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SEARCH FOR SUPERLIGHT GRAVITINOS AT HERA

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A search for gravitinos produced in positron-proton scattering is presented using the H1 detector at HERA. In models where the gravitino is the lightest supersymmetric particle, an R-parity violating t-channel exchange of a scalar electron can produce a neutralino, which subsequently decays into a photon and a superlight gravitino. The resulting event signature involves an isolated photon and missing transverse energy. No deviation from the Standard Model has been found. Limits on R-parity violating Yukawa couplings have been derived for different neutralino and selectron masses in the framework of a Gauge Mediated Supersymmetry Breaking scenario.

1 Introduction

At HERA, in previous analyses of R-parity (R_P) violating Supersymmetry (SUSY) resonant squark production has been investigated [1]. Limits on various R_P-violating Yukawa couplings have been derived dependent on the squark mass. In this analysis, neutralino (χ_1^0) production has been studied via R_P-violating t-channel selectron exchange in positron proton scattering. The masses of squarks are assumed to be beyond the reach of HERA.

In Gauge Mediated Supersymmetry Breaking (GMSB) scenarios the slepton masses are usually much lower than the squark masses [2]. Therefore, the above process is studied within the framework of GMSB. Here the prompt decay of the neutralino into a photon and a gravitino is studied, which leads to prominent event signatures with a photon and large missing transverse momentum. Thus, the theoretical model investigated in this analysis is a combination of R_P-violating SUSY and GMSB. The gravitino is the lightest supersymmetric particle (LSP), while the neutralino is assumed to be the next-to-lightest supersymmetric particle (NLSP).

The data were taken from 1999 to 2000, when HERA was operating with a center of mass energy of $\sqrt{s} = 319$ GeV. They correspond to an integrated luminosity of 65.4 pb^{-1} (e^+p data) and 14.0 pb^{-1} (e^-p data).

2 Theoretical Framework

R-parity is a discrete multiplicative symmetry. It can be written as $R_P = (-1)^{3B+L+2S}$, where B denotes the baryon number, L the lepton number and S the spin of a particle. For all superfields of the supersymmetric Standard Model, each Standard Model (SM) field has the quantum number $R_P = +1$ and its superpartner $R_P = -1$. The most general gauge and supersymmetry invariant superpotential [3] contains an R_P-violating Yukawa coupling between a left-handed selectron $\tilde{e}_L$, a left-handed up-type quark u^i_L and a right-handed down type anti-quark $\bar{d}^j_R$, where i and j denote generation indices. The corresponding part of the Lagrangian reads as:

$$\mathcal{L}_{\mathrm{RPV}} = \lambda'_{1jk}(-\tilde{e}_L u^j_L \bar{d}^k_R) + h.c. \tag{1}$$

At HERA, the presence of interactions (1) lead to neutralino production via t-channel selectron exchange. The search presented here is performed under the simplifying assumption that one of the couplings λ'_{1j1} $(j = 1, 2)$ dominates. In GMSB models the gravitino mass is given by

$$m_{\tilde{G}} = \frac{F}{\sqrt{3}M_P} \tag{2}$$

where $M_P = 2.4 \cdot 10^{18}$ GeV is the reduced Planck mass and F the fundamental squared scale of Supersymmetry breaking. This leads to typically light (< 1 GeV) gravitino masses. Therefore the gravitino is the lightest SUSY particle. The couplings of SUSY particles to the gravitino are small, so the gravitino only emerges in the decay of the NLSP (which is the neutralino in our scenario), provided that the R_P-violating decay of the NLSP is not largely dominant.

3 Event Selection

The decay $\chi^0 \to \gamma\tilde{G}$ is characterized by missing transverse energy and by an electromagnetic cluster in the calorimeter. The main SM background is expected from CC DIS. Events characteristic [4] of non-ep interactions are rejected. Events are selected with a total vector sum of the transverse momentum in all calorimeters greater than 25 GeV and an identified isolated photon of transverse momentum greater than 15 GeV.

