Dirac Neutralinos and Electroweak Scalar Bosons of N=1/N=2 Hybrid Supersymmetry at Colliders

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arXiv:1005.0818 [hep-ph], JHEP to appear

Outline

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- A hybrid N=1/N=2 SUSY model
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  - gaugino sector
- Phenomenology at colliders
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  - neutralino production
  - EW scalar boson production and decays
- Summary and outlook

Motivation

Supersymmetry – the most elegant and respected proposition for the beyond SM physics

In the simplest realisation each SM particle is paired with a sparticle that differs in spin by ½:

- quarks – squarks
- gauge bosons – gauginos
- leptons – sleptons
- Higgses – higgsinos

If gauginos are seen – Majorana or Dirac ?

Need a model to differentiate

Actually Dirac gauginos might be welcome …..

for example, Dirac gauginos (in contrast to Majorana in the MSSM) forbid some couplings and often lead to additional suppression in flavor-changing processes from gauginos running in the loops.

Antoniadis, Benakli, Delgado, Quiros 0610265
Kribs, Poppitz, Weiner 0712.2039
Blechman, Ng 0803.3811

- Dirac gauginos offer an attractive formulation with distinct phenomenology
- and the Dirac gauginos bring in scalar partners – **sgluons and EW scalar bosons**

Plehn, Tait 0810.3919
Kane, Petrov, Shao, Wang 0805.1397
Belanger et al., 0905.1043

A hybrid N=1/N=2 SUSY model

In the MSSM gauginos are Majorana particles with two degrees of freedom to match gauge bosons in a vector supermultiplet.

$$\hat{G}^{a}_{\chi} = \tilde{g}^{a}_{\alpha} + D^{a}\theta_{\alpha} + (\sigma^{\mu\nu})_{\alpha}{}^{\beta}\theta_{\beta}G^{a}_{\mu\nu} + \ldots$$

To provide two additional degrees, the N=1 vector supermultiplet can be paired with an additional N=1 chiral, gauge supermultiplet

$$\hat{\Sigma}^{a} = \sigma^{a} + \sqrt{2}\theta\,\tilde{g}'^{a} + \theta\theta\,F^{a}$$

to a vector hyper-multiplet of N=2 supersymmetry $\mathcal{G} = \{\hat{G}, \hat{\Sigma}\}$

Fayet 1976
Del Aguila, Dugan, Grinstein, Hall, Ross, West, 1985
Alvarez-Gaume, Hassan hep-ph/9701069
Fox, Nelson, Weiner hep-ph/0206102
.....

Schematically, the N=2 gauge hyper-multiplet can be decomposed into the usual N=1 vector and chiral gauge supermultiplets:

superfields	$SU(3)_C, SU(2)_I, U(1)_Y$	Spin 1	Spin 1/2	Spin 0	
$\hat{G}_C$ / color	$8,1,0$	g^a	$\tilde{g}^a$		vector
$\hat{G}_I$ / isospin	$1,3,0$	W^i	$\tilde{W}^i$		vector
$\hat{G}_Y$ / hypercharge	$1,1,0$	B	$\tilde{B}$		vector
$\hat{\Sigma}_C$ / color	$8,1,0$		$\tilde{g}'^a$	σ_C^a	chiral
$\hat{\Sigma}_I$ / isospin	$1,3,0$		$\tilde{W}'^i$	σ_I^i	chiral
$\hat{\Sigma}_Y$ / hypercharge	$1,1,0$		$\tilde{B}'$	σ_Y^0	chiral

Gauge scalars are R-parity even

N=2 mirror (s)fermions are assumed to be heavy to avoid chirality problems → a hybrid N=1/N=2 SUSY model

EW scalars two Higgs doublets + iso-triplet σ_I^i and hypercharge singlet σ_Y^0

$$H_u^0 = \frac{1}{\sqrt{2}}\left[s_\beta(v+h) + c_\beta H + i(c_\beta A - s_\beta a)\right], \qquad H_u^+ = c_\beta H^+ - s_\beta a^+$$

$$H_d^0 = \frac{1}{\sqrt{2}}\left[c_\beta(v+h) - s_\beta H + i(s_\beta A + c_\beta a)\right], \qquad H_d^- = s_\beta H^- + c_\beta a^-$$

