Single Neutralino Production via LQD at RunII

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Outline

- General Overview of R Parity Violation
- Bounds on couplings λ'_{1jk} and λ'_{2jk}
- Signal Process $u_j\bar{d}_k \longrightarrow l_i^+\tilde{\chi}^0$, $\tilde{\chi}^0 \longrightarrow l_i^+\bar{u}_jd_k$
- Background Simulation
- Signal Monte Carlo
- Conclusions

General Overview of R Parity Violation

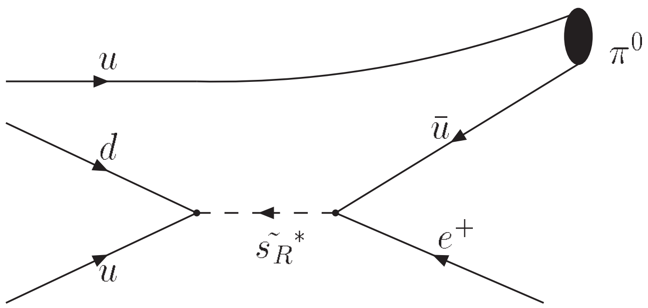
- **In addition to the MSSM superpotential we can have.**

$$\mathbf{W_{\not R_p}} = \lambda_{ijk}\varepsilon^{ab}L_a^i L_b^j \overline{E}^k + \lambda'_{ijk}\varepsilon^{ab}L_a^i Q_b^j \overline{D}^k + \lambda'''_{ijk}\varepsilon^{\alpha\beta\gamma}\overline{U}_\alpha^i \overline{D}_\beta^j \overline{D}_\gamma^k \qquad (1)$$

- **Forbidden in the MSSM by imposing R-parity.**

$$\mathbf{R_p} = (-1)^{3B+L+2S} \qquad (2)$$

- R_p **prevents fast proton decay**



- **Instead impose a symmetry forbidding 2nd or 3rd terms**

e.g. Baryon Parity $\begin{array}{lcl} \{Q_i, U_i, D_i\} & \longrightarrow & -\{Q_i, U_i, D_i\} \\ \{L_i, E_i\} & \longrightarrow & \{L_i, E_i\} \end{array}$

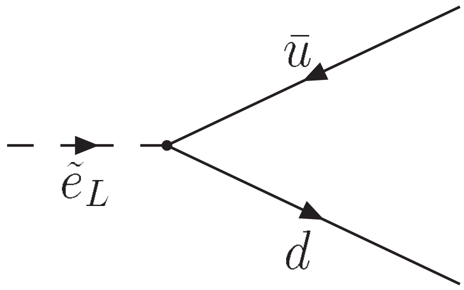
- **Here we concentrate only on LQD non-zero**

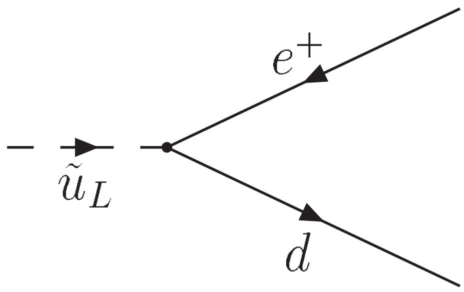
LQD Lagrangian

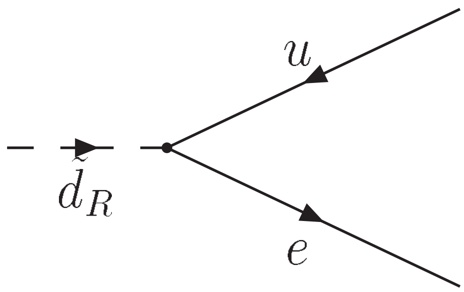
- **We can derive the Lagrangian from $W_{\not{R}_p}$**

$$\mathcal{L}_{LQD} = \lambda'_{ijk} \Big(\tilde{d}^{*\,k}_R \bar{\nu}_c{}^i P_L d^j - \tilde{d}^{*\,k}_R \bar{e}_c{}^i P_L u j + \tilde{d}_L{}^j \bar{d}^k P_L \nu^i \\ - \tilde{u}_L{}^j_L \bar{d}^k P_L e^i + \tilde{\nu}^i \bar{d}^k P_L d^j - \tilde{e}^i_L \bar{d}^k P_L u^j + h.c. \Big) \tag{3}$$

- **This gives a number of interactions, e.g.**







Bounds on couplings λ'_{1jk} and λ'_{2jk}

Restrict to e and μ

All for $\tilde{m} = 100 GeV$

jk	λ'_{1jk}	jk	λ'_{2jk}
11	0.001^{d}	11	0.09^{h}
12	$0.02^{a\dagger}$	12	0.09^{h}
13	$0.02^{a\dagger}$	13	0.09^{h}
21	$0.035^{e\dagger}$	21	0.18^{i}
22	0.06^{c}	22	0.18^{i}
23	0.20^{f*}	23	0.18^{i}
31	$0.035^{e\dagger}$	31	$0.22^{j\dagger}$
32	0.33^{g}	32	0.39^{g}
33	0.002^{c}	33	0.39^{g}

These bounds are obtained from a number of sources.

a) charged current universality

b) $\Gamma(\tau \to e\nu\overline{\nu})/\Gamma(\tau \to \mu\nu\overline{\nu})$

c) bound on the mass of ν_e

d) neutrinoless double-beta decay

e) atomic parity violation

f) $D^0 - \overline{D}^0$ mixing

g) $R_l = \Gamma_{had}(Z^0)/\Gamma_l(Z^0)$

h) $\Gamma(\pi \to e\overline{\nu})/\Gamma(\pi \to \mu\overline{\nu})$

i) $\Gamma(D^+ \to \overline{K}^{0*}\mu^+\nu_\mu)/\Gamma(D^+ \to \overline{K}^{0*}e^+\nu_\mu)$

j) ν_μ deep inelastic scattering

Signal Process: $u_j\bar{d}_k \longrightarrow l_i^+\tilde{\chi}^0, \quad \tilde{\chi}^0 \longrightarrow l_i^+\bar{u}_j d_k$

