Majorana and Dirac neutralinos in N=1/N=2 hybrid SUSY

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S. Y. Choi, D. Choudhury, A. Freitas, J. Kalinowski, J. M. Kim, P. M. Zerwas, arXiv:1005.0818

1. N=2 SUSY and Dirac gauginos
2. Collider signatures of electroweak Dirac gauginos
3. Electroweak adjoint scalars

N=2 SUSY and Dirac gauginos

N=2 SUSY gauge multiplet:

- One 2-helicity vector boson
- **Two** 2-helicity Majorana fermions
- One complex scalar

Superfields	Spin 1	Spin 1/2	Spin 0	
SU(3) gauge	g	$\tilde{g}$		N=2 gauge
SU(3) chiral		$\tilde{g}'$	σ_C	hypermultiplet
SU(2) gauge	$W^{\pm,0}$	$\tilde{W}^{\pm,0}$		
SU(2) chiral		$\tilde{W}'^{\pm,0}$	σ_I	
U(1) gauge	B	$\tilde{B}$		
U(1) chiral		$\tilde{B}'$	σ_Y	

Other fields: Benakli, Moura '08

- $\hat{H}_u + \hat{H}_d$ from chiral/anti-chiral hypermultiplet
- N=1 matter multiplets (other N=2 components very heavy)

Gaugino states

Example: SU(3) sector

Choi, Drees, Freitas, Zerwas '08

Superpotential and SUSY-breaking mass terms [SU(3) as example]:

$$\mathcal{L}^m_{\text{QCD}} = -\frac{1}{2}\left[M_3' \,\text{Tr}(\overline{\tilde{g}'}\tilde{g}') + M_3 \,\text{Tr}(\overline{\tilde{g}}\tilde{g}) + M_3^D \,\text{Tr}(\overline{\tilde{g}'}\tilde{g} + \overline{\tilde{g}}\tilde{g}')\right]$$

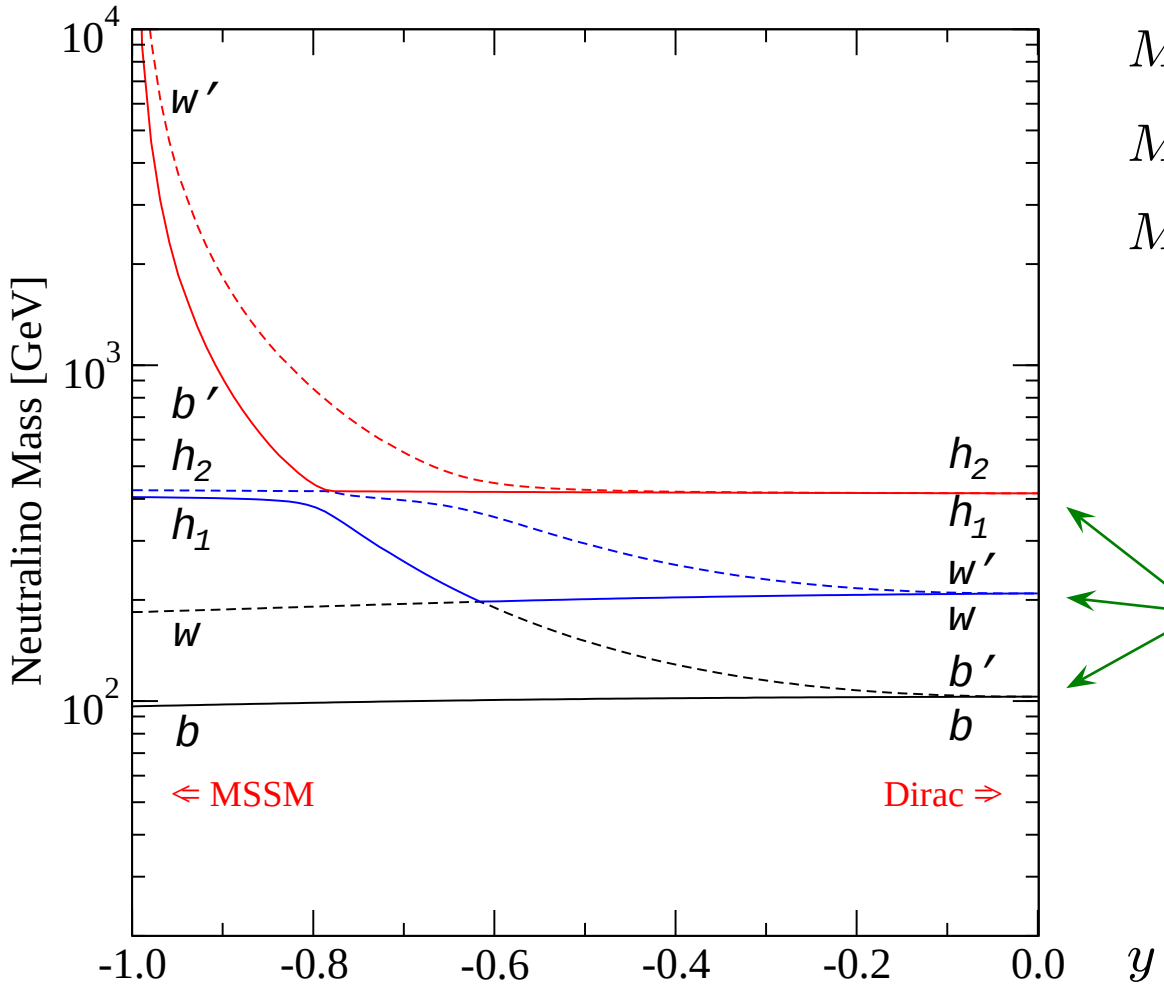
$\rightarrow$ Matrix in $\{\tilde{g}', \tilde{g}\}$-space: $\qquad \mathcal{M}_g = \begin{pmatrix} M_3' & M_3^D \\ M_3^D & M_3 \end{pmatrix}$

