supersymmetry

DIS 2009
Madrid
04/28/2009
Dirk Zerwas
LAL Orsay

- **Introduction**
- **Vintage Supersymmetry**
- **Difficult supersymmetry**
- **New models/signatures and studies**
- **Summary**

LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE

cnrs IN2P3 Les deux infinis

Supersymmetry

- fermion ↔boson
- has “no” problems with radiative corrections (quadrat. div.)
- has a light Higgs Boson (<150GeV)
- interesting pheno at the TeV scale

spin-0	spin-1/2	spin-1
squarks: $\tilde{q}_R, \tilde{q}_L$	q	
	gluino: $\tilde{g}$	g
sleptons: $\tilde{\ell}_R, \tilde{\ell}_L$	ℓ	
h,H,A	neutralino $\chi_{i=1-4}$	Z, γ
$H^{\pm}$	charginos: $\chi^{\pm}_{i=1-2}$	$W^{\pm}$

3 (or more) neutral Higgs bosons: h, A, H
1 (or more) charged Higgs boson(s): $H^{\pm}$
and supersymmetric particles

Many different models:

- MSSM (low scale many parameters)
- mSUGRA (high scale few parameters)
- DSS (SUSY with heavy scalars)
- GMSB
- AMB

Additional (s)particles:

- NMSSM
- MRSSM/N=1/N=2 hybrid

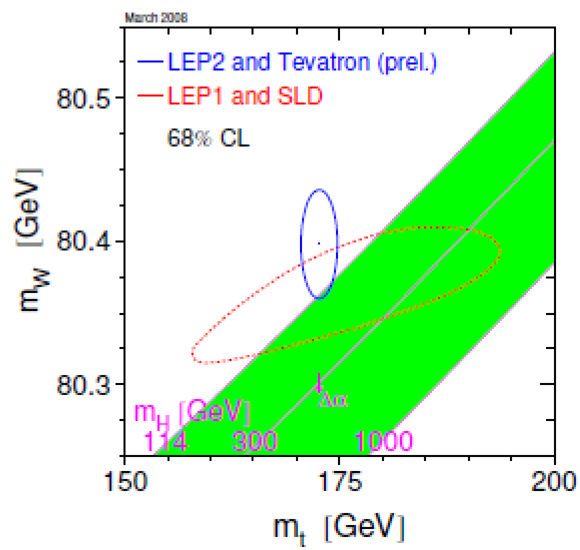
R-parity

- production of SUSY particles in pairs
- (Cascade-) decays to the lightest SUSY particle
- LSP stable, neutral and weakly interacting: neutralino (χ_1)
- experimental signature: missing E_T

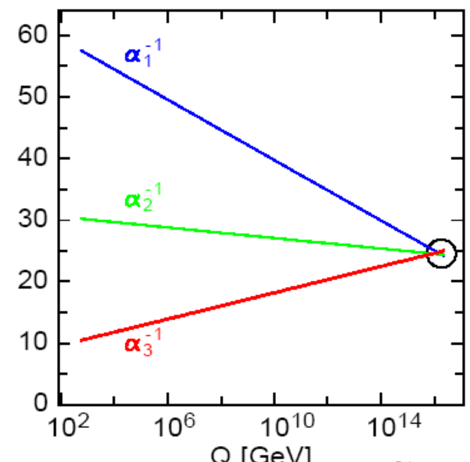
Why Supersymmetry?

- Bayesian argument: many papers published so it must be correct
- resistant against experiments
- resistant against absolute exclusions

- stabilizes the gap between the EW and Planck scale
- unifies the couplings of the three forces
- induces electroweak symmetry breaking
- link to physics at the GUT/Planck scale
- provides a candidate for dark matter



Allanach et al, hep-ph/0403133



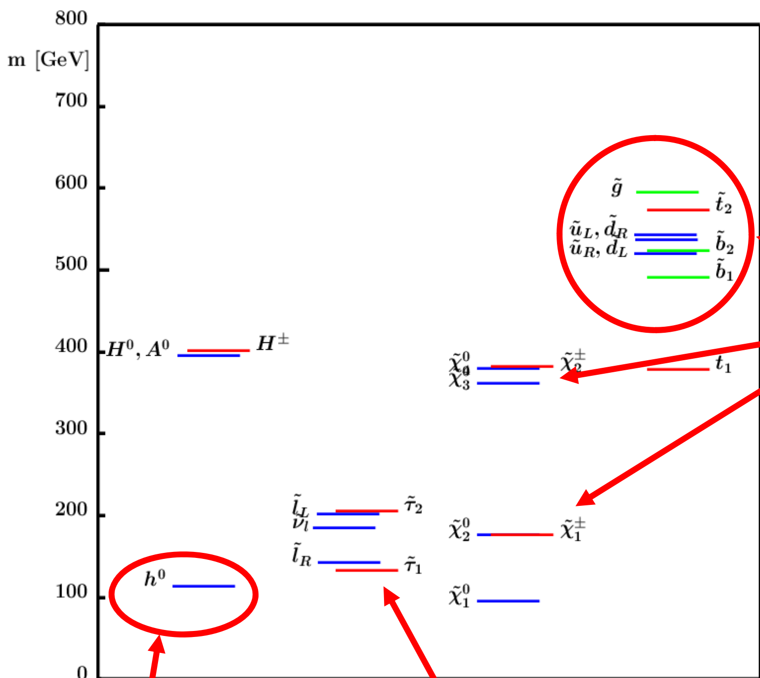
EW-Scale 10^2GeV GUT 10^{16}GeV

- Higgs boson mass light
- mSUGRA/CMSSM fit favours (slightly) SUSY
- top and W boson mass like light supersymmetry

A typical (optimistic) point

"Physics Interplay of the LHC and ILC"
G. Weiglein et al

	SPS1a	SPS1a'	SU3	LM1
M_0 (GeV)	100	70	100	60
$m_{1/2}$ (GeV)	250	250	300	250
tanβ	10	10	6	10
A0 (GeV)	-100	-300	-300	0



gluinos and squarks (not too heavy)

heavy and light gauginos

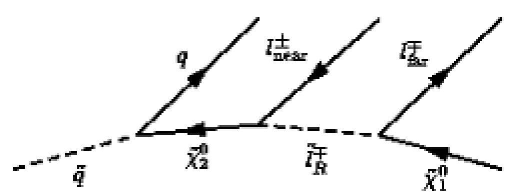
Higgs boson mass at the LEP limit

light sleptons

$\tilde{\tau}_1$ lighter than the lightest $\chi^\pm$:

- $\chi^\pm$ BR 100% $\tilde{\tau}\nu$
- χ_2 BR 90% $\tilde{\tau}\tau$
- cascade:

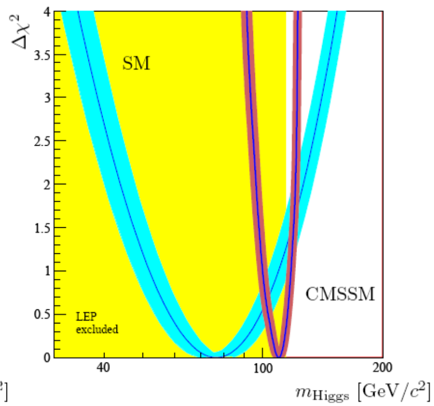
$\tilde{q}_L \rightarrow \chi_2 q \rightarrow \tilde{\ell}_R \ell q \rightarrow \ell \ell q \chi_1$



hard jets with leptons invariant mass:

