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Search for Supersymmetry with R-Parity violation at LEP

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ABSTRACT: Supersymmetry with R-parity violation has been searched for at LEP in a large number of channels and final state topologies, at centre-of-mass energies up to 209 GeV. In this presentation these searches are motivated and their results reported. No signal was found in any of the channels and limits at 95% CL on cross-sections and masses were derived. All results are preliminary

1. Introduction

Supersymmetry (SUSY) is the theory behind most particle searches at colliders. R-parity is a discrete, multiplicative symmetry related to matter parity:

$$R_p = (-1)^{2S+3B+L} \tag{1.1}$$

where S is the spin of the particle and B and L are the barion and lepton number, respectively. In the SUSY searches at LEP R-parity conservation (RpC) is most frequently assumed. Scenarios with R-parity violation (RpV) will be considered in this presentation. In fact, RpC is not required neither by SUSY nor by Gauge Invariance. On the other hand, it is interesting to know how dependent the complex SUSY exclusions derived at LEP are on the RpC assumption. Finally, RpV could produce some striking signatures (many jets and/or leptons, large visible energy) and be a good way to discover SUSY.

2. Explicit R-parity violation

R-parity can be explicitly violated [1] by introducing the following trilinear terms in the superpotential:

$$\lambda_{ijk} L^i_L L^j_L \overline{E}^k_R + \lambda'_{ijk} L^i_L Q^j_L \overline{D}^k_R + \lambda''_{ijk} \overline{U}^i_R \overline{D}^j_R \overline{D}^k_R, \tag{2.1}$$

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where L_L, Q_L (E_R, U_R, D_R) are left-handed (right-handed) lepton and quark doublets (singlets) and i, j, k are family indices. This leads to 45 new couplings, violating L (λ and $\lambda^{'}$) or B ($\lambda^{''}$) conservation.

The occurrence of RpV has some major phenomenological consequences. SUSY particles (sparticles) can be singly produced, and can decay directly into SM particles. The Lightest SUSY Particle (LSP) is no longer stable, and can be charged or neutral. This different phenomenology, with many new possible topologies and not necessarily preserving the traditional missing energy signature, makes that the limits derived under the RpC assumption cannot be taken for granted.

Although RpV is still an open possibility, limits on its coupling parameters exist already, from the non-observation of a certain number of effects in Standard Model (SM) processes (e.g. lepton universality violation, fast proton decay). The order of magnitude of these limits varies with the λ coupling considered (in most of the cases they are roughly in the range 1-10^{-2}). Very stringent limits exist on the simultaneous presence of certain couplings ($\lambda^{'}_{11k} \times \lambda^{''}_{11k} < 10^{-24}$).

At LEP, SUSY with RpV is searched for both in sparticle production and decay. In the first case single sneutrino production through either $e^+e^- \to \tilde{\nu}$ [2] or $e^+\gamma \to \tilde{\nu}\ell$ [3] are considered. In the second case, RpC sfermion and gaugino pair production is considered and two scenarios are investigated for the decay [4, 5, 6, 7, 8]:

- direct decays: RpV decays of sparticles into SM fermions, e.g. $\tilde{f} \to ff$ and $\chi^0_1 \to \tilde{f}^* f \to fff$,

- indirect decays: cascade (RpC) decays of sparticles into the LSP, which decays via RpV, e.g. $\chi^\pm_1 \to W\chi^0_1 \to f\tilde{f}^* \to fff$.

It is assumed in all cases that only one of the λ couplings is non-negligible at a time and that sparticles decay promptly ($\sim$ 1 cm). This limits the sensitivity on λ to values of the order of 10^{-5}. In these searches the minimal particle content of the Minimal Supersymmetric Standard Model (MSSM) with gravity mediated SUSY breaking is assumed. Further assumptions (in particular gaugino mass unification at the GUT scale) are relevant for some of the interpretations.

These searches are characterized by the fact that a very large number of channels and final state topologies have to be covered and combined. The challenges in the analyses range from the treatment of topologies with many jets to lepton and in particular tau identification (crucial to identify some striking signatures). Usually several topological analyses are developed and combined. Results are given for the different couplings or choosing the worst case. While the background from SM processes is very dependent on the channel, 4-fermions final states are in many cases the most relevant ones. Signal simulation was produced for different relevant combinations of parameters using SUSYGEN2.2 (3.0) [9].