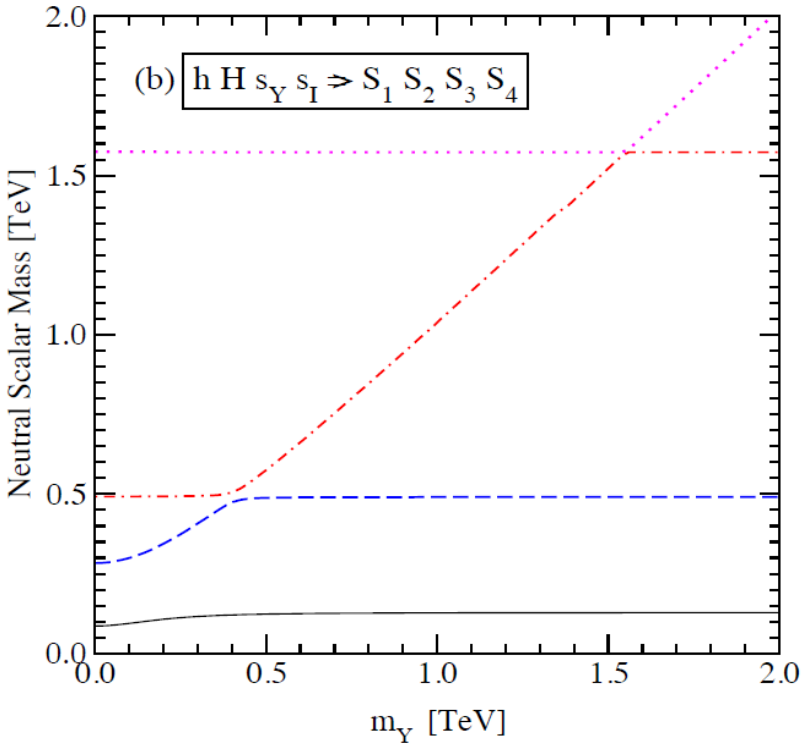
$$\sigma_Y^0 = \frac{1}{\sqrt{2}}(v_Y + s_Y + i a_Y),$$

$$\sigma_I^3 = \frac{1}{\sqrt{2}}(v_I + s_I + i a_I), \quad \sigma_I^1 = \frac{1}{\sqrt{2}}(\sigma_2^+ + \sigma_1^-), \quad \sigma_I^2 = \frac{i}{\sqrt{2}}(\sigma_2^+ - \sigma_1^-)$$

Gauge boson masses $m_Z^2 = \frac{1}{4}(g'^2 + g^2)v^2, \qquad m_W^2 = \frac{1}{4}g^2v^2 + g^2v_I^2$

$\Delta\rho = \rho - 1 = 4v_I^2/v^2$ ➡ $v_I \leq 3\,\text{GeV}$

pseudoscalars A, a_Y, a_I
neutral scalars h, H, s_Y, s_I
charged scalars $H^\pm, s_1^\pm, s_2^\pm$



Gauginos:

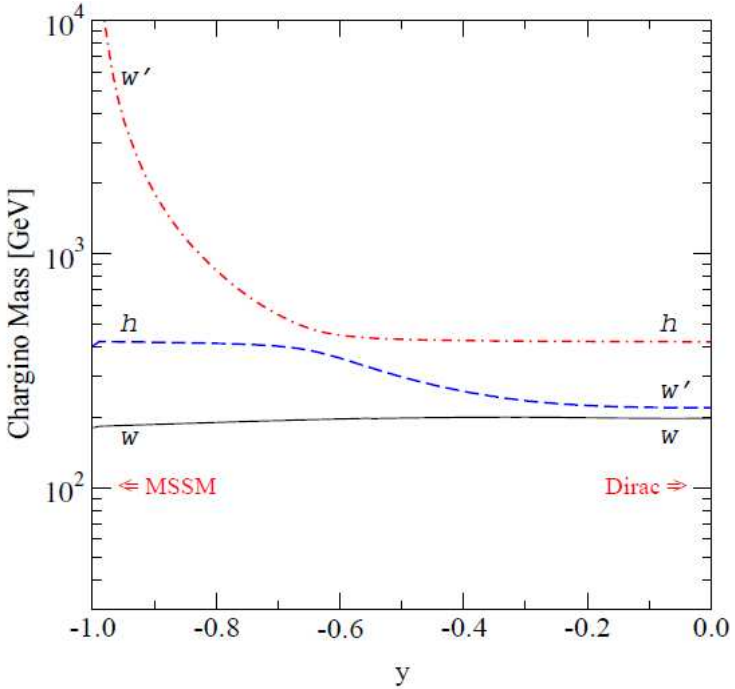
Dirac-type mass $\mathcal{A}_D = \int d^4x\, d^2\theta\, M^D\, \theta^\alpha\, \mathrm{tr}\, \hat{G}_\alpha \hat{\Sigma}$