- jet-lepton
- lepton-lepton-jet
- lepton-lepton

EWPO and inference from current data



Buchmueller et al: Phys.Lett.B657:87-94,2007

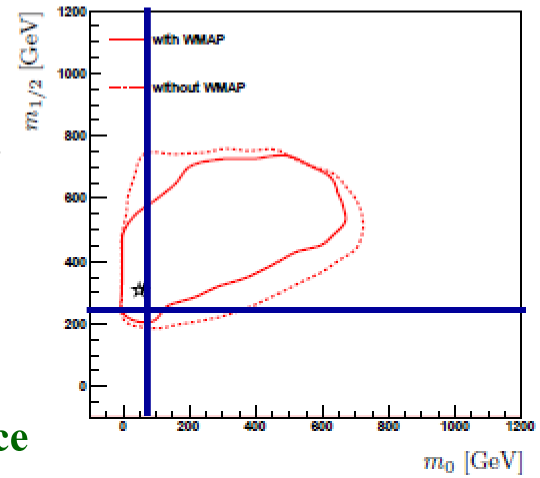
electroweak plus dark matter, b→sγ, b→μμ

CMSSM χ^2 slightly better than SM

$m_h=110^{+8}_{-10}\pm3$GeV

Buchmueller et al: JHEP 0809:117,2008

CMSSM best fit close to SPS1a' ☺

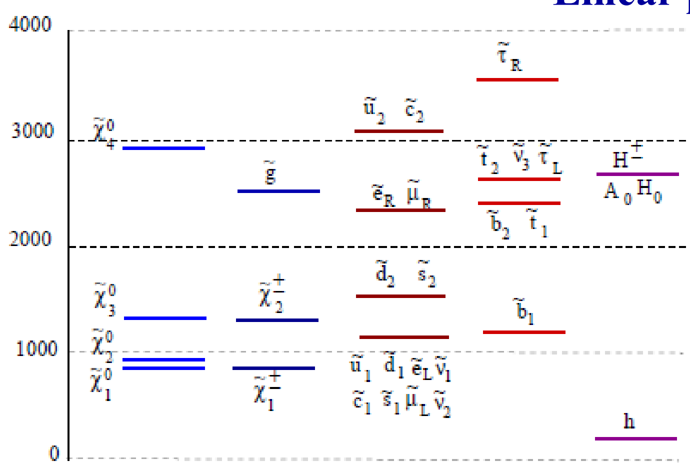


S. AbdusSalam, B. Allanach, F. Ferhoz, M. Hobson, F. Quevedo arXiv:0904.2548

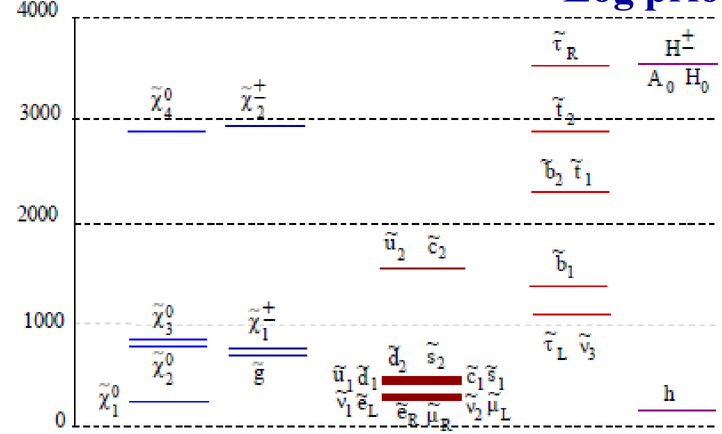
EWPO+dark matter, superIso

Infere on MSSM parameters, difference log/lin prior should reduce with further data

Mass Spectrum [GeV] **Linear prior**



Mass Spectrum [GeV] **Log prior**



Bayesian analysis shows no preference for sign of μ

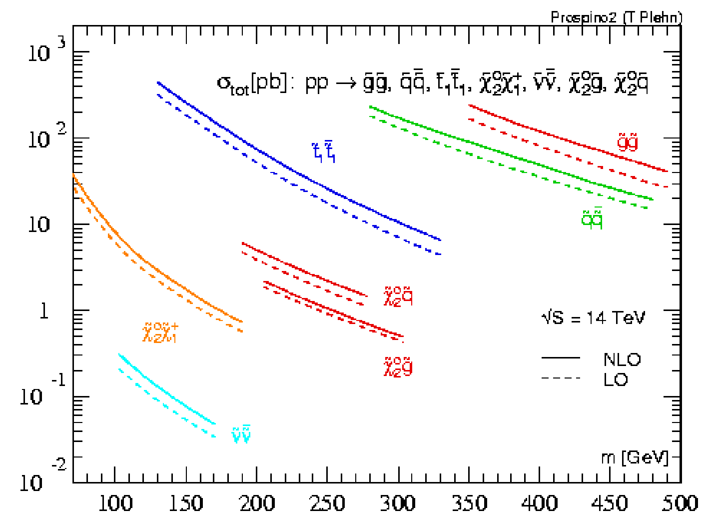
Understanding SUSY:Determination of Supersymmetric Parameters

from edges, masses (etc) to fundamental parameters:
e.g.: mSUGRA
m(Smuon) = f(m_0, $m_{1/2}$, tanβ)
m(Chargino) = f($m_{1/2}$, tanβ,…)
correlations exp and theoretical
treatment of theory errors!
→ global ansatz necessary

Eur.Phys.J.C59:427-443,2009 : Allanach, Hugonie, Kneur, Djouadi, Mambrini, Muehlleitner, Heinemeyer, Weiglein, Spira……..

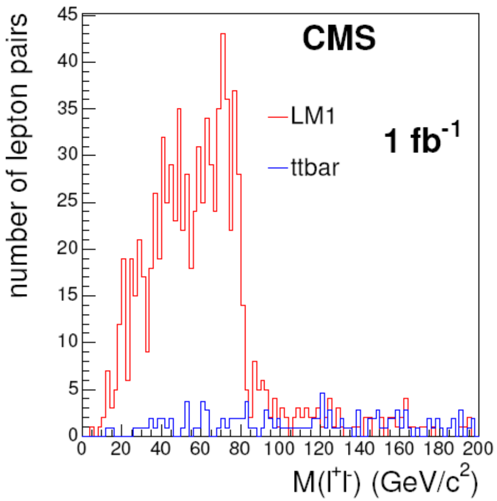
- mass spectra and decays: SOFTSUSY, SUSPECT, FeynHiggs, ISASUSY,SPHENO, SDecay, SUSY-HIT, HDECAY, NMSSMtools,…
- NLO cross sections from Prospino2.0,…
- dark matter: micrOMEGAS, DarkSUSY, IsaRED,…

Prospino2 (Plehn)



Search for parameter point, determine errors including treatement of error correlations:
Pioneers: G. Blair, W. Porod and P.M. Zerwas (Eur.Phys.J.C27:263-281,2003) /
Allanach et al. hep-ph/0403133
FITTINO: P. Bechtle, K. Desch, P. Wienemann with W. Porod (Eur.Phys.J.C46:533-544,2006)
SFITTER: R. Lafaye, T. Plehn, M. Rauch, D. Z. (Eur.Phys.J.C54:617-644,2008)
GFITTER: M. Goebel, J. Haller, A. Hoecker, K. Moenig, J. Stelzer (EW fit)
MasterCode: O.Buchmueller et al, Phys.Lett.B657:87-94,2007
Super-Bayes: R.R. de Austri, R. Trotta, (MCMC, collider observables and dark matter…)
CMSSM fits and weather forcasts: B. Allanach, K. Cranmer, C. Lester, A. Weber
…

Vintage SUSY Measurements



Experimental studies:
Talks ATLAS+CMS
Patricia Lobelle Prado
Sandra Horvat
Diego Casadei,
Raimund Strőhmer

