Submitted to the
XXII International Symposium on Lepton-Photon Interactions at High Energy
June 30 - July 5, Uppsala, Sweden

Abstract: 259 **Session: EW&B**

Search for gaugino production at HERA

ZEUS Collaboration

June 2005

Abstract

A search for gaugino production in R-parity violating supersymmetry has been performed with the ZEUS detector at HERA using a data set corresponding to an integrated luminosity of 121 pb^{-1}. Processes in which a scalar lepton is exchanged in the t-channel and neutralinos are produced via an R-parity violating Yukawa coupling λ'_{ijk} have been considered, for example $e^+d \to \tilde{\chi}_1^0 u$. It was assumed that the single Yukawa coupling λ'_{111} associated with pure first generation particle interaction dominates and the contributions from the other Yukawa couplings were negligible. No deviation from the Standard Model was observed. Exclusion limits on parameters in the framework of the Minimal Supersymmetric Extension of the Standard Model were derived.

1 Introduction

The Standard Model (SM) of particle physics is a very successful theory in describing particles and interactions at low energy scales. However, it is expected to break down as the energy scale approaches 1 TeV. Supersymmetric models provide a promising path for extending the SM (for a review on supersymmetry (SUSY) see [1]).

R-parity is a discrete, multiplicative symmetry defined by $(-1)^{3B+L+2S}$, where B is the baryon number, L the lepton number and S the spin of the particle. SM particles have R-parity $+1$, while SUSY particles have R-parity -1. R-parity conserving (RPC) SUSY models are often favoured over R-parity violating (RPV) models, mainly because they provide a promising cold dark matter candidate, the neutralino, but also because the number of possible experimental signatures is reduced significantly. On the other hand the most general langrangian for supersymmetric theories does not exclude RPV terms explicitely and HERA is an ideal place to look for RPV SUSY. RPV leads to additional terms in the superpotential:

$$W_{\mathrm{RPV}} = \lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k \; ... \tag{1}$$

At HERA leading order diagrams proceed through the second term in Eq. 1 via the Yukawa coupling λ'_{ijk}, where ijk denote family indices. Previous searches at HERA considered resonant production of squarks in the s-channel [2]. Special attention was given to stop production [3], since large mixings can be significant in the third family, which can lead to very light mass states for large tanβ[1]. Since no deviation from the SM was observed in any of these searches, upper bounds on the Yukawa couplings λ'_{ijk} as a function of the squark masses were derived.

In this analysis a search is made for gaugino production via the RPV t-channel process (Fig. 1), where the cross section is independent of the squark sector, but depends on the slepton and gaugino masses. The gauginos decay subsequently via a cascade into two quarks and an electron or positron (Fig. 2a) or into two quarks and a neutrino or anti-neutrino (Fig. 2b). The presented results are obtained only from the analysis of the electron/positron decay channel[2]. It is assumed that the single Yukawa coupling λ'_{111} associated with pure first generation particle interaction dominates and the contributions from the other Yukawa couplings are negligible. The data set corresponds to an integrated luminosity of 121 pb^{-1} and was taken at centre-of-mass energies of $\sqrt{s} = 300$ GeV and $\sqrt{s} = 318$ GeV collected during the 1996-2000 running period.

[1] β is the ratio of the vacuum expectation values of the two Higgs doublet.

[2] Unless stated otherwise, the term 'electron' refers to both positron and electron and the term 'neutrino' refers to both neutrino and anti-neutrino.

2 Event Simulation and Selection

The events from gaugino production via t-channel exchange of a slepton, where the gaugino decays to an electron, are expected to have high transverse energy, at least two jets with large transverse momentum and an electron candidate. The main SM background is from dijet events in neutral current deep inelastic scattering (NC DIS). There is also contribution from photoproduction, where the cross section is large and a non-negligible number of events can fake the signal topology, due to detector mismeasurements. Background from charge current deep inelastic scattering (CC DIS) was also considered, although the contribution is expected to be small.