charginos $\{\tilde{W}_L'^-, \tilde{W}_L^-, \tilde{H}_{dL}^-\}$

$$\begin{pmatrix} M_2' & M_2^D - g v_I & -\lambda_I v_u \\ M_2^D + g v_I & M_2 & \frac{1}{\sqrt{2}} g v_d \\ \lambda_I v_d & \frac{1}{\sqrt{2}} g v_u & \mu_c \end{pmatrix}$$

neutralinos $\{\tilde{B}', \tilde{B}, \tilde{W}'^0, \tilde{W}^0, \tilde{H}_u^0, \tilde{H}_d^0\}$

$$\begin{pmatrix} M_1' & M_1^D & 0 & 0 & -\frac{1}{\sqrt{2}}\lambda_Y v_d & -\frac{1}{\sqrt{2}}\lambda_Y v_u \\ M_1^D & M_1 & 0 & 0 & \frac{1}{2} g' v_u & -\frac{1}{2} g' v_d \\ 0 & 0 & M_2' & M_2^D & -\frac{1}{\sqrt{2}}\lambda_I v_d & -\frac{1}{\sqrt{2}}\lambda_I v_u \\ 0 & 0 & M_2^D & M_2 & -\frac{1}{2} g v_u & \frac{1}{2} g v_d \\ -\frac{1}{\sqrt{2}}\lambda_Y v_d & \frac{1}{2} g' v_u & -\frac{1}{\sqrt{2}}\lambda_I v_d & -\frac{1}{2} g v_u & 0 & -\mu_n \\ -\frac{1}{\sqrt{2}}\lambda_Y v_u & -\frac{1}{2} g' v_d & -\frac{1}{\sqrt{2}}\lambda_I v_u & \frac{1}{2} g v_d & -\mu_n & 0 \end{pmatrix}$$



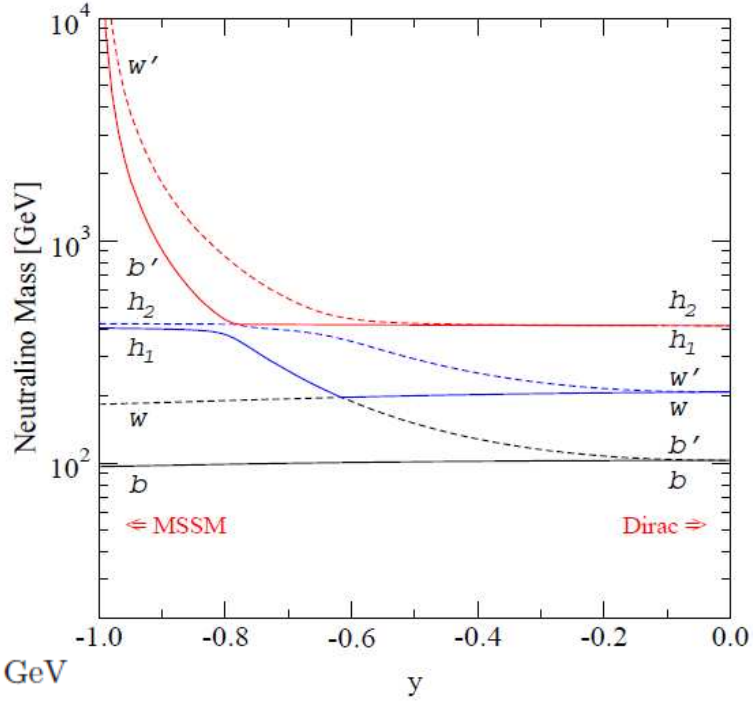
$M_1^{(D)} \approx M_2^{(D)}/2$

$M_2' = my/(1+y)\,,$

$M_2 = -my\,,$

$M_2^D = m\,,$

$\mu = 2m\,,$ $\quad m = 200$ GeV



Phenomenology at colliders

- Squark cascade decays
- Neutralino pair production
- EW scalar boson production and decays

