Split-Supersymmetry and Waterzooïs
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Outline

- The case for Split-Susy
- Phenomenology
- Collider signatures
- Parameter determination at the LHC

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 SUSY is broken at high scale ($\gtrsim 10$ TeV):

- Dark Matter candidate
- Grand Unification
- Heavier Higgs

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

Split-Supersymmetry

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

SUSY is broken at $M_S = \mathcal{O}(10^{4 \text{ to } 16} \text{ GeV})$.

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}.

- 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 phenomenologic **MSSM** : 24 parameters

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

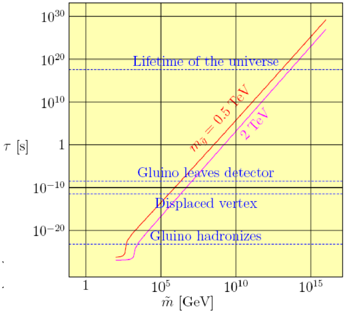
mSUGRA more constrained : 5 parameters

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

For **Split-SUSY**, parameters are

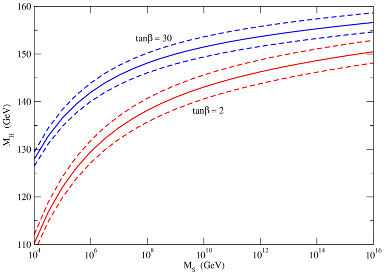
- M_S : breaking scale, scalars mass,
- M_1, M_2, $M_3(M_{\text{GUT}})$: gauginos mass parameters at the GUT scale.
- $\mu(M_Z)$: Higgs mass parameter at the EW scale.
- $A_t(M_S)$: trilinear $H - \tilde{t} - \tilde{t}$ coupling at the breaking scale.
- $\tan\beta(M_S)$: vevs ratio at M_S.

Phenomenology

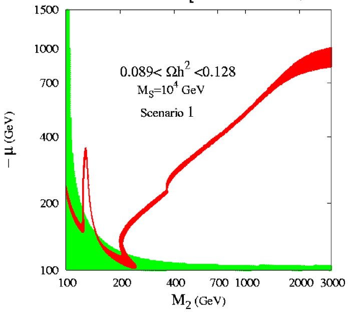


[Kilian *et al*, 2004]

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



[Bernal *et al.*, 2007]



Observables @ LHC

Parameter point

M_S	10 TeV
$M_{2,EW}$	129 GeV
μ	290 GeV
$\tan\beta$	30
A_t	0.

- low fine-tuning
- $\Omega_{\mathrm{DM}} h^2$ in agreement with WMAP

Masses in GeV (SuSpect)

h	129	$\tilde{g}$	438	$\tilde{\chi}_1^\pm$	117	$\tilde{\chi}_2^\pm$	313
$\tilde{\chi}_1^0$	60	$\tilde{\chi}_2^0$	117	$\tilde{\chi}_3^0$	296	$\tilde{\chi}_4^0$	310

SplitSusy in SuSpect $\rightarrow$ [Bernal *et al.*, 07]

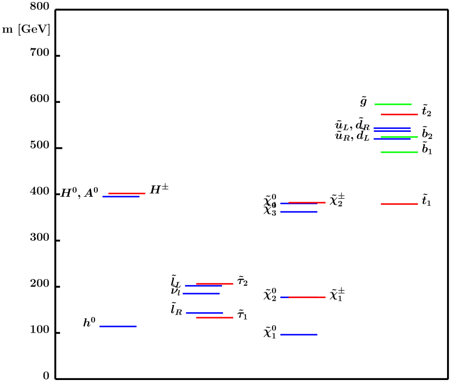
NLO production (Prospino)

$\tilde{g}\tilde{g}$	63 pb	$\tilde{\chi}^\pm\tilde{g}$	311 fb
$\tilde{\chi}^\pm\tilde{\chi}^0$	12 pb	$\tilde{\chi}^0\tilde{g}$	223 fb
$\tilde{\chi}^\pm\tilde{\chi}^\pm$	6 pb	$\tilde{\chi}^0\tilde{\chi}^0$	98 fb
Total		82 pb	
$\sigma_{\mathrm{SPS1a}} \sim 60$ pb		$\sigma_{\mathrm{SPS1a}}(\tilde{g}\tilde{g}) \sim 8$ pb	