- **There are 3 tree-level diagrams**

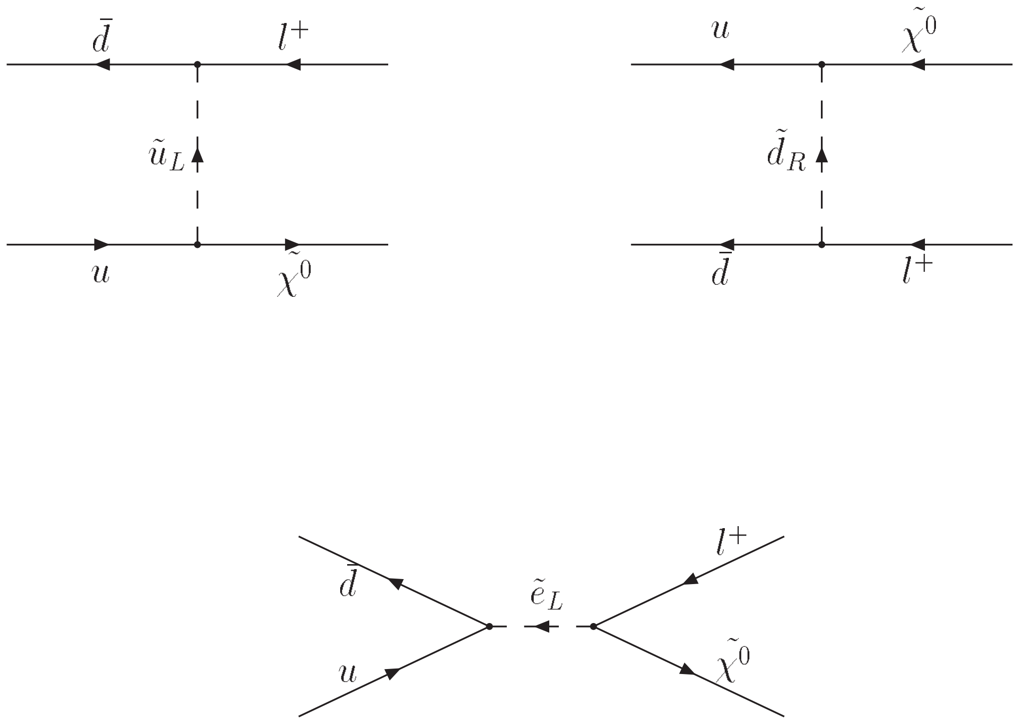


Figure 1: Production of $\tilde{\chi}^0 l^+$.

- **The neutralino can then decay by the crossed process**

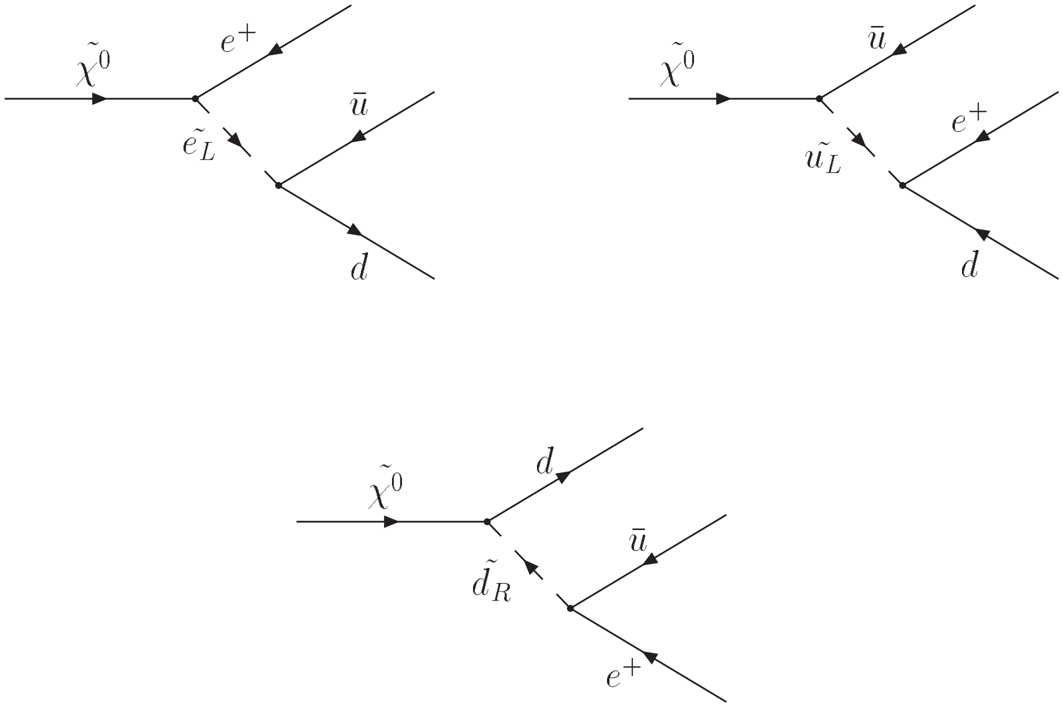


Figure 2: LQD decay of $\tilde{\chi}^0$.

- **There are other $\not{R}_p$ decay modes**

  1. $\tilde{\chi}^0 \longrightarrow e^-\bar{u}d$
  2. $\tilde{\chi}^0 \longrightarrow \bar{\nu}\bar{d}d$
  3. $\tilde{\chi}^0 \longrightarrow \nu\bar{d}d$

- **Note the charge conjugate modes as $\tilde{\chi}^0$ is Majorana**
- **The branching ratios are computed in the program**

- **This gives a SIGNATURE of**

  $e^+e^+, \quad e^-e^-, \quad \mu^+\mu^+, \quad \mu^-\mu^-.$

- **i.e. 2 isolated high P_t like-sign charged leptons.**

Backgrounds

- $b\bar{b}$ production followed by the production of a B_d^0 or B_s^0 meson which can undergo mixing

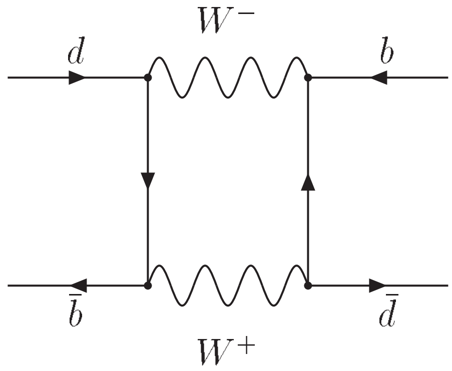


Figure 3: $b\bar{b}$ mixing.

If the two B mesons in the event decay semi-leptonically this gives two like sign charged leptons

- $t\bar{t}$ production followed by

$$t \to W^+ b \to e^+ \bar{\nu}_e b$$
$$\bar{t} \to W^- \bar{b} \to q\bar{q}\bar{b} \to q\bar{q}W^+\bar{c} \to q\bar{q}e^+\bar{\nu}_e\bar{c}$$

- single top production (s and t channel)

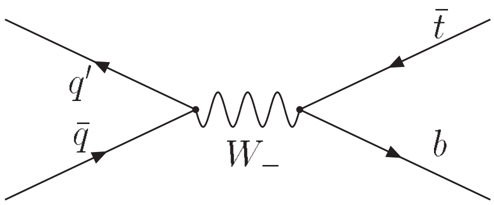


Figure 4: Single Top Production.

followed by semi-leptonic decay of the $\bar{t}$ and B meson

- There will also be non-physics backgrounds, which we ignore here, but should be included in an experimental search.

