SEARCH FOR R-PARITY VIOLATING DECAYS OF SUPERSYMMETRIC PARTICLES AT LEP

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Searches for pair-produced charginos, neutralinos and scalar fermions decaying via R-parity violating λ, λ' and λ'' couplings with the OPAL detector at LEP are presented at $\sqrt{s} = 189$ GeV. Partial updates using data up to the highest energies of LEP, $\sqrt{s} = 209$ GeV, are also given.

If supersymmetry (SUSY) is the answer to the hierarchy problem of the Standard Model (SM), there should be a superpartner to each SM particle. We present here a search for pair-produced supersymmetric particles in e^+e^- collisions with the OPAL detector, assuming that R-parity can be violated.

R-parity violating (RPV) interactions are parametrized with a gauge-invariant superpotential that includes the following Yukawa coupling terms:

$$\mathcal{W}_{RPV} = \lambda_{ijk}L_iL_j\overline{E}_k + \lambda'_{ijk}L_iQ_j\overline{D}_k + \lambda''_{ijk}\overline{U}_i\overline{D}_j\overline{D}_k, \tag{1}$$

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, while $\overline{E}$, $\overline{D}$ and $\overline{U}$ are right-handed singlet charge-conjugate superfields for the charged leptons, down- and up-type quarks, respectively. There are nine λ, 27 λ' and nine λ'' couplings, giving a total of 45 λ-like R-parity violating couplings.

R-parity is a discreet, multiplicative quantum number, which is $+1$ for SM particles and -1 for their superpartners. There is no *a priori* law, that requires the conservation of R-parity. Moreover there is no experimental result, which excludes the presence of $\mathcal{W}_{RPV}$ under the assumption that only one λ-like coupling is significantly different from zero.

The model used in this work is the Constrained Minimal Supersymmetric Standard Model (CMSSM). Not counting the 45 RPV Yukawa couplings, this model has only five free parameters: a common mass for the gauginos ($m_{1/2}$) and the sfermions (m_0) at the GUT scale, the mixing parameter of the two Higgs field doublets (μ), the ratio of the vacuum expectation values of the two Higgs doublets ($\tan\beta$) and the common trilinear coupling (A).

Both the theoretical results and the details of the experimental analyses relevant for this paper are summarized in our previous publications.[1,2] We assume, that there

is only one λ-like coupling different from zero, and that SUSY particles are heavy and decay promptly in the detector. This corresponds to a sensitivity for couplings larger than $\mathcal{O}(10^{-5})$.

The bulk of the results,[3,4] presented in Section 1 to 3, are based on the combination of the data sample collected at $\sqrt{s} = 189$ GeV corresponding to an integrated luminosity of approximately 180 pb^{-1} with previous OPAL results.[1,2] Partial updates using data collected up to $\sqrt{s} = 209$ are presented Section 4.

1. Chargino and Neutralino Searches

The direct decays of neutralinos result in three SM fermions: $\nu\ell^{+}\ell^{-}$ via λ, νqq or ℓqq via λ' and qqq via λ'' couplings. Thus, the final state topologies of their pair-production vary from four leptons with missing energy to six jets.

Charginos can decay directly to SM fermions, or indirectly through a neutralino and a (virtual) W boson. In direct decays, three SM fermions are produced: $\nu\nu\ell$ or $\ell\ell\ell$ via λ, νqq or ℓqq via λ' and qqq via λ'' couplings. When decaying indirectly, five SM fermions are created, their type depending on the decay modes of the neutralino and the W boson. Therefore, pair-production of charginos may be observed in widely different final states, ranging from two leptons with missing energy to ten jets.

When interpreting the results of all these topological searches, first cross-section limits are derived for the individual channels with the minimal model assumptions given above. We combine the individual results to get cross-section limits for the direct and the indirect modes. It is assumed that the indirect decays proceed through the production of a (virtual) W boson and the lightest neutralino, which is assumed to be the lightest SUSY particle, and that the mass difference between the chargino and the neutralino is greater than 5 GeV. Different channels are combined according to the measured W branching ratios.

Decay mode independent results are calculated by varying the relative branching ratio of the direct and indirect decays between 0 and 1, and taking the worst case.

For any λ coupling, the upper limit on the neutralino pair-production cross-section is smaller than 0.16 pb in the full mass range from 45 GeV to the kinematic limit. The cross-section limits for charginos are summarized in Table 1.

