Three Body Decays of $\tilde{\chi}_1^0$ in R_p violating models with dominant λ and λ' couplings.

Rohini M. Godbole

(*CERN, Geneva*)

Plan :

1. R_p violation in SUSY: why consider it and a few relevant facts.
2. Effects of $\not{R}_p$ at colliders.
3. Three body decays of $\tilde{\chi}_1^0$ via $\not{R}_p$
   - Couplings we consider
   - Why these particular ones?
4. Results
5. Conclusions

(hep-ph/ 0108244)

In collaboration with F. Borzumati, J.L. Kneur and F. Takayama.

Introduction

R_p violation in SUSY:

• No deep theoretical reason for its conservation ☺

▷ Actually B, L symmetries of the SM but NOT of the MSSM

▷ Supersymmetry and Gauge Invariance allow $\not R_p$ terms in the Superpotential

$$W_{\not R_p} = \frac{1}{2}\lambda_{ijk} L_i L_j E_k^c + \lambda'_{ijk} L_i Q_j D_k^c + \frac{1}{2}\lambda''_{ijk} U_i^c D_j^c D_k^c + \kappa_i L_i H_2, \quad (1)$$

L_i,Q_i: doublet Lepton, Quark superfields, E_i, U_i, D_i the singlet Lepton and Quark superfields.

• ν masses can be generated in an economical way without introducing any new fields. ☺

▷ Tree level via the Bilinear κ_i,

▷ Quantum one or two loop level via the Trilinears λ, λ',

▷ Kamioka, SNO $\longrightarrow$ Unambiguous proof of ν masses.

▷ Enough freedom to generate the mass patterns required by all the data.

Introduction

- No DM candidate, as the $\tilde{\chi}_1^0$ not stable, ☹

- Proton will decay **very rapidly** for **TeV** scale SUSY breaking.☹

- Can be cured by adopting B conservation $\lambda'' = 0$. This choice preferred if we don't want $R\!\!\!/_p$ terms to wash out baryogenesis.

- Unified string theories actually prefer models with B conservation and R_p violation. ☺

▷ L.E.Ibanez and G.G.Ross, Nucl. Phys.**B368** (1992) 3

These models treat the Lepton and the Quark fields differently and have two discrete symmetries. B conservation and $R\!\!\!/_p$ eliminates not just the dimension 4 operators for proton decay BUT also dimension 5.

- All this makes $R\!\!\!/_p$ theoretically interesting

- A large no. 48 Yukawa type couplings. No theoretical indications about their sizes. ☹

- Many of the unknown couplings constrained by low energy processes, e.g. Proton Decay, μ decay, cosmological arguments, e.g. the baryogenesis.☺

Introduction

▷ A host of references!!

$\Downarrow$

Host of constraints on λ, λ'

$\Uparrow$

Majority of these come from virtual effects caused by sparticle exchanges via $\not{R}_p$ interactions (loops).

•Constraints get less severe for λ, λ' with increasing number of third generation indices.

•Virtual effects depend on sparticle masses.

•Sometimes can also depend on a lot of other details of the SUSY model e.g. the L-R mixing in the sfermion sector etc.

• The L violating couplings can be constrained severely particularly by ν masses. Constraints quite model dependent.

Important to study the effects of the same $\not{R}_p$ couplings in collider environment, which can help clarify model building.

R_p violation at the colliders.

Effects of R_p violation at Colliders:

- Depend on the size of the coupling.

▷ LSP no longer stable. It need not even be $\tilde{\chi}_1^0$. If ANY $\not{R}_p$ coupling is $> 10^{-6}$ it WILL decay within the detector

S. Dawson, NPB**261**(1985) 297.

▷ We take $\tilde{\chi}_1^0$ to be the LSP. The decays can and will give rise to strikingly different final states.

For example, RMG, P.Roy,X.Tata, NPB**401** (1993) 67.