- $M_3' \to \infty$: recover MSSM gluino sector
- $M_3 = M_3' = 0$, $M_3^D \neq 0$: two Majorana states $\tilde{g}', \tilde{g}$ paired to one Dirac state $\tilde{g}_D$
- intermediate: two Majorana mass eigenstates:

$$\begin{pmatrix} \tilde{g}_{1R} \\ \tilde{g}_{2R} \end{pmatrix} = \mathcal{U}^T \begin{pmatrix} \tilde{g}'_R \\ \tilde{g}_R \end{pmatrix} \quad \text{and} \quad \begin{pmatrix} \tilde{g}_{1L} \\ \tilde{g}_{2L} \end{pmatrix} = \mathcal{U}^\dagger \begin{pmatrix} \tilde{g}'_L \\ \tilde{g}_L \end{pmatrix}$$

Electroweak sector

- Charginos: 3 charged Dirac mass eigenstates ($\tilde{W}$, $\tilde{W}'$, $\tilde{H}$)
- Neutralinos: 6 ntrl. Majorana mass eigenstates ($\tilde{B}$, $\tilde{B}'$, $\tilde{W}$, $\tilde{W}'$, $\tilde{H}_u$, $\tilde{H}_d$)



$$M_1' = m_{\tilde{B}_1} \frac{y}{1+y}$$
$$M_1^D = m_{\tilde{B}_1}$$
$$M_1 = m_{\tilde{B}_1} M_1'/(M_1' - m_{\tilde{B}_1})$$
$$-1 \leq y \leq 0$$

Dirac neutralinos

Collider signatures of electroweak Dirac gauginos

LHC

Chirality of neutralino interactions differ between
Majorana and Dirac theory

$\rightarrow$ Spin correlation effects in decay $\tilde{q}_L \to q\tilde{\chi}_2^0 \to q\, l^{\pm}\, \tilde{l}_R^{\mp} \to q\, l^{\pm}\, l^{\mp}\, \tilde{\chi}_1^0$

(for $m_{\tilde{\chi}_2^0} > m_{\tilde{l}_R} > m_{\tilde{\chi}_1^0}$)

Majorana: $\tilde{\chi}_2^0$ can decay into sleptons of $\pm$ charge:

$$\tilde{q}_L \to q\, \tilde{\chi}_2^0 \to q\, l_n^{\mp} \tilde{l}_R^{\pm} \to q\, l_n^{\mp}\, l_f^{\pm}\, \tilde{\chi}_1^0$$

