Exotic SUSY Scenarios

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Which exotic scenarios do I cover in this talk?.

i) Nonuniversal Gaugino Masses at high scale (NGM)

$\Rightarrow$ Effect of the nonuniversality on the B.R. ($h \to \tilde{\chi}_1^0 \tilde{\chi}_1^0$), on Higgs search at the LHC and the contribution of $\tilde{\chi}_1^0$ relic density to the Dark Matter (DM)

Abstract 176: R.G. et al

ii) R_p violation (RPV).

ii.a) Effects of dominant $\not{R}_p$ and $\not{L}$, trilinear λ and λ' couplings on the decay of $\tilde{\chi}_1^0$

Abstract 103: R.G. et al

ii.b) Effect of Bilinear $\not{R}_p, \not{L}$ couplings on the decays of $\tilde{\chi}_1^0, \tilde{\chi}_1^+$ and the trilepton signal at the Tevatron

Abstract 115: F. de Campos et al.

iii) Signals of Heavy Majorana Neutrinos(HMN) at the LHC

Calculation of LSD signal due to resonant production of a Heavy Majorana Neutrino N and that due to WW fusion via a N exchange.

Abstract 962: O. Panella et al.

Introduction

Abstract 176: (hep-ph/ 0108244, JHEP 07 , 2002, 037.)

R. Godbole in collaboration with F. Borzumati, J.L. Kneur and F. Takayama.

Abstract 103: (Phys. Lett. B 519, 2001, 93.)

R. Godbole in collaboration with G. Bélanger, F. Boudjema,, F. Contrant and A. Semenov.

Abstract 115: ((ABS 115 at ICHEP02.)

F. de Campos, O.J.P. Eboli, M.B. Magro, W. Porod, D. Restrepo and J.W.F. Valle.

Abstract 962: (Phys. Rev. D 65, 2002, 035005.)

O. Panella, M. Cannoni, C. Carimalo and Y.N. Srivastava.

Introduction

INTERNATIONAL CONFERENCE ON HIGH ENERGY PHYSICS
AMSTERDAM 2002

Abstract ID=ABS176
Beyond the Standard Model (experiment and theory)
Particle astrophysics and cosmology
Experiment: N.A.
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Invisible SUSY Higgs and dark matter

F. Boudjema, G. Belanger, R.M. Godbole, A. semenov

Abstract

Giving up the assumption of the gaugino mass unification at the GUT scale, the latest LEP and Tevatron data still allow the lightest supersymmetric Higgs to have a large branching fraction into invisible neutralinos. Such a Higgs may be difficult to discover at the LHC and is practically unreachable at the Tevatron. We argue that, for some of these models to be compatible with the relic density, light sleptons with masses not far above the current limits are needed. There are however models that allow for larger sleptons masses without being in conflict with the relic density constraint. This is possible because these neutralinos can annihilate efficiently through a Z-pole. In all cases one expects that even though the Higgs might escape detection, one would have a rich SUSY phenomenology even at the Tevatron, through the production of charginos and neutralinos.

Introduction

INTERNATIONAL CONFERENCE ON HIGH ENERGY PHYSICS
AMSTERDAM 2002

Abstract ID=ABS103
Beyond the Standard Model (experiment and theory)
Experiment: NA
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Lightest-Neutralino Decays in R_p-violating Models with Dominant λ' and λ Couplings.

F. Borzumati, R. M. Godbole, J-L. Kneur and F. Takayama

Abstract

Decays of the lightest neutralino are studied in R_p-violating models with operators $\lambda' LQD^c$ and λLLE^c involving third-generation matter fields and with dominant λ' and λ couplings. Generalizations to decays of the lightest neutralino induced by subdominant λ' and λ couplings are straightforward. Decays with the top-quark among the particles produced are considered, in addition to those with an almost massless final state. Phenomenological analyses for examples of both classes of decays are presented. No specific assumption on the composition of the lightest neutralino is made, and the formulae listed here can be easily generalized to study decays of heavier neutralinos. As recently pointed out, for a sizable coupling λ'_{333}, tau-sleptons may be copiously produced at the LHC as single supersymmetric particles, in association with top- and bottom-quark pairs. This analysis of neutralino decays is, therefore, a first step towards a reconstruction of the complete final state produced in this case.

Introduction

INTERNATIONAL CONFERENCE ON HIGH ENERGY PHYSICS
AMSTERDAM 2002

Abstract ID=ABS115
Beyond the Standard Model (experiment and theory)
Electroweak physics
Experiment: -
Contact Person: Oscar J.P. Eboli
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Trilepton Lepton Signal for Bilinear R-Parity Violation

F. de Campos, O.J.P. Eboli, M.B. Magro, P.G. Mercadante, D Restrepo, and J.W.F. Valle

Abstract

The usual analysis of the trilepton production at the Tevatron assumes R-parity conservation. In this work, we study this process in a a scenario with bilinear R–parity violation. This class of models leads to mixings between the standard model particles and supersymmetric ones which change the low energy phenomenology and searches for supersymmetry. In the framework of SUGRA, we analyze the changes in the trilepton production and determine the regions of parameter space where we can discover supersymmetric from this topology.

