Phenomenology of Supersymmetric Large Extra Dimensions:

Gravitino Effects in Selectron Pair Production & Decay

JLH, D. Sadri

hep-ph/0204063

hep-ph/0301xxx

Supersymmetric Large Extra Dimensions

Original Model: Gravity in bulk
SM on brane
Solve hierarchy problem w/o SUSY

$M_D \sim$ TeV

Arkani-Hamed, Dimopoulos, Dvali

Introduce Supersymmetry: Motivation

- Embed ADD in string theory
- SUSY stabilizes bulk radii
- Extra Dims provide new SUSY breaking mechanisms

Kaplan etal.
Chacko etal.
Di Clemente etal
Arkani-Hamed etal
⋮

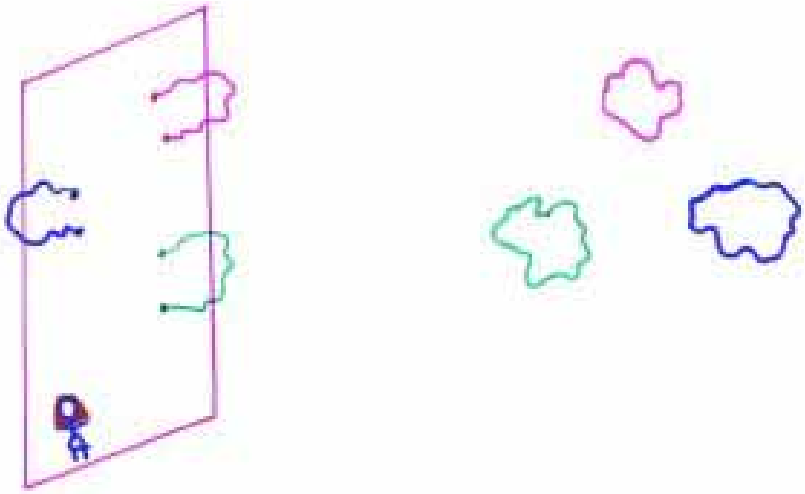
SM supermultiplets on brane
Gravity supermultiplet in bulk

⇒ Graviton + Gravitino expand into KK towers

Phenomenology: KK Gravitino Exchange
KK Gravitino Emission

see talk by J. Song

The Model:



Near Brane

D=10, N=1

1 gravitino (Majorana-Weyl)

Bulk

D=10, N=2

Type IIB

2 gravitinos (Majorana)

On Brane

D=4, N=1

4 Majorana spin-3/2 : Assume 3 have $\sim m_D$

24 Majorana spin-1/2

1 is $m_0 \sim \Lambda_{susy}^2 / m_{Pl}$

4-D Effective Theory

$$E^{-1}\mathcal{L}_{kin} = \frac{i}{2}\,\bar{\Psi}_{\hat{A}}\,\Gamma^{\hat{M}\hat{N}\hat{P}}\,\nabla_{\hat{N}}\,\Psi_{\hat{P}}$$

$$\nabla_{\hat{N}} = \partial_{\hat{N}} + \frac{i}{4}\,\omega_{\hat{N}\hat{B}\hat{R}}\,\Sigma^{\hat{B}\hat{R}}$$

Expand: $$\Psi_{\hat{A}}(x,y) = \sum_{\vec{n}} \frac{\Psi^{\vec{n}}_{\hat{A}}(x)}{\sqrt{V_6}}\, e^{i\vec{n}\cdot\vec{y}/R_c}$$

Decompose $D=10$ Majorana-Weyl gravitino

Redefine fields to separate spin $3/2$ + $1/2$ in $\mathcal{L}_{kin}$

Choose $\Gamma^m \chi^{\vec{n}}_m = 0$ to project out spin $-1/2$ comp.

$$\mathcal{L}_{eff}(x) = \int dy^6\, \mathcal{L}(x,y)$$

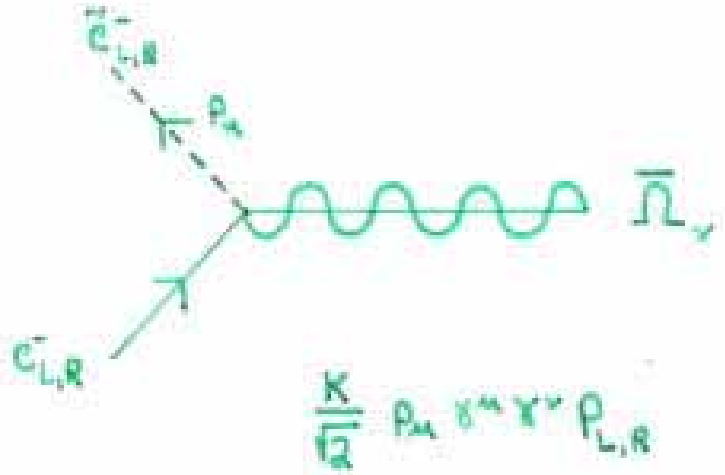
$$e^{-1}\mathcal{L}_{eff}(x) = -\frac{1}{2}\,\epsilon^{mnpr}\,\bar{\omega}^{\vec{n}}_m\,\gamma_5\gamma_n\,\partial_r\,\omega^{\vec{n}}_p - \frac{m_{\vec{n}}}{4}\,\bar{\omega}^{\vec{n}}_m\,[\gamma^m,\gamma^p]\,\omega^{\vec{n}}_p$$