Background Analysis

- **The leptons from the signal will have**

  high p_t

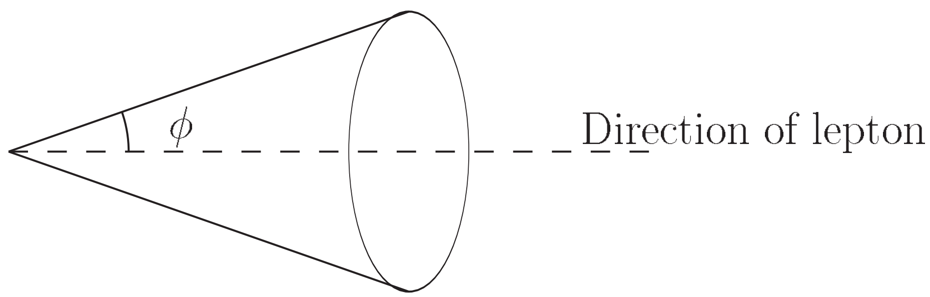
  be well isolated

- **The leptons from the backgrounds will have**

  lower p_t

  be poorly isolated

- **therefore we hope an isolation and a p_t cut can reduce the background**



- **The isolation cut requires the transverse energy in a cone of angle 0.4 radians about the direction of the lepton to be below a certain value.**

Background Simulation

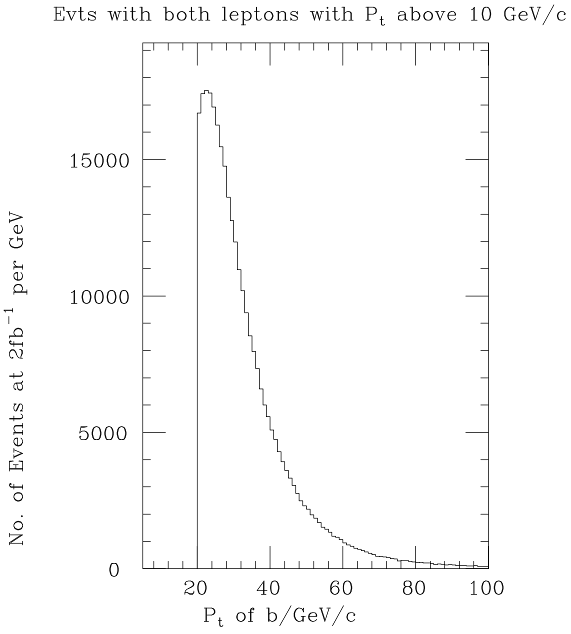
We used HERWIG 6.0 to simulate the backgrounds and apply isolation and p_t cuts

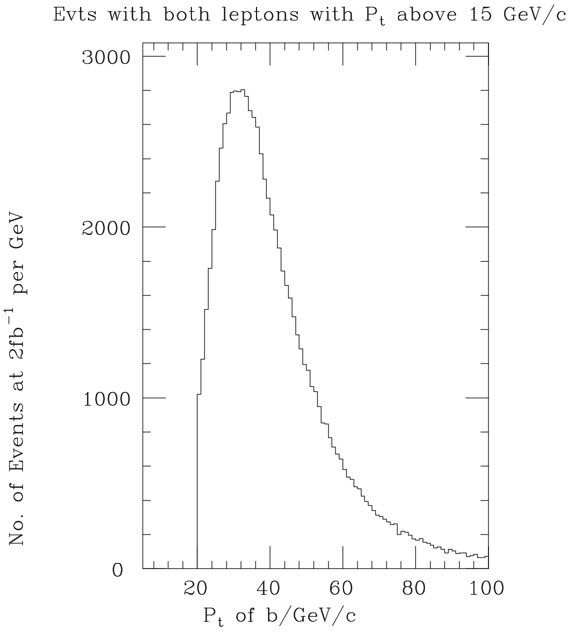
1. $b\bar{b}$

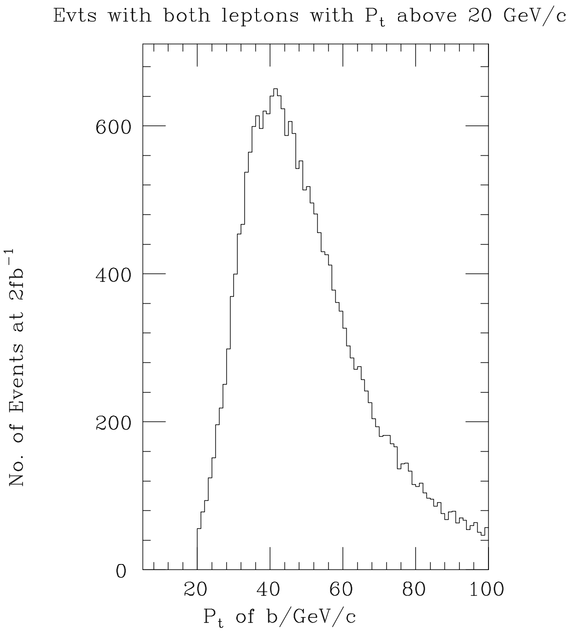
In order to simulate the background we need to make some parton level cuts to reduce the number of events we need to simulate

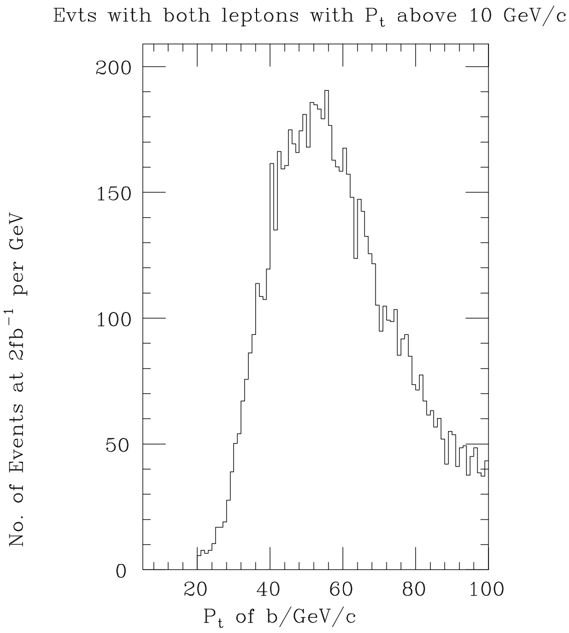
- **A parton level cut of 20 GeV/c on the P_t of the bottom**
- **Include only the leptonic decays of the B's**
- **Force the mixing of the B^0 and B^0_s**