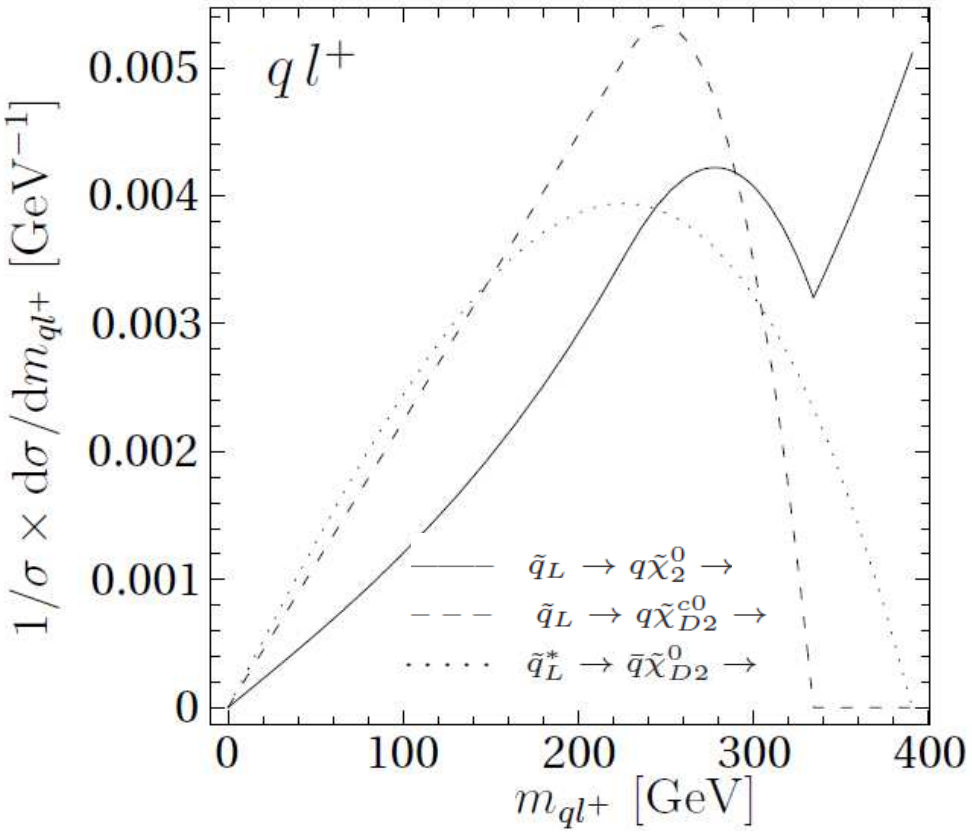
only few examples to be shown: more in
arXiv:1005.0818 [hep-ph]