Introduction

INTERNATIONAL CONFERENCE ON HIGH ENERGY PHYSICS
AMSTERDAM 2002

Abstract ID=ABS962
Beyond the Standard Model (experiment and theory)
Neutrino masses and mixings
Experiment: -
Contact Person: Yogendra N. Srivastava
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Signals of Heavy Majorana Neutrinos at Hadron Colliders

O. Panella, M. Cannoni, C. Carimalo and Y.N. Srivastava

Abstract

The lepton number violating signal of like-sign-dileptons (LSD), $pp \to \ell^\pm \ell^\pm + 2$jets, is investigated within a model of mixing in the neutrino sector assuming the existence of heavy Majorana neutrino states with a left–handed coupling to the light leptons. The LSD signal receives contributions both from the resonant production of a heavy Majorana neutrino (N) and from the exchange of a virtual N in the WW fusion mechanisms. These two possibilities are discussed in detail and compared. Helicity amplitudes are given pointing out differences with calculations previously reported by other authors. The signal cross–sections are computed at the energy of the LHC collider ($\sqrt{S} =$ 14 TeV) at CERN and within the existing experimental limits on the mixing couplings, including those coming from neutrinoless double beta decay. Detailed angular distributions of signal reactions which are complementary to previous studies on the argument are presented.

Introduction

Common to RPV and HMN:

Interplay between the low energy constraints from the 'virtual effects' such as ν masses AND collider signatures due to the *same* couplings / particles.

- SUSY and ν masses form a big part of all the BSM discussions.

- Effects of relaxing some of the assumptions normally made in SUSY, to simplify the phenomenology such as, Universal gaugino masses and R_p conservation are discussed in the first three abstracts.

▷ $\not R_p$ models provide very economical description of ν masses and are of great interest for ν mass model building

▷ Heavy majorana ν is a MUST in ALMOST all the non-$\not R_p$ generation of ν masses. The model considered by Panella et al. is a little different than the normal.

The scenarios are not ALL THAT exotic!
Small deviations from those that are considered often

Invisible Higgs decay, DM and NGM

• Usual SUSY models assume Universal masses at high scale for $U(1), SU(2)$ and $SU(3)$ gauginos.

• The assumption *need* not be true even in the most restrictive mSUGRA model.

▷ M. Drees, PL B 158, 1985, 409; Tata et. al, PR D 61, 2000, 095005....

• Alternative SUSY breaking scenarios such as moduli induced SUSY breaking or Anomaly Mediated SUSY Breaking Models (AMSB) also predict nonuniversal gaugino masses.

▷ A. Brignole et al, NPB 422, 1994, 125, T. Kobayashi et al, NPB 502, 1997, 37....,

▷ Randall and Sundrum NPB 567, 1999, 79, Giudice et al, JHEP 9812, 1998, 27.....

• Universal gaugino masses, $M_1 = M_2$, at the GUT scale give

$$M_1 \simeq 0.5 M_2$$

at the EW scale.

•We take $M_1 = 2rM_2$ at the GUT scale and hence have

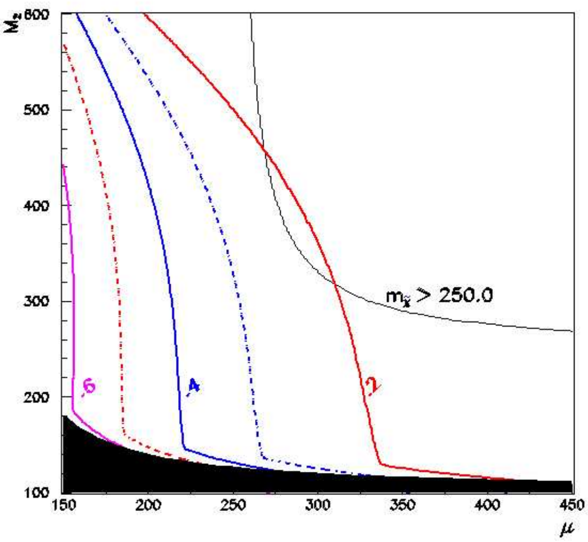
$$M_1 = rM_2$$

at the EW scale, with r = 0.1,0.2.

Invisible Higgs decay, DM and NGM.

What effect does this have?

- For a given $\tilde{\chi}_1^{\pm}$ mass, the mass of the $\tilde{\chi}_1^0$ is smaller than that in the universal case.
- It is possible to have $h \to \tilde{\chi}_1^0 \tilde{\chi}_1^0$ while respecting all the LEP constraints.
- B.R. $(h \to \tilde{\chi}_1^0 \tilde{\chi}_1^0)$ is maximised for moderate $\tan\beta$, small μ and M_2.
- Large regions of M_2–μ plane where B.R. for the 'invisible' $\tilde{\chi}_1^0 \tilde{\chi}_1^0$, decay mode can be as large as 0.65 *even* after all the LEP constraints are imposed.