- High tri-lepton signal (no hard jet) : $\sigma_{3\ell} = 180$ fb $= 140 \times \sigma_{3\ell}(\mathrm{SPS1a})$
  $\sigma(\tilde{\chi}_1^\pm \tilde{\chi}_2^0) \simeq 12$ pb, no t-channel destructive interference
- End-point : $m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0}$ in $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 \ell^+ \ell^-$
- $\sigma(\tilde{g}\tilde{g})$ and $R(\tilde{g} \rightarrow b/!b) = BR(\tilde{g} \rightarrow bX)/BR(\tilde{g} \rightarrow bX)$
- $m_h \pm 0.1\%$ in $h \rightarrow \gamma\gamma$

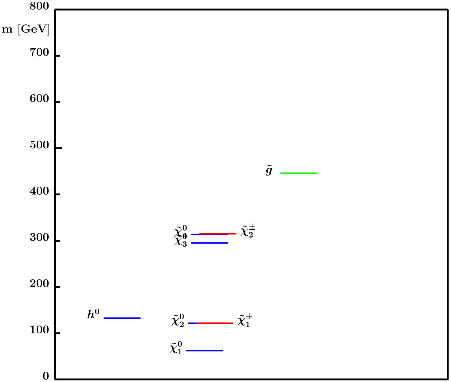
Spectrum

SPS1a



$m_0 = 100$; $m_{1/2} = 250$; $A_0 = -100$;
sgn $\mu = +$; $\tan\beta = 10$

Split-Susy point A



- Heavier Higgs
- Lighter LSP ($\tilde{\chi}_1^0$)
- Lighter gluino

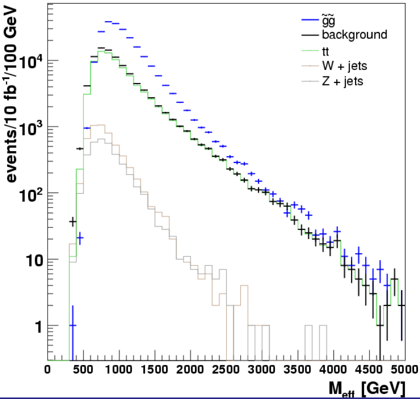
Inclusive signature

feasability study with fast-sim : PYTHIA + LHC detector simulator.
Dominant SUSY channels : $\tilde{g}\tilde{g}$ and $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \Rightarrow$ multijets, $\not{E}_T$, leptons
Background : $t\bar{t}$, W+jets and Z+jets
Very large σ_{SUSY} : Important signal with little luminosity

Standard cuts :

- 4 jets with $P_T > 150, 100, 50$ GeV
- $M_{\mathrm{eff}} = \not{E}_T + \sum P_T(\mathrm{jet}) > 600$ GeV
- $\not{E}_T > \max(100 \text{ GeV}, 0.2 \times M_{\mathrm{eff}})$

	σ	after cuts
$\tilde{g}\tilde{g}$	63 pb	9.7 pb
bkg	1080 pb	6 pb
$t\bar{t}$	590 pb	4.2 pb
W+jets	300 pb	1.1 pb
Z+jets	190 pb	0.7 pb



$10\ \mathrm{fb}^{-1} \Rightarrow S/\sqrt{B} = 396$
$1\ \mathrm{fb}^{-1} \Rightarrow S/\sqrt{B} = 125$

The trilepton signal

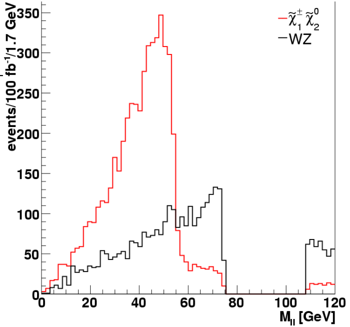
Fast simulation of 100 fb^{-1} with PYTHIA and LHC detector simulator.

Main backgrounds $\rightarrow$ WZ and ZZ

- Acceptance : $|\eta| < 2.5$ and $P_T\{e, \mu\} > \{5, 6\}$ GeV
- Leptons : 2 OS-SF + 1 lepton with $P_T\{e, \mu\} > \{20, 10\}$ GeV
- OF-SF di-leptons invariant mass $\neq M_Z \pm 5\sigma_Z$
- No high-P_T jets

	Leptons ($e + \mu$)	3ℓ reco.	M_Z
$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$	180 fb	39 fb	35 fb
WZ	390 fb	121 fb	5.6 fb
ZZ	72 fb	16.2 fb	1.8 fb

FastSim : almost full lepton efficiency.
$\Rightarrow$ What about full simulation?



