SEARCHES FOR R-PARITY VIOLATING DECAYS AT LEP

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R-parity violating signatures within the Minimal Supersymetric Model has been searched for by the four LEP experiments, using the data set collected at 183 GeV and 189 GeV. After an introduction and a description of the analyses, all updated results since last Vancouver 98 summer conference will be presented.

1 Introduction

A complete description of the MSSM can be found in [1]. We will focus here on the R-parity description.

1.1 *The R-Parity*

One particle has the following R parity quantum number :

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

where B, S and L are respectively the baryonic number, spin and leptonic number of the particle. A SUSY particule ($R_p = -1$) can decay into a lighter SUSY particle ($R_p = -1$) and a particle ($R_p = 1$), such that the product of the R_p quantum numbers is conserved during the decay. Assuming the R parity conservation :

- SUSY particles are produced by pair
- the lightest SUSY particle (LSP) is stable, as it cannot decay into particles.

Nevertheless, no theoretical argument imposes R_p conservation.

1.2 *The R-Parity Violation*

When considering the most general SUSY superpotential $\mathcal{W}_{\rm SUSY}$, three terms violate the R-parity conservation :

$$\mathcal{W}_{\rm SUSY} = \mathcal{W}_{\rm Rp\ Conserved} + \lambda_{ijk\ (i<j)}\ L_i L_j \bar{E}_k + \lambda'_{ijk}\ L_i Q_j \bar{D}_k + \lambda''_{ijk\ (j<k)}\ \bar{U}_i \bar{D}_j \bar{D}_k \qquad (2)$$

where i, j, k are the generation indices of the superfields L, Q, E, D and U. L and Q are lepton and quark left-handed doublets, respectively. $\bar{E}, \bar{D}$ and $\bar{U}$ are right-handed singlet charge-conjugate superfields for the charged leptons and down and up-like quarks, respectively. Yukawa couplings are denoted λ, λ' and λ''. The 9 $\lambda_{ijk} L_i L_j \bar{E}_k$ terms describes the coupling between a slepton and a pair of leptons, the 27 $\lambda'_{ijk} L_i Q_j \bar{D}_k$ terms between a slepton, a quark and a lepton, or between a squark, a quark and a lepton, and the 9 $\lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k$ between a squark and a pair of quarks (figure 1).

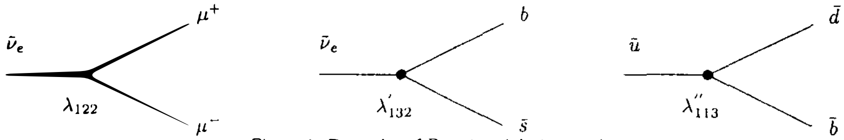

Figure 1: Examples of R-parity violating vertices

Experimental constraints exist on the product of two λ couplings, and therefore the R-parity violation (RpV) is not excluded by experimental results, under the assumption that only one coupling is significantly different from 0. For example, the non-observation of the proton decay results in the limits $\lambda'_{11k} \cdot \lambda''_{11k} \leq 10^{-22}$ for $k = 2, 3$. A complete listing of all existing limits is given in [2].

2 Decay Topologies and Search Strategies

Allowing RpV has the following consequences :

- at the production level, new resonant channels (figure 2a, 2b) in addition to the usual MSSM processes ;
- at the decay level, all SUSY particles can decay into particles In particular, the LSP is no more stable. (figure 2c)

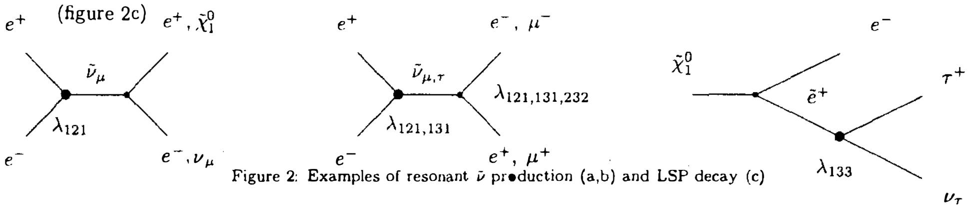

Figure 2: Examples of resonant $\tilde{\nu}$ production (a,b) and LSP decay (c)

R parity violating SUSY decays can be classified into two categories : the direct decays with one RpV vertex and the indirect decays with an intermediate on shell SUSY particle followed by one RpV vertex (figure 3).