▷ One has to rework all the LEP constraints for NGM, which we do.

Invisible Higgs decay, DM and NGM.

- Why should this bother us?
- If we define,

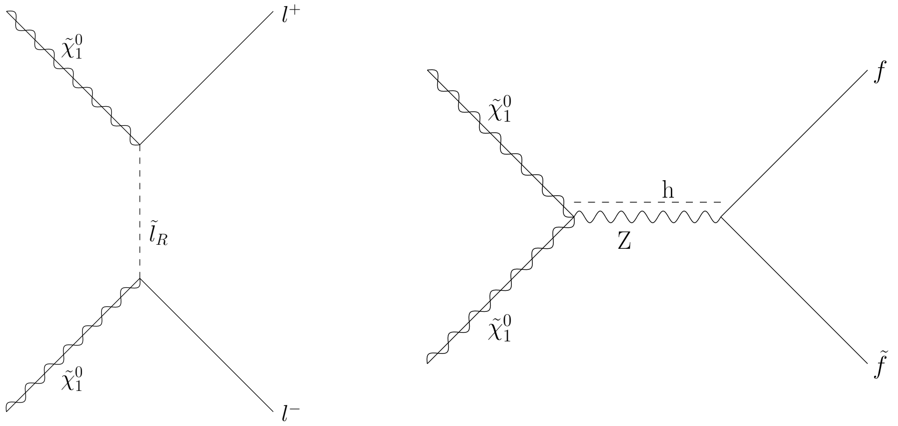
$$R_{\gamma\gamma} = \frac{B.R.(h \to \gamma\gamma)_{SUSY}}{(h \to \gamma\gamma)_{SM}}$$

and $R_{b\bar{b}}$ similarly, we find that

$$R_{\gamma\gamma} = R_{b\bar{b}} = 1.0 - B.R.(h \to \tilde{\chi}_1^0 \tilde{\chi}_1^0).$$

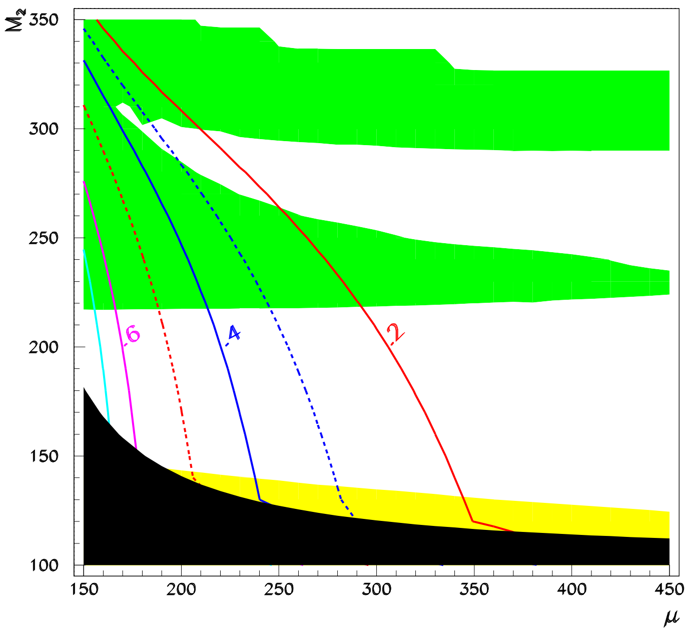
$R_{\gamma\gamma} = R_{b\bar{b}} = 0.3$–$0.4$ can mean loss of the signal for the lightest Higgs at the LHC. ☹

- $\sigma(\tilde{\chi}_1^0 \tilde{\chi}_1^0 \to f^+ f^-)$ decides the relic density of $\tilde{\chi}_1^0$.