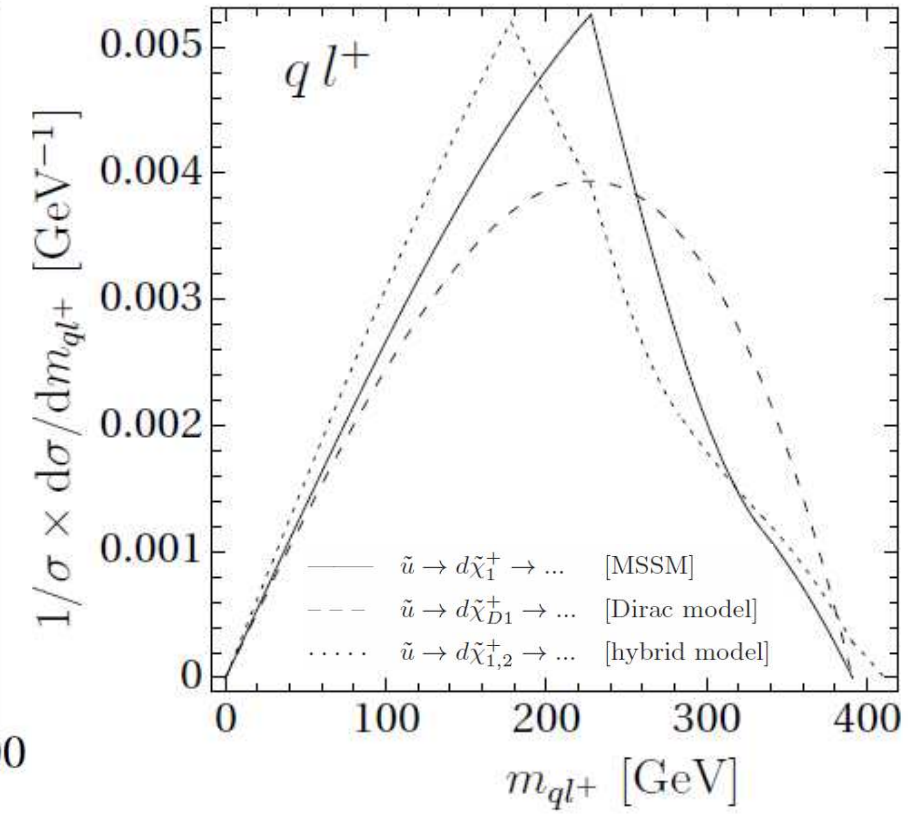
Squark cascade decays

	via neutralino	via chagino
MSSM:	$\tilde{q}_L \to q\,\tilde{\chi}_2^0 \to q\,l^{\pm}\,\tilde{l}_L^{\mp} \to q\,l^{\pm}\,l^{\mp}\,\tilde{\chi}_1^0,$	$\tilde{u}_L \to d\,\tilde{\chi}_1^+ \to d\,\nu_l\,\tilde{l}_L^+,\ d\,l^+\,\tilde{\nu}_l \to d\,l^+\,\nu_l\,\tilde{\chi}_1^0$
Dirac:	$\tilde{q}_L \to q\,\tilde{\chi}_{D2}^{c0} \to q\,l^+\,\tilde{l}_L^- \to q\,l^+\,l^-\,\tilde{\chi}_1^0$	$\tilde{u}_L \to d\,\tilde{\chi}_{D1}^+ \to d\,l^+\,\tilde{\nu}_l \to d\,l^+\,\nu_l\,\tilde{\chi}_{D1}^{0c}$

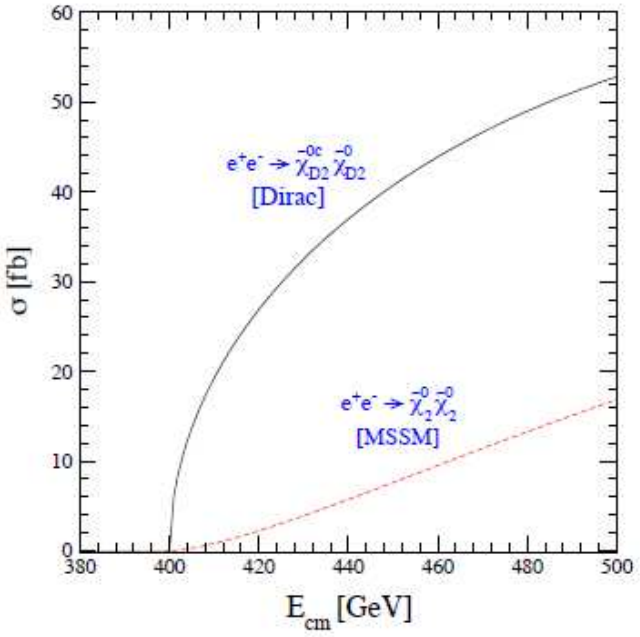
MSSM vs Dirac: different chirality structure

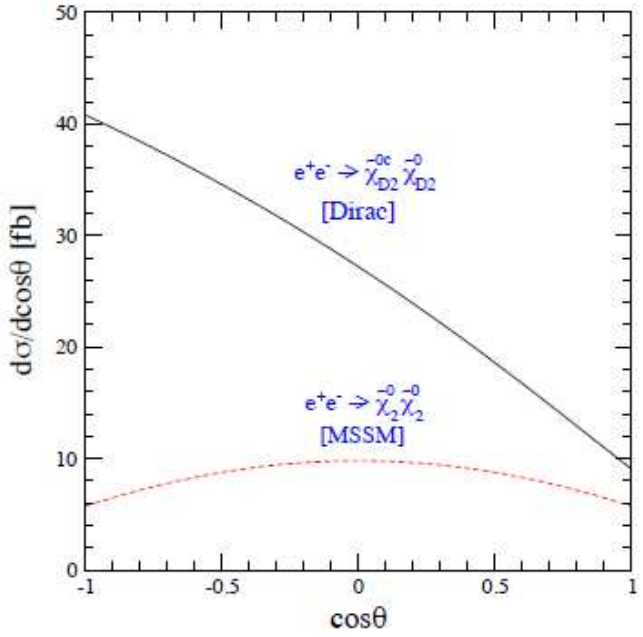
➡ imprint in angular distributions





Neutralino pair production





Diagonal pairs of Dirac neutralinos are excited in S-waves near threshold,
while Majorana in P-waves

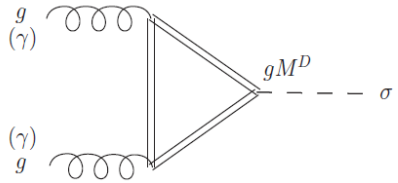
→ consequences for dark matter

Belanger et al., 0905.1043

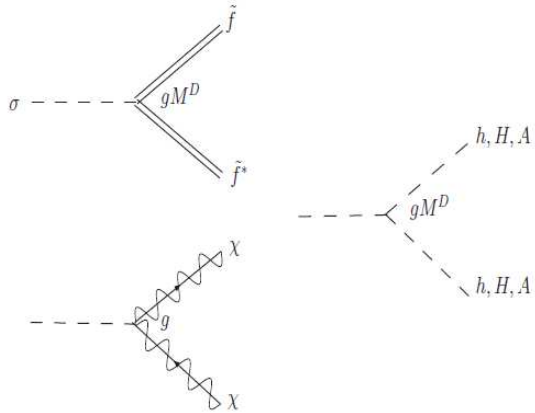
Dirac particle production is not forward-backward symmetric