LHC: lepton energy scale 0.1%
LHC: jet energy scale 1%
luminosity 100fb^{-1}

Linear collider
- **e+e- collisions**
- **up to 1TeV**

Lester, Nojiri, Osland, Polesello and many more

−1

Edge	Nominal Value	Fit Value	Syst. Error Energy Scale	Statistical Error
$m(ll)^{\text{edge}}$	77.077	77.024	0.08	0.05
$m(qll)^{\text{edge}}$	431.1	431.3	4.3	2.4
$m(ql)^{\text{edge}}_{\text{min}}$	302.1	300.8	3.0	1.5
$m(ql)^{\text{edge}}_{\text{max}}$	380.3	379.4	3.8	1.8
$m(qll)^{\text{thres}}$	203.0	204.6	2.0	2.8
$m(bll)^{\text{thres}}$	183.1	181.1	1.8	6.3

$$(m^2_{ll})^{\text{edge}} = \frac{(m^2_{\tilde{\chi}^0_2} - m^2_{\tilde{l}_R})(m^2_{\tilde{l}_R} - m^2_{\tilde{\chi}^0_1})}{m^2_{\tilde{l}_R}}$$

	Mass, ideal	"LHC"	"LC"	"LHC+LC"
$\tilde{\chi}^\pm_1$	179.7		0.55	0.55
$\tilde{\chi}^\pm_2$	382.3	–	3.0	3.0
$\tilde{\chi}^0_1$	97.2	4.8	0.05	0.05
$\tilde{\chi}^0_2$	180.7	4.7	1.2	0.08
$\tilde{\chi}^0_3$	364.7		3-5	3-5
$\tilde{\chi}^0_4$	381.9	5.1	3-5	2.23
$\tilde{e}_R$	143.9	4.8	0.05	0.05
$\tilde{e}_L$	207.1	5.0	0.2	0.2
$\tilde{\nu}_e$	191.3	–	1.2	1.2
$\tilde{\mu}_R$	143.9	4.8	0.2	0.2
$\tilde{\mu}_L$	207.1	5.0	0.5	0.5
$\tilde{\nu}_\mu$	191.3	–		
$\tilde{\tau}_1$	134.8	5-8	0.3	0.3
$\tilde{\tau}_2$	210.7	–	1.1	1.1
$\tilde{\nu}_\tau$	190.4	–	–	–
$\tilde{q}_R$	547.6	7-12	–	5-11
$\tilde{q}_L$	570.6	8.7	–	4.9
$\tilde{t}_1$	399.5		2.0	2.0
$\tilde{t}_2$	586.3		–	
$\tilde{b}_1$	515.1	7.5	–	5.7
$\tilde{b}_2$	547.1	7.9	–	6.2
$\tilde{g}$	604.0	8.0	–	6.5
h^0	110.8	0.25	0.05	0.05
H^0	399.8		1.5	1.5
A^0	399.4		1.5	1.5
$H^\pm$	407.7	–	1.5	1.5

SPS1a

LHC:
- **from edges/thresholds to masses: toy/fit**

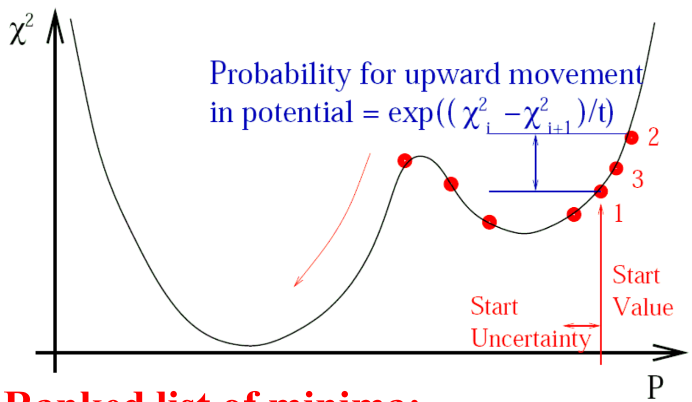
for the following continue with vintage supersymmetry: SPS1a as example

Lagrangian@GUT scale: mSUGRA

- **Sample a multi-dimensional parameter space**
- **correlated measurements**
- **find secondary minima**

- **Fittino:**

Simulated annealing/Markov chains



Ranked list of minima:

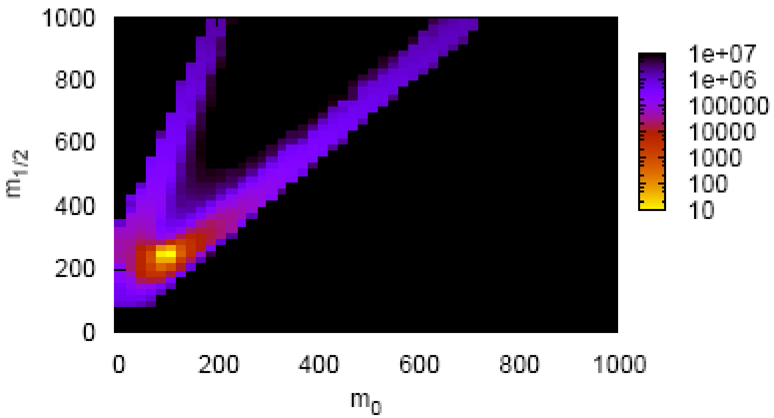
	χ^2	m_0	$m_{1/2}$	$\tan(\beta)$	A_0	μ	m_t
SPS1a		100.0	250.0	10.0	-100.0	+	171.4
1)	1.32	100.4	251.2	12.7	-71.7	+	171.9
2)	7.18	106.3	243.6	14.3	-103.3	−	170.7
3)	13.9	103.5	258.2	12.2	848.4	+	174.4
4)	75.1	107.3	251.4	15.1	778.8	−	173.6

SFitter:

Markov Chains (efficient sampling in high dimensions, linear in number of parameters)

Full dimensional exclusive likelihood map with the possibility of different types of projections:

- **marginalisation (Bayes) introduces a measure**
- **profile likelihood (Frequentist approach)**

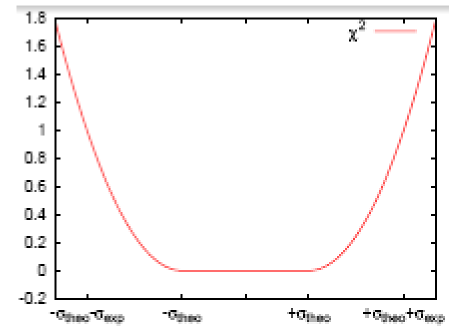


- **secondary minima exist (LHC)**
- **discarded by χ^2 alone**
- **interplay with top mass (parameter!)**

Impact of Theory Errors

RFit Scheme: Höcker, Lacker, Laplace, Lediberder

$$\chi^2 = \sum_{\text{measurements}} \begin{cases} 0 & \text{for } |x_{\text{data}} - x_{\text{pred}}| < \sigma_{\text{theo}} \\ \left(\frac{|x_{\text{data}} - x_{\text{pred}}| - \sigma_{\text{theo}}}{\sigma_{\text{exp}}} \right)^2 & \text{for } |x_{\text{data}} - x_{\text{pred}}| \geq \sigma_{\text{theo}} \end{cases}$$



- **No information within theory errors: flat distribution**

- **ILC improves by 3-4x on LHC**

Higgs	sleptons	squarks, gluinos	neutralinos, charginos
2GeV	1%	3%	1%

- **LHC+ILC better than any machine alone**

SFitter

	SPS1a	$\Delta_{\text{endpoints}}$	Δ_{ILC}	$\Delta_{\text{LHC+ILC}}$	$\Delta_{\text{endpoints}}$	Δ_{ILC}	$\Delta_{\text{LHC+ILC}}$
		exp. errors			exp. and theo. errors		
m_0	100	0.50	0.18	0.13	2.17	0.71	0.58
$m_{1/2}$	250	0.73	0.14	0.11	2.64	0.66	0.59
$\tan\beta$	10	0.65	0.14	0.14	2.45	0.35	0.34
A_0	-100	21.2	5.8	5.2	49.6	12.0	11.3
m_t	171.4	0.26	0.12	0.12	0.97	0.12	0.12