The final states topologies of RpV decays are numerous, depending on the considered λ term and the generation indices i, j, k : with or without leptons, jets and/or missing energy.

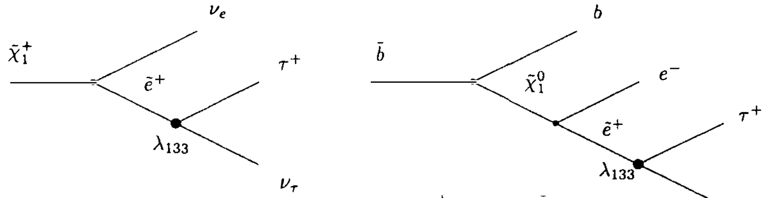

Figure 3: Example of R-parity violating $\chi^\pm$ direct and $\bar{b}$ indirect decay

2.1 Symplifying Hypotheses

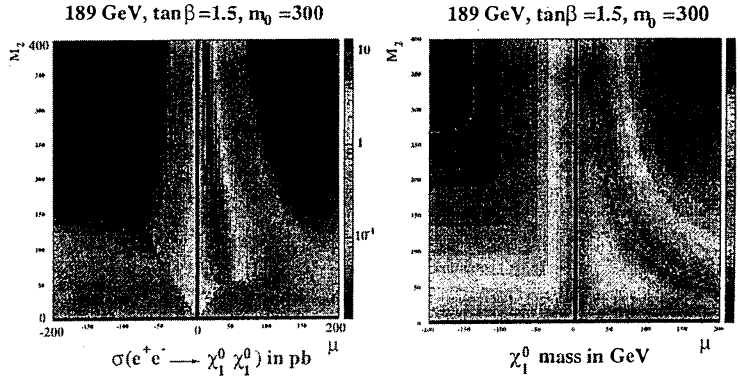

Figure 4: production cross section and mass of the χ^0 in the (M_2, μ) plane with $\tan\beta = 1.5$, $m_0 = 300$ GeV and a center of mass energy of 189 GeV.

In addition to the sparticle couplings and masses depending on the MSSM parameters $(M_0, m_2, \mu, \tan\beta)$ (figure 4), new topologies and couplings appears when introducing RpV decays. Symplyfing hypotheses have been used in all analyses :

- the numerous final states are sorted out into a resonable number of topologies. As an example, OPAL[3] ; used ten topologies (table 1)
- the neutralino mass is assumed to be larger than 10 GeV ;
- only one λ coupling is set to a non zero value at a time, and has to be smaller than 10^{-5}, such that the sparticles decay into the detector.

2.2 Search strategies

Depending on the experiment, different search strategies were used :

1. Set one coupling $\lambda_{ijk}^{(\prime\,\prime\prime)} \neq 0$ and consider a given topology (e.g : 4 jets + leptons) ;
2. Optimize selection criterias and get gauginos - sfermions reconstruction efficiency for different gaugino - sfermions masses ;
3. Iterate on point 1 until all topologies have been studied for the coupling $\lambda_{ijk}^{(\prime\,\prime\prime)}$.

1. Set one $\lambda_{ijk}^{(\prime\,\prime\prime)} \neq 0$;
2. Generate all sfermions-gauginos (SUSYGEN with different sets of $\tan\beta, m_0, M_2, \mu$;
3. Optimize selection criterias and get signal reco struction efficiency.

As no significant excess w.r.t. standard model processes was seen, 95% CL limits were set :

- first on production cross-sections ;
- then as exclusion plots in the $(M_0, m_2, \mu, \tan\beta)$ plane ;
- finally, on the couplings and the sparticle masses.