First the effect of the parton level cuts

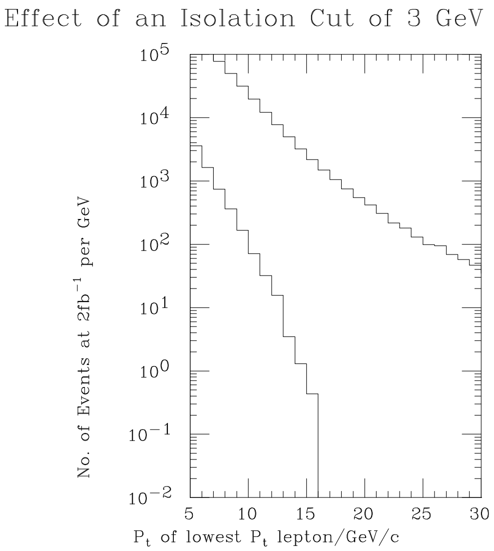


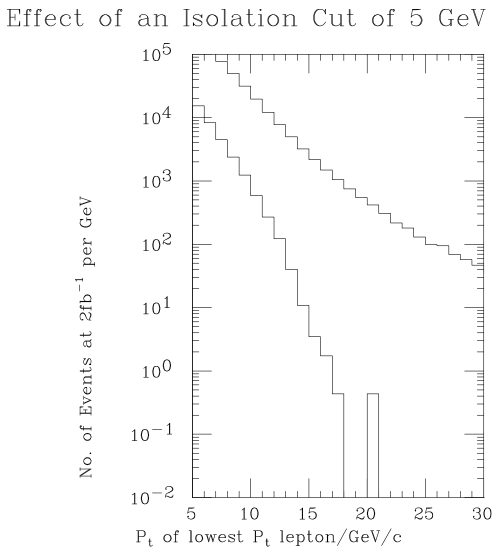


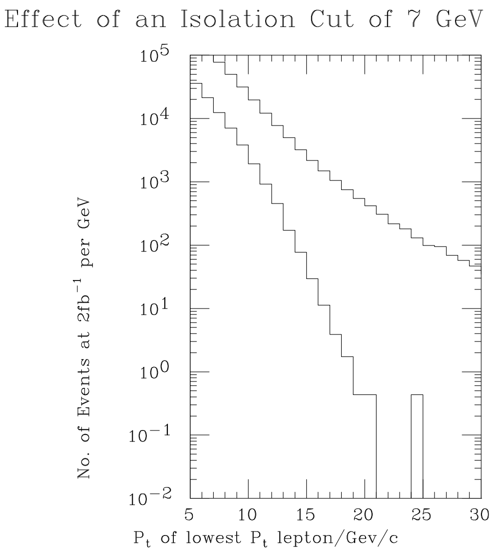


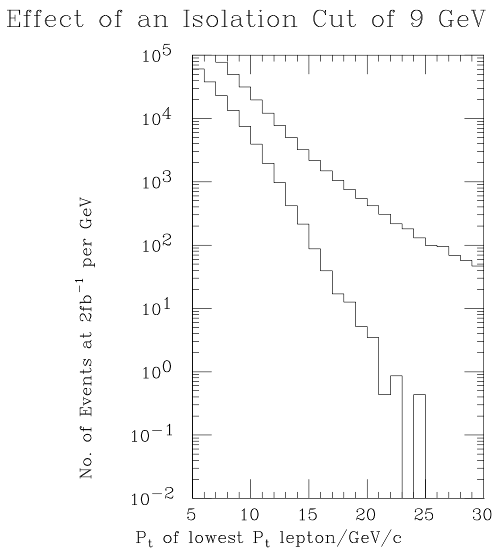


and the effect of the isolation cut



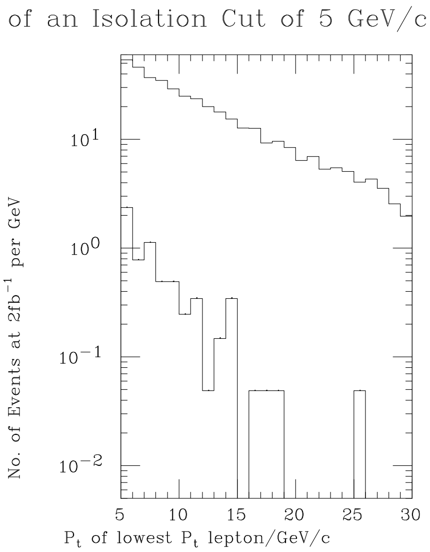


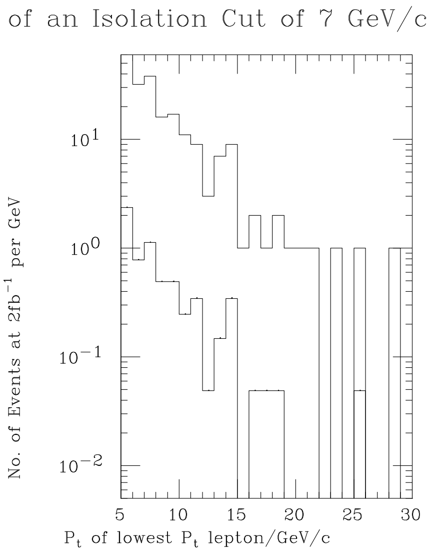




2. $t\bar{t}$

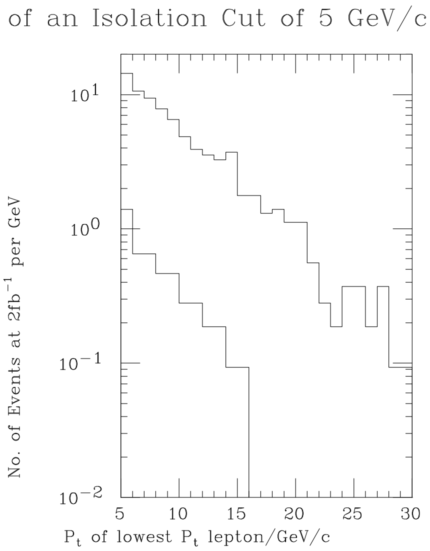
The Cross-section is 4.92 ± 0.01 pb and we simulated 20.30 ± 0.02 times the Run II luminosity.