with $$m_{\vec{n}} = \frac{\sqrt{\vec{n}\cdot\vec{n}}}{R_c}$$

Interactions obtained via general Noether procedure

$$\mathcal{L}_I = -\frac{\kappa}{\sqrt{2}} |e| \left[(\partial_\mu \Psi_L) \bar{\Pi}_\nu \gamma^\mu \gamma^\nu \psi_L + (\partial_\mu \Psi_R) \bar{\Pi}_\nu \gamma^\mu \gamma^\nu \psi_R \right] + h.c.$$

$$\kappa = \sqrt{8\pi G_N}$$



$$\frac{\kappa}{\sqrt{2}} p_\mu \gamma^\mu \gamma^\nu \rho_{L,R}$$

Contributions to $e^+e^- \to \tilde{e}^+_{L,R}\,\tilde{e}^-_{L,R}$

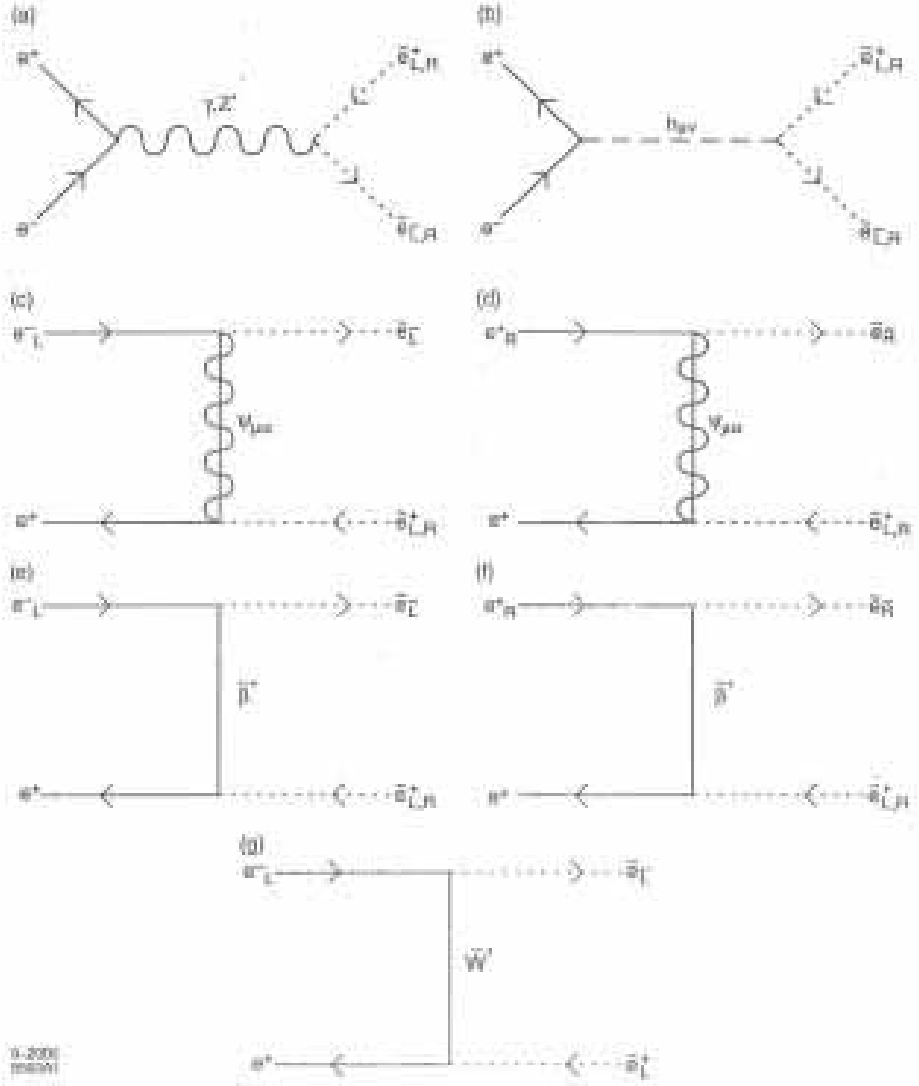


Figure 2: Various processes contributing to scalar pair production.

$e^+e^- \to \tilde{e}^+\tilde{e}^-$

Polarized Scattering:

	$\tilde{e}^-_L\tilde{e}^+_L$	$\tilde{e}^-_R\tilde{e}^+_L$	$\tilde{e}^-_L\tilde{e}^+_R$	$\tilde{e}^-_R\tilde{e}^+_R$
$e^-_L e^+$	s-channel $\gamma, Z, \tilde{G}_n$ t-channel $\tilde{W}, \tilde{B}, \tilde{G}_n$		t-channel $\tilde{B}, \tilde{G}_n$	s-channel $\gamma, Z, \tilde{G}_n$
$e^-_R e^+$	s-channel $\gamma, Z, \tilde{G}_n$	t-channel $\tilde{B}, \tilde{G}_n$		s-channel $\gamma, Z, \tilde{G}_n$ t-channel $\tilde{B}, \tilde{G}_n$

$$\mathcal{M}_{\tilde{G}_n} = \frac{2}{\Lambda_c^4}\,(t-u)(K_1-K_2)_\mu\,\bar{e}\,\gamma^\mu e \qquad \text{Dim-8}$$

$$\mathcal{M}_{\tilde{G}_n} = \frac{\kappa^2}{2}\sum_n \frac{K_1^\nu K_2^\rho}{t-m^2_{\tilde{n}}}\;\bar{e}\,\gamma_\mu\gamma_\nu\,p^{\tilde{n},\mu\tau}\,\gamma_\rho\gamma_\tau\,e$$