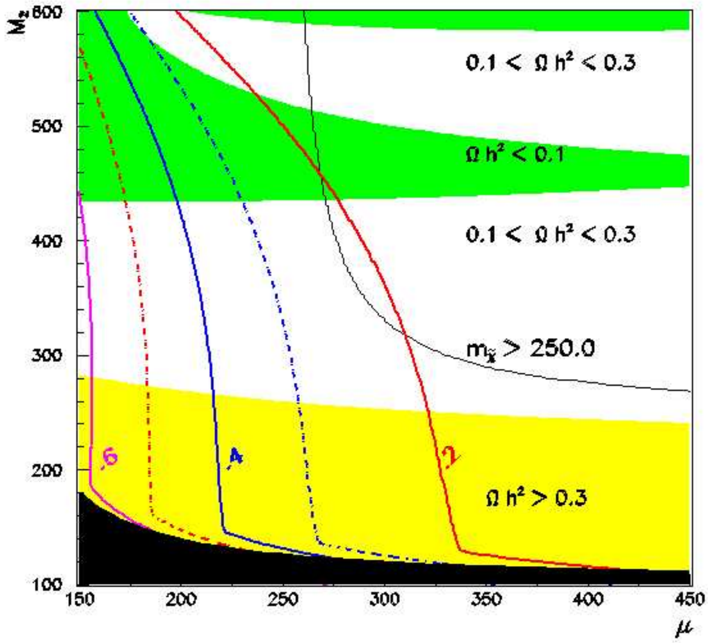


•For a light $\tilde{\chi}_1^0$, the Z/h mediated process contributes to the annihilation as well as the light $\tilde{l}_R$ mediated one. Even with light $\tilde{\chi}_1^0$ and not-so-light-sleptons ($\sim$ 200 GeV), it is possible to have acceptable relic density. Constrains the region where h can have 'large' ($> 0.5 - 0.6$) invisible B.R.☺

Invisible Higgs decay, DM and NGM.



$$\frac{M_1}{M_2} = 0.2$$



$$\frac{M_1}{M_2} = 0.1.$$

$\tan\beta = 5$, $M_{\tilde{l}_R} \simeq 100$ GeV for both the panels.

☹ Substantial regions where LEP constraints, relic density constraints are satisfied and yet the 'invisible' B.R. of h is not small.

• The $\tilde{\chi}_1^0$ relic density calculated using the 'micrOMEGAs' which includes ALL the processes.

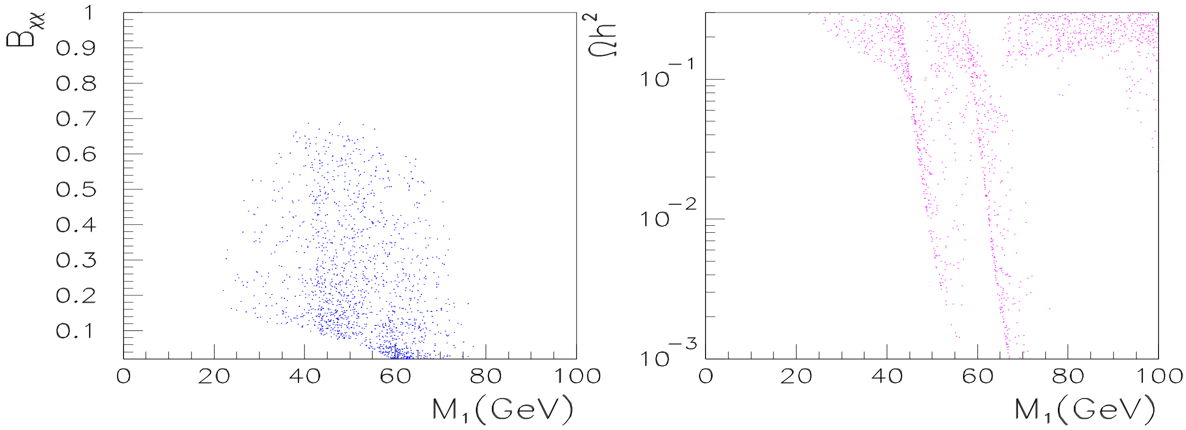
☺ The phenomneology of $\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^0$ search at the Tevatron quite different for this scenario. Can thus be probed at the Tevatron

Work in progress: G. Bélanger, F. Boudjema, R.G. and G. Polesello

Invisible Higgs decay, DM and NGM.

☺Possible to obtain a model independent limit on M_1

(G. Bélanger et al use it to obtain a limit on $\tilde{\chi}^0_1$ mass.)



• tan β =5, Scan over a wide range of M_2, M_1 and m_0 values,

• $M_1 = 20$ GeV is then a *model independent* lower limit.

• Conclusion for this discussion:

▷With NGM, there exist regions in the M_2–μ plane satisfying all the LEP constraints as well as the the DM constraints, where the h can have 'invisible' B.R. upto 0.6 threatening the usual $\gamma\gamma, b\bar{b}$ signal at the LHC.