$\tilde{\chi}_1^0 \to f \bar{f}_1 f_2$ (more on these decays later). For masses of $\tilde{\chi}_1^0, \tilde{\chi}_1^\pm$ of interest at LHC,NLC, even a t in the final state will be allowed.

▷For larger $\not{R}_p$ couplings more things can happen

- Decays of particles and sparticles other than the LSP via $\not{R}_p$ interactions

For example, D.K.Ghosh et al, PLB **396** (1997) 177; T.Han, M.B.Magro, PLB **476** (2000) 79; A.Belyaev et al, PLB **484** (2000) 79, G. Polesello et al, 2002.

$\tilde{t} \to bl, t \to b\tilde{l}$

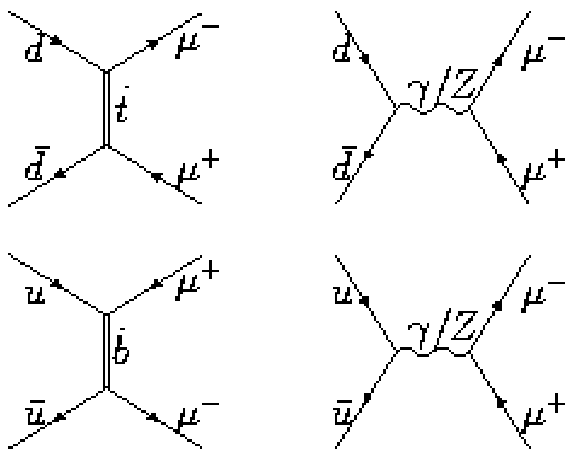
- Some more on the particle decays later.

R_p violation at the colliders.

- Virtual effects of sparticle exchange on tree level processes.

$pp \longrightarrow \mu^+\mu^-$

G.Bhattacharyya, et al PLB **349**, 118 (1995), J.Hewett, T.Rizzo, PRD **56** (1997) 5709, D. Choudhury, R.M.G, hep-ph/0005142.



$pp \longrightarrow t\bar{t}$

D. Choudhury, R.M. Godbole, P. Poulose and S.D. Rindani (in preparation), K.Hikasa, J.M.Yang and B.Young, Phys. Rev. D **60** (1999) 114041.

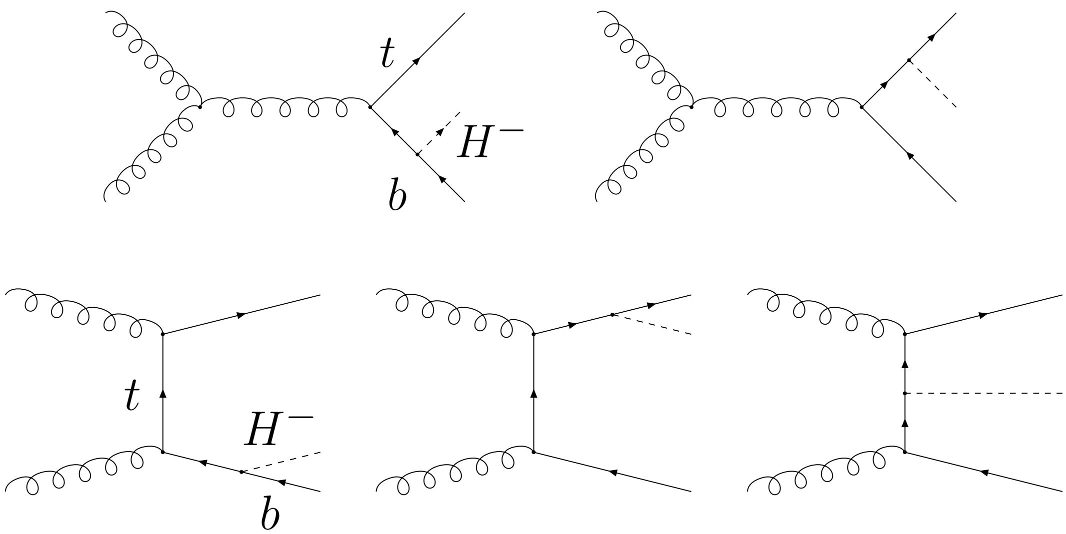
$\not{R}_p$ contribution to $t\bar{t}$ produces a polarisation asymmetry bet. t and $\bar{t}$.