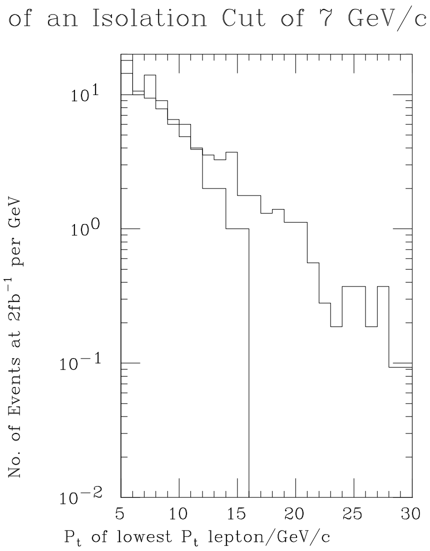




3. Single top

The Cross-section is 1.60 ± 0.01 pb and we simulated 10.72 ± 0.03 times the Run II luminosity.





Background Summary

- **With a cut on the p_t of the leptons and an isolation cut of 5 GeV the background is very low**

Process	**No. of Events at** $2fb^{-1}$
$b\bar{b}$ **mixing**	0.43 ± 0.43
$t\bar{t}$	0.05 ± 0.05
single top	0.0 ± 0.10

- **So the process has background** 0.48 ± 0.44
- **Reminder: We have only considered physics backgrounds.**
- **Now what range of SUSY parameter space can we probe?**

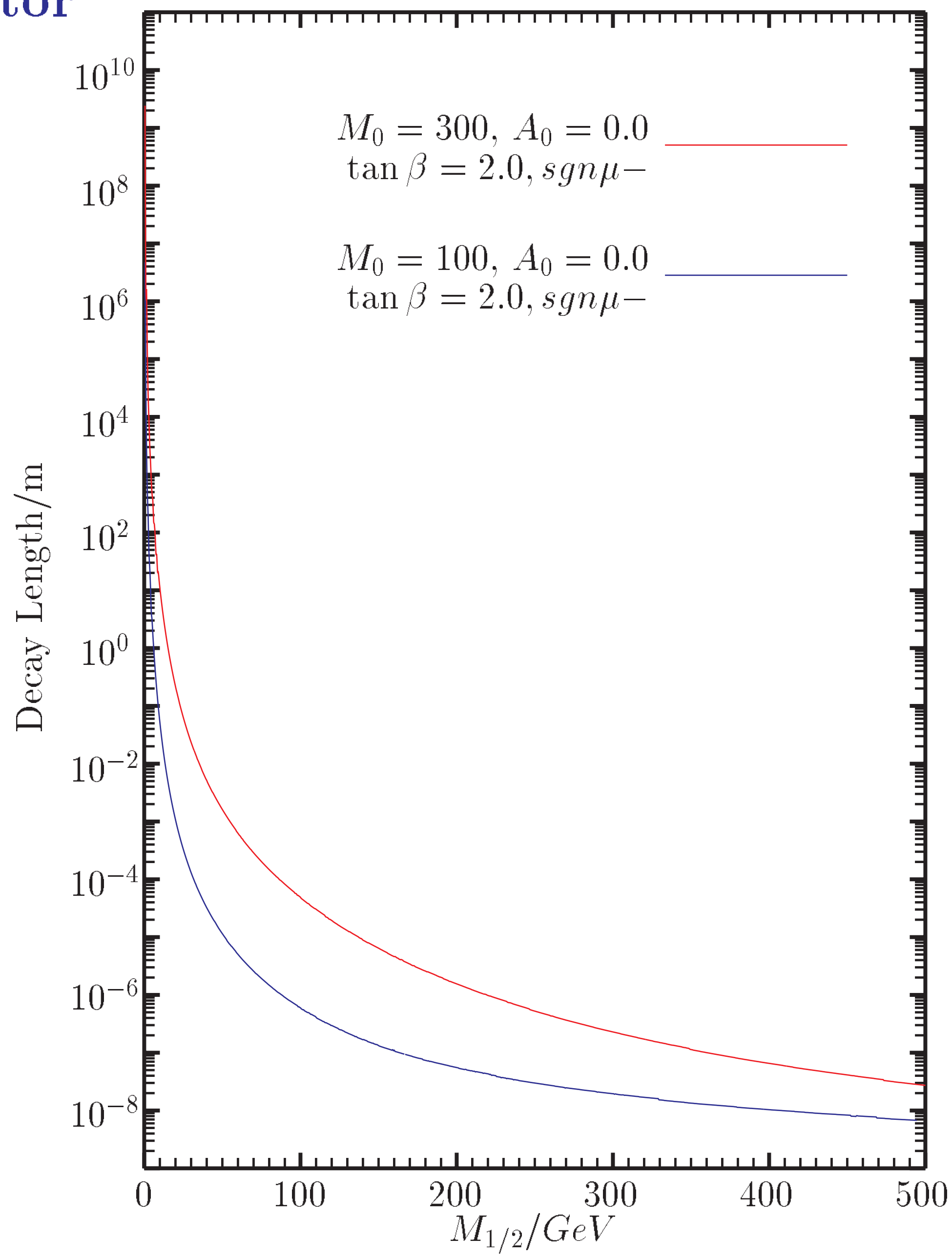
Signal

- **The cross-section is dominated by the resonance.**
- **Hence it depends on the resonant mass $M_{\tilde{e}_L}$, and the neutralino parameters M_1, M_2, μ, $\tan\beta$ via the branching ratio.**
- **If we assume grand unification**

  $M_1 = \frac{5}{3}\tan^2(\theta_W)M_2$
- **We can then plot the cross-section for given M_2, $M_{\tilde{e}_L}$, $\tan\beta$ as a function of μ**
- **However the decay of the neutralino will also depend on $M_{\tilde{u}_L}$ and $M_{\tilde{d}_R}$ and hence to run the Monte Carlo we need to specify a SUGRA point.**

Decay Length

- As we are looking for the decay products of the neutralino it's essential that it decays in the detector