Summation of KK Gravitino States

$$\rho^{\vec{n},\mu\nu} = i(\not{k} + m_{\vec{n}})\left(\frac{k^\mu k^\nu}{m_{\vec{n}}^2} - \eta^{\mu\nu}\right) - \frac{i}{3}\left(\gamma^\mu + \frac{k^\mu}{m_{\vec{n}}^2}\right)(\not{k} - m_{\vec{n}})\left(\gamma^\nu + \frac{k^\nu}{m_{\vec{n}}^2}\right)$$

Integrate over density of states

$$\int_{m_0^2}^{\Lambda_c^2} dm_{\vec{n}}^2\, \rho(m_{\vec{n}}^2)\, \frac{\rho^{\vec{n},\mu\nu}}{t - m_{\vec{n}}^2}$$

Evaluated via Appell's hypergeometric function

Leading order term:

$$\int \sim \frac{m_{Pl}^2}{\Lambda_c^3} \quad \Rightarrow \text{independent of } m_0$$

$$\frac{\kappa^2}{2} \sum_{\vec{n}} \frac{\rho^{\vec{n},\mu\nu}}{t - m_{\vec{n}}^2} \longrightarrow \frac{-i\,8\pi}{5\Lambda_c^3}\left(\eta^{\mu\nu} - \frac{1}{3}\gamma^\mu\gamma^\nu\right)$$

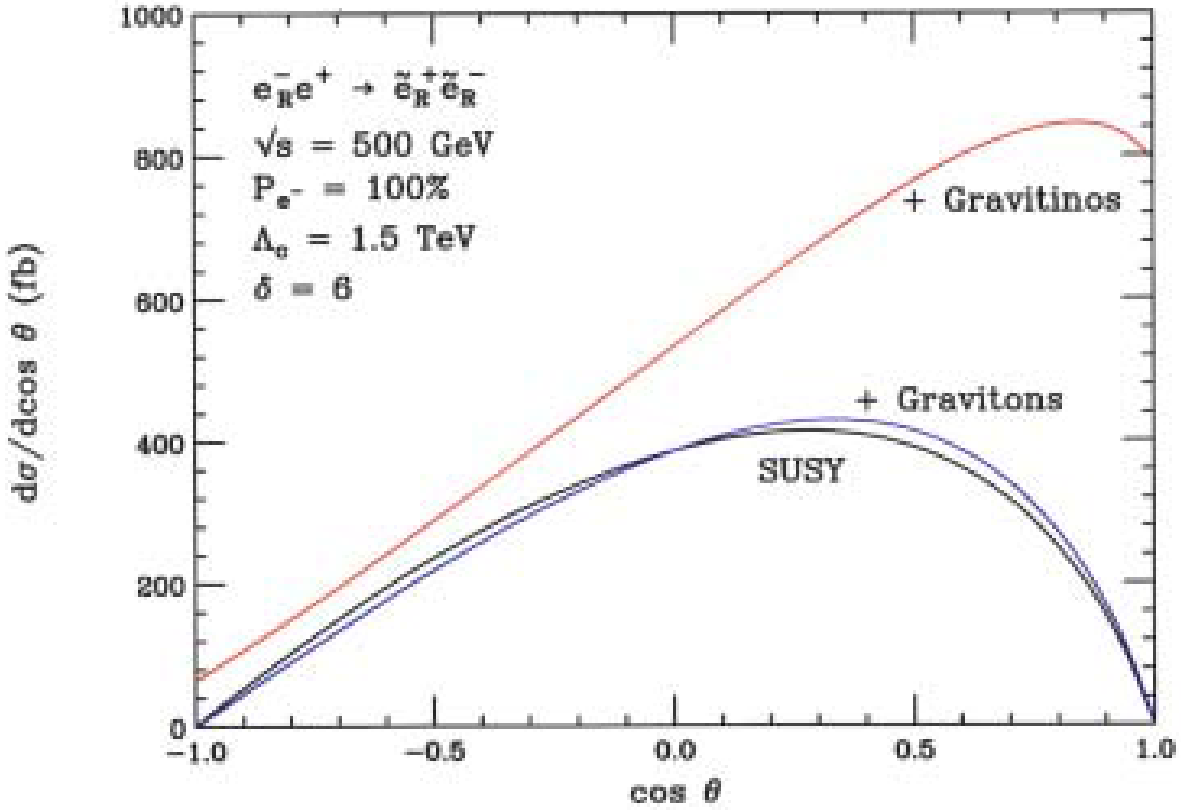
is Dimension - 6 !!!

Specify SUSY Model (D=4)

Choose GMSB : Naturally light zero-mode gravitino

2 sample sets of parameters :

	$m_{\tilde{e}_L}$	$m_{\tilde{e}_R}$	$\tilde{\chi}_1^0$
Set I	217 GeV	108 GeV	Bino-like
Set II	210.5 GeV	104.5 GeV	Higgsino-like


$e_R^- e^+ \to \tilde{e}_R^+ \tilde{e}_R^-$
$\sqrt{s}$ = 500 GeV
P_{e^-} = 100%
Λ_c = 1.5 TeV
δ = 6
+ Gravitinos
+ Gravitons
SUSY
$d\sigma/d\cos\theta$ (fb)
cos θ
1000
800
600
400
200
0
−1.0
−0.5
0.0
0.5
1.0