$\not{R}_p$ violation at the colliders.

- Resonant or nonresonant production of a single sparticle via the $\not{R}_p$ couplings

G.Moreau, et al, NPB **604** (2001) 3; H.Dreiner et al, PRD **63** (2001) 055008, F. Borzumati, et al PR**D60** (1999) 115011.

For example, $pp \to t\bar{b}\tilde{\tau}$ via λ'_{333}. Similar to H^- produced via $t\bar{b}H^-$ coupling.



$\triangleright$ Even for $m_{\tilde{t}} > m_t$ rates appreciable for λ'_{333} as small as 0.05.
$\triangleright$ $\tilde{\tau}$ so produced will have both $\not{R}_p$ and RPC decays. RPC decays will produce $\tilde{\chi}_1^0$.

$\triangleright$ Some of these decays can fake the charged Higgs signal.

$\triangleright$ A comprehensive study requires full analysis of the three body decays of the $\tilde{\chi}_1^0, \tilde{\chi}_1^\pm$.

Three body $R\!\!\!/_p$ decays of $\tilde{\chi}_1^0$.

- λ with more than one third generation index not constrained too much by collider experiments.
- Models for ν masses on the other hand can constrain these.
- Probes of the L violating λ, λ' couplings at the colliders that involve studying the physics of the third generation t, b and τ will certainly provide important inputs to model building when taken in conjunction with ν mass issue.
- Third generation sfermions likely to give rise to larger virtual effects as they are expected to be lighter.
- For $\tilde{\chi}_1^0, \tilde{\chi}_1^+$ with masses of interest at the LHC, NLC, final states with third generation fermions including t are possible.
- One needs a study of the $R\!\!\!/_p$ decays of $\tilde{\chi}_1^0, \tilde{\chi}_1^\pm$ retaining effects of the mass of the third generation fermions, for L violating coupling.
- Formulae had been derived including the mass effects by Dreiner et al, JHEP **0004** (2000) 008. Our formulae, in the limit of real L-R sfermion mass term, agree with theirs. Their analysis focuses on the effects of the B violating couplings.

Three body $\not{R}_p$ decays of $\tilde{\chi}_1^0$.

- What has been done by us?

- Calculated 3 body $\not{R}_p$ decays of the $\tilde{\chi}_1^0$ with dominant λ, λ' couplings involving at least two three generation indices.

- Kept the mass effects of the third generation fermions and the sfermion L-R mixing terms complex.

- Analysed numerically for cases with unified/ununified gaugino masses, including effect of subdominant λ, λ'.

- Our code can be used to implement three body decays of the lightest neutralino with one dominant $\not{R}_p$ and L violating coupling. Generalisation to more than one subdominant couplings is easy.

- Analysed decays into purely third generation final state fermions including t.

Three body $\not R_p$ decays of $\tilde{\chi}_1^0$.

λ'_{333}

Decays of the $\tilde{\tau}$:

R_p conserving decay:

$\tilde{\tau} \to \tau \tilde{\chi}_1^0, \tilde{\tau} \to \nu_\tau \tilde{\chi}_1^-,$ $\qquad m_t > m_{\tilde{\tau}}$

$\not R_p$ decay:

$\tilde{\tau} \to b\bar{t}$ $\qquad m_t < m_{\tilde{\tau}}.$

If the $\not R_p$ coupling is sizable the net final state produced decided by relative branching ratios of $\tilde{\chi}_1^0, \tilde{\chi}_1^+$ into different channels.

Production of $\tilde{\tau}$ through $\not R_p$ couplings and its decay via the same will give rise to

$pp \to t\bar{b}\tilde{\tau}X \to t\bar{b}t\bar{b}X$

* The same final state as the $H^\pm$.