Dirac: $\tilde{\chi}_{D2}^0$ decays only to $\tilde{l}_R^-$,
while $\tilde{\chi}_{D2}^{0c}$ decays only to $\tilde{l}_R^+$:

$$\tilde{q}_L \to q\, \tilde{\chi}_{D2}^{0c} \to q\, l_n^-\, \tilde{l}_R^+ \to q\, l_n^-\, l_f^+\, \tilde{\chi}_{D1}^{0c}$$

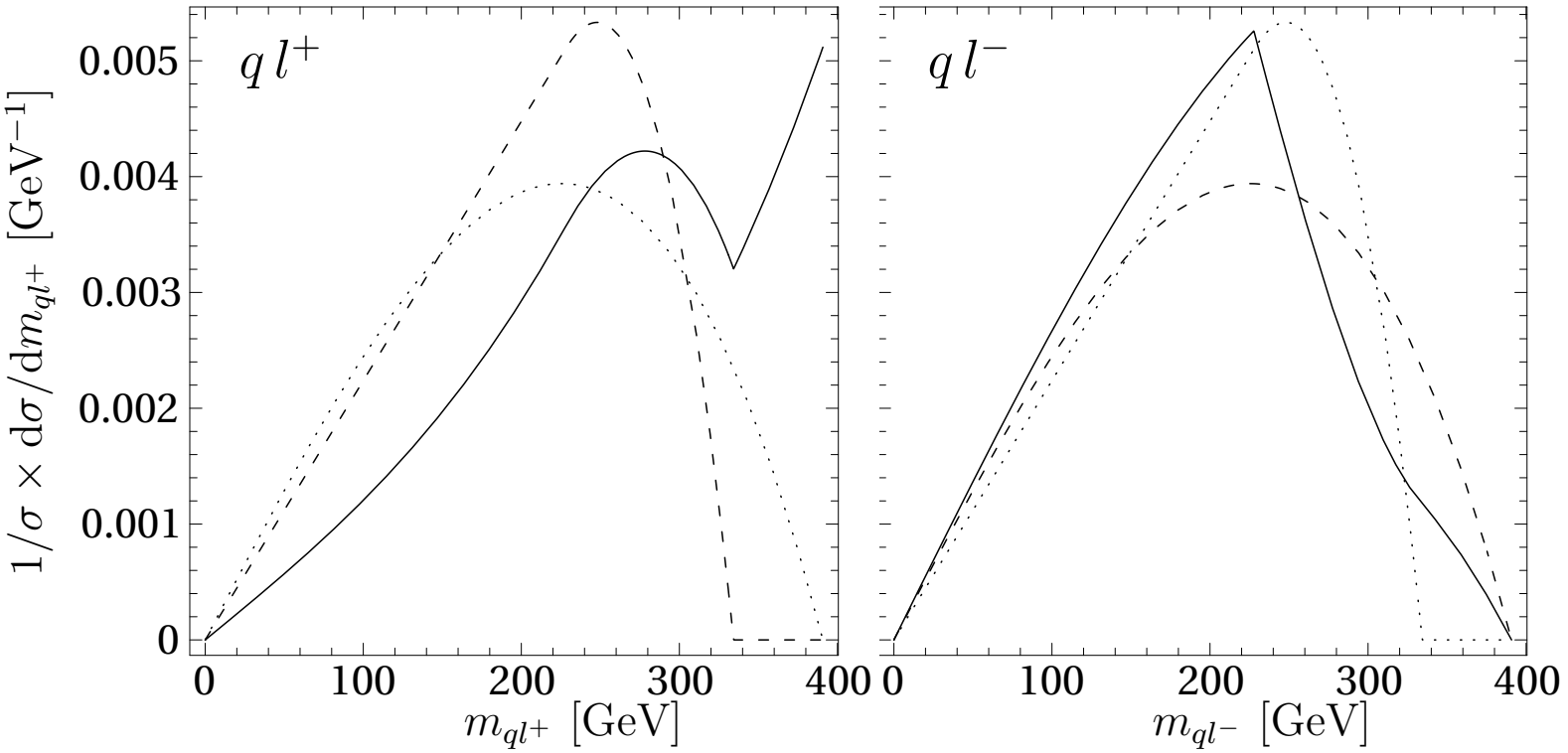
$$\tilde{q}_L^* \to \bar{q}\, \tilde{\chi}_{D2}^0 \to \bar{q}\, l_n^+\, \tilde{l}_R^- \to \bar{q}\, l_n^+\, l_f^-\, \tilde{\chi}_{D1}^0$$