Analysis	Production and decay sequence	
(A) **2 leptons +** $E_{T miss}$	$\tilde{\chi}_1^+\tilde{\chi}_1^- \to$	$\nu_i\nu_j\ell_k \ \nu_i\nu_j\ell_k$
(B) **4 leptons +** $E_{T miss}$	$\tilde{\chi}_1^0\tilde{\chi}_1^0 \to$	$\nu\ell^+\ell^- \ \nu\ell^+\ell^-$
(C) **6 leptons +** $E_{T miss}$	$\tilde{\chi}_1^+\tilde{\chi}_1^- \to \mathrm{W}^{(*)}\ \mathrm{W}^{(*)}\ \tilde{\chi}_1^0\ \tilde{\chi}_1^0 \to$	$\ell^+\nu\ \ell^-\nu\ \nu\ell^+\ell^-\ \nu\ell^+\ell^-$
(D) **6 leptons**	$\tilde{\chi}_1^+\tilde{\chi}_1^- \to$	$\ell_i\ell_j\ell_k\ \ell_i\ell_j\ell_k$
(E) **leptons plus jets**	$\tilde{\chi}_1^+\tilde{\chi}_1^- \to \mathrm{W}^{(*)}\ \mathrm{W}^{(*)}\ \tilde{\chi}_1^0\ \tilde{\chi}_1^0 \to$	$\mathrm{W}^{(*)}\ \mathrm{W}^{(*)}\ \nu\ell^+\ell^-\ \nu\ell^+\ell^-$
		$\mathrm{W}^{(*)}\ \mathrm{W}^{(*)}\ \ell_iqq\ \ell_iqq$
		$\mathrm{W}^{(*)}\ \mathrm{W}^{(*)}\ \ell_iqq\ \nu_iqq$
	$\tilde{\chi}_1^+\tilde{\chi}_1^-,\quad \tilde{\chi}_1^0\tilde{\chi}_1^0 \to$	$\ell_iqq\ \ell_iqq$
		$\ell_iqq\ \nu_iqq$
(F) **2 taus +** $\geq$ **4 jets**	$\tilde{\chi}_1^+\tilde{\chi}_1^-,\quad \tilde{\chi}_1^0\tilde{\chi}_1^0 \to$	$\tau qq\ \tau qq$
	$\tilde{\chi}_1^+\tilde{\chi}_1^- \to \mathrm{W}^{(*)}\ \mathrm{W}^{(*)}\ \tilde{\chi}_1^0\ \tilde{\chi}_1^0 \to$	$\mathrm{W}^{(*)}\ \mathrm{W}^{(*)}\ \tau qq\ \tau qq$
(G) **4 jets +** $E_{T miss}$	$\tilde{\chi}_1^+\tilde{\chi}_1^-,\quad \tilde{\chi}_1^0\tilde{\chi}_1^0 \to$	$\nu qq\ \nu qq$
(H) **>4 jets +** $E_{T miss}$	$\tilde{\chi}_1^+\tilde{\chi}_1^- \to \mathrm{W}^{(*)}\ \mathrm{W}^{(*)}\ \tilde{\chi}_1^0\ \tilde{\chi}_1^0 \to$	$\mathrm{W}^{(*)}\ \mathrm{W}^{(*)}\ \nu_iqq\ \nu_iqq$
(I) $\geq$**6 jets**	$\tilde{\chi}_1^+\tilde{\chi}_1^- \to \mathrm{W}^{(*)}\ \mathrm{W}^{(*)}\ \tilde{\chi}_1^0\ \tilde{\chi}_1^0 \to$	$\mathrm{W}^{(*)}\ \mathrm{W}^{(*)}\ qqq\ qqq$
	$\tilde{\chi}_1^+\tilde{\chi}_1^- \to$	$qqq\ qqq$

Table 1: Final state classification used by OPAL

2.3 Backgrounds

There are many standard model processes that mimics RpV final states : $\gamma\gamma$, $\mathrm{f\bar{f}}\gamma$, $\mathrm{ZZ}^{(*)}$, Zee, WW, $We\nu$... Specific background rejection criterais were used depending on the considered topology.

3 Review of Updated Analyses

The four LEP experiments have searched for R-parity violating signatures. Some have updated their analyses with the data collected in 1998 at 189 GeV while others have refined their results with the 183 GeV data collected in 1997. Nevertheless, different hypothesis and sets of $\tan\beta, m_0, M_2, \mu$ have been used and a direct comparaison of mass limits and cross-sections is not possible.

In the following, new results since last Vancouver HEP conference will be presented, experiment by experiment.