RPC decays of the $\tilde{\tau}$ and $\not R_p$ decays of the $\tilde{\chi}_1^0$ can also produce

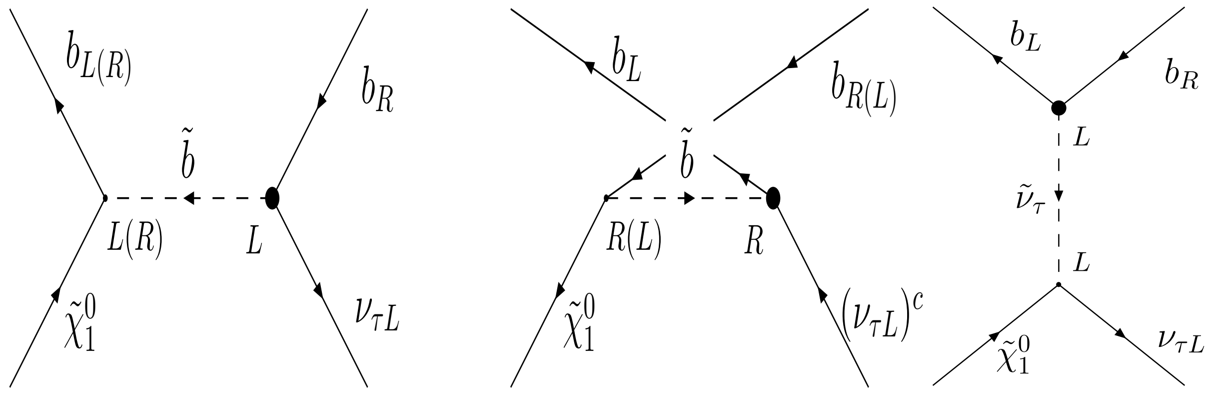
$$pp \to t\bar{b}\tilde{\tau}X \to (2t)(2b)(2\tau)X$$
$$\to tb\ (2\bar{b})\ \tau\nu_\tau X$$

etc.

* Characteristic L violating decays of $\tilde{\chi}_1^0$: like sign fermion pairs.

Results.

λ'_{333} Dominant:



- Decays of the $\tilde{\chi}_1^0$

▷ $\tilde{\chi}_1^0 \rightarrow b\bar{b}\nu_\tau$ $\quad m_{\tilde{\chi}_1^0} < m_t$ MASSLESS

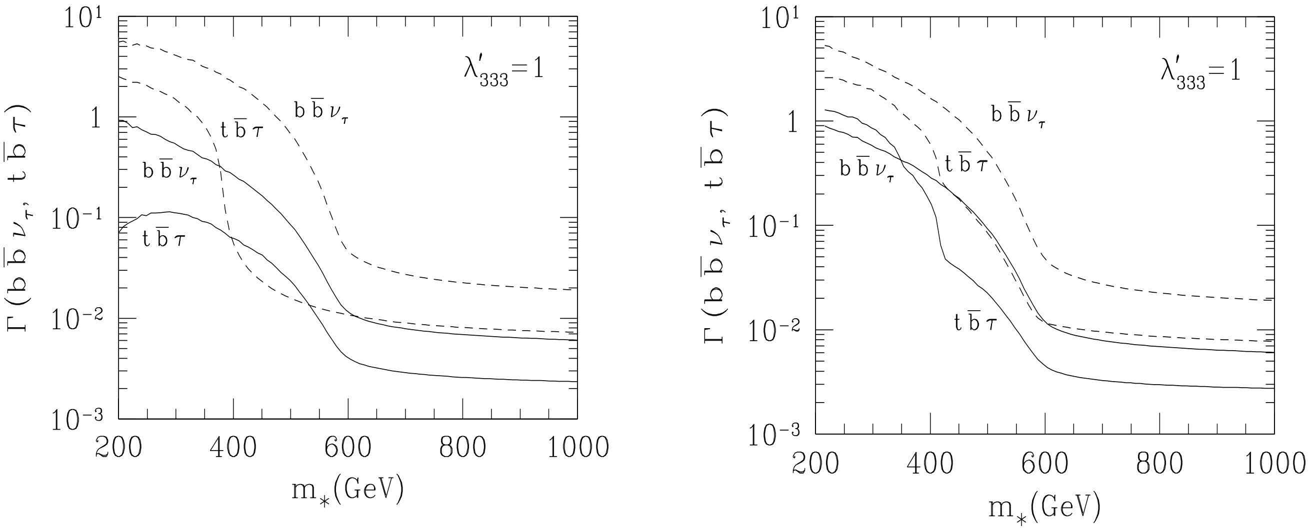
▷ $\tilde{\chi}_1^0 \rightarrow \bar{b}t\nu_\tau$ + C.C. $\quad m_{\tilde{\chi}_1^0} > m_t$ MASSIVE

