Searches for Supersymmetry at HERA

Claus Horn, H1 collaboration, and ZEUS collaboration

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Searches for Supersymmetry at HERA

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Abstract. The H1 and ZEUS collaborations at HERA have searched for R_p-violating supersymmetry in ep collisions at center-of-mass energies of 300 GeV and 318 GeV. The results were interpreted in the minimal supersymmetry model (MSSM), the minimal supergravity model (mSUGRA) and the model of gauge mediated supersymmetry breaking (GMSB).

Keywords: HERA;SUSY;RPV;MSSM;mSUGRA;GMSB
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INTRODUCTION

Supersymmetry provides one of the most promising candidates for a theory beyond the Standard Model (SM). In the most general supersymmetric theory that is renormalizable and invariant under the SM gauge interactions the superpotential contains three trilinear terms

$$W_{RPV}^{tril} = \lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k + h.c. \quad (1)$$

which violate R-parity, defined as $R_p = (-1)^{3B+L+2S}$, where B, L and S are the baryon number, the lepton number and the spin of the particle, respectively. Through these interactions, sparticles can be single produced and the lightest sparticle (LSP) can decay into SM particles.

Because of its unique initial state which provides both leptonic and baryonic quantum numbers, the ep collider HERA is an ideal tool to investigate λ' couplings. At HERA 27 GeV electrons (or positrons) and 920 GeV protons (820 GeV before 1998) collide, resulting in center-of-mass energies of 318 GeV (300 GeV). In the HERA I phase (1993-2000) both experiments, H1 and ZEUS, have collected around 130 pb^{-1}, mostly with positron beams (85% e^+p, 15% e^-p). After an upgrade including an increase in instantaneous luminosity by a factor of about 3 and the installation of spin flip devices enabling longitudinally polarised lepton beams, HERA II is in operation since 2002. Since efficient data taking started only in 2004, the new results presented here use only HERA I data.

A non-zero Yukawa coupling λ' may lead to the production of squarks in the s-channel or gauginos via a t-channel slepton exchange (Fig. 1). Depending on the masses of the squarks and sleptons either the first or the second diagram will be dominant. The subsequent decay of the produced sparticles leads to characteristic signatures for different SUSY models mainly determined by the nature of the LSP.

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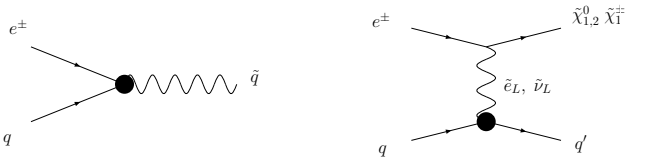

FIGURE 1. Leading order diagrams for sparticle production at HERA. Squark production (left) and gaugino production (right). R_P-violating couplings are marked by a dot.

SQUARK SEARCHES

In the presence of R_P-violating couplings the produced squarks decay in both R_P-violating modes eq or νq, or via gauge decays leading to a large variety of channels with multi-lepton and multi-jet final states. The H1 collaboration performed a complete search for these final states covering most of the decay width of the produced quarks. In the absence of a signal, squark-mass dependent limits for λ'_{1j1} (Fig. 2 left) and λ'_{11k} were calculated in the MSSM. Additionally, the results were interpreted in the mSUGRA model as limits in the $m_{1/2} - m_0$ plane [1, 2].

A similar search was performed by the ZEUS collaboration looking for stop squarks, using an integrated luminosity of $65\,\mathrm{pb}^{-1}$. The investigated decay channels include the R_P-violating decay into an electron and a jet and the gauge decay into $b\,\tilde{\chi}^+_1$ leading to a multi jet final state with either a high-P_T electron or neutrino. Limits on λ'_{131} were derived as a function of $m(\tilde{t})$ [3]. The limits for the mSUGRA model (Fig. 2 right) are consistent with the H1 results. For $\lambda'_{131} = 0.3$ stop masses of up to 260 GeV are excluded for a large part of the parameter space.