$\rightarrow$ Effect on $ql^{\pm}$ invariant mass distributions

Neutralino cascade decays

———	$\tilde{q}_L \to q\tilde{\chi}_2^0 \to q l_n^{\mp} \tilde{l}_R^{\pm} \to q l_n^{\mp} l_f^{\pm} \tilde{\chi}_1^0$
– – –	$\tilde{q}_L \to q\tilde{\chi}_{D2}^{0c} \to q l_n^{-} \tilde{l}_R^{+} \to q l_n^{-} l_f^{+} \tilde{\chi}_{D1}^{0c}$
.....	$\tilde{q}_L^* \to \bar{q}\tilde{\chi}_{D2}^{0} \to \bar{q} l_n^{+} \tilde{l}_R^{-} \to \bar{q} l_n^{+} l_f^{-} \tilde{\chi}_{D1}^{0}$

SPS1a' scenario



CP-invariance relates decay distributions of $\tilde{q}_L$ and $\tilde{q}_L^*$ for Dirac case

Chargino cascade decays

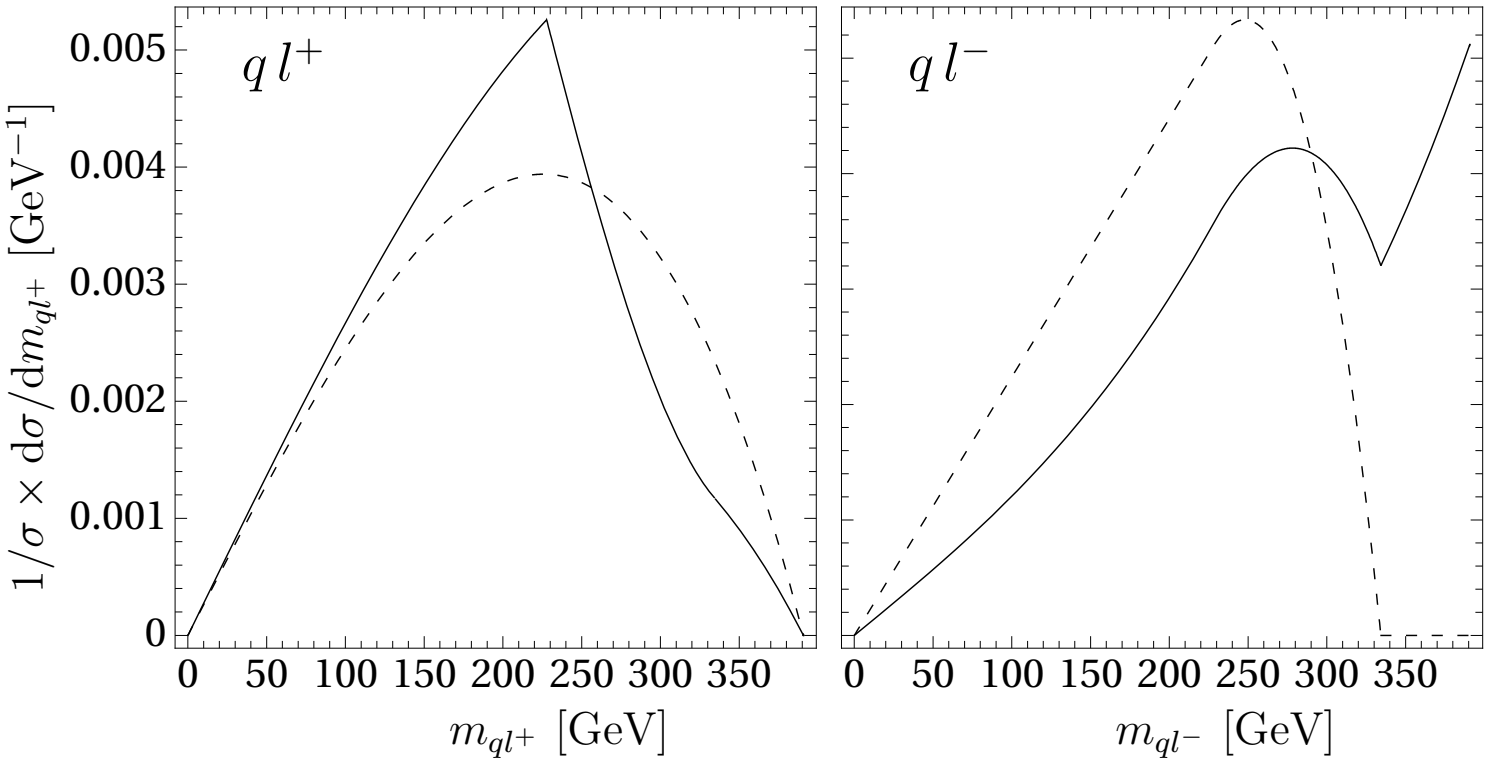
MSSM: ——— $\tilde{u}_L \to d\,\tilde{\chi}_1^+ \to d\,\nu_l\,\tilde{l}_L^+,\ d\,l^+\,\tilde{\nu}_l \to d\,l^+\,\nu_l\,\tilde{\chi}_1^0,$