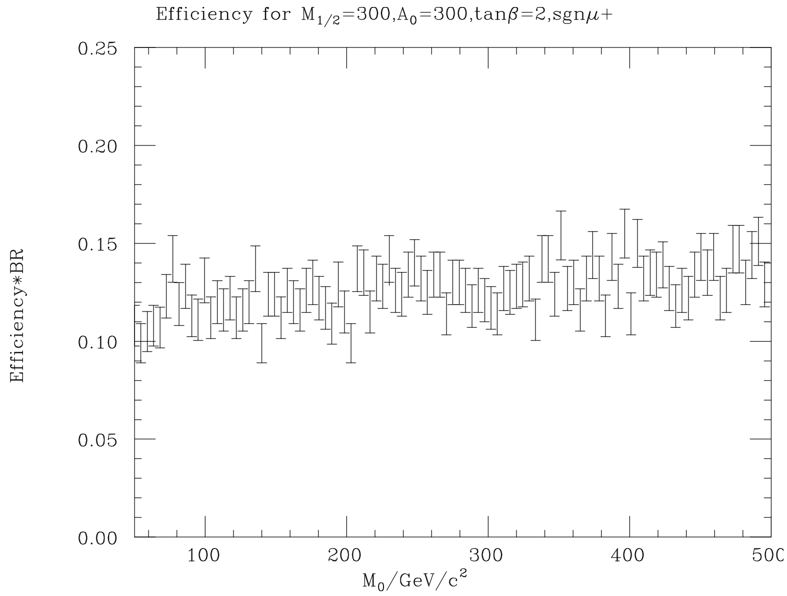


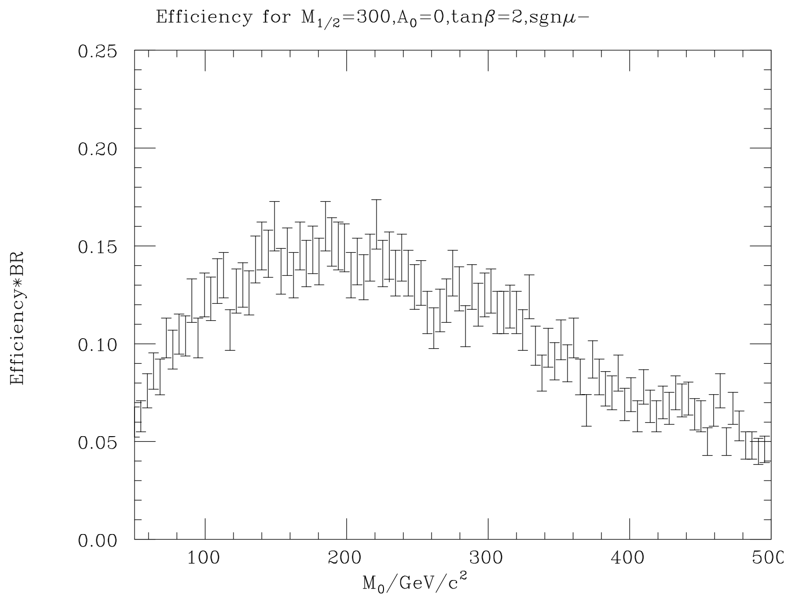
- So with $\lambda'_{111} = 10^{-2}$ the neutralino decays in the detector except when its higgsino-like and very light.
- The decay length scales as $1/\lambda'^{2}_{111}$

Monte Carlo

- **We need to know how much signal is removed by the cuts**
- **We did this by adding the process to HERWIG6.0 to simulate it.**
- **The $\tilde{\chi}^0$ lifetime was calculated and included in the code.**
- **The matrix elements for all the $\tilde{\chi}^0{}_i$ decay were included.**
- **We can now look at the effect of the cuts**

We can plot the efficiency i.e. the fraction of events surviving the cuts



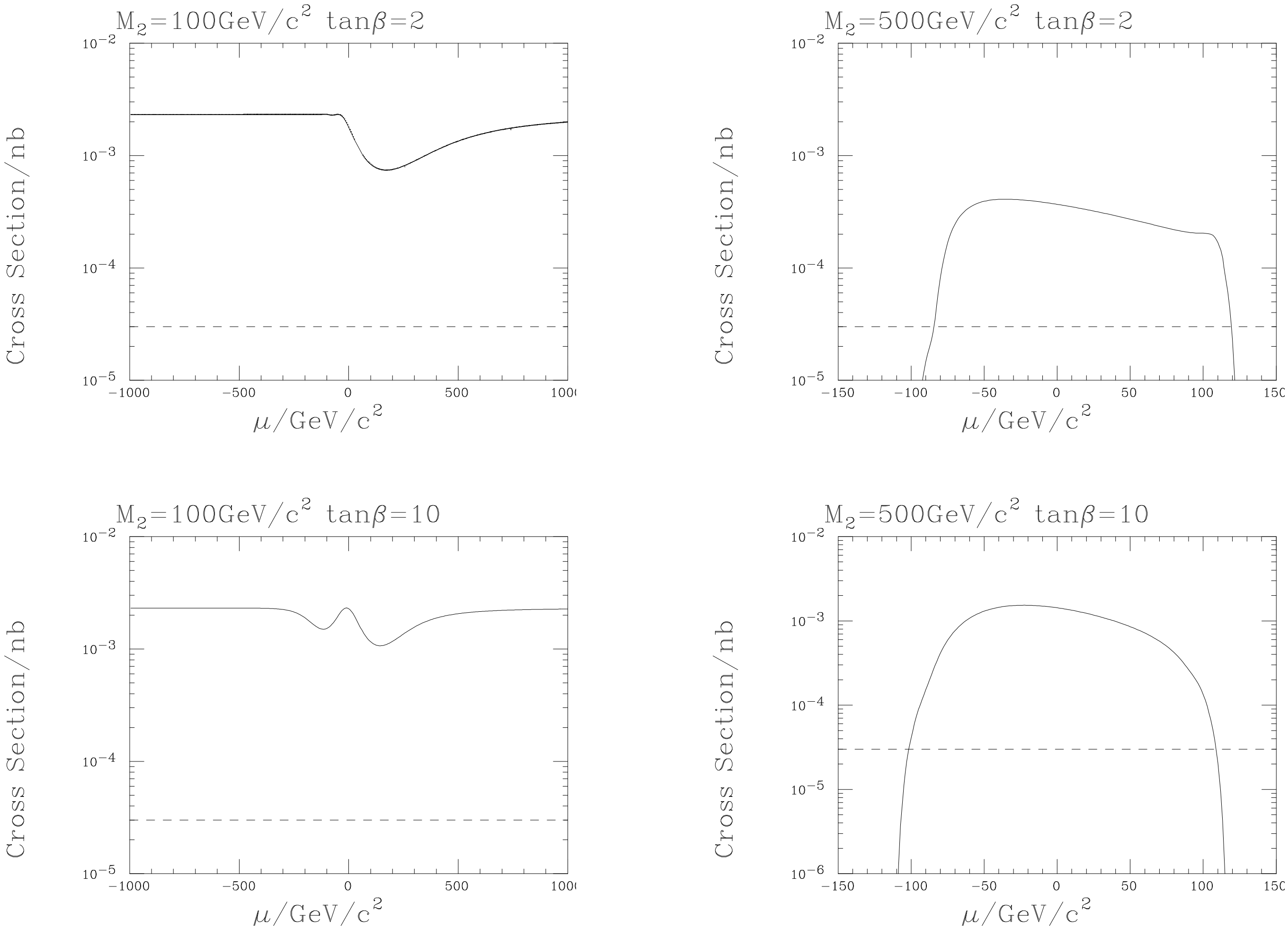


- the efficiency decreases in two regions.
  1. Where the χ^0 is much lighter than the slepton.
  2. Where the χ^0 is not much lighter than the slepton.

