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# Search for Light Gravitinos in Events with Photons and Missing Transverse Momentum at HERA

H1 Collaboration

**Abstract**

A search for gravitinos produced in $e^{\pm}p$ collisions is performed using the H1 detector at HERA. The data were taken at a centre-of-mass energy of $319\,\mathrm{GeV}$ and correspond to an integrated luminosity of $64.3\,\mathrm{pb}^{-1}$ for $e^{+}p$ collisions and $13.5\,\mathrm{pb}^{-1}$ for $e^{-}p$ collisions. If $R$-parity is not conserved, the $t$-channel exchange of a selectron can produce a neutralino, which, in models where the gravitino is the lightest supersymmetric particle, subsequently decays into a photon and a light gravitino. The resulting event signature, which involves an isolated photon, a jet and missing transverse energy, is analysed for the first time at HERA. No deviation from the Standard Model is found. Exclusion limits on the cross section and on $R$-parity-violating Yukawa couplings are derived in a Gauge Mediated Supersymmetry Breaking scenario. The results are independent of the squark sector. Neutralinos and supersymmetric partners of the left-handed electron with masses up to $112\,\mathrm{GeV}$ and $164\,\mathrm{GeV}$, respectively, can be ruled out at the $95\,\%$ confidence level for $R$-parity-violating couplings $\lambda'$ equal to 1.

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# 1 Introduction

Supersymmetry (SUSY) [1] is an attractive concept which remedies some shortcomings of the Standard Model (SM). This fermion-boson symmetry leads to an extension of the particle spectrum by associating to each SM particle a supersymmetric partner, differing in its spin by half a unit. The masses of the new particles are related to the symmetry breaking mechanism. In Gauge Mediated Supersymmetry Breaking (GMSB) models, new "messenger" fields are introduced which couple to the source of supersymmetry breaking. The breaking is then transmitted to the SM fields and their superpartners by gauge interactions [2]. The gravitino, $\tilde{G}$, is the lightest supersymmetric particle (LSP) and can be as light as $10^{-3}$ eV.

The next-to-lightest supersymmetric particle (NLSP) is generally either the lightest neutralino $\tilde{\chi}_1^0$ or a slepton $\tilde{\ell}$, which decays to the stable gravitino via $\tilde{\chi}_1^0 \to \gamma\tilde{G}$ or $\tilde{\ell} \to \ell\tilde{G}$. The distinguishing event topology involves a high energy photon or lepton and significant missing energy due to the undetected gravitino. Such topologies have been studied at LEP [3] and the Tevatron [4, 5]. No significant deviation from the SM was found. In these studies $R$-parity ($R_p$) was assumed to be conserved. An investigation of $R_p$-violating ($\not{R}_p$) SUSY in a GMSB scenario is performed in this analysis. A search for $\not{R}_p$ resonant single neutralino production $\tilde{\chi}_1^0$ via $t$-channel selectron exchange, $e^{\pm}q \to \tilde{\chi}_1^0 q'$, is performed in $e^+p$ and $e^-p$ collisions. It is assumed that the $\tilde{\chi}_1^0$ is the NLSP and that the decay $\tilde{\chi}_1^0 \to \gamma\tilde{G}$ occurs with an unobservably small lifetime and dominates over $\not{R}_p$ neutralino decays. Feynman diagrams of the analysed processes are depicted in Fig. 1. The resulting experimental signature is a photon, a jet originating from the scattered quark and missing transverse momentum due to the escaping gravitino. The main SM background arises from radiative charged current (CC) deep inelastic scattering (DIS) with a jet, a photon and a neutrino in the final state.

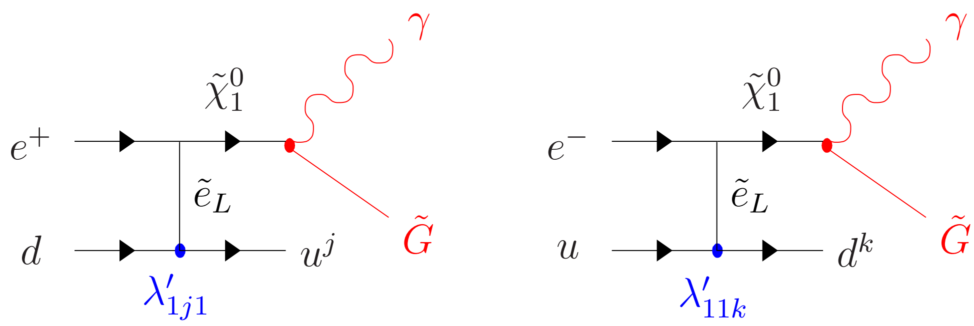


Figure 1: Dominant diagrams for neutralino production via $\not{R}_p$ selectron exchange in $e^+p$ and $e^-p$ scattering, with subsequent neutralino decay into a gravitino and a photon.