2.1 Event Simulation

Complete Monte Carlo (MC) simulations of the ZEUS detector response were performed, in order to determine the detector efficiencies of the potential SUSY signature and to estimate the SM contribution to the signal signature under investigation. The number of generated SM events for each background source corresponds to at least twice the luminosity of the data analysed.

NC and CC DIS events were simulated using DJANGO 6 version 2.4 [4] and DJANGOH 1.1 [5], which both use HERACLES 4.6.2 [6] to model first-order QED radiation and are interfaced to the hadronisation programme Ariadne [7]. The CTEQ5D [8] parametrisation was used to evaluate the parton densities in the proton. PYTHIA 6.2 [9] and HERWIG 6.1 [10] were used to simulate direct and resolved photoproduction events.

The programme SUSYGEN [11] was used to generate the signal events within the framework of the Minimal Supersymmetric Extension of the SM (MSSM). All squark masses are set to be large and all slepton masses to be degenerate. A parameter scan was performed in the plane spanned by $|\mu| < 500$ GeV and $\mathrm{M}_2 < 250$ GeV[(3)] with typical steps of 15-50 GeV. The fixed parameters are tan$\beta = 30$, $\mathrm{M}_{\tilde{l}} = 100$ GeV and $\lambda'_{111} = 1.0$. The cross sections were evaluated using the CTEQ4M [12] parametrisation for the parton densities in the proton. The cross section are scaled to account for the different lepton beams and centre-of-mass energies during the different running periods.

[3] μ is the supersymmetric Higgs mass term and M_2 the supersymmetric mass breaking term associated with the $SU_L(2)$ group.

2.2 Trigger and preselection

The data events were triggered using the standard ZEUS trigger configuration for NC DIS. It mainly requires a good electron candidate at the third level of the trigger chain: $E_e > 4$ GeV, $P_T^e > 2$ GeV, $E\text{-}P_z > 32$ GeV[4] and $Q^2 > 160$ GeV^2.

At the offline preselection level the following cuts were applied in order to select an inclusive multijet NC DIS sample which has a high signal efficiency:

- $E_T > 75$ GeV
- $45 < E\text{-}P_z < 62$ GeV
- $y_{JB} > 0.4$[5]
- $Q^2_{JB} > 100$ GeV^2
- ≥ 2 jets, with $E_T^{jet} > 10$ GeV, $-0.5 < \eta^{jet} < 2.7$
- ≥ 1 electron candidate, with $P_T^e > 6$ GeV, $\theta^e < 90°$

Additional cleaning cuts were applied to reject photoproduction events, cosmic events and events from beam-gas collisions and halo muons. The typical signal efficiency times branching ratio (BR) after the preselection is roughly 30 %, where the BRs vary from 30-70 %, depending on the SUSY parameters.

2.3 Final selection

A multi-variate discriminant method described elsewhere [14] was used to distinguish the signal from the background. Seven event observables were used as input variables for the evaluation of the discriminant: E_T, log(Circ), $E\text{-}P_z$, y_{JB}, E_T^{jet1}, E_T^{jet2} and the number of tracks. The signal events are expected to have larger E_T, E_T^{jet1} and E_T^{jet2} due to the harder underlying process. As more final state particles are produced, higher multiplicities and larger circularity (Circ)[6] values are expected for the signal events. The distributions of the event observables after the preselection are shown in Fig. 3. This discriminant method uses probablity density distributions obtained from MC simulations of the background and the signal and takes into account all correlations between the input variables. In

[4] The ZEUS coordinate system is a right-handed Cartesian system, with the Z axis pointing in the proton beam direction, referred to as the "forward direction", and the X axis pointing left towards the center of HERA. The coordinate origin is at the nominal interaction point.

[5] The kinematic variables having the subscript JB are calculated with the Jaquet-Blondel method [13].

[6] The circularity is the two-dimensional equivalent to sphericity which is defined elsewhere [15]. It is a measure for the distribution of calorimeter energy deposits in the plane transverse to the beamline. For example a single jet NC DIS event with back-to-back topology typically has a circularity close to 0.

this way the signal efficiency and the signal-to-background (s/b) ratio is optimised. The discriminant distribution is depicted in Fig. 4. As can be seen a good discrimination between signal and background is obtained. The efficiency and s/b ratio as a function of the discriminant cut is shown in Fig. 5.

