Decoupled Scalars Supersymmetry at the LHC

GDR SUSY 08

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The MSSM : yes but...

Traditional MSSM $\Rightarrow m_{\text{SUSY}} \simeq \mathcal{O}(1\text{ TeV})$

SPS1a : $m_{\tilde{q}} \simeq 540$ GeV ; $m_{\tilde{l}} \simeq 170$ GeV ; $m_{\chi} \simeq 260$ GeV ; $m_{\tilde{g}} \simeq 600$ GeV

Advantages

- Control over $m_h \simeq \mathcal{O}(100\text{ GeV})$ $\Rightarrow$ no fine tuning
- Dark Matter candidate
- Grand Unification

Inconvenients

- No Higgs/SUSY @ LEP $\Rightarrow$ fine tuning
- expected FCNC
- Proton decay
- CP violation
- Fine tuning of Λ

If scalar scale is large ($\gtrsim 10$ TeV):

- Dark Matter candidate
- Grand Unification
- Heavier Higgs

- m_h not protected by SUSY anymore $\Rightarrow$ fine tuning
- Fine tuning of Λ

Decoupled Scalars Supersymmetry

[Arkani-Hamed & Dimopoulos, 2004] and [Giudice & Romanino, 2004]

Scalar mass scale $M_S = \mathcal{O}(10^{4\text{ to }16}\text{ GeV})$.

Spectrum

- **Scalars** ($\tilde{q}$, $\tilde{l}$, H and A) @ M_S.
- **Fermions** ($\tilde{\chi}$ and $\tilde{g}$) protected by sym. @ $M_{EW} \sim \mathcal{O}(1\text{ TeV})$.
- **SM Higgs** h fine-tuned @ M_{EW}.

- All scalars (but h) are decoupled from the low energy spectrum.
- Effective theory below M_S (eff. RGE).
- At M_S, matching with the complete theory and MSSM RGE beyond.

Model parameters

In the phenomenological **MSSM** : 24 parameters

$\tan\beta$	M_1	M_2	M_3	M_A	μ
$A_{\tilde{\tau}}$	$A_{\tilde{t}}$	$A_{\tilde{b}}$	$m_{\tilde{\tau}_R}$	$m_{\tilde{\tau}_L}$	$m_{\tilde{\mu}_R}$
$m_{\tilde{\mu}_L}$	$m_{\tilde{e}_R}$	$m_{\tilde{e}_L}$	$m^1_{\tilde{q}_L}$	$m^2_{\tilde{q}_L}$	$m^3_{\tilde{q}_L}$
$m_{\tilde{t}_R}$	$m_{\tilde{b}_R}$	$m_{\tilde{c}_R}$	$m_{\tilde{s}_R}$	$m_{\tilde{u}_R}$	$m_{\tilde{d}_R}$

mSUGRA : 5 parameters

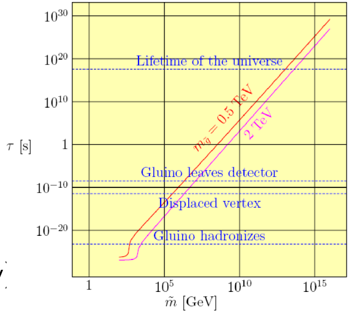
$$m_0 \; ; \; m_{1/2} \; ; \; A_0 \; ; \; \mathrm{sgn}\,\mu \; ; \; \tan\beta$$

For **DSS**, parameters are

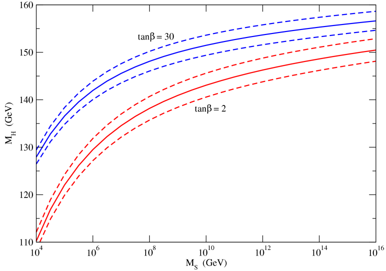
- M_S : decoupling scale, scalar masses.
- $m_{1/2}$: gauginos mass parameter at the GUT scale.
- μ : Higgs mass parameter at the EW scale.
- A_t : trilinear $H - \tilde{t} - \tilde{t}$ coupling at M_S.
- $\tan\beta$: mixing angle between Higgses at M_S.