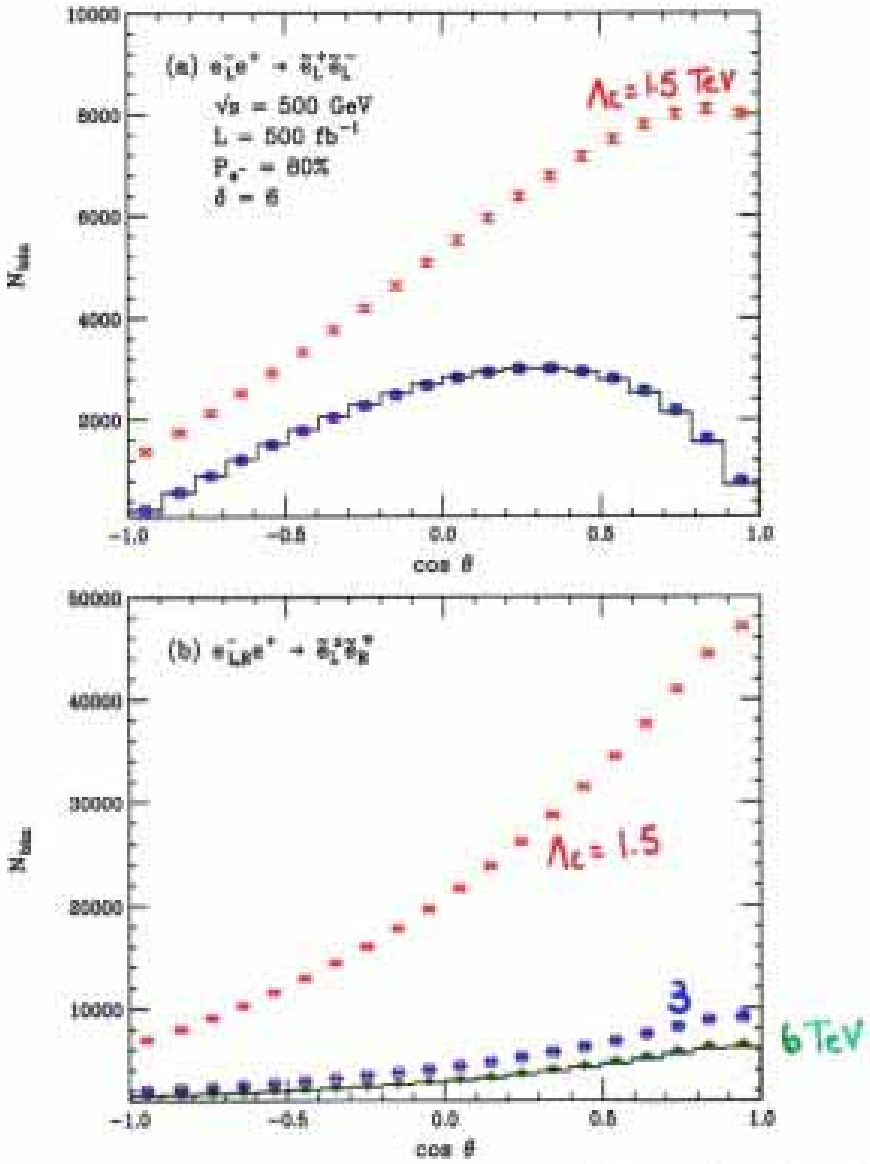
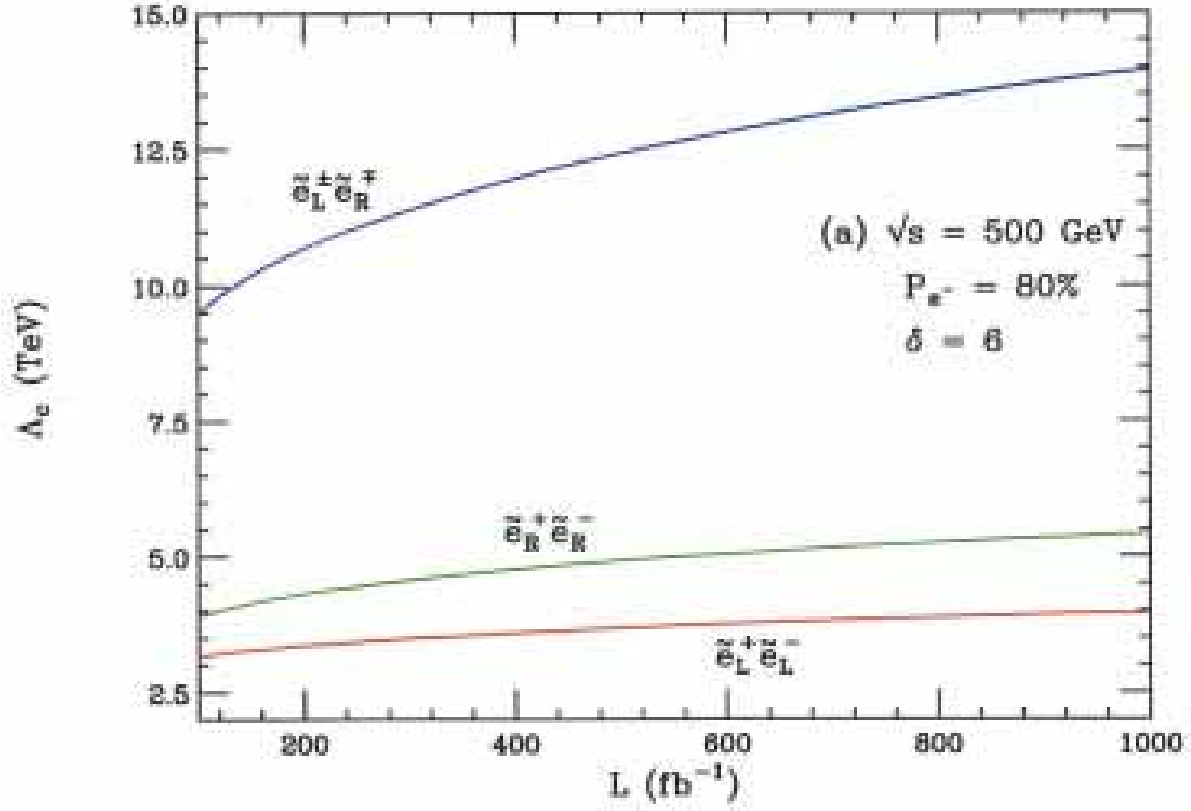