$\tilde{d}_L \to u\,\tilde{\chi}_1^- \to u\,\bar{\nu}_l\,\tilde{l}_L^-,\ u\,l^-\,\tilde{\nu}_l^* \to u\,l^-\,\bar{\nu}_l\,\tilde{\chi}_1^0,$

Dirac: – – – $\tilde{u}_L \to d\,\tilde{\chi}_{D1}^+ \to d\,l^+\,\tilde{\nu}_l \to d\,l^+\,\nu_l\,\tilde{\chi}_{D1}^{0c},$

$\tilde{d}_L \to u\,\tilde{\chi}_{D2}^- \to u\,\bar{\nu}_l\,\tilde{l}_L^- \to u\,l^-\,\bar{\nu}_l\,\tilde{\chi}_{D1}^{0c},$

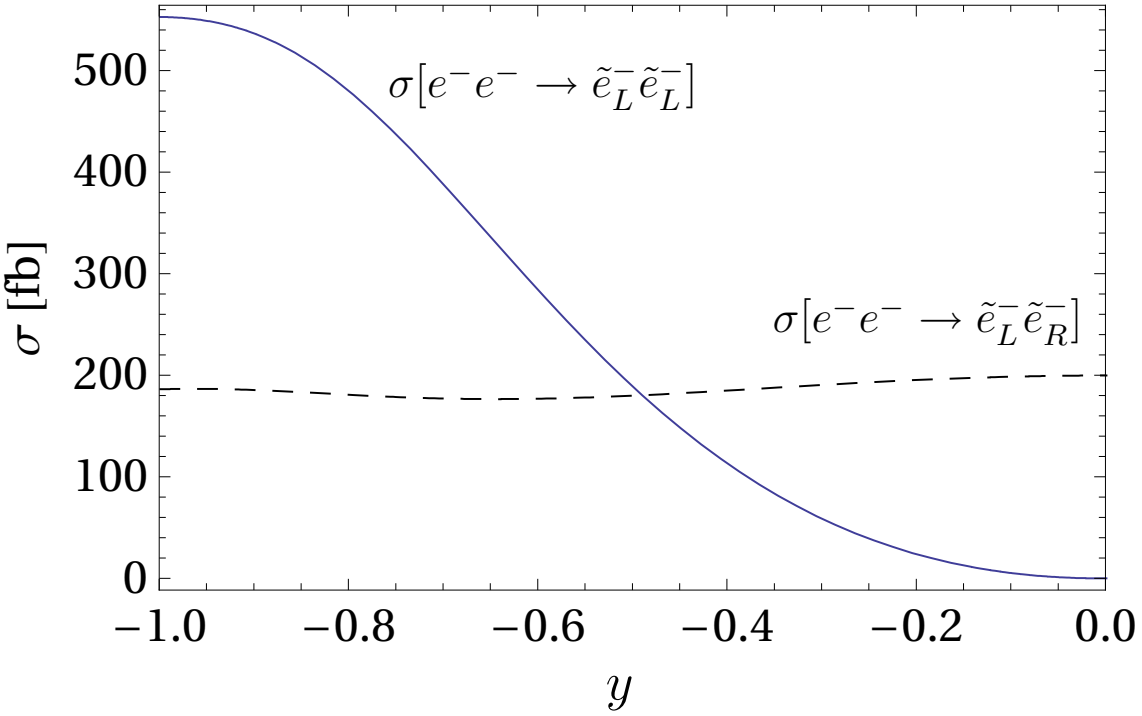
SPS1a' scenario



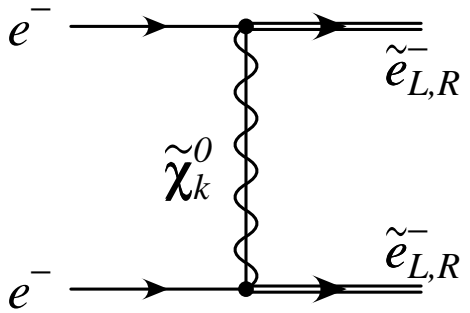
Selectron production in e^-e^- collisions

Majorana neutralinos can mediate **same-sign same-chirality** selectron production in e^-e^- collisions