Phenomenology

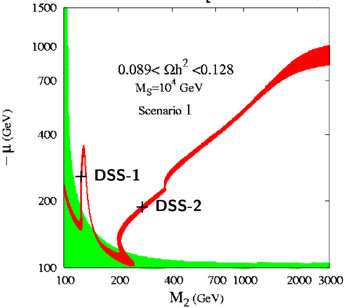
- No scalars within the reach of the LHC
- Light Higgs between 110 and 160 GeV
- Relic density in agreement with WMAP
- Possibility of gluino stability (not in this study)



[Kilian *et al*, 2004]



[Bernal *et al.*, 2007]



Parameter points

	M_S	$m_{1/2}$	μ	$\tan\beta$	A_t
DSS-1	10 TeV	132.4 GeV	290 GeV	30	0
DSS-2	10 TeV	296.5 GeV	200 GeV	30	0

	DSS-1	DSS-2
h	129	129
$\tilde{g}$	438	880
$\tilde{N}_1$	60	125
$\tilde{N}_2$	117	185
$\tilde{N}_3$	296	206
$\tilde{N}_4$	310	317
$\tilde{C}_1$	117	175
$\tilde{C}_2$	313	317

Masses in GeV (SuSpect)

	DSS-1		DSS-2
$\tilde{g}\tilde{g}$	63 pb	$\tilde{g}\tilde{g}$	950 fb
$\tilde{C}\tilde{N}$	12 pb	$\tilde{C}_1\tilde{N}_2$	850 fb
$\tilde{C}\tilde{C}$	6 pb	$\tilde{C}_1\tilde{C}_1$	640 fb
$\tilde{C}\tilde{g}$	310 fb	$\tilde{C}_1\tilde{N}_3$	500 fb
$\tilde{N}\tilde{g}$	220 fb	$\tilde{C}_1\tilde{N}_1$	450 fb
$\tilde{N}\tilde{N}$	100 fb	$\tilde{C}_2\tilde{N}_4$	300 fb
Total	82 pb	Total	4 pb

NLO LHC Production (Prospino)

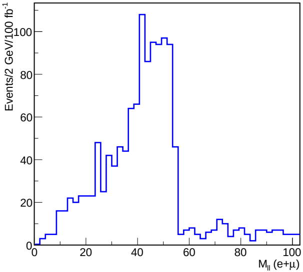
Discovery : Inclusive search

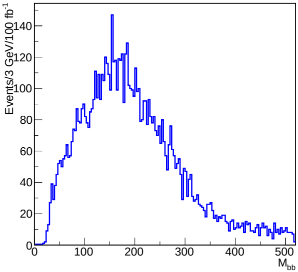
- Signal is mostly made of gluino pairs.
- Typical chain : $\tilde{g} \rightarrow 2j + \tilde{C} \rightarrow 2j + \tilde{N}_1 \Rightarrow \not{E}_T$ + numerous hard jets.
- Background = $t\bar{t}$, Z+jets, ZZ and WZ.
- Event selection :
  - ≥ 4 jets with $P_T > 150,\ 100,\ 50,\ 50$ GeV,
  - $M_{\text{eff}} = \not{E}_T + \sum P_T(\text{jets}) > 600$ GeV,
  - $\not{E}_T > 0.2 \times M_{\text{eff}}$,
  - no lepton (e, μ).

Event count (MC generation + LHC-like fast-simulation)

	generation	production	no e, μ final state	cuts
DSS-1	Pythia	63 pb	46 pb	9.5 pb
DSS-2		1 pb	876 fb	275 fb
$t\bar{t}$	MC@NLO+Jimmy	833 pb	369 pb	18 fb
Z+jets	Alpgen+Jimmy	220 pb	205 pb	60 fb
WZ	Pythia	27 pb	20 pb	5 fb
ZZ		15 pb	13 pb	4 fb