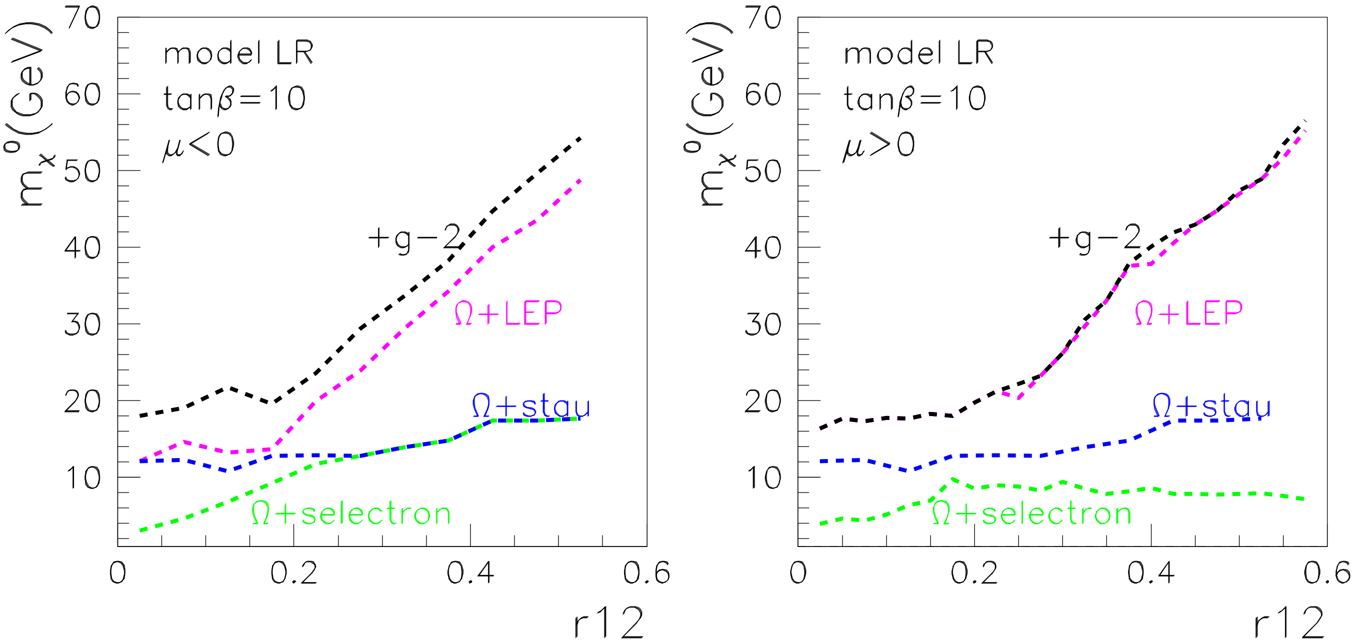
▷This region has predictions which can be tested at the Tevatron.

▷It is possible to put a model independent lower limit on M_1 (hence on the $\tilde{\chi}^0_1$ mass) from these considerations.

Invisible Higgs decay, DM and NGM.

- Model independent limit on the $\tilde{\chi}_1^0$ mass.

(G.B'elanger, F. Boudjema, A. Pukhov and S. Rossier-lees.)



- Scan over $M_2 < 2000, |\mu| < 100, M_{e_R} < 1000, M_{e_L} < 1000$ GeV.
- LEP constraints on selectron, stau and $\tilde{\chi}_1^{\pm}$ masses implemented, along with the $g-2$ and DM constraint.

$R\!\!\!/_p$ violation in SUSY.

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 $R\!\!\!/_p$ terms in the Superpotential

$$W_{R\!\!\!/_p} = \frac{1}{2}\lambda_{ijk} L_i L_j E_k^c + \lambda'_{ijk} L_i Q_j D_k^c + \frac{1}{2}\lambda''_{ijk} U_i^c D_j^c D_k^c + \kappa_i L_i H_2, \quad (1)$$

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. Testable predictions at the Colliders.

$\not{R}_p$ violation in SUSY.

• 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.☺

▷ For $\Delta L = 1$ couplings some of the strongest constraints from ν masses. Latest analysis F.Borzumati and J. S. Lee : /hep-ph/0207184. One and Two loop analysis.

▷ A host of references!!

⇓

Host of constraints on λ, λ'

⇑

Majority of these come from virtual effects caused by sparticle exchanges via $\not{R}_p$ interactions (loops) and can depend on the details of the models.

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

Effect of the $\not{L}$ Trilinear couplings.

• 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 and NLC, final states with third generation fermions including t are possible.

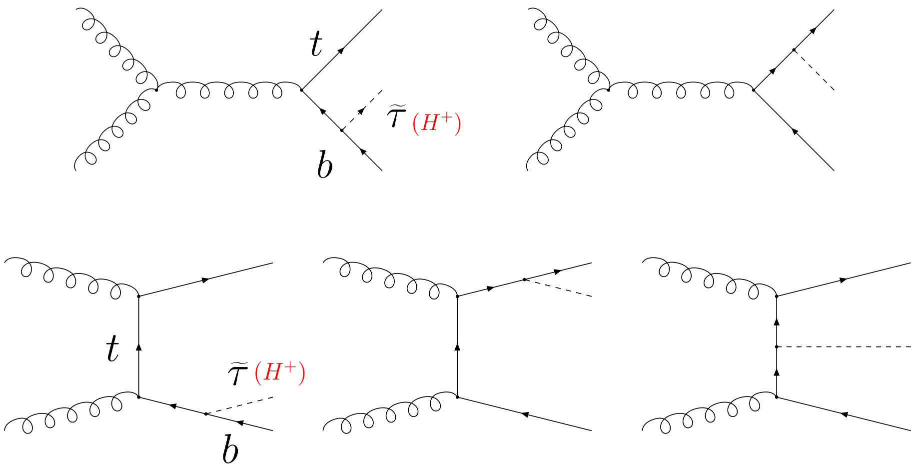
• One needs a study of the $\not{R}_p$ decays of $\tilde{\chi}_1^0, \tilde{\chi}_1^\pm$ retaining effects of the mass of the third generation fermions, for L violating coupling.