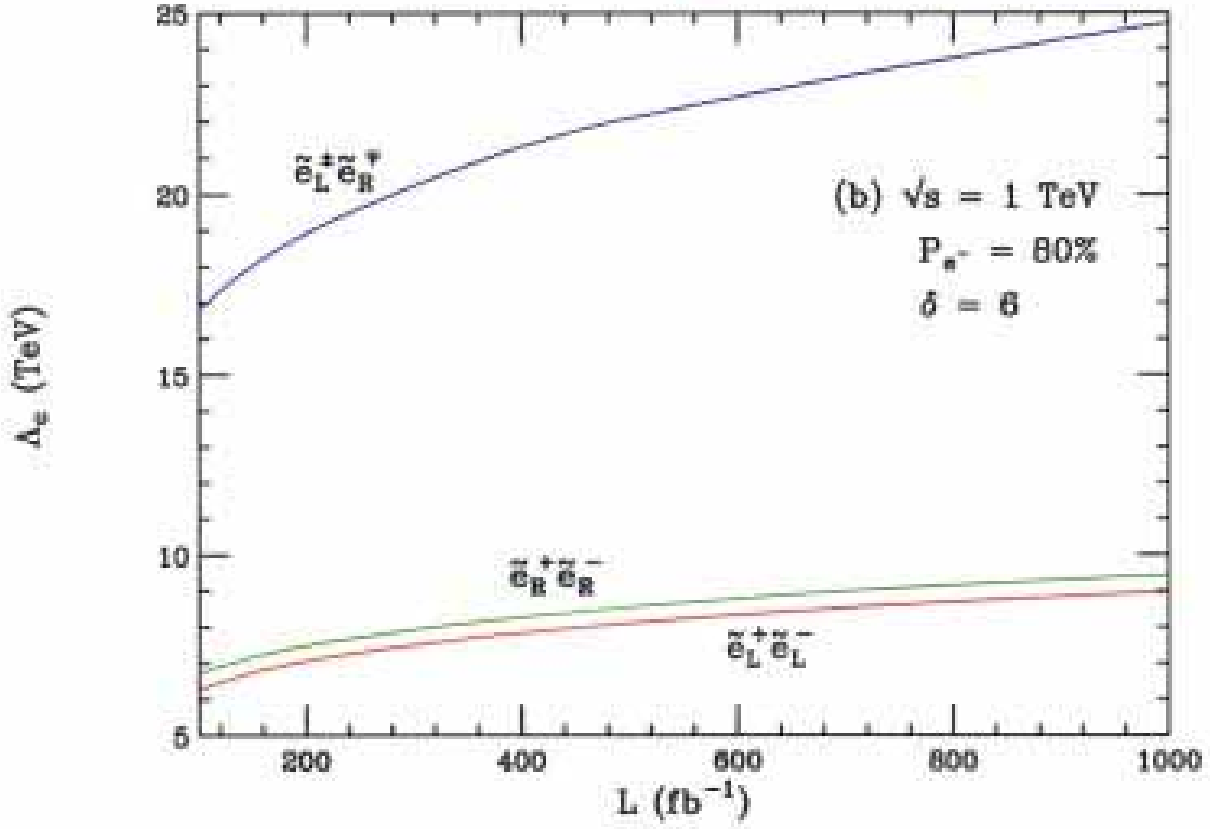