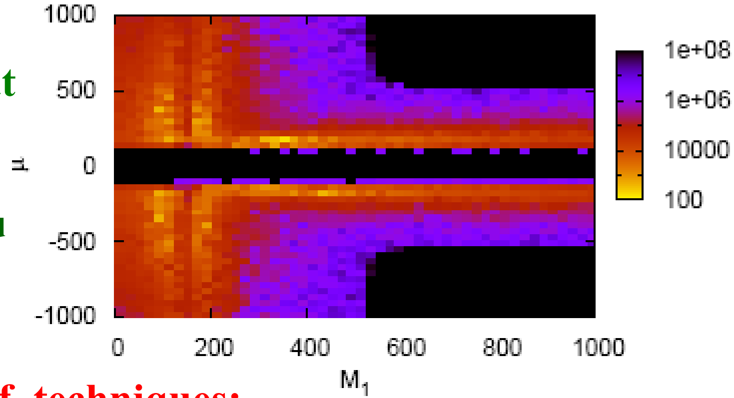
remember the standard model (top quark mass 1GeV at LHC) 10%.

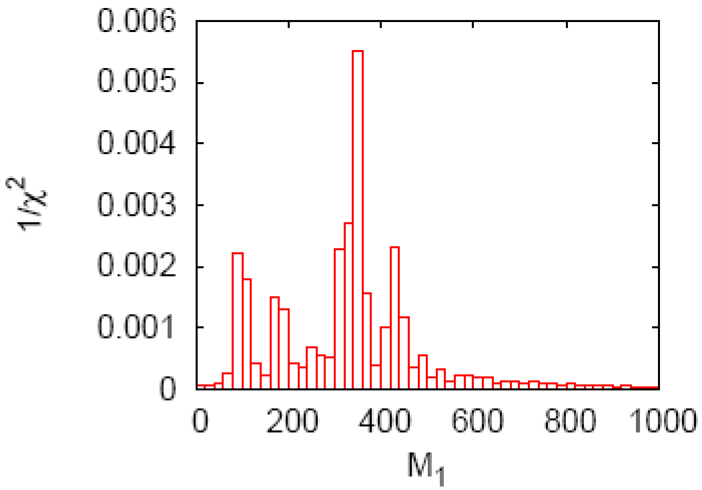
- **theory errors impact the expected precision at all machines also at LHC**

SPA project: precision of the theoretical calculations **Eur.Phys.J.C46:43-60,2006**

MSSM

19 parameters at the EW scale
no unification of the 1st and 2nd generation





Sequential use of techniques:

- markov flat full Parameter space
- MINUIT in 5 best points
- Markov flat gaugino-higgsino space
- MINUIT on 15 best points
- BW pdf on remaining parameters
- MINUIT on 5 best solutions (all parameters)

- 3 neutralino masses at LHC
- M1, M2, μ
- 8 fold ambiguity in Gaugino-Higgsino subspace at the LHC!

	$\mu < 0$				$\mu > 0$			
					SPS1a			
M_1	96.6	175.1	103.5	365.8	98.3	176.4	105.9	365.3
M_2	181.2	98.4	350.0	130.9	187.5	103.9	348.4	137.8
μ	-354.1	-357.6	-177.7	-159.9	347.8	352.6	178.0	161.5
$\tan\beta$	14.6	14.5	29.1	32.1	15.0	14.8	29.2	32.1
M_3	583.2	583.3	583.3	583.5	583.1	583.1	583.3	583.4
m_t	171.4	171.4	171.4	171.4	171.4	171.4	171.4	171.4

LHC+ILC:

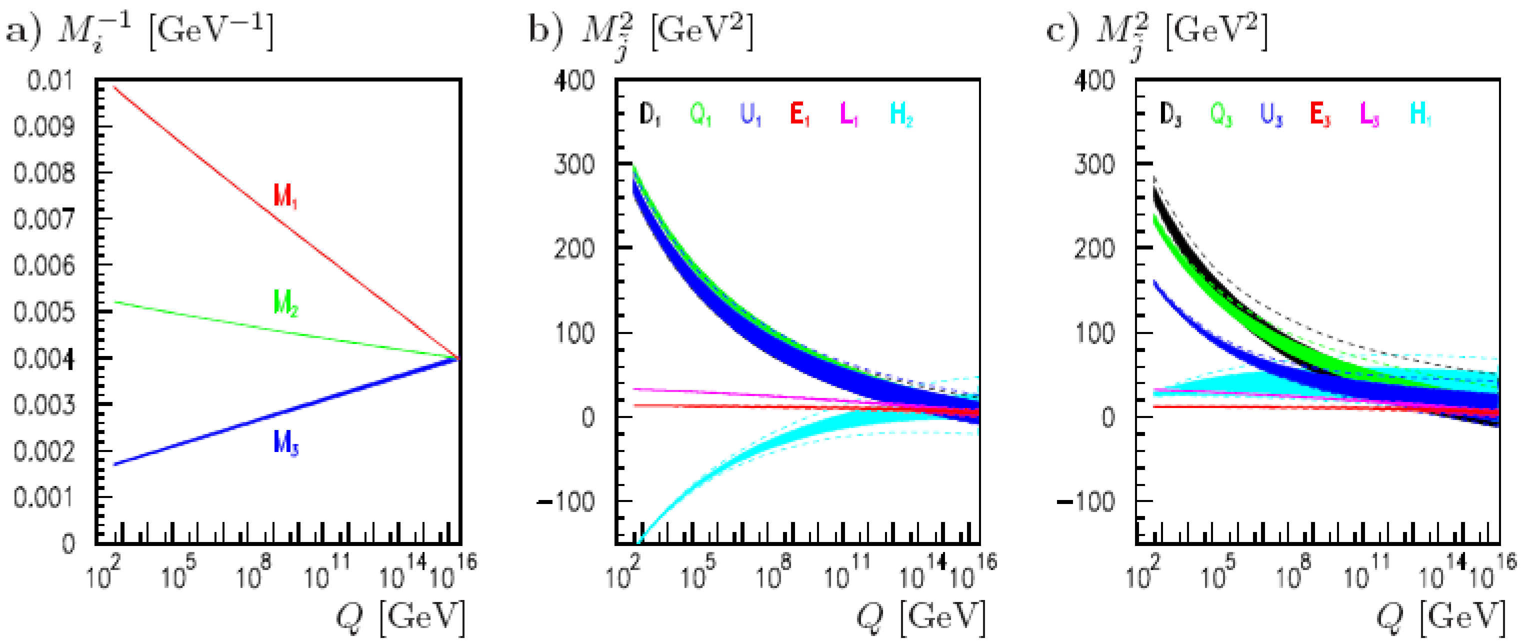
- all parameters determined
- several parameters improved

MSSM

Running up to the GUT scale:

G. Blair, W. Porod and P.M. Zerwas **(Eur.Phys.J.C27:263-281,2003)**

P. Bechtle, K. Desch, P. Wienemann with W. Porod **(Eur.Phys.J.C46:533-544,2006)**



SPS1a (SPA1):

dashed bands: today's theory errors included

unification measured from low energy (TeV) data from LHC+ILC

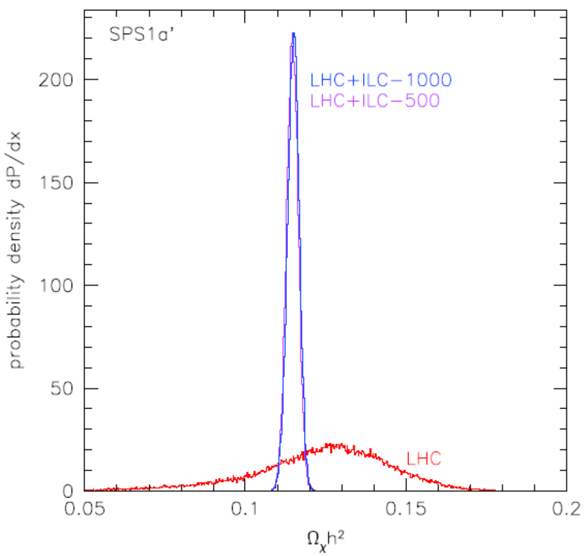
remember: all results valid within a well defined model/hypothesis

Connection Colliders-Cosmology

E. Baltz,M.Battaglia, M.Peskin, T.Wizansky: Phys.Rev.D74:103521,2006
Nojiri et al/Dutta et al

- SUSY breaking parameters (determined)
- spectrum and couplings (deduced)
- darkSUSY, isaRed or micrOMEGAs

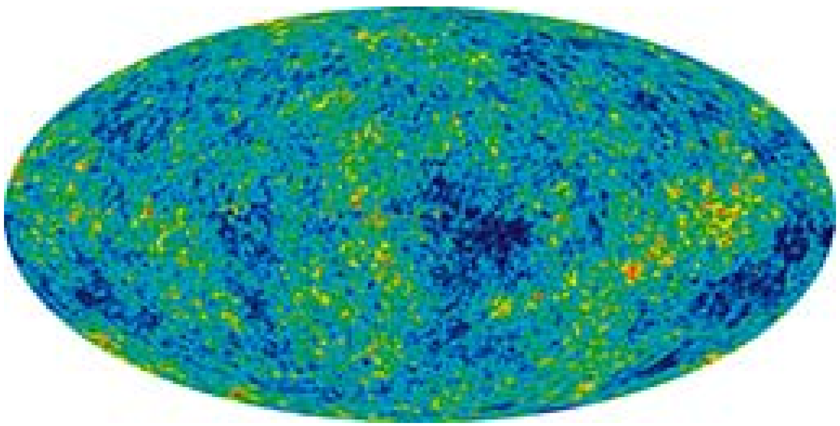
$\Omega_{CDM}h^2=n_{LSP}*m_{LSP}$ (relic density)



SPS1a'

MSUGRA SPS1a (central value irrelevant)
- LHC : $\Omega h^2 = 0.1906\pm0.0033$
- LHC+ILC: $\Omega h^2 = 0.1910\pm0.0003$
- % precision at LHC, permil LHC+ILC
- theory errors and parameter set dependent!

NASA/WMAP science team



Temperature range: ±200μK

Measurement of the fluctuations of the cosmic microwave background

WMAP
- $\Omega_{CDM}h^2=0.127\pm0.01$ (astro-ph/0603449)

Planck
- $\Omega_{CDM}h^2 \sim 2\%$

Comparable precision of CMB and Collider data possible

A difficult example: SUSY with heavy scalars

Arkani-Hamed & Dimopoulos 2004
Giudice, Romanino 2004
W. Kilian, T. Plehn, P. Richardson, E. Schmidt EPJC 2004

N. Bernal, A. Djouadi, P. Slavich 2007
E. Turlay (LAL 2009/37)

Phenomenology:

- scalar Mass scale $10^{4 \text{ to } 16}$ GeV
- scalars are at M_S
- fermions O(TeV)
- SM Higgs h

- effective theory below M_S
- at M_S matching with complete theory and standard RGE

DSS parameters:

- M_S: decoupling scale, scalar masses
- M1, M2, M3: gaugino mass parameters
- μ: Higgs mass parameter
- At: trilinear coupling at MS
- tanβ: mixing angle between Higgs at MS

		STAT		SYST		TH	
		Δ	%	Δ	%	Δ	%
DSS1	M_1	1.9	1.4	0.2	0.2	4	3.0
	M_2	0.9	1.4	0.1	0.1	2	1.5
	M_3	0.3	0.2	0.1	0.1	4	1.5
	μ	0.5	0.2	0.2	0.1	10	3.4
	$\tan\beta$	12.7	42.3	1.3	4.4	undet.	
DSS2	M_1	21.3	7.2	0.9	0.3	6.1	2.1
	M_2	9.8	3.3	0.4	0.1	0.8	0.3
	M_3	2.3	0.8	1.6	0.5	undet.	
	μ	10.5	5.3	0.4	0.2	4.4	2.2
	$\tan\beta$	17.6	58.7	1.4	4.7	undet.	

	Observables		Uncertainties (%)			
			Stat.	Systematic		Th.
				Value	Source	
DSS1	m_h	129 GeV	0.1	0.1	energy scale	4
	$m_{\tilde{N}_2} - m_{\tilde{N}_1}$	55.2 GeV	1	0.1	energy scale	1
	$m_{\tilde{g}} - m_{\tilde{N}_1}$	382.8 GeV	1.5	1	energy scale	1
	$\sigma(3\ell)$	340 fb	2	> 5	luminosity	12
	R_Z	< 0.004	0.01	1	lepton id.	1
	$\sigma(\tilde{g}\tilde{g})$	62.8 pb	0.1	> 5	luminosity	30
DSS2	m_h	129 GeV	0.1	0.1	energy scale	4
	$m_{\tilde{N}_2} - m_{\tilde{N}_1}$	61.3 GeV	3.3	0.1	energy scale	1
	$m_{\tilde{N}_3} - m_{\tilde{N}_1}$	76.4 GeV	3.7	0.1	energy scale	1
	$\sigma(3\ell)$	24 fb	14	> 5	luminosity	12
	R_Z	0.195	0.7	1	lepton id.	1
	$\sigma(\tilde{g}\tilde{g})$	954 fb	3	> 5	luminosity	30

Parameter determination at LHC possible in this difficult scenario

cNMSSM

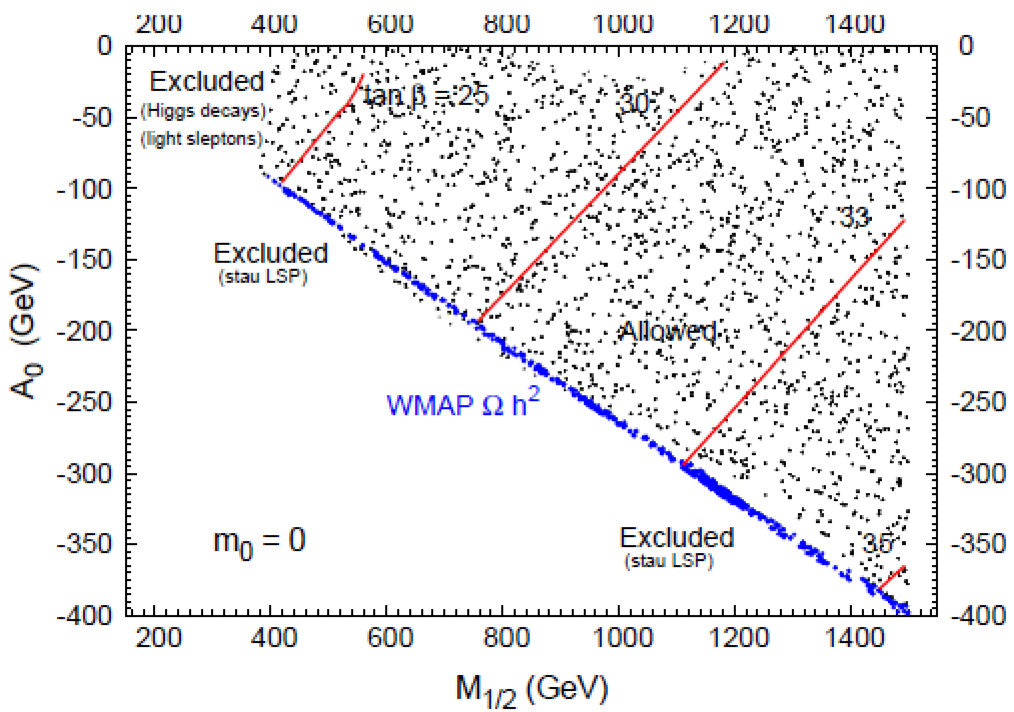
- MSSM + 1 singlet
- explains the μ term by dynamical generation
- Higgs sector: 3 CP even, 2 CP odd
- neutralinos: 5
- cNMSSM: $m_{1/2}$, m_0, A_0, λ (replaces μ), κ (for the singlet Higgs field)
- require correct m_Z leads to 4 parameters: $m_{1/2}$, m_0, A_0, λ