Effect of the $\not{L}$ Trilinear couplings.

- Resonant or nonresonant production of a single sparticle via the $R\!\!\!/_p$ 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.



▷ Even for $m_{\tilde{t}} > m_t$ rates appreciable for λ'_{333} as small as 0.01.

▷ $\tilde{\tau}$ so produced will have both $R\!\!\!/_p$ and RPC decays. RPC decays will produce $\tilde{\chi}_1^0$.

▷ Some of these decays can fake the charged Higgs signal.

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

Effect of the $\not{L}$ Trilinear couplings.

λ'_{333}

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

R_p conserving decay:

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

$\not{R}_p$ decay:

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

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

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

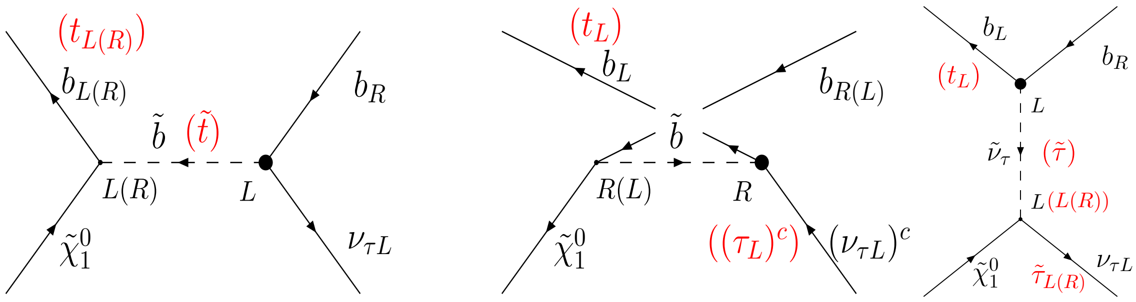
$$\to tb\ (2\bar{b})\ \tau\nu_\tau X$$

etc.

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

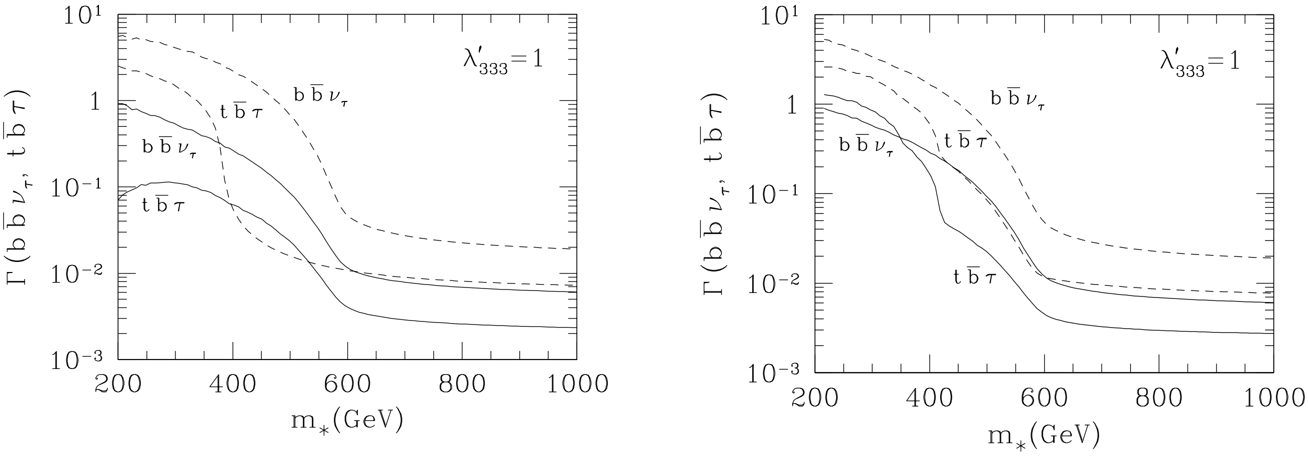
Three body $R\!\!\!/_p$ decays of $\tilde{\chi}_1^0$.

λ'_{333} Dominant:



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

▷ $\tilde{\chi}_1^0 \to b\bar{b}\nu_\tau$ $m_{\tilde{\chi}_1^0} < m_t$ MASSLESS ; $\tilde{\chi}_1^0 \to \bar{b}t\nu_\tau$. $m_{\tilde{\chi}_1^0} > m_t$ MASSIVE



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

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

Dashed line: Wino like $\tilde{\chi}_1^0$; Solid line: Bino like $\tilde{\chi}_1^0$.