▷ For a Wino like $\tilde{\chi}_1^0$, in the absence of the L-R mixing the second diagram with a $\tilde{b}_R$ exchange will not contribute.

▷ A substantial gaugino/higgsino mixing causes an increase in the width into massive mode for low $\tan\beta$ and into massless mode for large $\tan\beta$.

▷ In the results we present widths of the charge conjugate modes $t\bar{b}\nu_\tau$ and $\bar{t}b\bar{\nu}_\tau$ is given separately.

Results.



— — —Wino like $\tilde{\chi}_1^0$ Solid line $\tilde{\chi}_1^0$ Bino like.

Left panel: no L-R mixing in the Squark sector.

Right Panel:Moderate left right entries. $A_t - \mu \cot\beta = 150$ GeV, $A_b - \mu \tan\beta = 2000$.

M_* is a squark mass scale. $M_{\tilde{\chi}_1^0} = 600$ GeV.

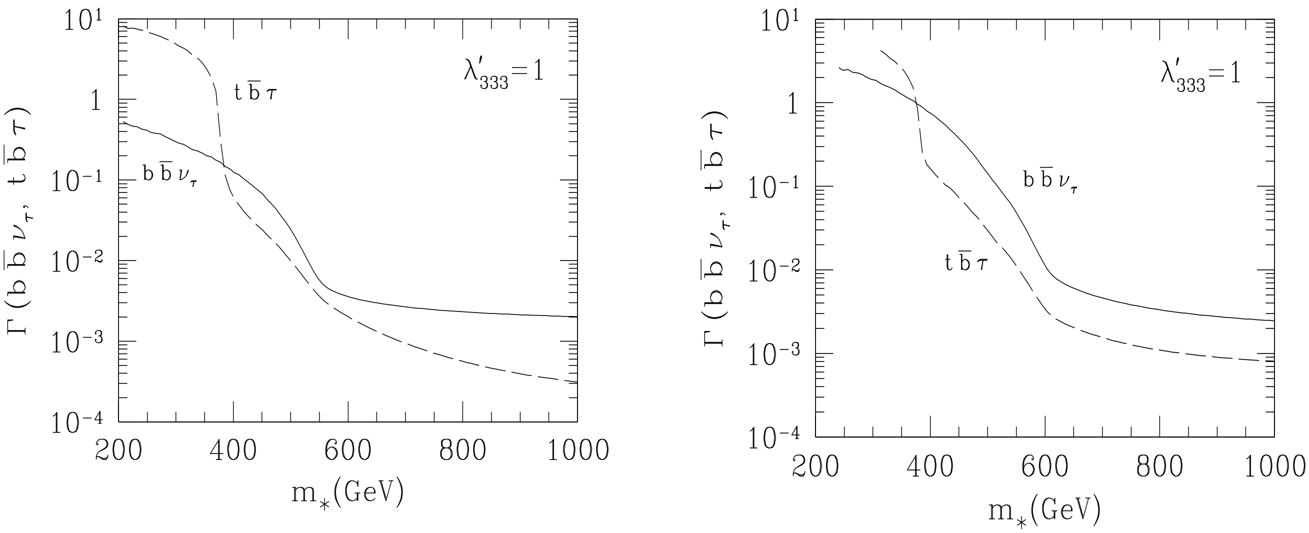
$\triangleright$ The massless mode is the larger one,but massive mode is not negligible either.