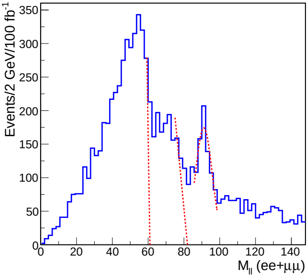
Observables for DSS-1





m_h	$h \to \gamma\gamma$ channel	**6 observables**
$\sigma(\tilde{g}\tilde{g})$	Inclusive no lepton signal.	
$\sigma(3\ell)$	$\tilde{g}\tilde{g}$ or $\tilde{C}_1\tilde{N}_2$	
$m_{\tilde{N}_2} - m_{\tilde{N}_1}$	$M_{\ell^+\ell^-}$ of $\tilde{N}_2 \to \tilde{N}_1\ell\ell$ decay	
$m_{\tilde{g}} - m_{\tilde{N}_1}$	$M_{b\bar{b}}$ of $\tilde{g} \to \tilde{N}_1 b\bar{b}$ decay	
$\frac{BR(\tilde{g}\to X+Z\to\ell\ell)}{BR(\tilde{g}\to\ell\ell+X)}$	Z peak over kinematic edge peak	

Observables for DSS-2



m_h	$h \rightarrow \gamma\gamma$ channel	
$\sigma(\tilde{g}\tilde{g})$	Inclusive no lepton signal.	
$\sigma(3\ell)$	$\tilde{g}\tilde{g}$	
$m_{\tilde{N}_2} - m_{\tilde{N}_1}$	$M_{\ell^+\ell^-}$ of $\tilde{N}_2 \rightarrow \tilde{N}_1\ell\ell$ decay	**6 observables**
$m_{\tilde{N}_3} - m_{\tilde{N}_1}$	$M_{\ell^+\ell^-}$ of $\tilde{N}_3 \rightarrow \tilde{N}_1\ell\ell$ decay	
$\frac{BR(\tilde{g}\rightarrow X+Z\rightarrow\ell\ell)}{BR(\tilde{g}\rightarrow\ell\ell+X)}$	Z peak over kinematic edge peak	

Parameter determination : SFITTER

- SFITTER fits a given model from collider observables and provides errors on parameters.
- Uses SuSpect, SDecay, Prospino, Minuit, MicroMegas, etc...
- Can fit mSUGRA, pMSSM, GMSB, AMSB and DSS

	Observables		Stat. errors	Exp. systematic errors		Th.
		Value	100 fb^{-1}	Error	Source	
DSS1	m_h	129 GeV	0.1%	0.1%	energy scale	4%
	$m_{\tilde{N}_2} - m_{\tilde{N}_1}$	57 GeV	0.3%	0.1%	energy scale	1%
	$m_{\tilde{g}} - m_{\tilde{N}_2}$	321 GeV	0.3%	1%	energy scale	1%
	$\sigma(3\ell)$	145 fb	3%	5%	luminosity	12%
	R_Z	0	.03	1%	lepton-ID	0
	$\sigma(\tilde{g}\tilde{g})$	69 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 GeV	2%	0.1%	energy scale	1%
	$m_{\tilde{N}_3} - m_{\tilde{N}_1}$	82 GeV	2%	0.1%	energy scale	1%
	$\sigma(3\ell)$	8.8 fb	10%	5%	luminosity	30%
	R_Z	0.56	.07	1%	lepton-ID	0
	$\sigma(\tilde{g}\tilde{g})$	1.03 pb	1%	5%	luminosity	30%

- Statistical errors based on 1 year of LHC operation at full luminosity.

Minimization : Markov Chain + MIGRAD

- Start from an arbitrary distant point
- Use Markov Chains to find correct region (repeat to check convergence)
- Minimize outcome of MC with `MIGRAD`

	Nominal	MC	`MIGRAD`
M_1	132.4	225	132.5
M_2	132.4	176	132.2
M_3	132.4	150	132.3
$\tan\beta$	30	70	30
μ	290	380	289

DSS-1

	Nominal	MC	`MIGRAD`
M_1	296.5	282	296.4
M_2	296.5	279	296.5
M_3	296.5	293	296.5
$\tan\beta$	30	64	30
μ	200	186	200

DSS-2

- M_S and A_t not fitted (no info on scalar sector)
- Markov Chains find correct region
- `MIGRAD` finds original point

Determination of errors : MINOS

Three fit strategies :

- Limited statistic (100 fb^{-1}) : systematic and statistical errors included.
- Infinite statistic : only systematic errors included.
- Infinite stat. and theoretical : systematic and theoretical errors included.