Djouadi, Ellwanger, Teixeira JHEP 0904:031,2009

- impose acceptable minimum of Higgs potential s!=0
  - favours low m_0
- Absence of tachyons A_0 <0
- Wmap (correct relic density in stau assisted annihilation)
- LEP constraints: λ<0.02
- g-2: favours low $m_{1/2}$ <1TeV (deviation version)

cNMSSM for low m0: line in $A_0/m_{1/2}$ plane!

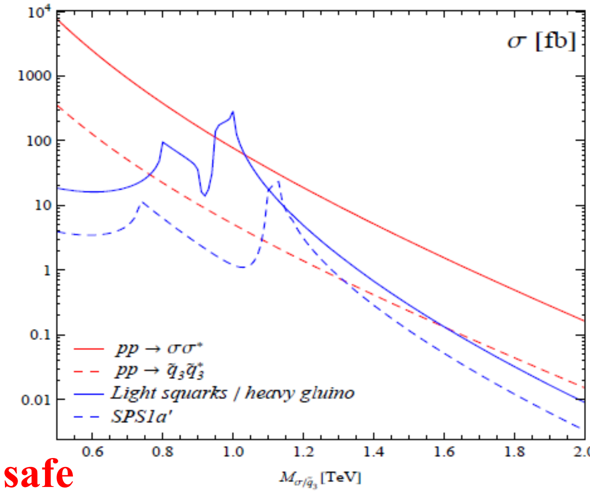
LHC pheno: NLSP is stau almost stable cm lifetime! Studies by ATLAS and CMS!



Sgluons

T. Plehn, T. Tait arXiv:0810.3919
S.Y. Choi, M. Drees, J. Kalinowski, J.M. Kim, E. Popenda, P.M. Zerwas Phys.Lett.B672:246-252,2009

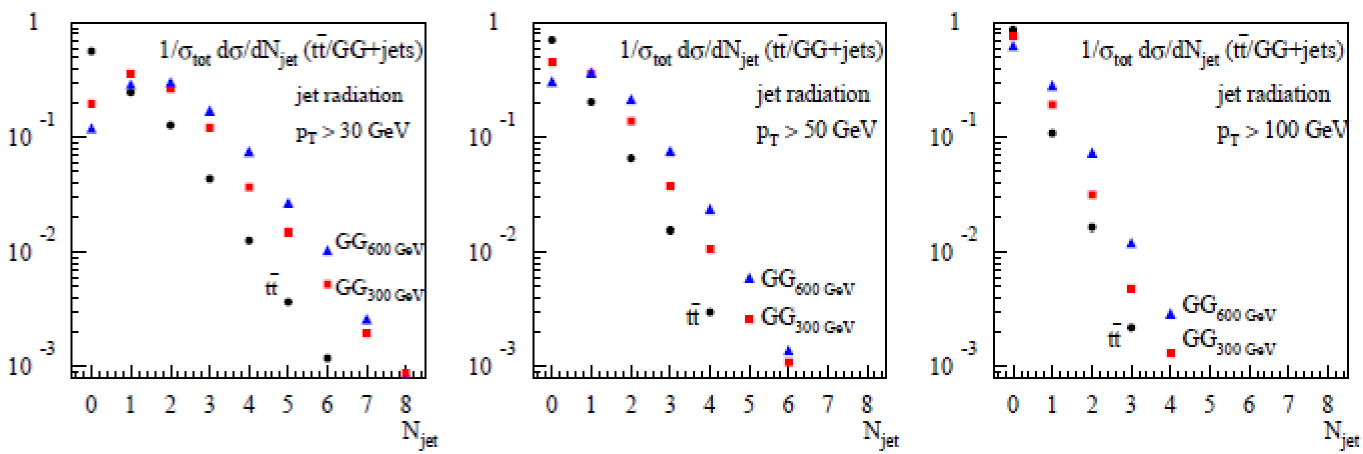
- N=1/N=2 hybrid model or MRSSM
- add N=1 color-octet chiral supermultiplet of (add) gluinos and scalar gluon fields (R=+1) to a vector hyper-multiplet of N=2 SUSY
- N=2 (s)fermions heavy



- sgluon pair production (red line): 10x $\tilde{q}_3$ (red dashed line) at LHC

- single scalar gluon production affected by model parameters (BR change at 700GeV etc)

- sgluons → t t qq → like-sign top
- beware of ISR QCD jets (mass reconstruction) PT>100GeV safe



The Higgs sector

+Michael Duehrssen
arxiv:0904.3866

A difficult scenario: only the lightest Higgs boson seen: several measurements possible
Can we tell it is a) not SM b) SUSY
LHC: Gluon fusion and VBF in well defined final states (many authors and papers)

production	decay	$S+B$	B	S	$\Delta S^{(\mathrm{exp})}$	$\Delta S^{(\mathrm{theo})}$
$gg \to H$	ZZ	13.4	6.6 ($\times$ 5)	6.8	3.9	0.8
qqH	ZZ	1.0	0.2 ($\times$ 5)	0.8	1.0	0.1
$gg \to H$	WW	1019.5	882.8 ($\times$ 1)	136.7	63.4	18.2
qqH	WW	59.4	37.5 ($\times$ 1)	21.9	10.2	1.7
$t\bar{t}H$	$WW(3\ell)$	23.9	21.2 ($\times$ 1)	2.7	6.8	0.4
$t\bar{t}H$	$WW(2\ell)$	24.0	19.6 ($\times$ 1)	4.4	6.7	0.6
inclusive	$\gamma\gamma$	12205.0	11820.0 ($\times$ 10)	385.0	164.9	44.5
qqH	$\gamma\gamma$	38.7	26.7 ($\times$ 10)	12.0	6.5	0.9
$t\bar{t}H$	$\gamma\gamma$	2.1	0.4 ($\times$ 10)	1.7	1.5	0.2
WH	$\gamma\gamma$	2.4	0.4 ($\times$ 10)	2.0	1.6	0.1
ZH	$\gamma\gamma$	1.1	0.7 ($\times$ 10)	0.4	1.1	0.1
qqH	$\tau\tau(2\ell)$	26.3	10.2 ($\times$ 2)	16.1	5.8	1.2
qqH	$\tau\tau(1\ell)$	29.6	11.6 ($\times$ 2)	18.0	6.6	1.3
$t\bar{t}H$	$b\bar{b}$	244.5	219.0 ($\times$ 1)	25.5	31.2	3.6
WH/ZH	$b\bar{b}$	228.6	180.0 ($\times$ 1)	48.6	20.7	4.0