$\triangleright$ Enhancement of the widths by an order of magnitude for $\tilde{\chi}_1^0 \sim \tilde{W}$.

$\triangleright$ With moderate L-R squark mixing, even for $\tilde{\chi}_1^0 \sim \tilde{W}$, the $\tilde{b}$ mediated diagram contributes to massive mode. Smaller $\tilde{t}_1, \tilde{b}_1$, masses enhance the width for the massive mode for a $\tilde{B}$ like $\tilde{\chi}_1^0$.

Results.

- Dependence on $\tan\beta$.



$b\bar{b}\nu_\tau$ decay width : solid line $t\bar{b}\nu$ width : dashed line.

Left panel: $\tan\beta = 3$ Trilinear soft terms = 350 GeV

Right Panel: $\tan\beta = 30$, Trilinear soft terms = 150 GeV.

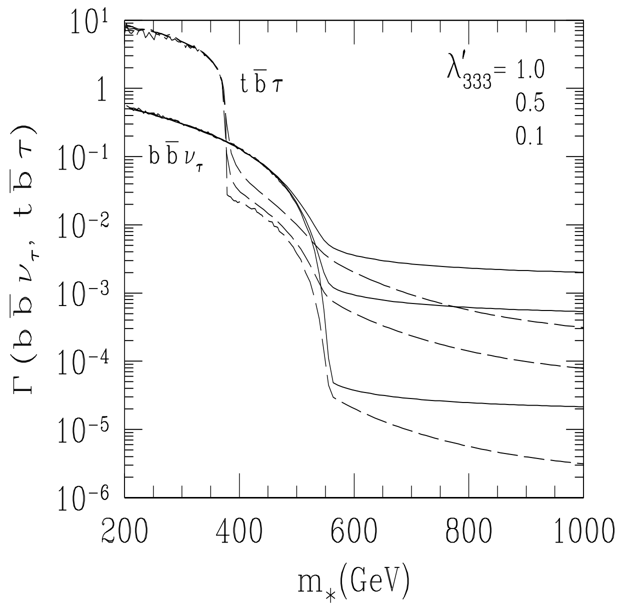
M_* is the squark mass scale. $M_{\tilde{B}}$, slepton mass and $\mu = 600$ GeV.

▷ The massive mode is larger at lower $\tan\beta$ and the massless one for the higher values.

▷ With λ'_{333} dominant, the massive decay has a large width for low $\tan\beta$ and large higgsino-gaugino mixing. Otherwise the massless mode is larger, though the massive mode is nonnegligible.

Results.

•Dependence on λ'_{333} value.