Table 1. Upper limits on the chargino pair-production cross-section for direct decays, indirect decays and independently of the decay mode for any λ, λ' and λ'' couplings. The first / second number corresponds to a chargino mass of 45 / 90 GeV.

coupling	direct	indirect	mode indep.
λ	1.1 / 0.55 pb	0.42 / 0.16 pb	2.0 / 0.9 pb
λ'	2.0 / 0.35 pb	4.5 / 0.7 pb	
λ''	1.4 / 0.50 pb	1.1 / 0.50 pb	1.4 /0.55 pb

Finally, the results are interpreted in CMSSM. The excluded topological cross-sections, and the measured Z boson width are used to constrain the CMSSM parameter space. The results for any λ and λ'' couplings are shown in Figure 1.
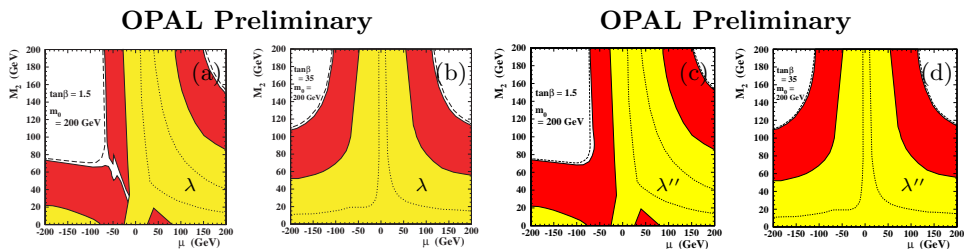
OPAL Preliminary   **OPAL Preliminary**

Fig. 1. Excluded regions in CMSSM in the $M_2 - \mu$ plane[a] for $m_0 = 200$ GeV and (a,c) $\tan\beta = 1.5$, (b,d) $\tan\beta = 35$ for any (a,b) λ and (c,d) λ'' couplings. The kinematic limit is shown by dashed lines.

2. Squark Searches

We have studied the direct decays of scalar top quarks to SM fermions via λ' and λ'' couplings. The cross-section upper limits are shown for both the $q\ell q\ell$ and the qqqq final states on Figure 2. In CMSSM the production cross-section depends on the stop mixing angle, $\theta_{\tilde{t}}$, defined as $\tilde{t}_1 = \cos\theta_{\tilde{t}}\tilde{t}_L + \sin\theta_{\tilde{t}}\tilde{t}_R$. The maximal cross-section is predicted for $\theta_{\tilde{t}} = 0$ rad, while the minimal for $\theta_{\tilde{t}} = 0.98$ rad. The limit on the stop mass varies between 79 and 90 GeV depending on which λ-like coupling is different from zero and the value of the mixing angle.
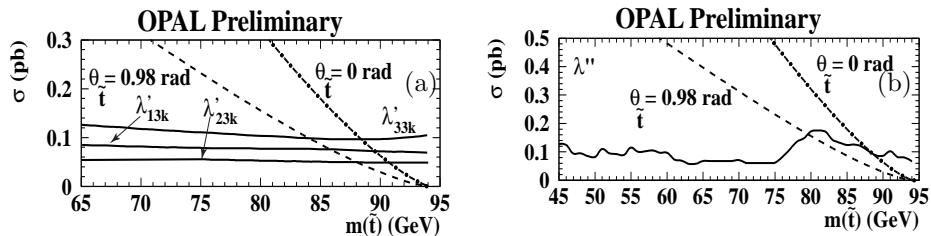

Fig. 2. Upper limits on the pair-production cross-section of (a) scalar top quarks decaying via λ' couplings and (b) a scalar quark of any flavor decaying via λ'' couplings. The predicted minimal and maximal cross-sections of stop pair-production in CMSSM are also shown.

3. Slepton Searches

Scalar leptons, charged or neutral, can decay directly to two SM fermions or indirectly, through the production of a SM lepton and a neutralino, to four SM fermions. Thus, when produced in pairs, the possible final states range from two leptons and missing energy to four leptons and four hadronic jets.

Similarly to the gaugino searches, first cross-section limits are computed with minimal model assumptions. Then a lower limit on the slepton mass is derived in CMSSM. In the case of direct decays, it is assumed that the branching ratio $BR(\tilde{f}_i \to f_j f_k) = 1$. For indirect decays the branching ratio $BR(\tilde{f} \to f\tilde{\chi}^0)$ is taken from CMSSM. Since the neutralino decay modes via λ' couplings depend on CMSSM parameters, we vary the branching ratio of the decay involving a charged lepton and the branching ratio of the decay involving a neutrino simultaneously

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[a] M_2, the SU(2) soft SUSY breaking gaugino mass, is related to $m_{1/2}$.

between 0 and 1, and take the worst case result.

As previously, only the weakest limits are shown. All CMSSM exclusion plots are given for $\tan\beta = 1.5$ and $\mu = -200$ GeV. This choice of parameters is conservative, since the theoretical cross-section usually increases for larger $\tan\beta$ and $|\mu|$.