	DSS-1						DSS-2					
	Lim stat.		∞ stat.		∞+th		Lim stat.		∞ stat.		∞+th	
M_1	2	1.7%	0.3	0.2%	4	3%	15	5%	0.8	0.3%	6	2%
M_2	2	1.7%	0.3	0.2%	2	1.5%	8	3%	0.4	0.1%	0.8	0.3%
M_3	0.3	0.2%	0.2	0.2%	4	1.5%	20	7%	1.2	0.4%	undet.	
μ	33	11%	1.1	0.4%	10	3.4%	7	3%	0.4	0.2%	4	2%
$\tan\beta$	15	50%	1.2	4%	undet.		24	78%	1.2	4%	undet.	

- Invisible Higgs sector (except h) : no sensitivity on $\tan\beta$.
- Fit converges to nominal values.
- Theoretical errors dominant for M_3 and $\tan\beta$.
- Still M_1, M_2 and μ determined to a few %.

Conclusion

- DSS model with no scalars at the LHC (but h)
- Provides good features and cure bad BUT small fine-tuning
- 2 points explored : both visible at the LHC
- Many non-trivial observables used to constrain parameters
- Both points can be fitted (fixing scalar scale)
- M_1 and M_2 determined within a few %
- Theoretical uncertainties still dominant on M_3 and $\tan\beta$

Outlook

- Include WMAP constrain (and others?)
- Further investigate M_3 and $\tan\beta$ determination (theoretical errors)
- More realistic observable analysis : full detector simulation
- Confirm expected invisibility of larger $m_{1/2}, \mu$ points

BACKUP

Gaugino mixing in DSS-1

- $\tilde{N}_1 \approx \tilde{\gamma}$
- $\tilde{N}_2 \approx \tilde{Z}^0$
- $\tilde{N}_3 \approx \tilde{H}$
- $\tilde{N}_4 \approx \tilde{H}$

- $\tilde{C}_1 \approx \tilde{W}^\pm$
- $\tilde{C}_2 \approx \tilde{H}$

$$\begin{array}{cc} \tilde{N}_2 \to \tilde{N}_1 q\bar{q} & 67\% \\ \tilde{N}_2 \to \tilde{N}_1 \ell\bar{\ell} & 30\% \end{array}$$

$$\begin{array}{cc} \tilde{N}_3 \to \tilde{C}_1 W & 65\% \\ \tilde{N}_3 \to \tilde{N} Z & 30\% \\ \tilde{N}_3 \to \tilde{N} h & 5\% \end{array}$$

$$\begin{array}{cc} \tilde{N}_4 \to \tilde{C}_1 W & 70\% \\ \tilde{N}_4 \to \tilde{N} h & 20\% \\ \tilde{N}_4 \to \tilde{N} Z & 10\% \end{array}$$

Gaugino mixing in DSS-2

- $\tilde{N}_1 \approx \tilde{\gamma} + \tilde{Z}^0$
- $\tilde{N}_2 \approx \tilde{\gamma} + \tilde{H}$
- $\tilde{N}_3 \approx \tilde{H}$
- $\tilde{N}_4 \approx \tilde{Z}^0$

- $\tilde{C}_1 \approx \tilde{H}$
- $\tilde{C}_2 \approx \tilde{W}^\pm$

$\tilde{N}_2 \to \tilde{N}_1 q\bar{q}$	67%
$\tilde{N}_2 \to \tilde{N}_1 \ell\bar{\ell}$	30%

$\tilde{N}_3 \to \tilde{N}_1 q\bar{q}$	65%
$\tilde{N}_3 \to \tilde{N}_1 \ell\bar{\ell}$	30%
$\tilde{N}_3 \to \tilde{C}_1 X$	5%

$\tilde{N}_4 \to \tilde{C}_1 W$	86%
$\tilde{N}_4 \to \tilde{N}_3 Z$	9%
$\tilde{N}_4 \to \tilde{N}_2 h$	4%
$\tilde{N}_4 \to \tilde{N}_2 Z$	2%