3.1 ALEPH

ALEPH searched for RpV decays of pair-produced SUSY particles $\chi^0, \chi^\pm, \tilde{l}, \tilde{\nu}, \tilde{q}$ using the data collected at 189 GeV in 1998 [5]. Analyses assuming a single dominant $LL\bar{E}$, $LQ\bar{D}$ or $\bar{U}\bar{D}\bar{D}$ coupling at a time were performed.

A new limit on the $\chi_1^\pm$ mass assuming a large m_0, for which production diagrams do not interfere destructivly was obtained : Mass $\chi_1^\pm \geq 94$ GeV. Others sparticles mass limits are quoted in table 2.

A study of single resonant sneutrino production was performed (figure 2a). All data taken from $\sqrt{s} = 130$ to 189 GeV were used. Figure 5a shows the excluded values of λ_{121} and λ_{131} as a function of the mass of the sneutrino.

3.2 DELPHI

DELPHI searched for RpV decays of pair-produced SUSY particles $\chi^0, \chi^\pm, \tilde{l}, \tilde{\nu}, \tilde{q}$. Results were updated using the LLE and LQD operators [6 7 8] at 189 GeV and UUD operators [9] at 183 GeV. The most conservative mass limits for direct and indirect searches are shown in table 3.

A study of single resonant sneutrino production was performed (figure 2a) using the data collected at $\sqrt{s} = 189$ GeV. Excluded are is shown in figure 5b

3.3 L3

L3 studed RpV decays of pair-produced gauginos $\chi_1^0, \chi_1^\pm$ Results were updated using the LLE operators [10] at 189 GeV and the UDD operators [11] at 183 GeV Limits on sparticle masses were set for two MSSM parameters domains :

	LLE direct	LLE indirect assuming $M(\chi^0) \geq 30$ GeV	LQD direct	LQD indirect assuming $M(\tilde{f}) - M(\chi) \geq 10$ GeV	UDD direct	UDD indirect assuming $M(\tilde{f}) - M(\chi) \geq 10$ GeV
$\tilde{e}_R$	84 GeV	87 GeV		81 GeV		81 GeV
$\tilde{\mu}_R$	60 GeV	83 GeV		77 GeV		80 GeV
$\tilde{\mu}_L$			67 GeV			
$\tilde{\tau}_R$		82 GeV		45 GeV		
$\tilde{\nu}_e$		90 GeV				75 GeV
$\tilde{\nu}_\mu$	78 GeV	68 GeV	56 GeV	56 GeV		
$\tilde{\nu}_\tau$		68 GeV		56 GeV		
$\tilde{u}_L$					67 GeV	
$\tilde{d}_L$					49 GeV	
$\tilde{t}_L$		83 GeV	89 GeV	54 GeV		65 GeV

Table 2: 95 % CL limits on masses obtained bt the ALEPH collaboration. $\tilde{e}_R$ and $\tilde{\nu}_e$ mass limits were evaluated at $\mu = -200$ GeV, $\tan\beta = 2$ GeV and the $\tilde{t}_L$ mass limit was obtained assuming no mixing angle.

	LLE 189 GeV direct and indirect	LQD 189 GeV direct and indirect	UDD 183 GeV direct and indirect	Remarks
$\tilde{\chi}_1^0$	30 GeV	30 GeV	21 GeV	
$\tilde{\chi}_1^+$	93 GeV	94 GeV	87 GeV	
$\tilde{e}_R$			70 GeV	$\Delta M \geq 5$ GeV
$\tilde{e}_L$			53 GeV	$\Delta M \geq 5$ GeV
$\tilde{\mu}_R$			68 GeV	$\Delta M \geq 5$ GeV and $(\chi_1^0) \geq 21$ GeV
$\tilde{\mu}_L$			69 GeV	$\Delta M \geq 5$ GeV and $(\chi_1^0) \geq 21$ GeV
$\tilde{\nu}_{e,\mu,\tau}$	77 GeV			
$\tilde{t}_1$			62 GeV	$\Phi_{mix} = 0$ rad
$\tilde{t}_1$			49 GeV	$\Phi_{mix} = 0.98$ rad
$\tilde{b}_1$			58 GeV	$\Phi_{mix} = 0$ rad

Table 3: 95% CL limits obtained on sparticle masses by the DELPHI collaboration

- χ_1^0 is the LSP : $m_0 \in [50, 500]$ GeV with any $\tan\beta$ OR any m_0 and $\tan\beta \in [2,40]$
- the lightest scalar lepton can be the LSP : $m_0 \in [0, 50]$ GeV and $\tan\beta \in [1,2]$

Results are shown in table 4.