The upper limit on the sneutrino pair-production cross-section is better than 0.22 pb in the mass range of interest for any λ coupling. The cross-section limits are generally weaker for λ' couplings. For example, for indirect decays of sneutrinos, the limit is $1.2-1.3$ pb for a mass of 45 GeV and 0.2 pb for a mass of 90 GeV. The CMSSM mass limits are shown in Figure 3(a) and (b) for any λ and λ' couplings.
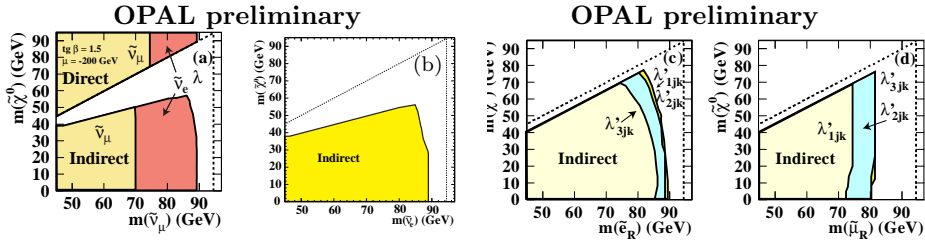

Fig. 3. Excluded mass regions in CMSSM (a) from direct and indirect decays of sneutrinos for any λ coupling, and from indirect decays of (b) electron sneutrinos, (b) right-handed selectrons and (c) right-handed smuons for any λ' coupling. No CMSSM exclusion is possible for muon and tau sneutrinos decaying via λ' couplings due to the small expected theoretical cross-section. The kinematic limit is shown by dashed lines.

The charged slepton limits for λ couplings have been updated using data collected at $\sqrt{s} = 192 - 209$ and are summarized in the next section. For λ' couplings, the selectron and smuon pair-production cross-section upper limits for indirect decays are better than 0.52 pb. The CMSSM mass limits are given in Figure 3 (c,d).

4. Updates at $\sqrt{s} = 192 - 209$ GeV

Preliminary updates[5] using data collected in 1999 and 2000, corresponding to an integrated luminosity of 400 pb^{-1}, are performed in the multi-lepton and in the jets+leptons final states. There is a nice agreement between data and the SM expectation, with the exception of events with multiple jets and identified tau leptons at the highest energy, $\sqrt{s} > 206.5$ GeV. The biggest excess, corresponding to a Poisson probability of 2×10^{-3}, is found in the final state with two tau leptons and at least four jets, in the search for indirect decays of gauginos via λ' coupling, with 8 events observed and 2.2 expected from SM processes.

Including around 285 pb^{-1} of $\sqrt{s} = 192 - 209$ GeV data collected by July 2000, new upper limits, shown in Figure 4(a), are set on the production cross-section of charged sleptons decaying via λ couplings.[6] Limits for direct decays are weaker, the cross-section limit, based on 200 pb^{-1} data collected at $\sqrt{s} = 192 - 202$ GeV and combined with previous results, is shown in Figure 5(a).[7]

The CMSSM interpretation of the results is given in Figure 4(b,c) for smuons and staus.[6] For selectrons, due to the higher expected CMSSM cross-sections, the
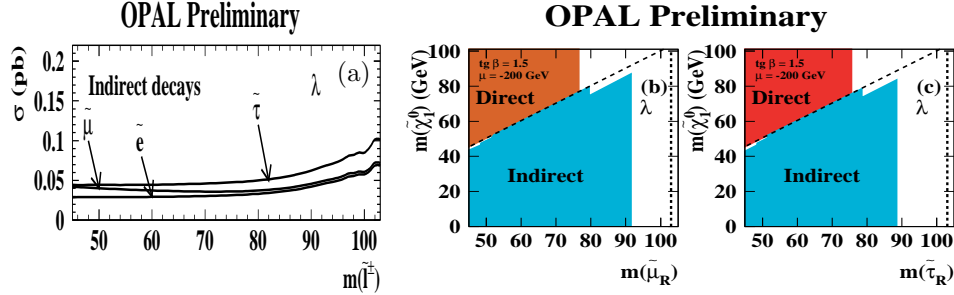
Fig. 4. (a) Upper limit on the pair-production cross-sections for indirect decays of $\tilde{\ell}_{\rm R}$. CMSSM exclusion regions for (b) smuon and (c) stau pair-production. The kinematic limit is shown by dashed lines.
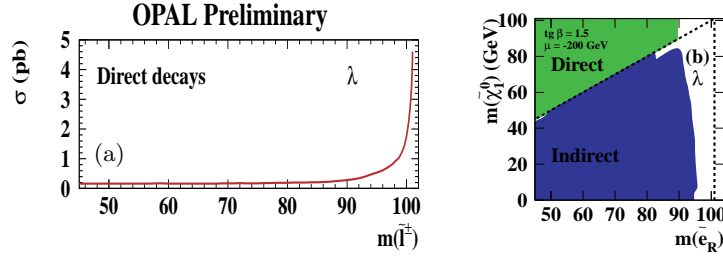

Fig. 5. (a) Upper limit on the pair-production cross-sections for direct decays. (b) CMSSM exclusion regions for selectron pair-production. The kinematic limit is shown by dashed lines.

excluded region is considerably larger. The mass limits based on the data collected up to 202 GeV are plotted in Figure 5(b).[7]

5. Summary

Searches for charginos, neutralinos and scalar fermions are performed by the OPAL detector. Since no evidence for supersymmetry with R-parity violation is found, limits are placed on production cross-sections, sparticle masses and the CMSSM parameter space.

References

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