Experimental Errors

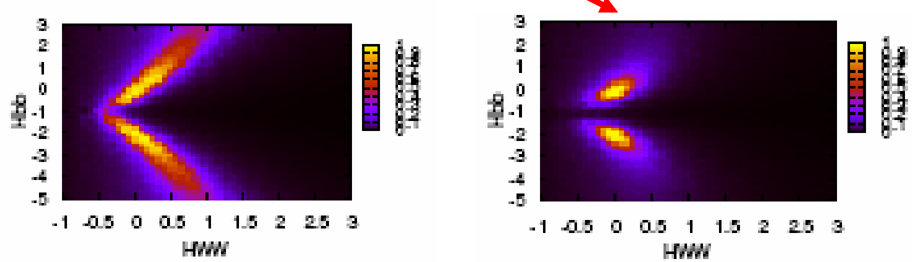
Measurement of luminosity	5 %
Detector efficiency	2 %
Lepton reconstruction efficiency	2 %
Photon reconstruction efficiency	2 %
WBF tag-jets / jet-veto efficiency	5 %
b-tagging efficiency	3 %
τ-tagging efficiency (hadronic decay)	3 %
Lepton isolation efficiency (decay $H \to ZZ \to 4l$)	3 %

Theory Errors

σ (gluon fusion)	13 %
σ (weak boson fusion)	7 %
σ (VH-associated)	7 %
σ ($t\bar{t}$-associated)	13 %

BR($H \to ZZ$)	1 %
BR($H \to WW$)	1 %
BR($H \to \tau\bar{\tau}$)	1 %
BR($H \to c\bar{c}$)	4 %
BR($H \to b\bar{b}$)	4 %
BR($H \to \gamma\gamma$)	1 %
BR($H \to Z\gamma$)	1 %
BR($H \to gg$)	2 %

Hbb: J. M. Butterworth, A. R. Davison , M. Rubin, G. P. Salam Phys.Rev.Lett.100:242001,2008.



Profile likelihood 30fb-1 theory errors

Coupling	without eff. couplings			including eff. couplings		
	σ_{symm}	σ_{neg}	σ_{pos}	σ_{symm}	σ_{neg}	σ_{pos}
Δ_{WWH}	± 0.23	-0.21	$+0.26$	± 0.24	-0.21	$+0.27$
Δ_{ZZH}	± 0.50	-0.74	$+0.30$	± 0.44	-0.65	$+0.24$
$\Delta_{t\bar{t}H}$	± 0.41	-0.37	$+0.45$	± 0.53	-0.65	$+0.43$
$\Delta_{b\bar{b}H}$	± 0.45	-0.33	$+0.56$	± 0.44	-0.30	$+0.59$
$\Delta_{\tau\bar{\tau}H}$	± 0.33	-0.21	$+0.46$	± 0.31	-0.19	$+0.46$
$\Delta_{\gamma\gamma H}$	—	—	—	± 0.31	-0.30	$+0.33$
Δ_{ggH}	—	—	—	± 0.61	-0.59	$+0.62$

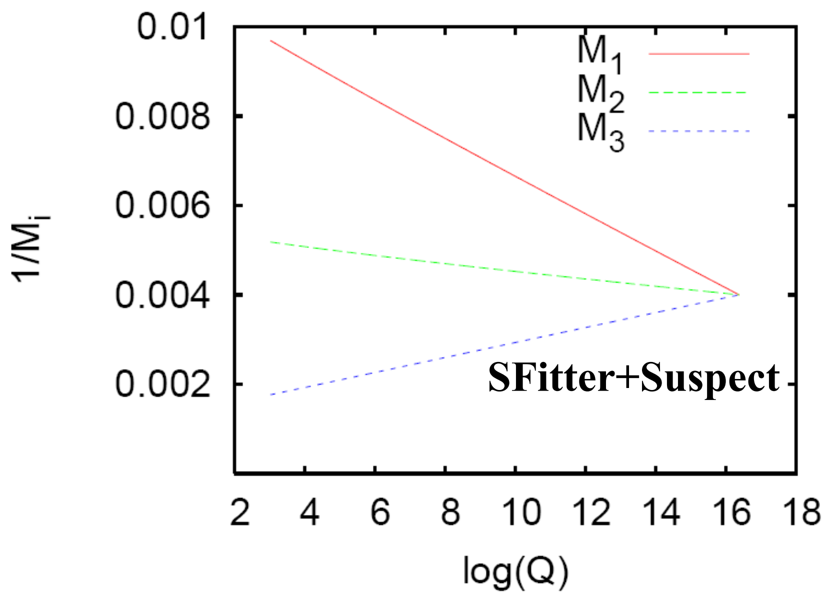
(=SPS1a with modified mA, tanβ, At to move out of decoupling)?

- loglikelihood as estimator (correlations)
- at 90% CL 77% of the toy-experiments not described by SM
- 4% better described by SUSY

Summary

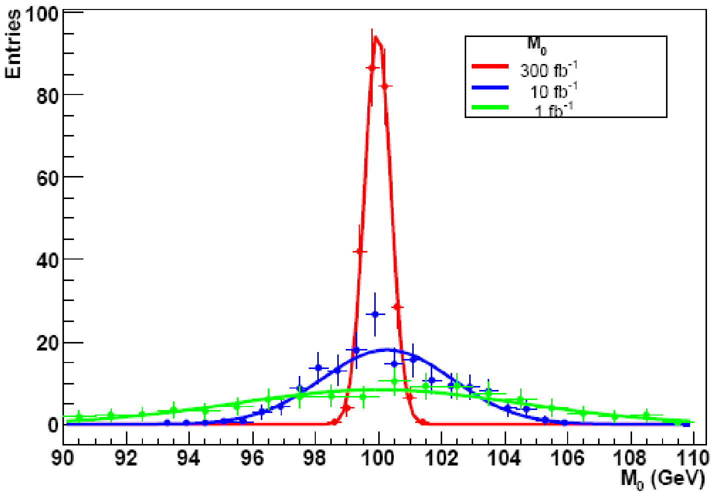
- **LHC could provide a wealth of measurements for SUSY**
- **LHC is ready for difficult scenarios: DSS, Higgs-only**
- **collider dark matter property predictions comparable to WMAP/Planck**

- **Hope to start testing grand unification soon!**



Thank you: Tilman Plehn, Peter Zerwas, Laurent Serin

mSUGRA: Errors LHC (and ILC)



Fittino:
- the beginning 1 fb^{-1}
- 1 year low lumi 10 fb-1
- 3 years nominal 300 fb-1

and then the ILC:

- ILC improves by 3-4x on LHC
- LHC+ILC better than any machine alone

SFitter

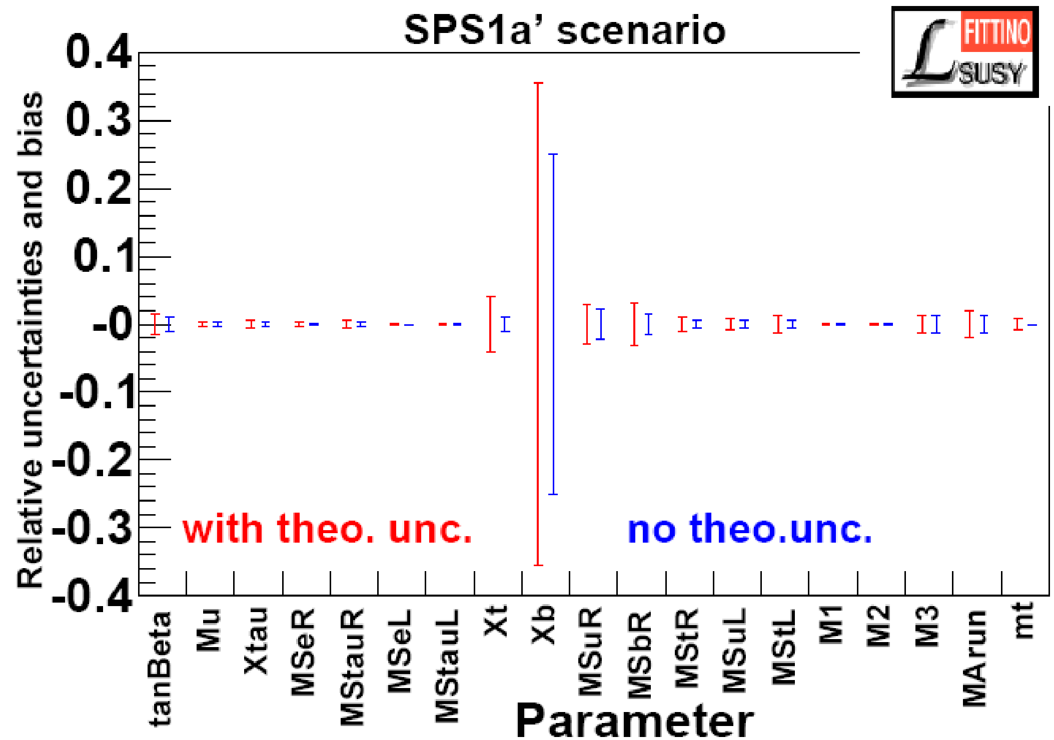
	SPS1a	$\Delta_{\text{endpoints}}$	Δ_{ILC}	$\Delta_{\text{LHC+ILC}}$	$\Delta_{\text{endpoints}}$	Δ_{ILC}	$\Delta_{\text{LHC+ILC}}$
		exp. errors			exp. and theo. errors		
m_0	100	0.50	0.18	0.13	2.17	0.71	0.58
$m_{1/2}$	250	0.73	0.14	0.11	2.64	0.66	0.59
$\tan\beta$	10	0.65	0.14	0.14	2.45	0.35	0.34
A_0	-100	21.2	5.8	5.2	49.6	12.0	11.3
m_t	171.4	0.26	0.12	0.12	0.97	0.12	0.12

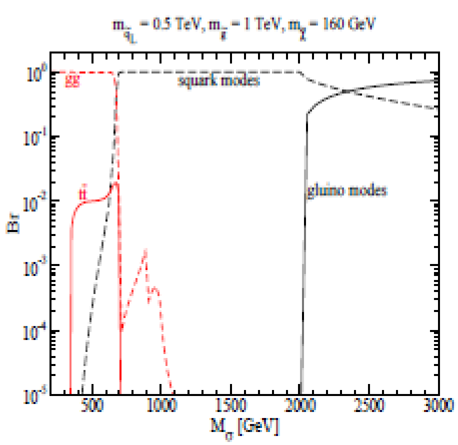
- theory errors impact the expected precision at all machines also at LHC

SPA project: precision of the theoretical calculations Eur.Phys.J.C46:43-60,2006

MSSM

	LHC	ILC	LHC+ILC	SPS1a
$\tan\beta$	$10.0\pm$ 4.5	$12.1\pm$ 7.0	$12.6\pm$ 6.2	10.0
M_1	$102.1\pm$ 7.8	$103.3\pm$ 1.1	$103.2\pm$ 0.95	103.1
M_2	$193.3\pm$ 7.8	$194.1\pm$ 3.3	$193.3\pm$ 2.6	192.9
M_3	$577.2\pm$ 14.5	fixed 500	$581.0\pm$ 15.1	577.9
$M_{\tilde{\tau}_L}$	$227.8\pm\mathcal{O}(10^3)$	$190.7\pm$ 9.1	$190.3\pm$ 9.8	193.6
$M_{\tilde{\tau}_R}$	$164.1\pm\mathcal{O}(10^3)$	$136.1\pm$ 10.3	$136.5\pm$ 11.1	133.4
$M_{\tilde{\mu}_L}$	$193.2\pm$ 8.8	$194.5\pm$ 1.3	$194.5\pm$ 1.2	194.4
$M_{\tilde{\mu}_R}$	$135.0\pm$ 8.3	$135.9\pm$ 0.87	$136.0\pm$ 0.79	135.8
$M_{\tilde{e}_L}$	$193.3\pm$ 8.8	$194.4\pm$ 0.91	$194.4\pm$ 0.84	194.4
$M_{\tilde{e}_R}$	$135.0\pm$ 8.3	$135.8\pm$ 0.82	$135.9\pm$ 0.73	135.8
$M_{\tilde{q}3_L}$	$481.4\pm$ 22.0	$499.4\pm$ $\mathcal{O}(10^2)$	$493.1\pm$ 23.2	480.8
$M_{\tilde{t}_R}$	$415.8\pm\mathcal{O}(10^2)$	$434.7\pm\mathcal{O}(4\cdot10^2)$	$412.7\pm$ 63.2	408.3
$M_{\tilde{b}_R}$	$501.7\pm$ 17.9	fixed 500	$502.4\pm$ 23.8	502.9
$M_{\tilde{q}_L}$	$524.6\pm$ 14.5	fixed 500	$526.1\pm$ 7.2	526.6
$M_{\tilde{q}_R}$	$507.3\pm$ 17.5	fixed 500	$509.0\pm$ 19.2	508.1
A_τ	fixed 0	$613.4\pm$ $\mathcal{O}(10^4)$	$764.7\pm\mathcal{O}(10^4)$	-249.4
A_t	$-509.1\pm$ 86.7	$-524.1\pm$ $\mathcal{O}(10^3)$	$-493.1\pm$ 262.9	-490.9
A_b	fixed 0	fixed 0	$199.6\pm\mathcal{O}(10^4)$	-763.4
$A_{l1,2}$	fixed 0	fixed 0	fixed 0	-251.1
$A_{u1,2}$	fixed 0	fixed 0	fixed 0	-657.2
$A_{d1,2}$	fixed 0	fixed 0	fixed 0	-821.8
m_A	$406.3\pm\mathcal{O}(10^3)$	$393.8\pm$ 1.6	$393.7\pm$ 1.6	394.9
μ	$350.5\pm$ 14.5	$354.8\pm$ 3.1	$354.7\pm$ 3.0	353.7
m_t	$171.4\pm$ 1.0	$171.4\pm$ 0.12	$171.4\pm$ 0.12	171.4





LHC:

- can assign errors on badly measured parameters

LHC+ILC:

- all parameters determined
- several parameters improved

Markov Chains

Markov Chain (MC):

- Sequence of points, chosen by an algorithm (Metropolis-Hastings), only depending on its direct predecessor
- Picks a set of "average" points according to a potential V (e.g. inverse log-likelihood, $1/\chi^2$)
- Point density resembles the value of V (i.e. more points in region with high V)
- Scans high dimensional parameter spaces efficiently [Baltz, Gondolo 2004]
- mSUGRA MC scans with current exp. limits

[Allanach, Lester, Weber 2005-7; Roszkowski, Ruiz de Austra, Trotta 2006/7]

Weighted Markov Chains: Improved evaluation algorithm for binning: [Plehn, MR]

- Weight points with value of V: $\left(\frac{\text{number of points}}{\sum_{\text{points}} 1/V(\text{point})}\right)$ [based on Ferrenberg, Swendsen 1988]
- Maintain additional chain which stores points rejected because $V(\text{point}) = 0$

\+ Fast scans of high-dimensional spaces $\mathcal{O}(N)$
\+ Does not rely on shape of χ^2 (no derivatives used)
\+ Can find secondary distinct solutions
– Exact minimum not found $\Rightarrow$ Additional gradient fit
– Bad choice of proposal function for next point leads to bad coverage of the space