	LLE, (LSP = χ_1^0 or lightest slepton)	UDD, (LSP = lightest slepton)
$\tilde{\chi}_1^0$	30 GeV	27 GeV
$\tilde{\chi}_2^0$	50 GeV	35 GeV
$\tilde{\chi}_1^+$	94 GeV	77 GeV

Table 4: 95 % CL limits on gauginos masses obtained by the L3 collaboration

From the exclusion contours in the $\tan\beta, m_0, M_2, \mu$ plane, limits were set on the lightest charged slepton mass :

- LLE analysis : $M(\tilde{l}_R) \geq 79$ GeV ($\tan\beta \geq 2$), $M(\tilde{l}_R) \geq 62$ GeV (any $\tan\beta$)
- UDD analysis : $M(\tilde{l}_R) \geq 73$ GeV ($\tan\beta \geq 2$), $M(\tilde{l}_R) \geq 29$ GeV (any $\tan\beta$)

Finally, resonant RpV $\tilde{\nu}$ production (figure 2b) was searched for using the whole data set collected at LEP1 and LEP2 [12]. Limits are shown in figure 5c.

3.4 OPAL

OPAL studied pair produced gauginos $\chi^0, \chi^\pm$ and updated their analyses on the LLE, LQD and UDD operators at $\sqrt{s} = 183$ GeV. 95% CL limits were set on gaugino masses, independant on the LLE. LQD or UDD operator [3]

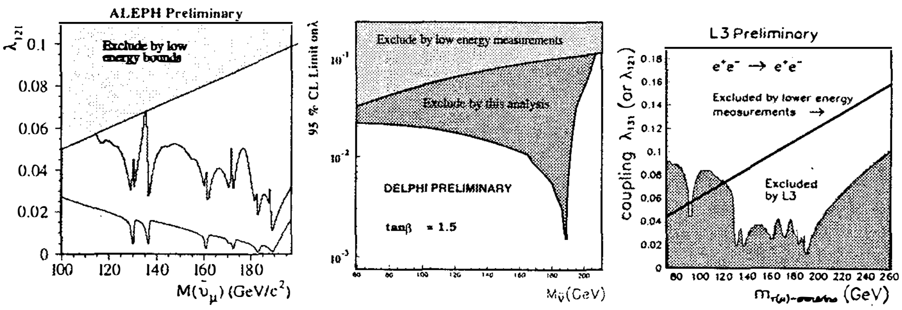

Figure 5: (a) : 95% CL exclusion on the value of the RpV coupling λ_{121} as a function of the sneutrino mass for single χ^0 production and indirect decays (lower curve). For comparaison the limit, assuming 100% branching ratio for the direct decay $e^+e^- \rightarrow \tilde{\nu} \rightarrow e^+e^-$ is also shown (upper curve). Exclusion are evaluated in the $\mu = -200$ GeV, $\tan\beta = 2$ GeV region. (b) Resonant $\tilde{\nu}$ production : upper limit on λ_{121} as a function of $M(\tilde{\nu})$. (c) 95% CL upper limits on the coupling strengh λ_{131} (λ_{121}) as a function of $m_{\tilde{\nu}_\tau}$ ($m_{\tilde{\nu}_\mu}$) obtained by L3.

- m $(\chi_1^0) \geq 29$ GeV for $m_0 = 500$ GeV and $\tan\beta \geq 1.2$
- m $(\chi_1^+) \geq 76$ GeV for $m_0 = 500$ GeV and $\tan\beta \geq 1.0$

With the data collected at $\sqrt{s} = 189$ GeV, RpV stop decays [13] via the LQD operator were searched for : $\tilde{t}_1 \rightarrow e, \mu + q$:

- m $(\tilde{t}_1) \geq 90$ GeV, $\Phi_{mix} = 0$ rad
- m $(\tilde{t}_1) \geq 87$ GeV, $\Phi_{mix} = 0.98$ rad

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