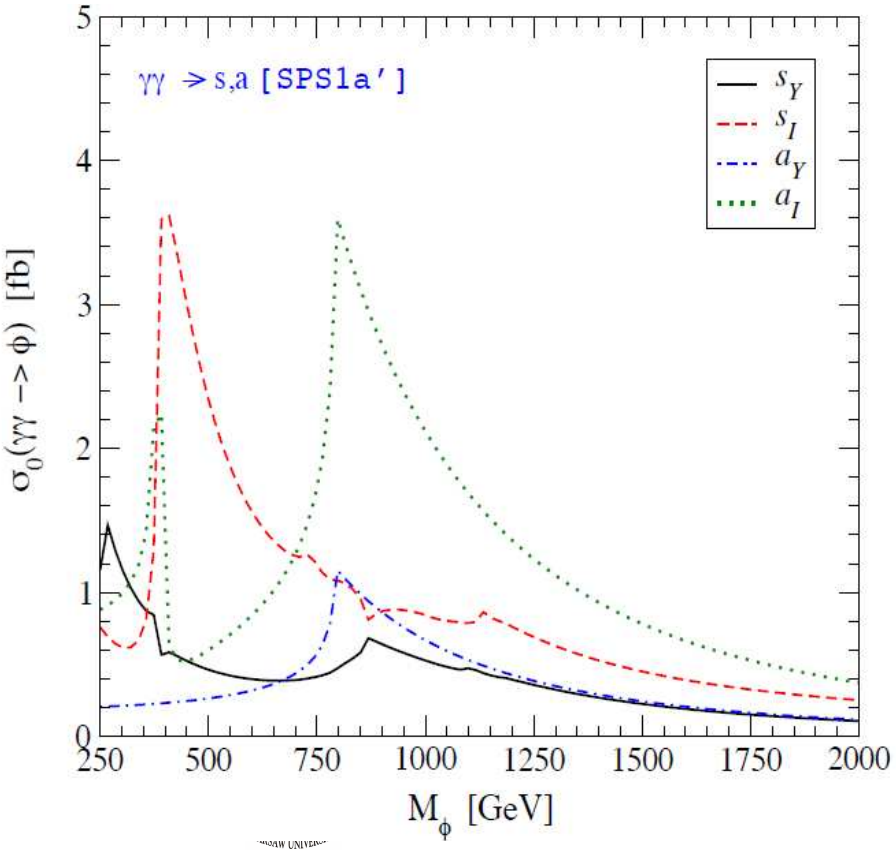
EW scalar boson production and decays

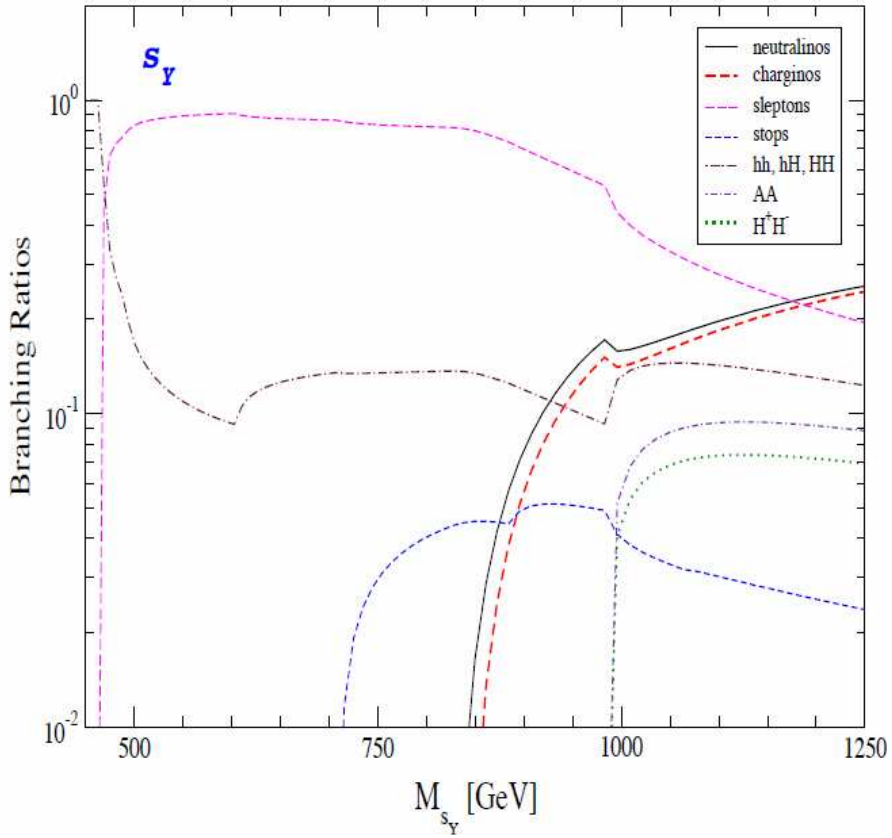
Gamma colliders are ideal for searching for heavy scalars/pseudoscalars