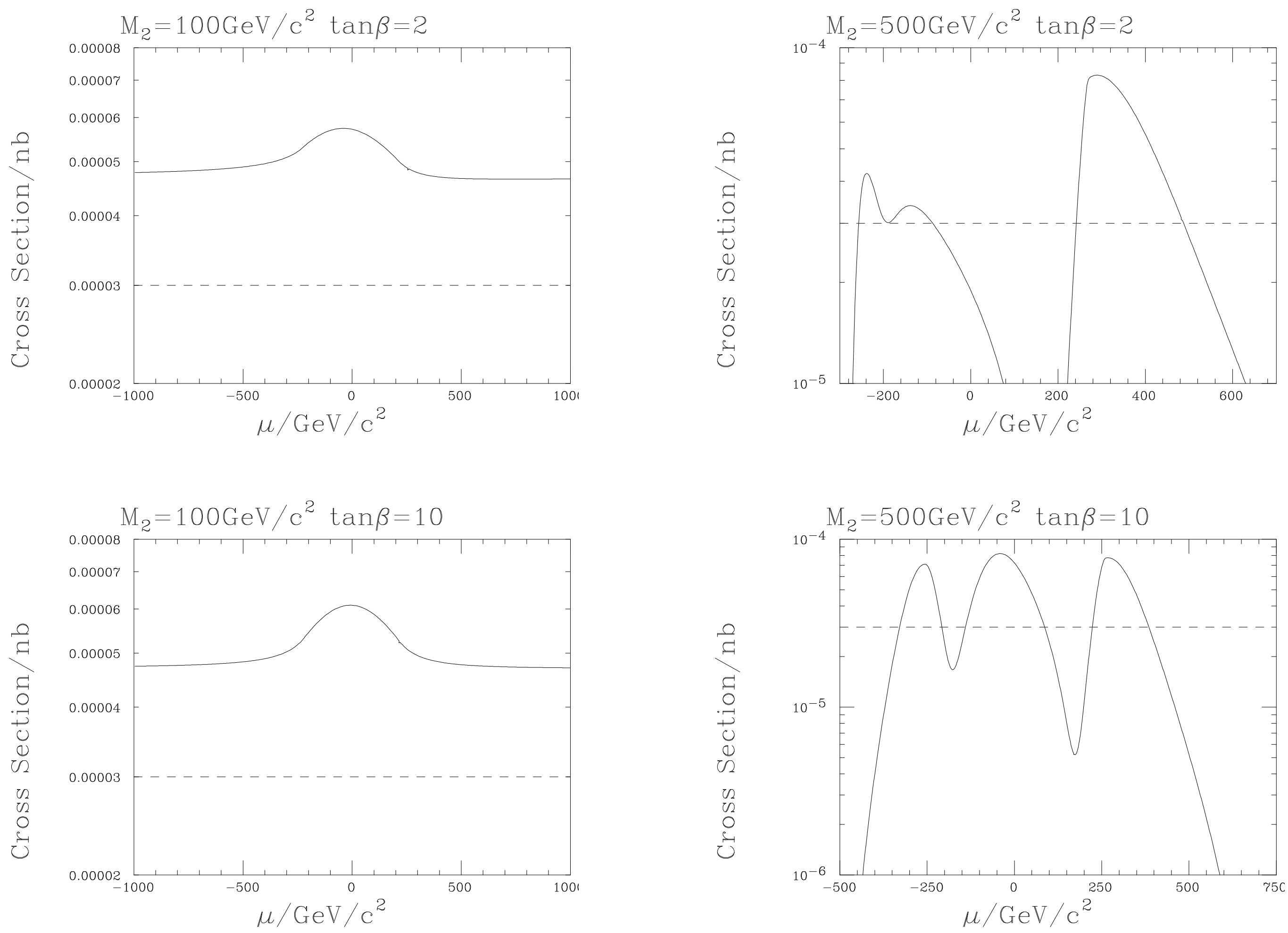
Signal Cross-section

- **We can look at the cross-section for a given M_2, $M_{\tilde{e}_L}$, and $\tan\beta$ as a function of μ**
- **Note also plotted on these graphs is the cross-section required for a discovery, i.e. 5σ above the expected background, assuming an efficiency of 10%.**
- **All the graphs have $\lambda'_{111} = 10^{-2}$**

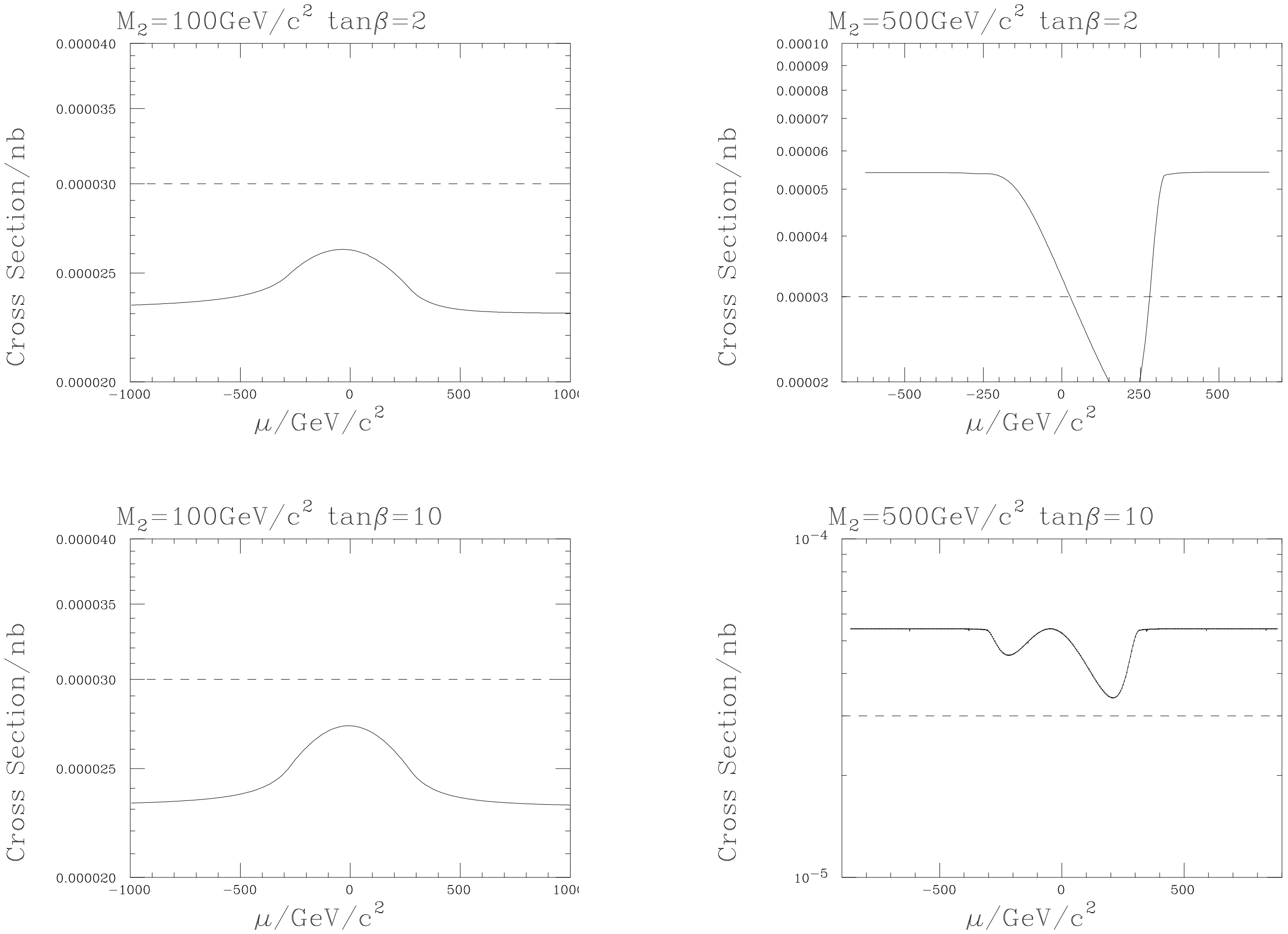
Cross-section for $M_{\tilde{e}_L} = 100 Gev/c^2$