3 Results

No deviation from the SM was observed in the high discriminant region, where the signal is expected to appear, as can be seen in Fig. 4. With a view to constraining the parameters of the MSSM, a parameter scan was performed as described in Section 2.1. A semi-bayesian likelihood approach as described elsewhere [16] was used to constrain the parameters μ and M_2. In order to maximise the limits the confidence level (C.L.) values are obtained by a multi-bin evaluation of the the discriminant distributions of the data, the SM background and the different SUSY signal samples after a discriminant cut at 0.7. An interpolation of the C.L. results is performed to obtain the limit contour as shown in Fig. 6.

3.1 Systematic uncertainties

Systematic uncertaintities from various sources were considered using MC studies. The uncertainty in the absolute calorimeter energy scale leads to uncertaintities in the background of 5.2 % and the signal of 5.5 %. Using MEPS [17] instead of ARIADNE for the simulation of the hadronic final states gives an uncertainty of 4.2 % in the background. A further signal cross section uncertainty is estimated as 6.4 % by using the CTEQ6M parametrisation instead of the CTEQ4M parametrisation. Variations of the z_{vtx} (the nominal threshold was $|z_{vtx}| < 40$ cm) and the E-P_z thresholds by ± 10 cm and ± 2 GeV, respectively, leads to uncertaintites in the background of 4.6 % and 1.3 %, respectively, and in the signal of 2.9 % and 1.4 %, respectively. These uncertainties were included in the numerical calculation of the limits as uncorrelated gaussian fluctuations of the expected number of signal and background events.

3.2 Contraints on the MSSM

The lightly-shaded area in Fig. 6 shows the region in the μ-M_2 plane which can be excluded at the 95% C.L. by the ALEPH and DELPHI experiments at LEP. This area was derived from the lower limit for the $\chi_1^\pm$ mass of 103 GeV, which was obtained by the two LEP experiments from the analysis of a possible production of chargino pairs at LEP [18]. The darkly-shaded area is the additional region which can be excluded by this anlysis at the 95% C.L. assuming tan$\beta = 30$, $M_{\tilde{l}} = 100$ GeV and $\lambda'_{111} = 1.0$.

4 Conclusions

A search for gaugino production in R-parity violating supersymmetry has been performed with the ZEUS detector at HERA using a data set corresponding to an integrated luminosity of 121 pb^{-1}. No evidence for gaugino production was found. A parameter scan was performed in the framework of the MSSM in order to constrain the parameters μ and M_2. For tan$\beta = 30$, $M_{\tilde{l}} = 100$ GeV and $\lambda'_{111} = 1.0$ the excluded regions in the μ-M_2 plane could be extended at the 95% C.L. by this analysis compared to previous analyses from ALEPH and DELPHI at LEP.

References

[1] H. E. Haber and G. L. Kane, Phys. Rept. **117**, 75 (1985).

[2] H1 Coll., A. Aktas et al., Eur. Phys. J. **C 36**, 425 (2004).

[3] H1 Coll., A. Aktas et al., Phys. Lett. **B 599**, 159 (2004).

[4] K. Charchula, G. A. Schuler and H. Spiesberger, Comput. Phys. Commun. **81**, 381 (1994) .

[5] H. Spiesberger, HERACLES *and* DJANGOH*: Event Generation for ep Interactions at HERA Including Radiative Processes*, 1998, available on `http://www.desy.de/~hspiesb/djangoh.html`.

[6] A. Kwiatkowski, H. Spiesberger and H.-J. Möhring, Comp. Phys. Comm. **69**, 155 (1992).

[7] L. Lönnblad, Comput. Phys. Commun. **71**, 15 (1992).

[8] CTEQ Coll., H. L. Lai et al., Eur. Phys. J.**C 12**, 375 (2000).

[9] T. Sjöstrand, L. Lönnblad and S. Mrenna, Preprint hep-ph/0108264, 2001.

[10] G. Corcella et al., Preprint hep-ph/9912396, 1999 .