To reject NC DIS background in which the scattered electron (sometimes misinterpreted as a photon) is dominantly scattered through small angles, photon candidates are accepted in the forward region of the detector only ($10^o < \theta_\gamma < 80^o$). For $\theta_\gamma > 20^o$ an electromagnetic cluster is only accepted if it is *not* associated with a charged track in the central tracking system fulfilling matching criteria of cluster energy and track momentum. Furthermore, $\sum(E - p_z) > 15$ GeV is required[a] to reduce CC-DIS background.

Having applied all selection cuts, 1 (0) event is found for an expected background of 1.2 ± 0.2 (1.9 ± 0.2) events in the e^-p (e^+p) data set. The selection efficiency for the signal ranges between 10% and 30%.

4 GMSB Model Dependent Interpretations

No significant deviation from the SM has been observed (see Section 3), so limits in a GMSB model are derived, using the search results including the effects of systematic errors on the signal detection efficiencies and background expectation

[a] The summation runs over all energy deposits in the calorimeters.

[5]. While there is no unique GMSB model, there are typically [6,7,8] six new parameters in addition to those of the SM:

$$F,\ \Lambda,\ M,\ N,\ \tan\beta \text{ and } \mathrm{sign}(\mu)\,. \tag{3}$$

The parameter $\sqrt{F}$ is the intrinsic SUSY breaking scale which determines the $\tilde{G}$ mass, Λ sets the overall mass scale for SUSY particles, M is the mass of the messenger particles, N is the number of sets of messenger particles, and $\tan\beta$ is the usual ratio of the Higgs vacuum expectation values. The final parameter sign(μ) is the sign of the Higgs sector mixing parameter, μ (the magnitude of μ is calculable from the other parameters in the minimal model by imposing radiative electroweak symmetry breaking).

We work in a theoretical framework based on [6], but assuming that the left-handed selectron mass is equal to the right-handed one. The theoretical calculations are embedded in the SUSYGEN [9] generator. For the limits presented below, $\tan\beta = 2$, $N = 1$ and a negative μ is chosen. The remaining free GMSB parameters Λ and M have been transformed into the parameters $m_{\tilde{e},R}$ $(= m_{\tilde{e},L} = m_{\tilde{e}})$ and $m_{\chi_1^0}$. So, in the following, the limits are presented as a function of $m_{\tilde{e}}$ and $m_{\chi_1^0}$. The parameter range considered in this analysis corresponds then to a scan of $17.3 \le \Lambda \le 51.5$ TeV and $450 \le M \le 5.3 \cdot 10^7$ TeV. In figure 1, excluded regions at the 95% confidence level are presented in the plane spanned by $m_{\tilde{e}} - m_{\chi_1^0}$ and $m_{\chi_1^0}$ for different values of λ'. For selectron masses very close to the neutralino mass and for $\lambda'_{1j1} = 1.0$, neutralino masses up to 108 GeV can be excluded.

The excluded regions in figure 1 can be compared to the region excluded by OPAL [10] analyzing $e^+e^- \to \chi_1^0\chi_1^0 \to \gamma\tilde{G}\gamma\tilde{G}$ in an R-parity-conserving SUSY scenario. OPAL are mostly sensitive to right-handed selectrons (exchanged in the t-channel) and perform a scan over the GMSB parameter space. Their result for $\tan\beta = 2$ excludes the region $m_{\chi_1^0} = 91$ GeV (almost independently of the selectron mass) at the 95% confidence level. Thus, for not too low values of λ'_{1j1}, H1 can extend the region excluded by OPAL.

In figure 2, lower limits at 95% confidence level on λ'_{1j1} $(j = 1, 2)$ and λ'_{11k} $(k = 1, 2, 3)$ are given as a function of $m_{\chi_1^0}$ for various assumptions for the difference between selectron and neutralino mass. While λ'_{111} is already tightly constrained by neutrinoless double beta decay searches [11], these are the first limits derived on λ'_{121} which are independent of squark masses.