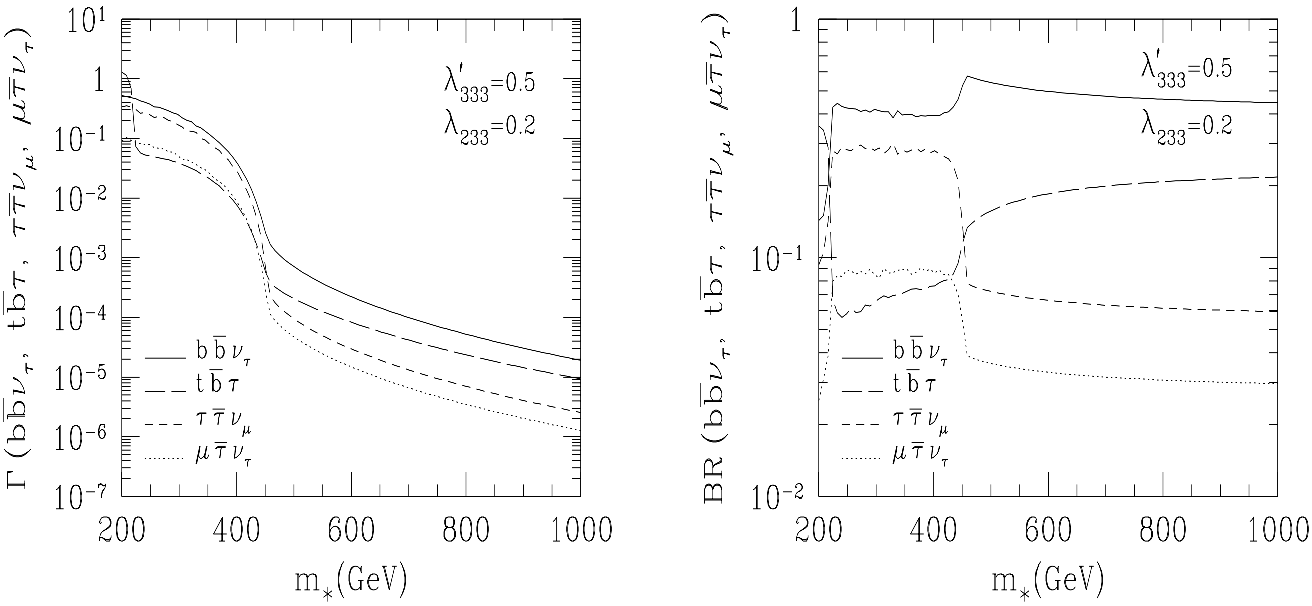
$b\bar{b}\nu_\tau$ decay width : solid line; $t\bar{b}\nu$ width : long dashed line.

All the other parameters same as in the earlier case.

▷ In the resonant sfermion region very little dependence on λ'_{333} and otherwise scales down simply like λ'^2_{333}.

Results.

- Comparable λ and λ' couplings.



$b\bar{b}\nu_\tau$ decay width : solid line; $t\bar{b}\tau$ width: long dashed line.

$\tau\bar{\tau}\nu_\mu$ decay width : small dashed line; $\mu\bar{\tau}\nu_\tau$ width : dotted line.

Left panel:Widths, Right Panel:B.R., No L-R mixing, $\mu = 500$ GeV, $\tan\beta = 3$, Bino mass $= 500$ GeV.

▷ All the widths are not too dissimilar

▷ B.R. into a final state with t is not too small.

Conclusions.

• Important to have a collider probe of the $\not{R}_p$, λ and λ' couplings with more than one third generation index.

• Single charged slepton production via the $\not{R}_p$ coupling λ'_{i33} can produce final states which can be confused with the $H^{\pm}$ signal.

• Even for smaller but dominant $\not{R}_p$, λ and λ' couplings with more than one third generation index, the three body $\not{R}_p$ decays of $\tilde{\chi}_1^0, \tilde{\chi}_1^+$ can have important phenomenological consequences for new particle searches at the future colliders.

• If the $\tilde{\chi}_1^0$ is 'Wino' like its decay widths increases by over an order of magnitude.

• If the $\tilde{\chi}_1^0$ is lighter than the t, its $\not{R}_p$ decays will be dominantly into massless fermions: $b\bar{b}\nu_\tau$ for dominant λ'_{333} coupling, $c\bar{b}\tau$, $s\bar{b}\nu_\tau$ and the charge conjugate modes $\bar{c}b\bar{\tau}$, $\bar{s}b\bar{\nu}_\tau$ for dominant λ'_{323}, whereas for λ_{233} it is $\bar{\mu}\tau\nu_\tau$ and $\mu\bar{\tau}\bar{\nu}_\tau$.

• For a $\tilde{\chi}_1^0$ heavier than the t the massive decay modes can become competitive for large L-R sfermion mass terrm and /or for substantial mixing in the higgsino/gaugino sector, at not too large tan β.

• All the $\not{R}_p$ decays of the $\tilde{\chi}_1^0$ produce final states with like sign dileptons as the telltale signature of the L violation, as long as the final state t decays hadronically.