[11] S. Katsanevas and P. Morawitz, Comput. Phys. Commun. **112**, 227 (1998);
N. Ghodbane, Preprint hep-ph/9909499, 1999;
E. Perez, *Proc. of Monte Carlo generators for HERA physics*, A. T. Doyle et al. (eds.), p. 635-651. DESY, Hamburg, Germany (1999). Also in preprint DESY-PROC-1999-02, available on http://www.desy.de/heramc/.

[12] CTEQ Coll., H. L. Lai et al., Phys. Rev. **D 55**, 1280 (1997).

[13] F. Jaquet and A. Blondel, *Proc. of the Study for an ep Facility for Europe*, U. Amaldi (ed.), p. 391. DESY, Hamburg, Germany (1979). Also in preprint DESY 79-48.

[14] T. Carli and B. Koblitz, Nucl. Inst. Meth. **A 501**, 576 (2003).

[15] S. Brandt and H. D. Dahmen, Z. Phys. **C 1**, 61 (1979).

[16] T. Junk, Nucl. Instrum. Meth. **A 434**, 435 (1999) .

[17] G. Ingelman, *Proc. of Workshop on Physics at HERA*, DESY, Hamburg, Germany (1991). Also in preprint TSL-ISV-92-0065 .

[18] DELPHI Coll., J. Abdallah et al., Eur. Phys. J. **C 36**, 1 (2004).
DELPHI Coll., J. Abdallah et al., Eur. Phys. J. **C 37**, 129 (2004)
ALEPH Coll., A. Heister et al., Eur. Phys. J. **C 31**, 1 (2003).

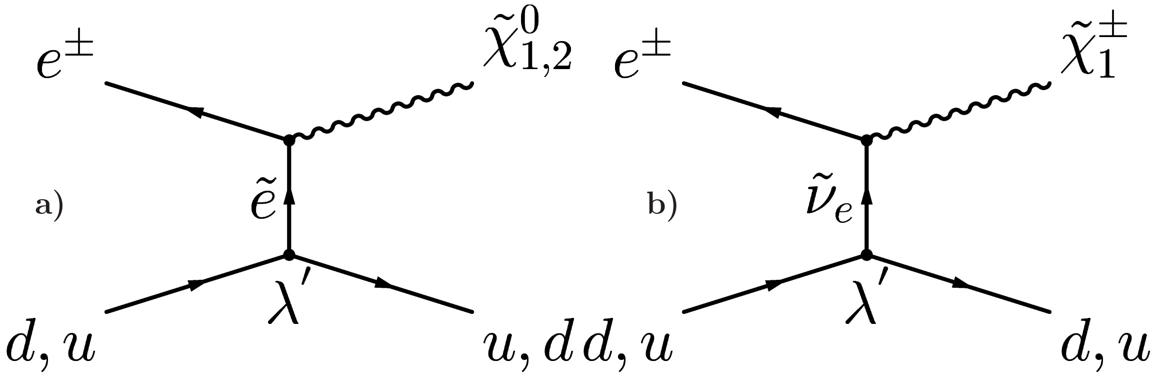

Figure 1: *Gaugino production via an R-parity violating exchange of an selectron (a) or a sneutrino (b) at HERA.*