All the data collected in the second phase of LEP were analysed, in a total of about 714 pb^{-1} per experiment at centre-of-mass energies ranging from 130 to 209 GeV. No evidence for a signal was observed in any of the channels and 95% confidence level (CL) limits were

derived. All results are preliminary. An exhaustive presentation of the results can be found in the references [2] to [8]. Selected channels are presented below.

Considering the sfermion pair production with direct RpV decay, the final state topologies arising for the different types of sfermions and couplings range from 2 acoplanar leptons to 4 jets. In particular, the 4-jets final state plays a role in the search for all sfermion types, since it is the expected final state for different types of couplings ($\lambda^{'}$ in the case of sleptons and sneutrinos, $\lambda^{''}$ in the case of squarks). Similar analyses can be used in the different cases. Figure 1 shows the cross-section limits obtained by ALEPH, together with expected MSSM cross-sections. Mass limits for the different sfermion types roughly in the range 75-85 GeV/c^2 can be derived from the figure.

If indirect sfermion decay modes are considered, the selection efficiencies are expected to depend on the difference between the sfermion mass and the mass of the LSP. Cross-section limits for stau pair production obtained by L3 in the plane of the two masses are shown in figure 2. Contrary to what happens under the assumption of RpC, if RpV occurs sneutrinos are expected to decay visibly in most of the parameter space. Figure 3 shows the excluded region in the plane of the sneutrino - lightest neutralino masses obtained by DELPHI assuming sneutrino pair production and indirect RpV decay through a λ type coupling. Similar results for sleptons and squarks, and for other types of couplings, can be found in the references. Single sneutrino production through RpV were also searched for. The results can be found in [2, 3]. While single production channels allow to extend the explored mass range, the results are limits on the coupling parameter, which in this case appears at the production vertex.

Considering now the pair production of charginos and neutralinos, in the MSSM parameter space regions not excluded by LEP1 data, indirect decay modes are expected to dominate, with $\chi^{\pm}\chi^{\pm} \rightarrow WW\chi^0\chi^0$ and the neutralinos then decaying through RpV into final states with 4 leptons and missing energy, 4 jets and leptons or 6 jets, depending on the coupling. This leads to complex topologies with up to 10 jets in the final state. The cross-section limits obtained in these channels can be translated into exclusions in the MSSM parameter space. Figure 4 shows the exclusion obtained by ALEPH in the (M_2,μ) plane, for $tan\beta = 1.4$ and a high value of m_0, assuming the presence of a $\lambda^{'}$ RpV coupling. Exclusions of this type can be converted into limits on the masses of sparticles. The mass limits obtained by L3 for χ^0_1, χ^0_2 and $\tilde{\ell}$, as a function of $tan\beta$, considering a low value of m_0 and RpV couplings of type λ and $\lambda^{''}$, are shown in figure 5. In the scenarios considered, RpV SUSY searches allow to exclude chargino masses up to 103 GeV/c^2 and LSP masses up to 38-40 GeV/c^2.

3. Spontaneous R-parity violation

R-parity could be spontaneously broken through a right-handed sneutrino acquiring a non-zero vacuum expectation value [10]. This can be parameterized by an effective bilinear term, $\epsilon_i L_I H_u$. In such scenarios a massless majoron J may arise and, through lepton-gaugino mixing, the decay $\chi^{\pm}_1 \rightarrow \tau^{\pm} J$ can be important (specially for large values of the violation parameter ϵ). Under the assumption of mixing in the third family, chargino pair

production and decay into a majoron and a tau lepton, with a signature of 2 acoplanar taus were searched for.

The data collected at centre-of-mass energies up to 202 GeV were analysed by DELPHI and no signal was observed in this channel. A cross-section limit of 0.14 pb was obtained, corresponding to a limit on the chargino mass of 100.9 GeV/c^2, as shown in figure 6. Exclusions on the MSSM parameter space were also derived in this scenario.

4. Conclusions

SUSY with RpV was searched for at LEP in a large number of channels and final state topologies. No signal was found, and 95% CL limits were derived on cross-sections, masses and RpV couplings. In general the excluded ranges are comparable for those obtained under the assumption of RpC. For comparable scenarios, chargino exclusion up to near the kinematic limit (101 GeV/c^2 in the case of spontaneous RpV) and an LSP mass limit of the order of 40 GeV/c^2 were obtained.