Keung, Littenberg '83
Aguilar-Saavedra, Teixeira '03



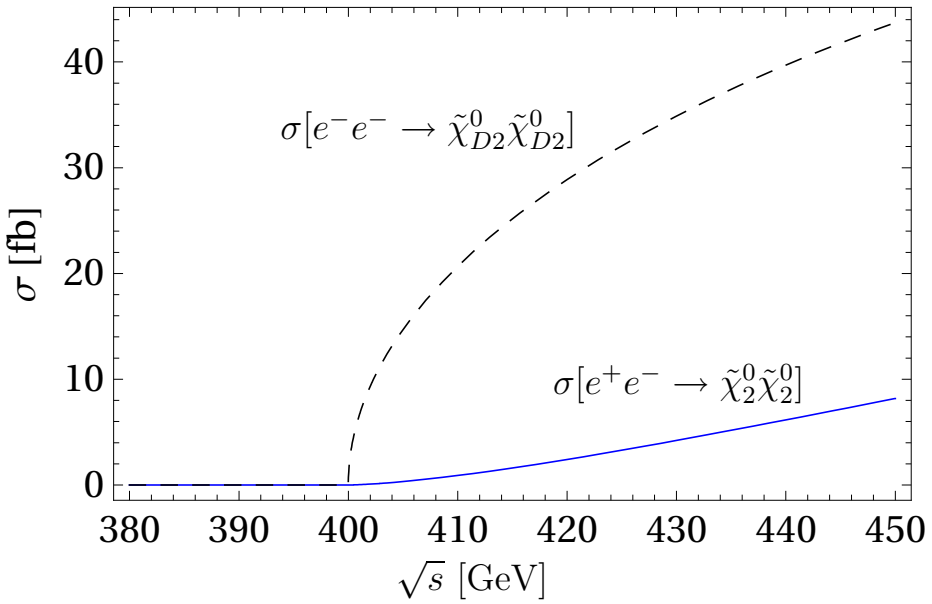
SPS1a' scenario

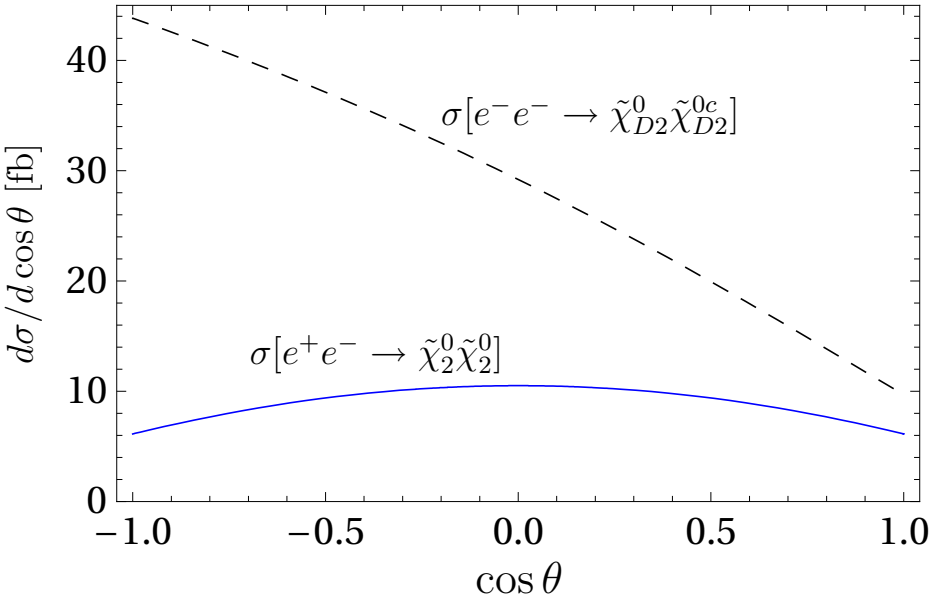


Neutralino production in e^+e^- collisions

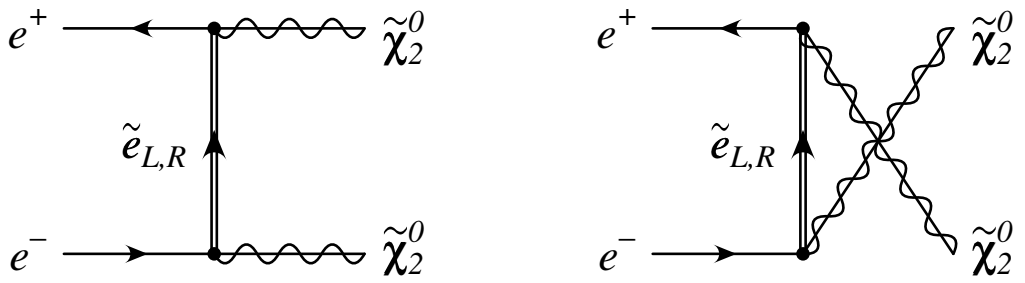
MSSM limit: p-wave, $t + u$ channels

Dirac limit: s-wave, t channel





($m_{\tilde{\chi}^0_2} = m_{\tilde{\chi}^0_{D2}} = 200$ GeV, $m_{\tilde{e}_L} = 400$ GeV)



Electroweak adjoint scalars

N=2 gauge hypermultiplet include (R-even) complex scalars σ_C, σ_I, σ_Y

(EWSB: σs mix with Higgs bosons)