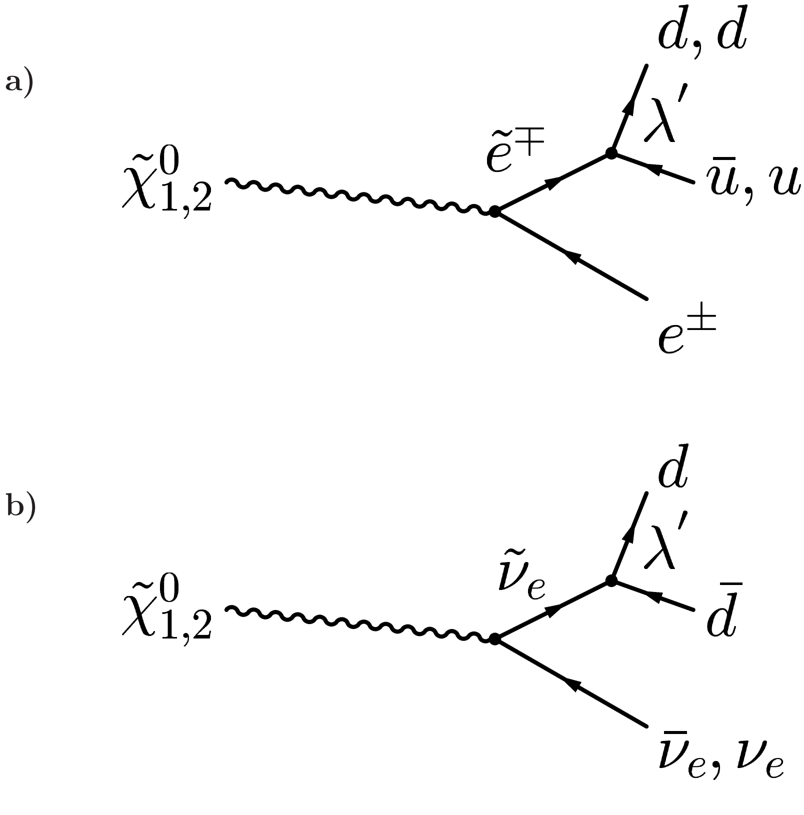

Figure 2: *Three-body decay of a neutralino into two quarks and an electron (a) or a neutrino (b).*