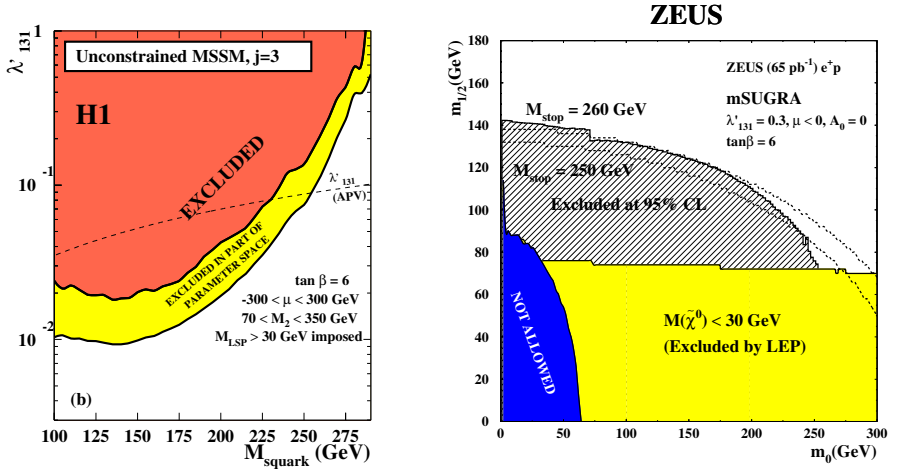

FIGURE 2. Exclusion limits for the MSSM from the H1 squark search (left) and for the mSUGRA model form the ZEUS stop analysis for $\lambda'_{131} = 0.3$ (right) where the dashed lines correspond to constant stop masses.

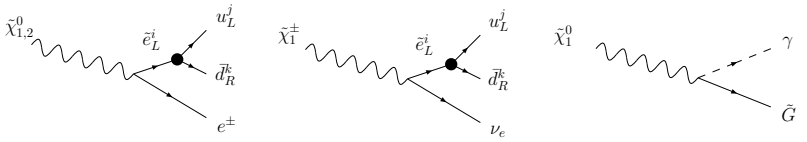

FIGURE 3. Diagrams for gaugino decay. Shown are examples for the R_P-violating three-body decays of neutralinos and charginos into multiple jets and electrons (left) or neutrinos (middle). On the right: GMSB decay of the lightest neutralino into a gravitino and a photon.

SEARCH FOR GAUGINO PRODUCTION IN THE MSSM

In the MSSM, where the lightest neutralino is the LSP, the produced gauginos decay through a cascade into two quarks and either an electron or positron (electron channel) or a neutrino or anti-neutrino (neutrino channel), as shown in Fig. 3. Thus, Yukawa couplings can be investigated independent of squark masses.

In addition to previous results [4, 5] the neutrino channel was investigated, requiring a total E_T of at least 50 GeV, $P_T^{miss} > 20$ GeV and at least one jet with $p_T^{jet} > 10$ GeV. Events with electrons in the final state were rejected. The analysis uses a data sample corresponding to a luminosity of 121 pb^{-1}. Since no deviation from SM expectations was observed, a semi-Bayesian likelihood approach was used to calculate 95% confidence limits in the plane spanned by the MSSM parameters M_2 and μ. Figure 4 shows the excluded regions for different slepton masses [6].