decays via







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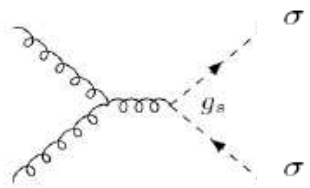
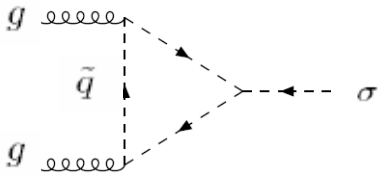
Comment on the scalar QCD sector

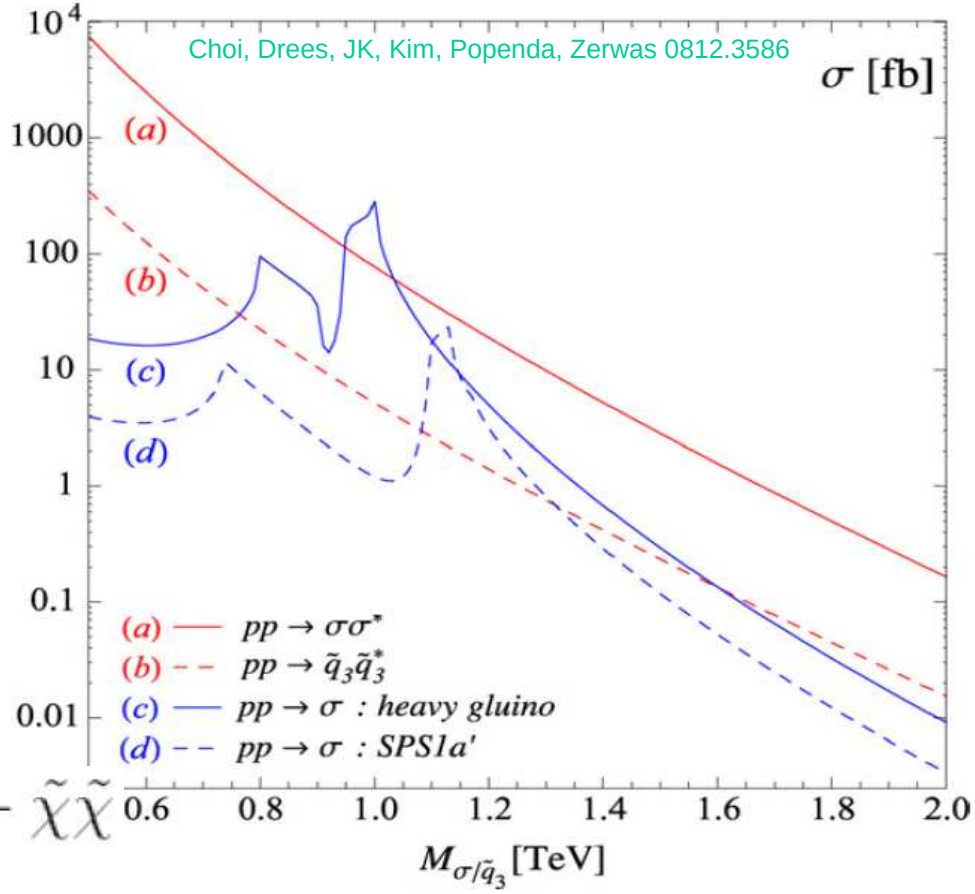
Sgluons can be produced

- in pairs



- singly





with spectacular decays

$$\sigma \longrightarrow \tilde{g}\tilde{g} \longrightarrow qq\tilde{q}\tilde{q} \longrightarrow qqqq + \tilde{\chi}\tilde{\chi}$$

$$\sigma \longrightarrow \tilde{q}\tilde{q} \longrightarrow qq + \tilde{\chi}\tilde{\chi}\,,$$

i.e. for sgluon pair productio at the LHC $\quad pp \longrightarrow 8\,\text{jets} + 4\,\text{LSP's}$

Summary and outlook

- Alternative N=1/N=2 SUSY hybrid realisation discussed
- Doubling of gauginos gives rise to new states