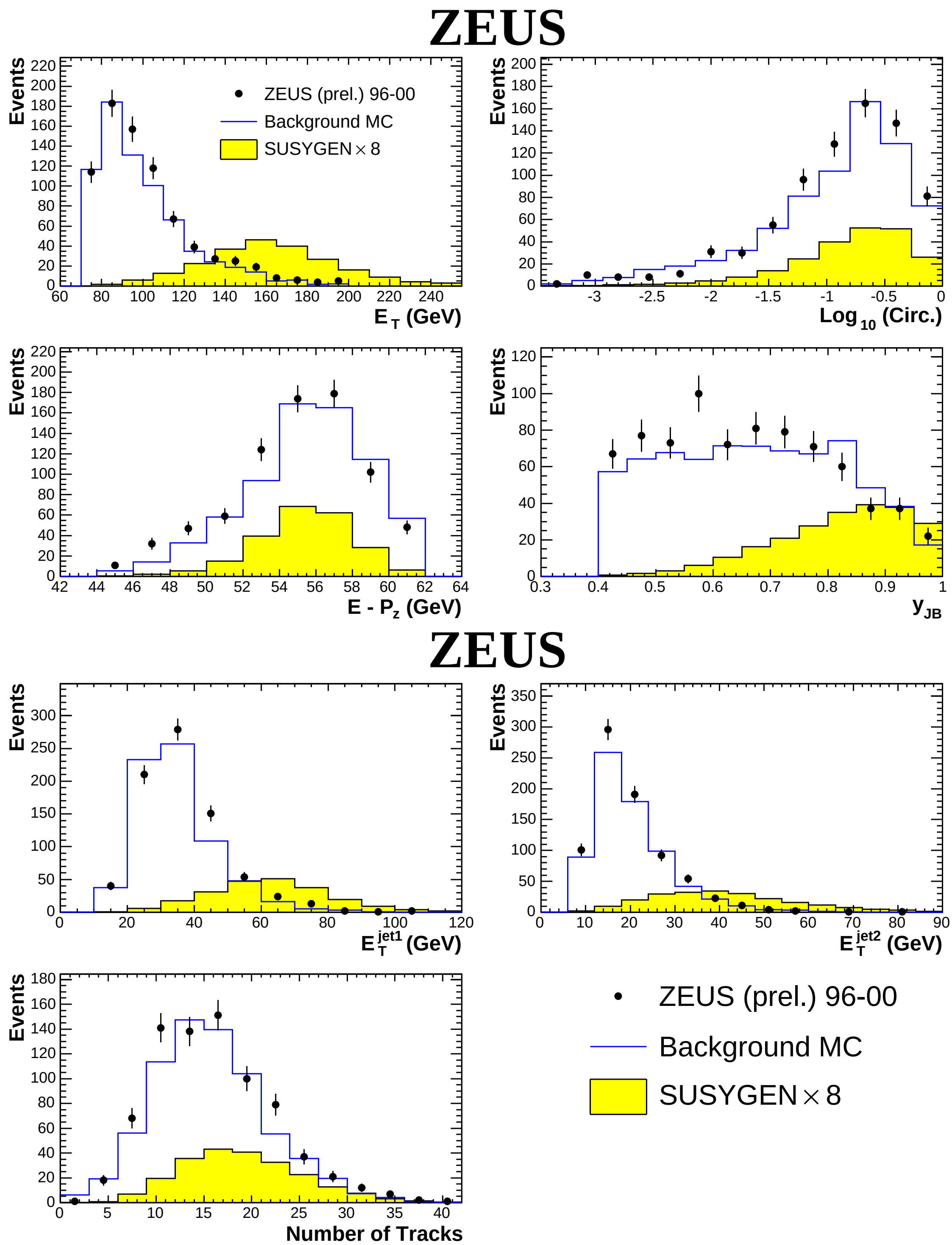

Figure 3: *Distribution of the event observables for the data (solid points), the SM simulation (solid line) and the SUSY signal (shaded area) after the preselection described in section 2.2. These observables are used in the discriminant method to distinguish the SUSY signal from the SM background. The SUSY signal represents a sample point in the parameter space ($\mu = -400$ GeV, $M_2 = 150$ GeV) and is scaled by a factor 8.*

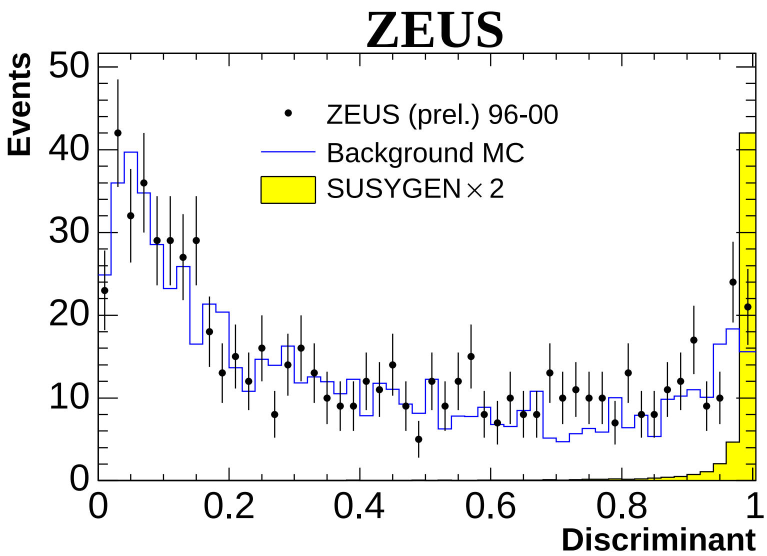

Figure 4: *Discriminant distribution for the data (solid points), the SM background (solid line) and the SUSY signal (shaded area). The SUSY signal represents a sample point in the parameter space as in Fig. 3 and is scaled by a factor 2.*