5 Conclusions

We have searched for events containing a photon and large missing transverse momentum, expected in R_P-violating models with gauge mediated SUSY breaking, at a center-of-mass energy of $\sqrt{s} = 319$ GeV with the H1 detector at HERA. No evidence for a deviation from the SM was found. Limits which constrain minimal models of gauge mediated supersymmetry breaking have been derived for different values of the R_P-violating coupling. For the first time, limits on the R_P-violating coupling λ'_{121} have been derived independently of squark masses.

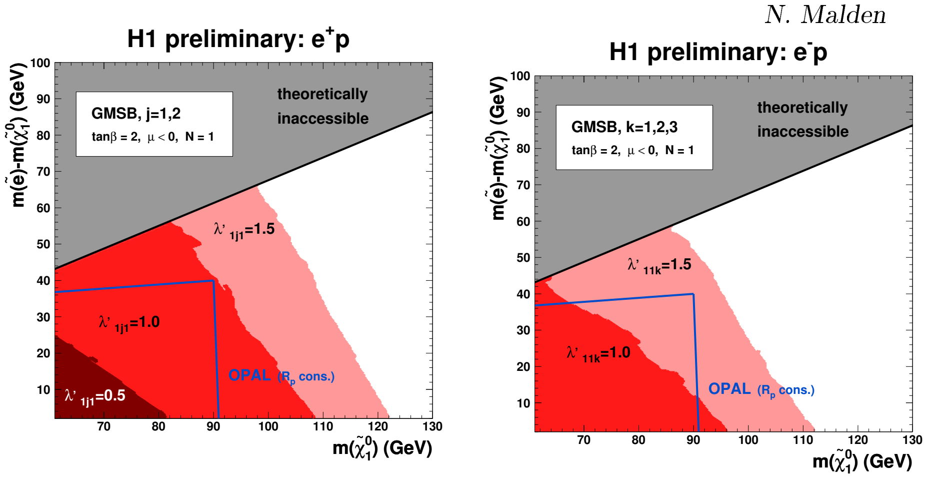

Figure 1. Excluded regions at the 95% C.L. in the plane spanned by $m_{\tilde{e}} - m_{\chi_1^0}$ and $m_{\chi_1^0}$ for different values of λ'.

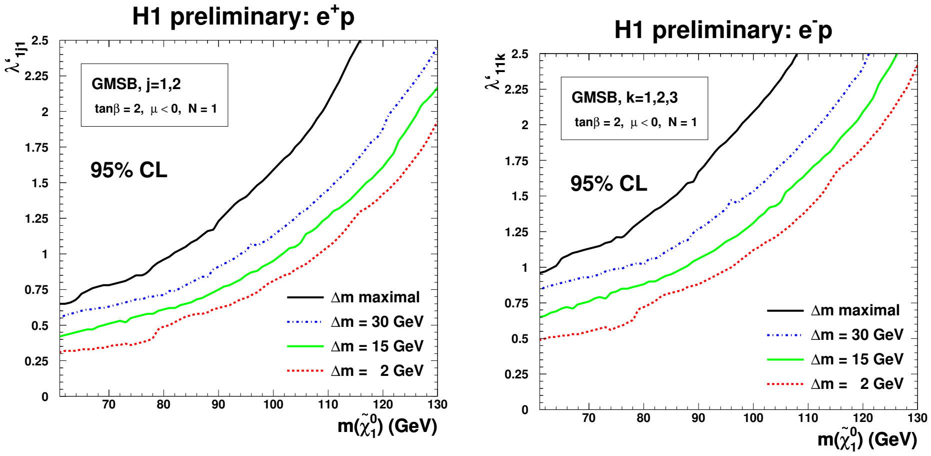

Figure 2. Lower limits at 95% C.L. on λ'_{1j1} $(j = 1, 2)$ and λ'_{11k} $(k = 1, 2, 3)$ as a function of $m_{\chi_1^0}$ for various assumptions for the difference between selectron and neutralino mass.

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