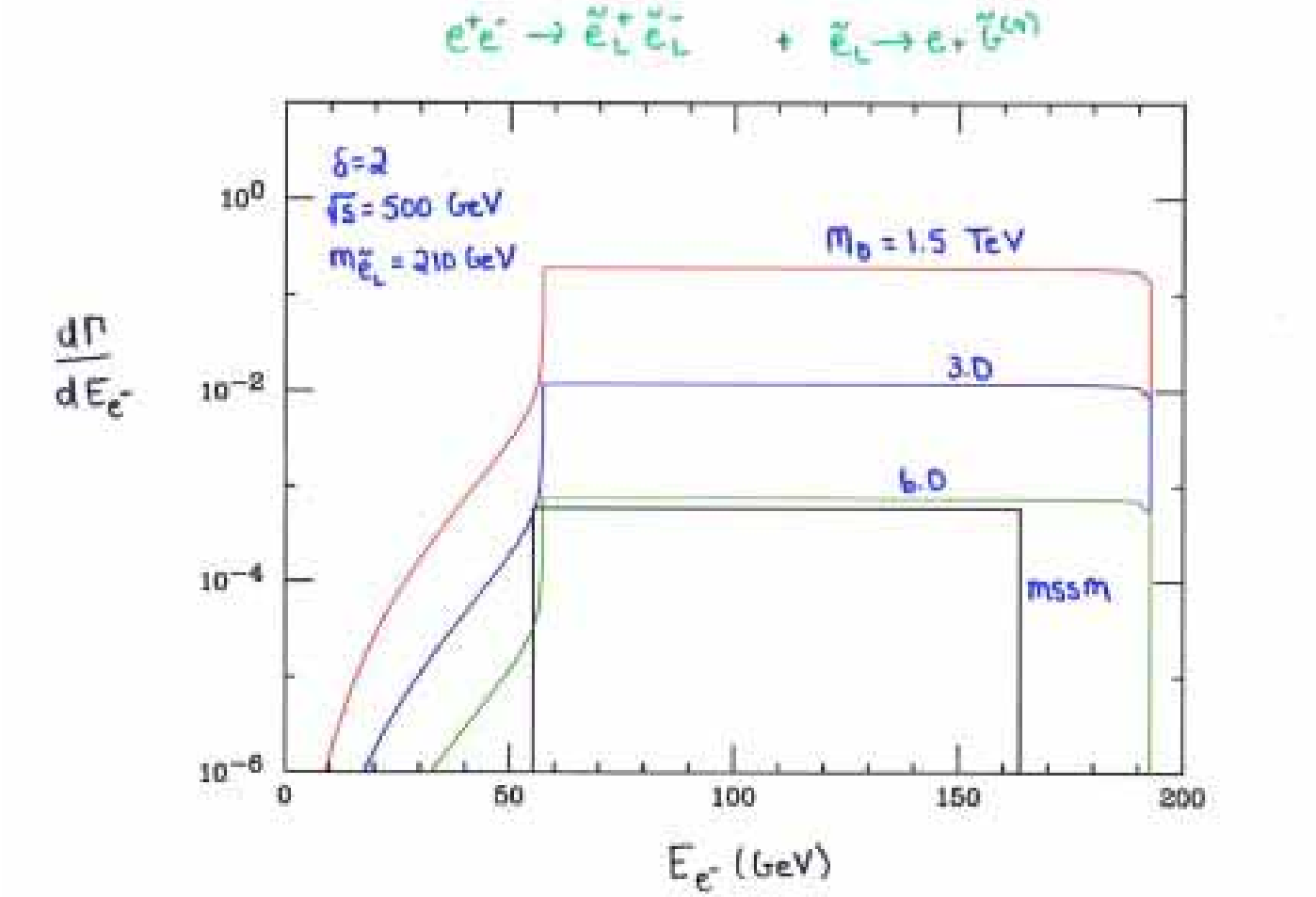
Figure 7: (a-b) Polarized binned angular distributions for each helicity configuration, taking an 80% polarization of the initial electron beam. The solid histogram represents the $D = 4$ bino-like model, while the "data" points correspond to the effects of a supersymmetric bulk with $\Lambda_c = 1.5, 3.0, 6.0$ TeV from top to bottom. The $\Lambda_c = 6.0$ TeV case is only discernable in Figure (b).