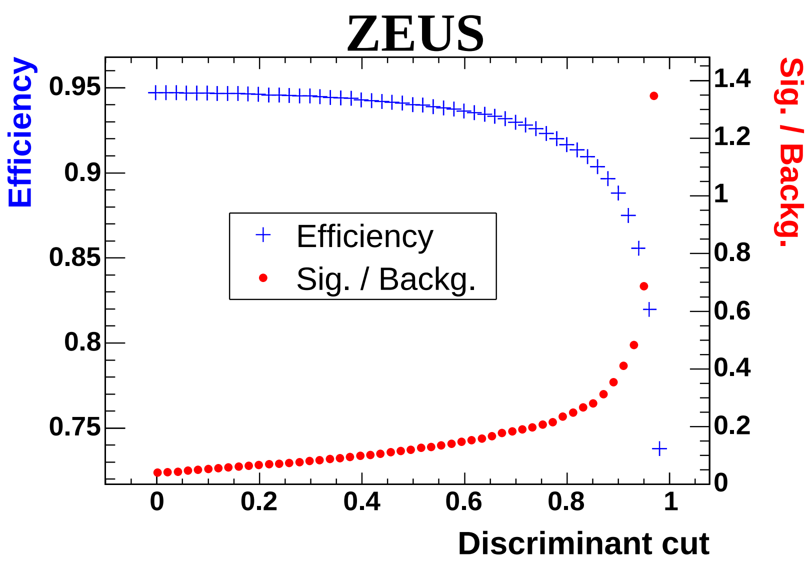

Figure 5: *Efficiency (crosses, left-axis scale) and signal-to-background ratio (solid points, right-axis scale) as a function of the cut on the discriminant. The results are based on the SUSY simulation at the same point in parameter space as in Fig. 3 and 4.*

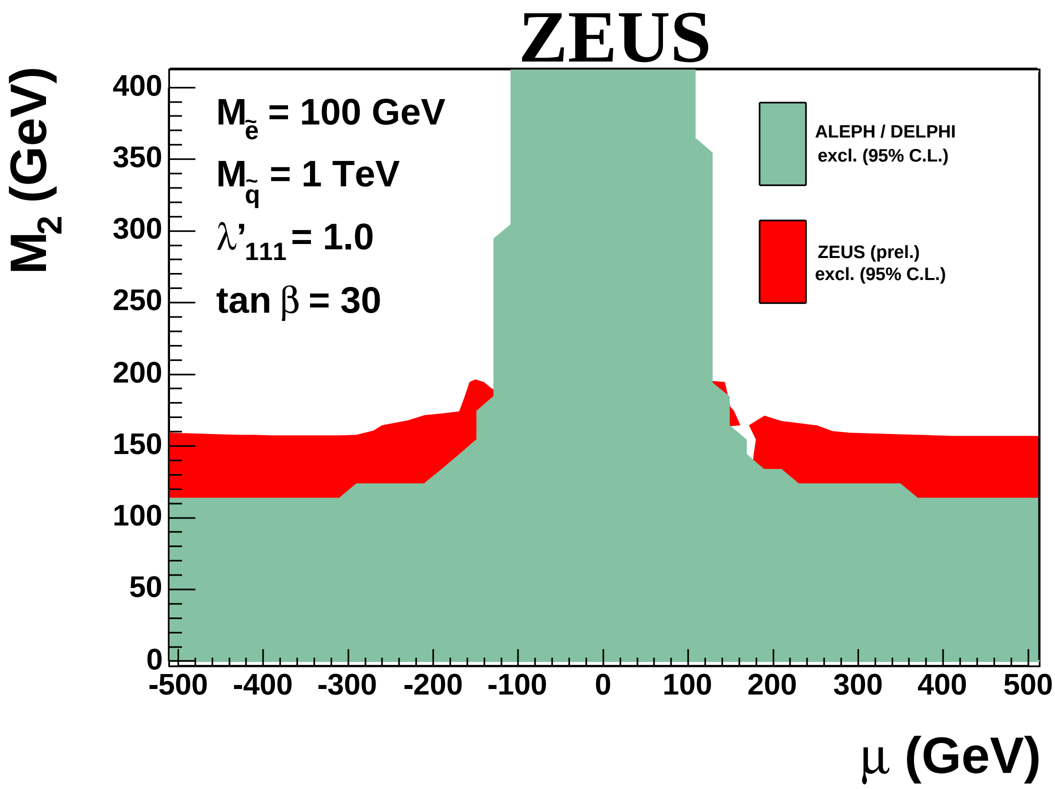

Figure 6: *Regions in the μ-M_2-plane which can be excluded at the 95% C.L. by the ALEPH and DELPHI experiments at LEP (lightly-shaded area) and by this anaysis (darkly-shaded area). In this plot the ALEPH/DELPHI exlusion region is derived from the lower limit for the $\chi_1^{\pm}$ mass of 103 GeV [18].*