$\longrightarrow$ If light enough σs can be produced at colliders

$\longrightarrow$ Do not couple to SM fermions (except through mixing)

Main decay channels:

$M_\sigma < M_{\text{SUSY}}$	$M_\sigma > M_{\text{SUSY}}$
$\sigma_Y \to \gamma\gamma$ (1loop)	$\sigma_Y \to \tilde{f}\tilde{f}^*, \tilde{\chi}\tilde{\chi}$
$\sigma_I^\pm \to W^\pm\gamma$ (1loop)	$\sigma_I^\pm \to \tilde{f}\tilde{f}'^*, \tilde{\chi}^\pm\tilde{\chi}^0$

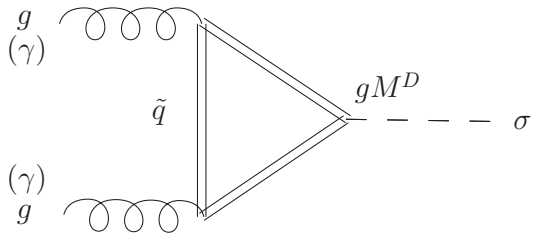
Drell-Yan pair production of $\sigma_I^+\sigma_I^-$:
$\mathcal{O}$(10 fb) for $M_{\sigma_I} \sim$ 200–300 GeV