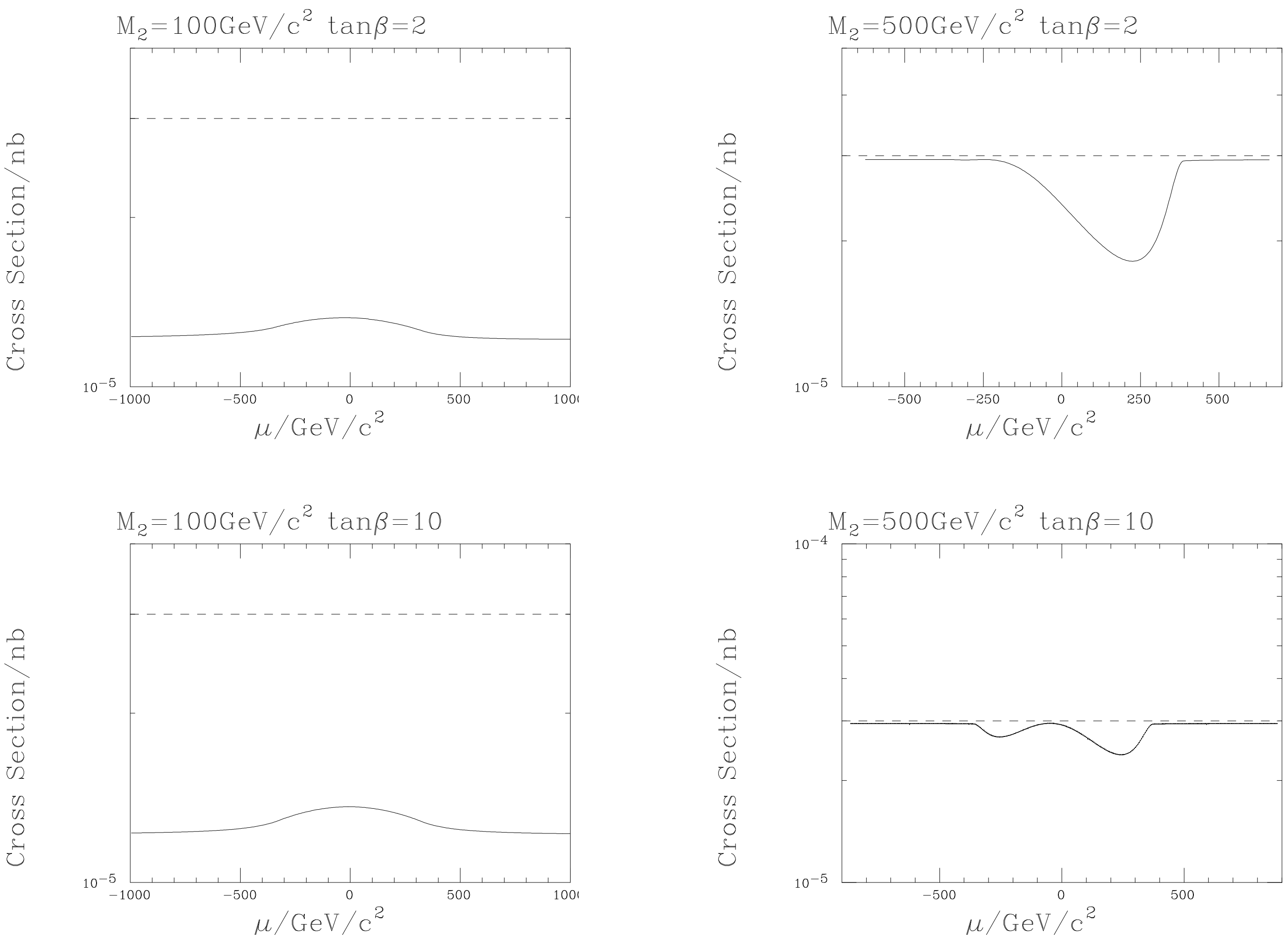
Cross-section for $M_{\tilde{e}_L} = 250 Gev/c^2$



Cross-section for $M_{\tilde{e}_L} = 300Gev/c^2$



Cross-section for $M_{\tilde{e}_L} = 350 Gev/c^2$



Conclusions

- **The limits which can be placed on this process will be weak in the regions of SUSY parameter space where the neutralino is very much lighter than the slepton or not much lighter than the slepton.**
- **We therefore need to perform a scan of the SUSY space using the Monte Carlo simulation. This remains to be done.**
- **However assuming an efficiency of 10% we can**
  1. **probe masses up to 300** GeV/c^2 **at** $\lambda' = 10^{-2}$ **and perhaps higher for larger couplings.**
  2. **probe couplings above** 4×10^{-3} **for** $\tilde{M}_{e_L} = 100GeV/c^2$

  for most of the region where the neutralino is lighter than the slepton.