For 100 fb^{-1}

Lepton identification in full simulation

Preliminary : ATLAS detector paper
(to be published end of 07).

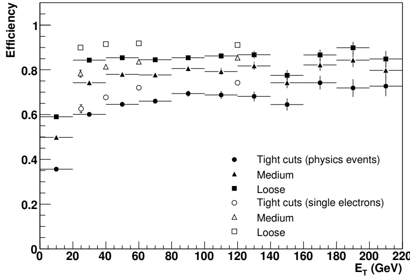
Electron-Id

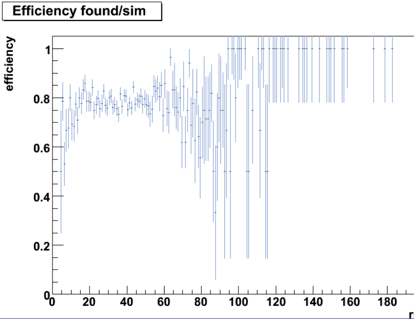
- Combined Id : Track det. + EM Calo.
  → matching tracks to EM clusters.
- Cut-based based identification
- 50 GeV P_T electron Identification efficiency ≈ 65%
- Jet rejection ≈ 10^5.

Muon-Id

- Combined Id : Track det. + Muon syst.
- Muon Id. efficiency ≈ 80%
- Fake rate ≈ 0.3%

3 leptons ⇒ 30% to 60% efficiency





Questions..

- Can Split-Susy be determined at the LHC?
  - Do we have enough observables with $\tilde{g}$, $\tilde{\chi}_1^{\pm}$ et $\tilde{\chi}_2^0$?
- How to tell it from the FOCUS Point?
  (mSUGRA with $m_0 = 3550$, $m_{1/2} = 300$, $\tan\beta = 10$, $A_0 = 100$)

	FOCUS Point	**Split SUSY**
Scalars	visible	totally decoupled
σ_{SUSY}	$\simeq 5$ pb	82 pb !!
Higgs	$\simeq 115$ GeV	$\simeq 130$ GeV
LSP	$\simeq 100$ GeV	$\simeq 60$ GeV
Observables	$\simeq 10$	3 part. visible + h

- What precision can be achieved?

Parameter determination : SFITTER

SFITTER : model fitting from collider observables (+errors).
Uses SuSpect, SDecay, Minuit, MicroMegas, etc...

New : Implémentation of Split-Susy

Observable	Value	Detailed			Conservative
		stat.	syst.	th.	gauss.
$\sigma_{3\ell}$	180 fb	5.5	7.3	0.03	20
$\|m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0}\|$	55 GeV	0.15	0.06		6
$R(\tilde{g} \to b/!b)$	9.5%	0.1	0.5		1
m_h	128.8 GeV	0.13	0.13	5	0.13
$\sigma(\tilde{g}\tilde{g})$	63 pb	0.07	3.5	0.2	14

Parameter determination

Parameter	Model	Detailed		Conservative	
		Fit	Error	Fit	Error
M_S	10^4	fixed		fixed	
M_1	132.4	135.3	2.6	138.1	29.7
M_2	132.4	133.3	1.6	133.6	9.7
M_3	132.4	132.7	0.6	133.0	7.3
$\tan\beta$	30.	fixed		fixed	
μ	290.	290.3	5.5	290.4	22.1
A_t	0.	fixed		fixed	

- No info on scalar sector (except non obs.) : we fix A_t and M_S.
- Invisible Higgs sector (except h) : no sensitivity on $\tan\beta$
- Fit converges
- few to 10% errors

Conclusions

- Split-SUSY : model with decoupled scalars (except h), breaking at $M_S = \mathcal{O}(10^{4 \text{ a } 16}$ GeV).
- Grande unification and DM respected but fine tuning of m_h required
- No scalars at the LHC but very high σ_{SUSY}
- $\tilde{g}\tilde{g}$ and trilepton visible $\rightarrow$ lepton-Id
- Few observables but Split-Susy can be determined
- Errors on parameters of the order of 10% or less

Outlook :

- Include indirect constraints ($\Omega_{\text{DM}} h^2$, $b \rightarrow s\gamma$ etc...)
- Look at other parameter points
- Further comparison with FOCUS point
- Look at full simulation