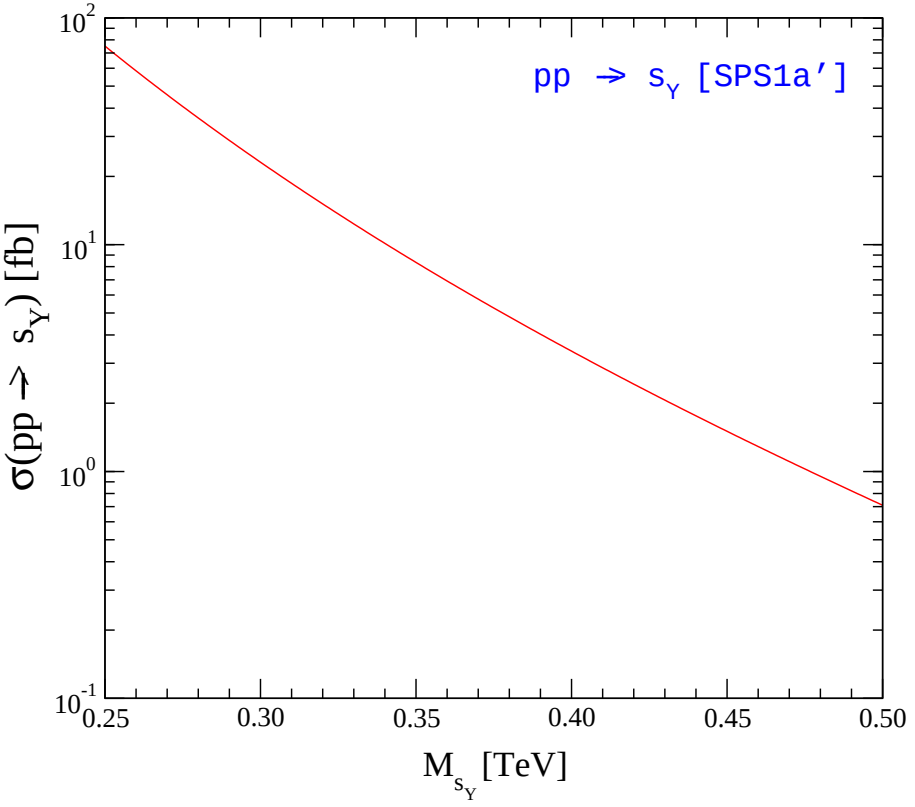
$\longrightarrow$ Possibility for discovery

Electroweak adjoint scalars

Single production of s_Y:

$gg \to \sigma_Y$





Large rate only for small M_{σ_Y}

$\to$ $\sigma_Y \to \gamma\gamma$ dominates

s_Y production in sfermion decay:

$\tilde{t}_2 \to \tilde{t}_1 + s_Y$

$\tilde{\tau}_2 \to \tilde{\tau}_1 + s_Y$

BR 1-10% possible for light s_Y, but again $\sigma_Y \to \gamma\gamma$

Summary

- Majorana gauginos are predicted in MSSM,
  but Dirac gauginos are possible in extended SUSY models:
  - N=2 SUSY
  - R-symmetric SUSY Hall, Randall '91

- The Majorana/Dirac nature in the ew. sector can be tested through
  - Distributions of cascade decays at LHC
  - Production processes at ILC

- Adjoint scalars predicted in N=2 SUSY

  likely within reach of LHC, but neutral states have low rates
  and difficult signatures

Backup slides

SPS1a′ scenario

Aguilar-Saavedra et al. '06

$\tilde{q}_L$	565 GeV
$\tilde{q}_R$	547 GeV
$\tilde{e}_L$	190 GeV
$\tilde{e}_R$	125 GeV

M_1	103 GeV
M_2	193 GeV
μ	396 GeV
$\tan\beta$	10

$\tilde{\chi}_1^0$	98 GeV
$\tilde{\chi}_2^0$	184 GeV
$\tilde{\chi}_4^0$	414 GeV
$\tilde{\chi}_1^\pm$	184 GeV

$\tilde{g}$	607 GeV