Acknowledgments

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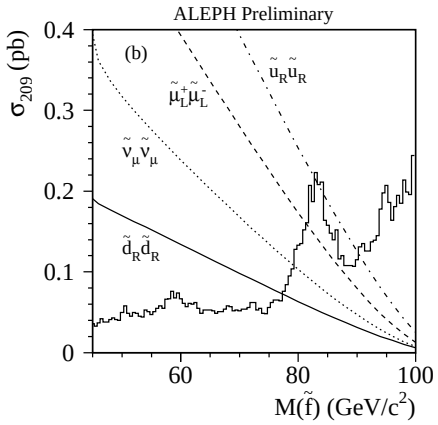

Figure 1: Excluded cross-sections for sleptons (via a $\lambda^{'}$ type coupling), sneutrinos (via $\lambda^{'}$) and squarks (via $\lambda^{''}$) decaying directly to 4 jets (histogram). The MSSM cross-sections are superimposed (lines).

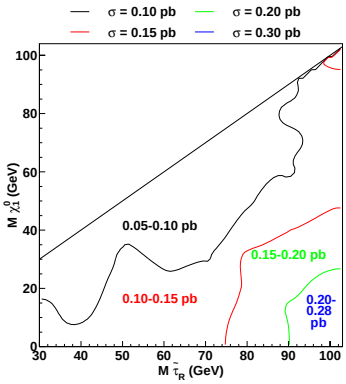

Figure 2: Stau pair production cross-section limit by the L3 collaboration for indirect RpV decay.

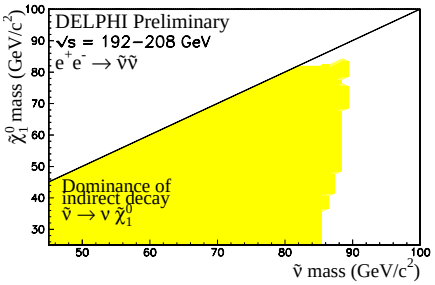

Figure 3: Excluded region in the sneutrino-LSP mass plane considering sneutrino indirect RpV decay through a λ type coupling.

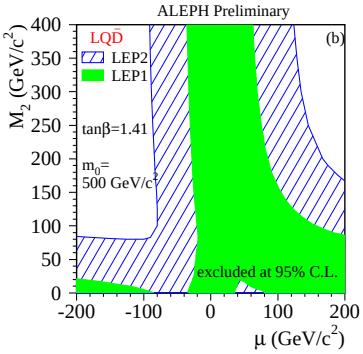

Figure 4: Excluded region in the (M_2,μ) plane, obtained for $tan\beta = 1.4$ and a high value of m_0, assuming the presence of a $\lambda^{'}$ RpV coupling.

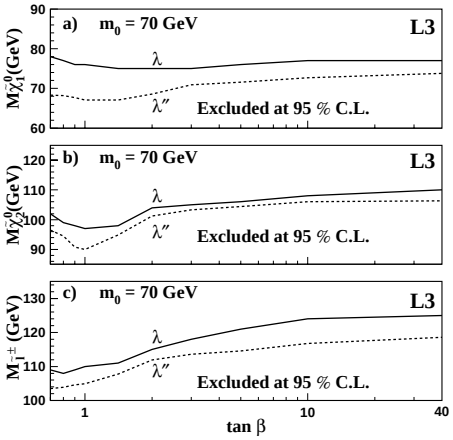

Figure 5: Limits on the sparticle masses as a function of $tan\beta$ considering a low value of m_0 and RpV couplings of type λ and $\lambda^{''}$.

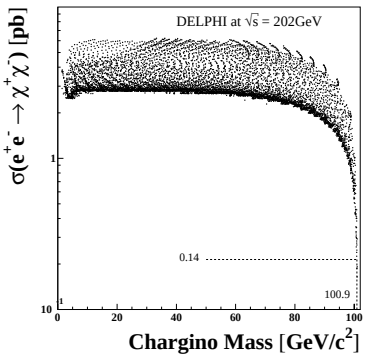

Figure 6: Expected chargino pair production cross-section at 202 GeV (dots) as a function of the chargino mass (the dots correspond to scans in the MSSM parameters. A high m_0 was assumed.) The obtained cross-section limit of 0.14 pb^{-1} translates into a limit of 100.9 GeV/c^2 in the chargino mass.