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

• Explicit expressions for the most general case of complex mass matrices and inlcuding the mass of the third generation fermions available.

• Effects depend on the L–R mixing in the sfermion sector as well as gaugino-higgsino mixing and $\tan\beta$. Of course depend also on which $\not{L}$ couplings are large.

• Studied all these effects.

• 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.

• Even for smaller but dominant $\not{R}_p, \lambda$ 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.

Bilinear $R\!\!\!/_p$, $L\!\!\!/$ terms.

▷ Previous discussion was for $\kappa_i = 0$.

▷ Bilinears can also give rise to nonzero ν masses.

▷ A lot of studies on Phenomenology of Bilinear $R\!\!\!/_p$.

- Otto C.W. Kong, hep-ph/0205205, E. J. Chun, hep-ph/0206030, Hirsch et al, hep-ph/0202149, hep-ph/0004115...

▷ Specific collider signatures are in the form of $L\!\!\!/$ signals caused by decays of the $\tilde{\chi}_1^0, \tilde{\chi}_1^{\pm}$ by the $R\!\!\!/_p$ interactions.

- F. de Campos et al. consider $\kappa_3 \neq 0$. Trilinears which do get generated if we have the bilinears are taken to be small.

- RPV decays:

$$\tilde{\chi}_1^0 \to \nu_\tau Z^* \to \nu_\tau f \bar{f}, \quad \tilde{\chi}_1^0 \to \tau W^{\pm} \to \tau f \bar{f}'$$
$$\tilde{\chi}_1^{\pm} \to \tau Z^* \to \tau f \bar{f}, \quad \tilde{\chi}_1^{\pm} \to \nu_\tau W^{\pm} \to \nu_\tau f \bar{f}'.$$

- RPC decays:

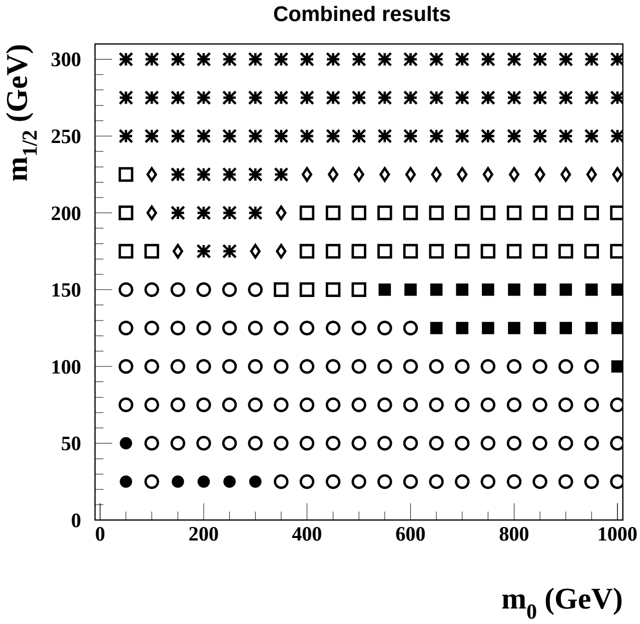
$$\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 \ell^+ \ell^-, \tilde{\chi}_1^{\pm} \to \tilde{\chi}_1^0 \ell \nu_\ell.$$

▷ RPV decays will enhance the number of leptons in the final state and give very clear signals.

▷ These authors analysed, in an mSUGRA picture, the multi-lepton signals at the Tevatron. Remember 'quiet' trileptons are a very promising signal for SUSY at the Tevatron.

Bilinear $R\!\!\!/_p$, $L\!\!\!/$ terms.

• Analysis in mSUGRA picture, with the same cuts as used in the *RPC* scenario as those are shown to reduce the SM background.



Legend:
Black/Open Squares : Signal at 5σ level with $2/25\ \text{fb}^{-1}$,
Diamonds : Signal at 3σ level with $2\ \text{fb}^{-1}$,
Black/Open Circles : Excluded Theoretically/Experimentally.

• $\tan\beta = 3$ and $A_0 = 0$, $\kappa_3 = 1$, consistent with ν mass values indicated by SuperK.

• Reach in the multilepton channel for *RPV* much more than for *RPC*, at large values of m_0. Vice versa at small m_0 due to slepton mediated $\tilde{\chi}^0_2$ decay.

Heavy Majorana Neutrinos.

•Models considered with an isosinglet neutrino N which mixes with ordinary light l.

•In normal models with single 'see-saw' mechanism, the mass and the mixing of the N are linked to each other.

•In some models it is possible to treat the mixing angle as an independent phenomenological parameter.

•Panella et al consider such a model. The mixing angle is constrained by the LEP precision measurements.