  16 Majorana gluinos ➔ 8 Dirac gluinos

  6 Majorana neutralinos ➔ 3 Dirac neutralinos

  3 charginos

- Adjoint scalars expand significantly the scalar sector

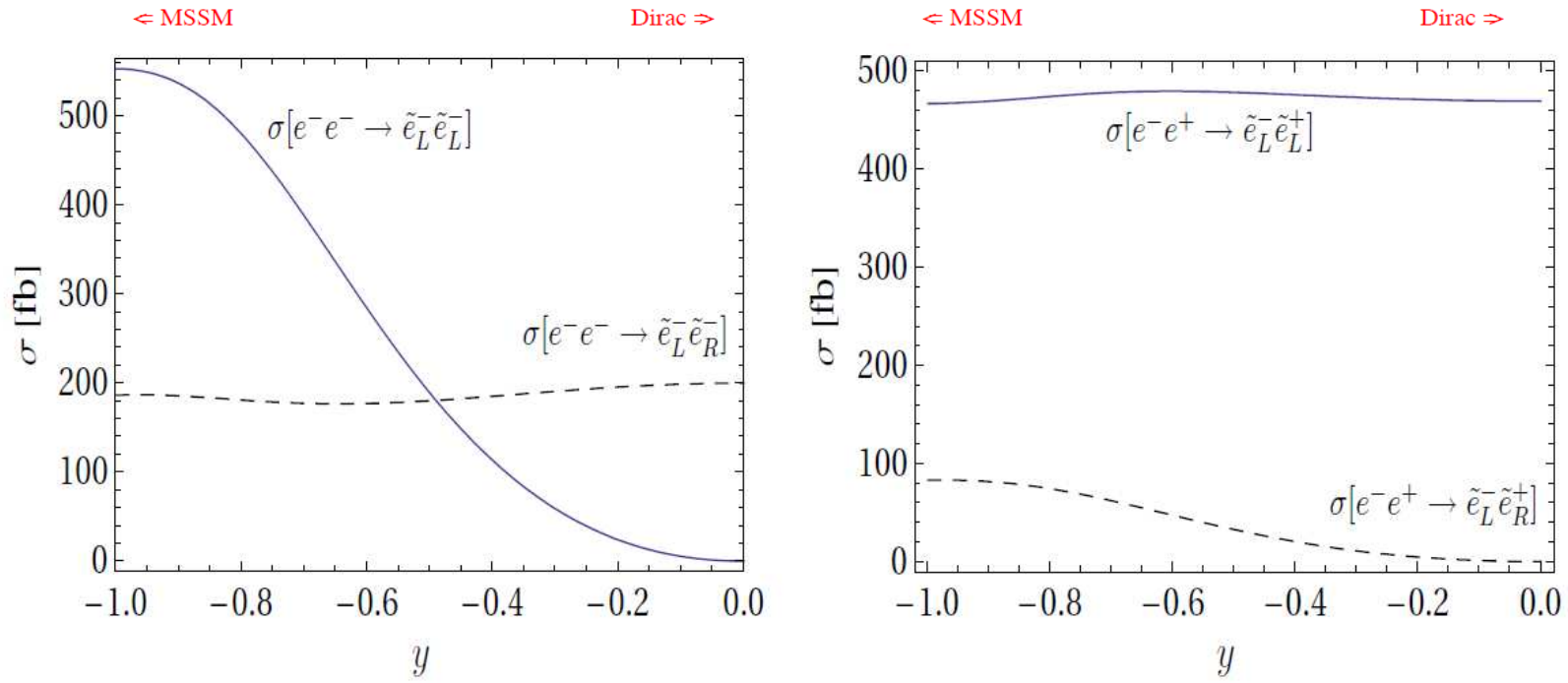
  8 sgluons and 4 new SU(2)xU(1) states that mix with Higgs fields

- Scale of new degrees is restricted by experiment
- A variety of production channels and decay modes

  rich phenomenology at colliders

  consequences for DM relic abundance

Selectron pair production



In the Dirac model: useful to define a Dirac charge

$$D[\tilde{q}_L^{1,2}] = D[\tilde{\ell}_L^{1,2}] = D[\tilde{\nu}^{1,2}] = D[\tilde{\chi}_D^{0c}] = D[\tilde{\chi}_{D1}^+] = D[\tilde{\chi}_{D2}^-] = -1\,,$$
$$D[\tilde{q}_R^{1,2}] = D[\tilde{\ell}_R^{1,2}] \qquad\qquad = D[\tilde{\chi}_D^0] = D[\tilde{\chi}_{D1}^-] = D[\tilde{\chi}_{D2}^+] = +1\,.$$

Allows a quick understanding of allowed and forbidden processes with the first two generations of sfermions