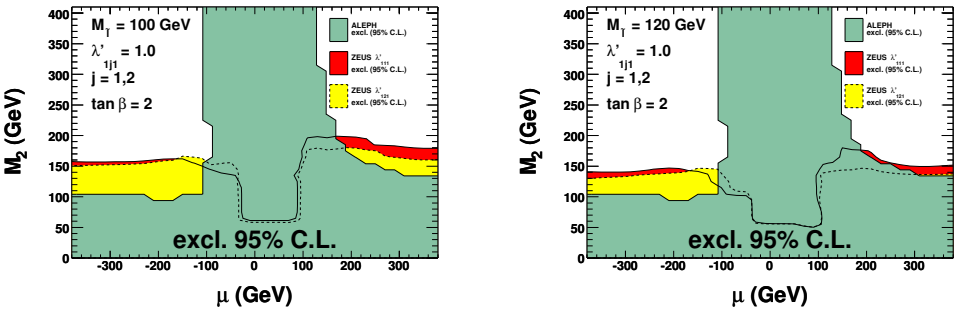

FIGURE 4. Regions in the (μ, M_2)-plane which can be excluded at 95% C.L. for λ'_{111} (red region) and λ'_{121} (yellow region) assuming a $\tan\beta = 2$ and slepton masses of 100 GeV (left) and 120 GeV (right).

SEARCHES FOR GRAVITIONS

In the GMSB model the gravitino is the LSP, and the produced neutralinos can decay via $\tilde{\chi}^0_1 \to \gamma\tilde{G}$. This channel is dominant for low value of $\sqrt{F}$, the scale at which supersymmetry is broken in the hidden sector.

The H1 collaboration has searched for events with an isolated high-P_T photon, one jet and missing E_T deriving common limits for the Yukawa couplings λ'_{1j1} (j=1, 2) and

λ'_{11k} (k=1,2) by using $64\,\mathrm{pb}^{-1}$ of positron and $14\,\mathrm{pb}^{-1}$ of electron data. Masses below 112 GeV for the lightest neutralino could be excluded at 95%*CL*. for $\lambda'_{111} = 1$ [7].

A similar analysis was performed by the ZEUS collaboration [8]. The investigated luminosity has now been extended to $121\,\mathrm{pb}^{-1}$. Limits were calculated in the mass plane of the left-handed selectron and the lightest neutralino (Fig. 5) excluding neutralino masses up to 150 GeV and selectron masses up to 260 GeV for $\lambda'_{111} = 1$. Scans were

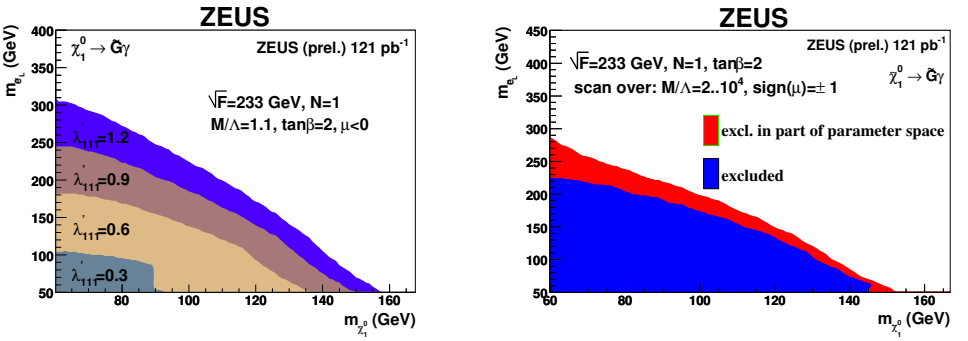

FIGURE 5. Regions in the $m(\tilde{e}_L) - m(\tilde{\chi}_1^0)$ plane which can be excluded at 95% C.L. for different values of λ'_{111} (left) and various values of M/Λ and $sign(\mu)$ (right, with $\lambda'_{111} = 1$).

performed over the entire GMSB parameter space. Figure 5 (right) shows an example for varying messenger mass scale M and $sign(\mu)$. Similar limits were found to hold in a large part of parameter space [9].

CONCLUSION AND OUTLOOK

The H1 and ZEUS collaborations continue to contribute significantly to the quest for SUSY phenomena. In HERA II roughly $240\,\mathrm{pb}^{-1}$ have been collected so far and until July 2007 another $100\,\mathrm{pb}^{-1}$ will be added. The analysis of this data is ongoing and new SUSY channels are under investigation.

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