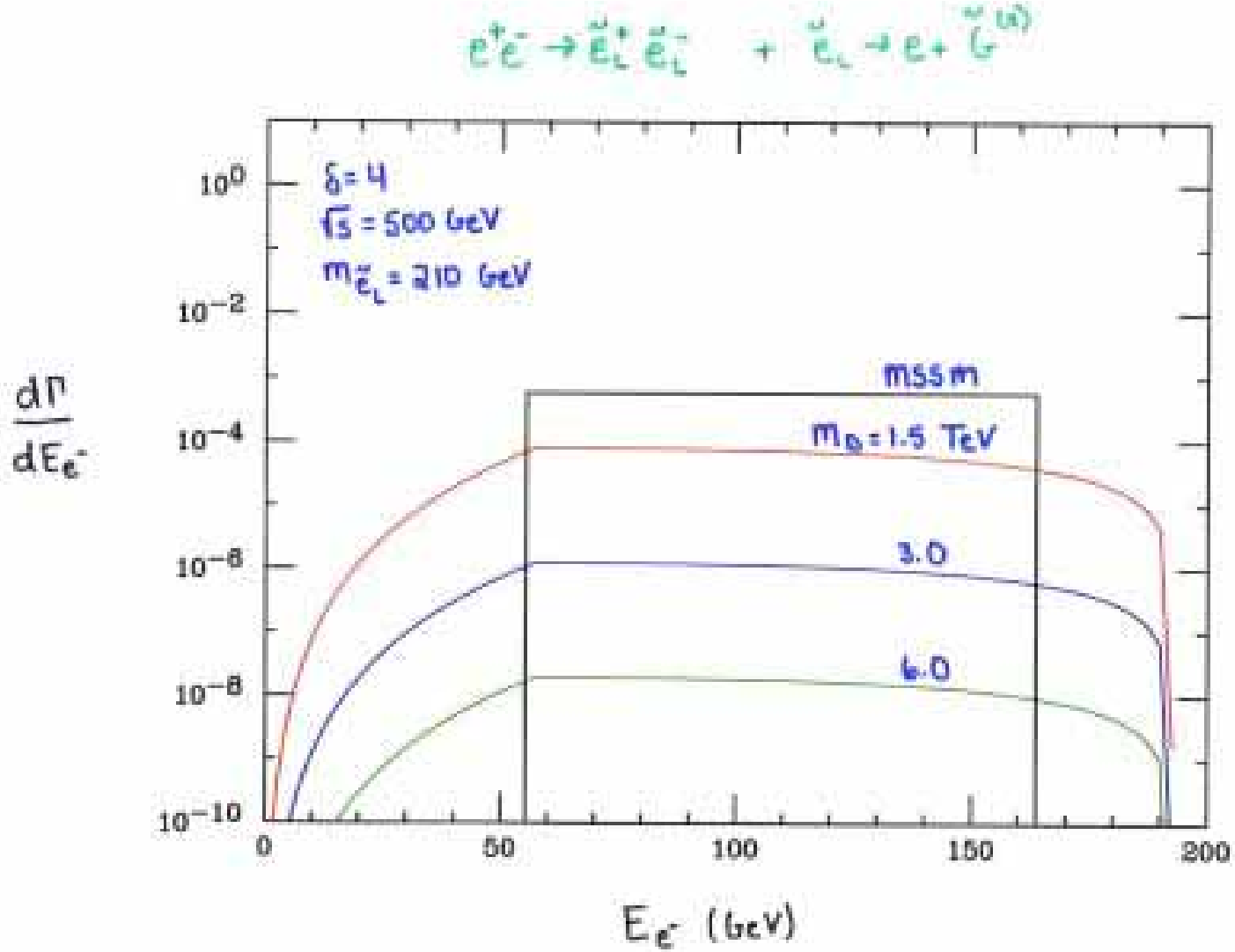
Search Reach for Λ_e

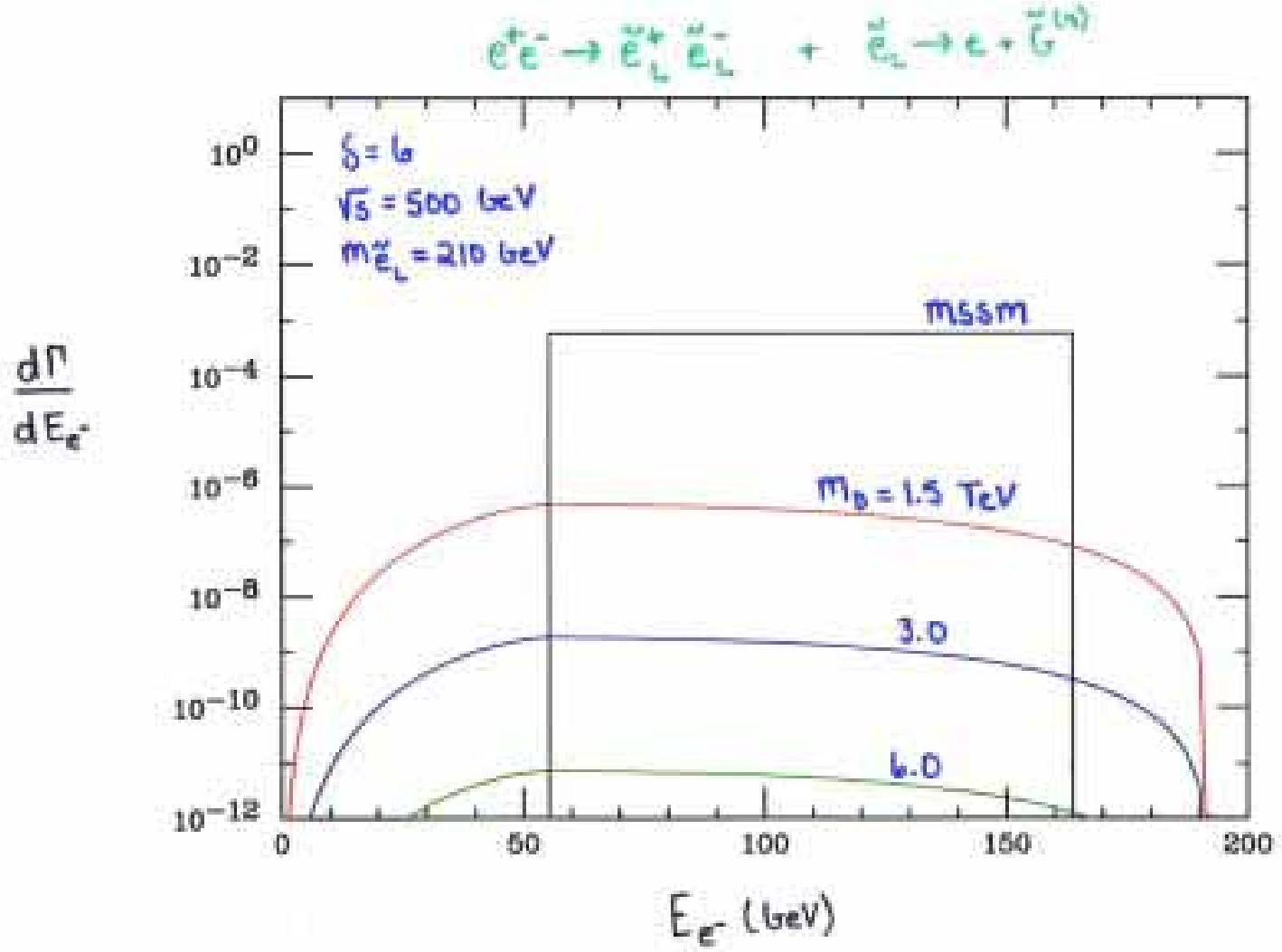


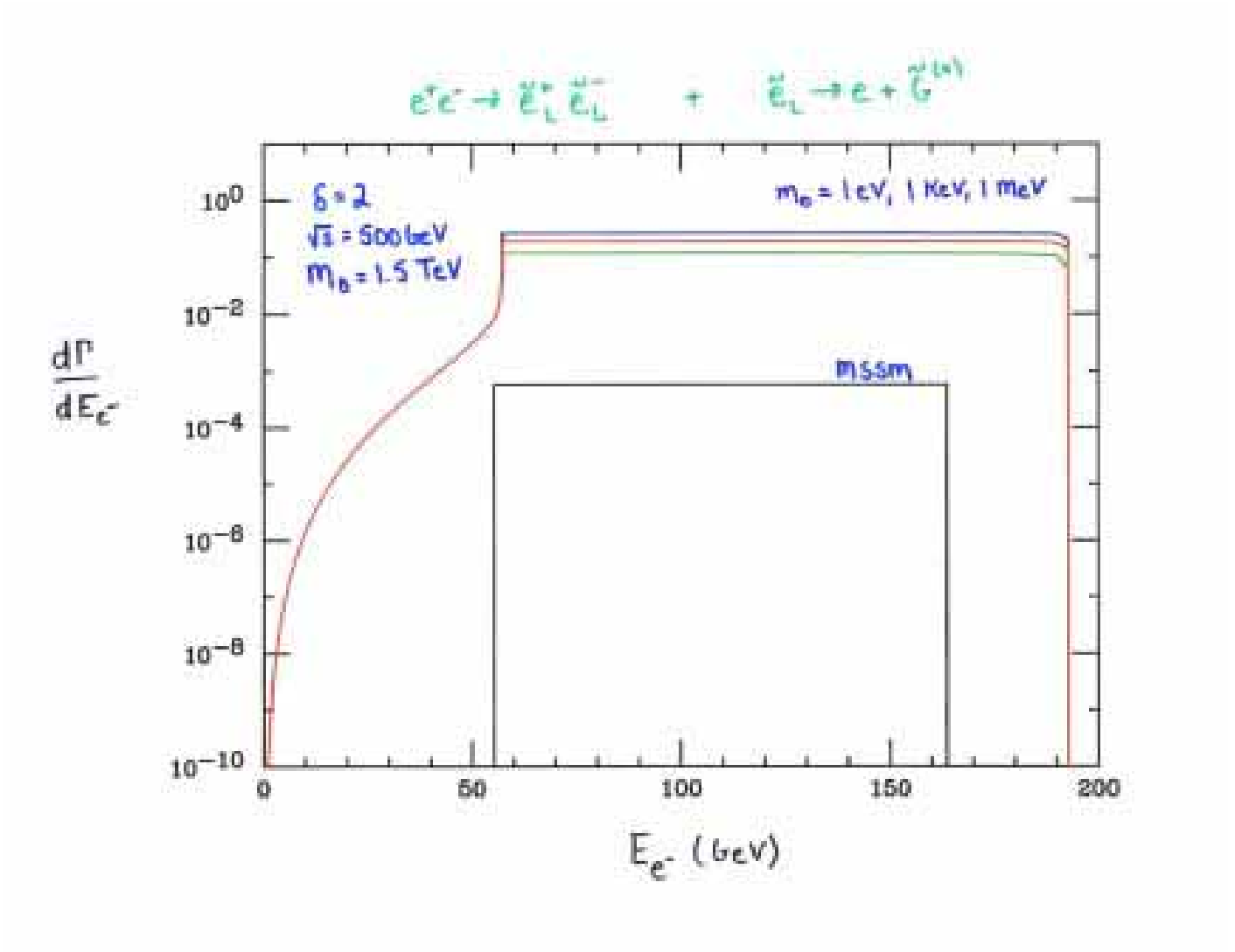
Search Reach for M_H / Λ_L




$e^+e^- \to \tilde{e}_L^+ \tilde{e}_L^-$ + $\tilde{e}_L \to e + \tilde{G}^{(n)}$
δ=2
$\sqrt{s}$ = 500 GeV
$m_{\tilde{e}_L}$ = 210 GeV
M_D = 1.5 TeV
3.0
6.0
mssm
$\frac{d\Gamma}{dE_{e^-}}$
10^0
10^{-2}
10^{-4}
10^{-6}
0
50
100
150
200
E_{e^-} (GeV)


$e^+e^- \to \tilde{e}_L^+ \tilde{e}_L^- + \tilde{e}_L \to e + \tilde{G}^{(n)}$
$\delta = 4$
$\sqrt{s} = 500$ GeV
$m_{\tilde{e}_L} = 210$ GeV
MSSM
$m_D = 1.5$ TeV
3.0
6.0
$\frac{d\Gamma}{dE_{e^-}}$
10^0
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
0
50
100
150
200
E_{e^-} (GeV)


$e^+e^- \to \tilde{e}_L^+ \tilde{e}_L^-$ + $\tilde{e}_L \to e + \tilde{G}^{(n)}$
$\delta = 6$
$\sqrt{s} = 500$ GeV
$m_{\tilde{e}_L} = 210$ GeV
MSSM
$m_b = 1.5$ TeV
3.0
4.0
$\frac{d\Gamma}{dE_{e^-}}$
10^0
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
10^{-12}
0
50
100
150
200
E_{e^-} (GeV)


$e^+e^- \to \tilde{e}_L^+ \tilde{e}_L^-$ + $\tilde{e}_L \to e + \tilde{G}^{(*)}$
$\delta = 2$
$\sqrt{s} = 500$ GeV
$m_0 = 1.5$ TeV
$m_0 = 1$ eV, 1 KeV, 1 MeV
MSSM
$\frac{d\Gamma}{dE_{e^-}}$
10^0
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
0
50
100
150
200
E_{e^-} (GeV)

Conclusions

- Have studied pheno of supersymmetric bulk

  Gravity bulk supermultiplet → KK tower of gravitinos

- Derived effective 4-d theory
- studied $\tilde{G}$ KK exchange in $e^- e^+ \to \tilde{e}^- \tilde{e}^+$

  Leading term is Dimension-6 !
- Strong search reach : $\Lambda_C \gtrsim 20\ \sqrt{s}$!
- Distorts $\tilde{e}$ decay distributions : $\tilde{e} \to e + \tilde{G}^{(n)}$
- Famous 'edges' which provide precise sparticle mass measurements may not be so clean....