•The limits on mixing angles are : (F.M. L. Almeida et al,PRD 62, 2000, 075004)

$$s^2_{\nu_e} < 0.005 \qquad s^2_{\nu_\mu} < 0.002 \qquad s^2_{\nu_\tau} < 0.01. \tag{2}$$

• These are true in models which involve certain fine tuning.

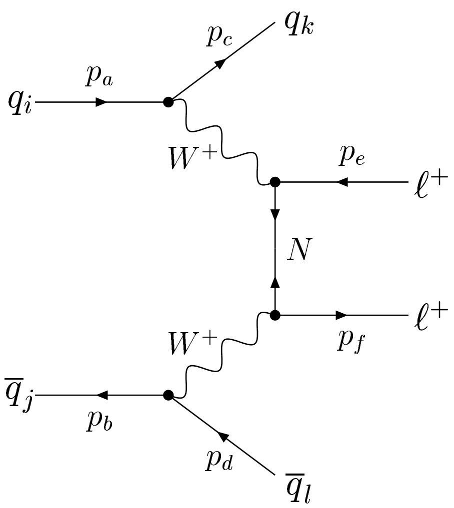
• Range of N masses allowed by the data on neutrinoless double beta decay: $(\beta\beta)_{0\nu}$, can be 'naturally' $100 < M_N < 1000$ GeV, in some models (e.g. Gluza et al, PRD 55, 1997, 7030).

▷ The upper limits on mixing angles lowered roughly by a factor 2 in these models.

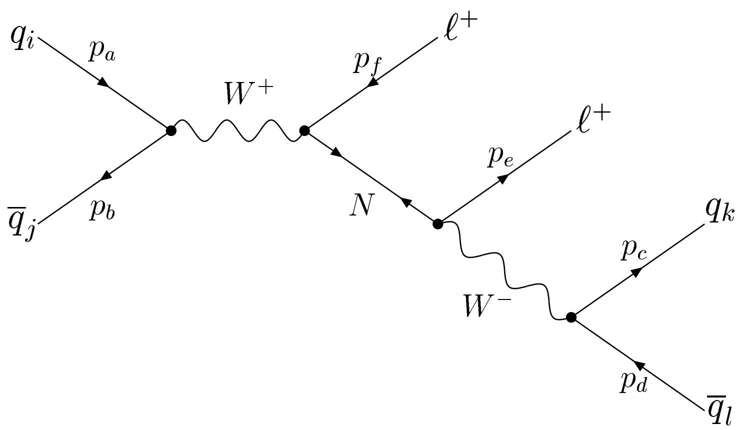
Heavy Majorana Neutrinos.

- What have Panella et al done?

- Looked at the effects at the LHC of such mixing, via Like Sign Dilepton (LSD) events signalling $\not{L}$.



Fusion Channel



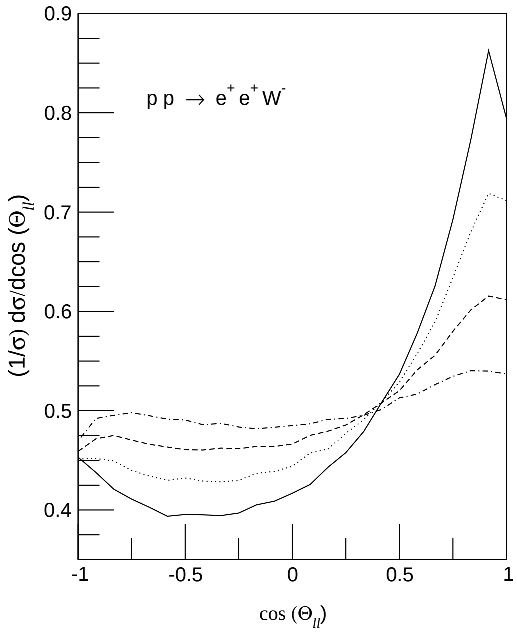
Resonant Production

- Both had been analysed before: Fusion : Dicus et al PRD 44, 1991, 2033, Resonant : Almeida et al PRD 50, 1994, 4589.

- In present work explicit formulae were obtained in helicity formalism. Differences with previous calculation of N width and resonant cross-section were traced to dropping of the ghost diagrams by the earlier authors.

- Resonant Contribution dominates the total cross-section. The correct N width higher by an order of magnitude than earlier evaluation. Changes the LSD cross-section by about 20%.

• The distributions in kinematic variables affected strongly by the inclusion of the dropped terms, which correspond to the contribution of longituinally polarised W's.



The dilepton opening angle distribution for $M_N = 200, 400, 600$ and 800 GeV. The one most (least) peaked in the forward direction is for the smallest (highest) N mass.

•The reach of LHC just from rates is $M_N = 250$ GeV (after taking into account the SM background a la Dreiner et al). The reach is reduced to 200 GeV if the smaller mixing angles of the model of Gluza et al. are used.

•Detailed simulations will be needed to make these conclusions firmer, as perhaps the cuts can be optimised.