Resonant squark production in $\not{R}_p$ SUSY has been investigated previously at HERA in models in which the LSP is either a gaugino [6] or a light squark [7]. Squark mass dependent limits on various $\not{R}_p$ Yukawa couplings have been derived. In contrast, the process considered in this analysis is completely independent of the squark sector.

The data correspond to an integrated luminosity of $64.3\,\mathrm{pb}^{-1}$ for $e^+p$ collisions recorded in 1999 and 2000 and $13.5\,\mathrm{pb}^{-1}$ for $e^-p$ collisions recorded in 1998 and 1999. The energy of the incoming electron[1] is $E_e = 27.6\,\mathrm{GeV}$ and the energy of the incoming proton is $E_p = 920\,\mathrm{GeV}$. Thus the electron-proton centre-of-mass energy is $319\,\mathrm{GeV}$.

# 2 The Supersymmetric Model

This analysis considers a supersymmetric model where the gravitino is the LSP and in which $R_p$ is not conserved – a scenario which has been used e.g. in [8] and has been considered before in the context of dark matter [9]. $R$-parity is a discrete multiplicative symmetry which 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. The most general supersymmetric theory that is renormalisable and gauge invariant with respect to the SM gauge group [10] contains $\not{R}_p$ Yukawa couplings between the supersymmetric partner of the left-handed electron $\tilde{e}_L$, a left-handed up-type quark $u_L^j$ and a right-handed down-type anti-quark $\bar{d}_R^k$, where $j$ and $k$ denote generation indices. The corresponding part of the Lagrangian reads

$$\mathcal{L}_{\not{R}_p} = -\lambda'_{1jk}\tilde{e}_L u_L^j \bar{d}_R^k + \mathrm{h.c.} \tag{1}$$

At HERA, the presence of couplings $\lambda'_{1j1}$ and $\lambda'_{11k}$ could lead to neutralino production in $e^+p$ and $e^-p$ collisions, respectively, via $t$-channel selectron exchange (see Fig. 1). The search presented here is performed under the simplifying assumption that one of the couplings $\lambda'_{1j1}$ ($j = 1, 2$) or $\lambda'_{11k}$ ($k = 1, 2, 3$) dominates[2]. If the initial state lepton is a positron the dominant hard scattering process at the large Bjorken $x$ values relevant here involves a down quark from the proton (see Fig. 1, left). If the initial state lepton is an electron mainly up quarks are probed (see Fig. 1, right). For a given $\not{R}_p$ coupling, the $\tilde{\chi}_1^0$ production cross section for an initial electron is roughly a factor of two larger than that for an initial positron, reflecting the different parton densities for valence up and down quarks in the proton. Due to the contribution of diagrams involving antiquarks in the initial state (not shown in Fig. 1), the cross section for $\tilde{\chi}_1^0$ production in $e^+p$ ($e^-p$) collisions via a $\lambda'_{111}$ coupling is larger than that for production via a $\lambda'_{121}$ ($\lambda'_{112}$) coupling of the same strength. The relative difference amounts to at most $15\%$ ($8\%$) for $e^+p$ ($e^-p$) processes, for low masses of the produced neutralino. The cross sections of the $e^-p$ processes induced by $\lambda'_{112}$ and $\lambda'_{113}$ are the same within a few percent.

The GMSB model used here is inspired by [11]. While the gaugino mass spectrum and gauge couplings are derived from this minimal model, the slepton masses are treated as free parameters. The supersymmetric partner of the left-handed electron can be much lighter than the supersymmetric partner of the right-handed one as, for example, in the Hybrid Multi-Scale Supersymmetric Model HMSSM-I [12]. This allows small mass differences $\Delta m = m(\tilde{e}_L) - m(\tilde{\chi}_1^0)$.

The GMSB model is characterised by six new parameters in addition to those of the SM:

$$\Lambda,\ M,\ N,\ \tan\beta,\ \mathrm{sign}(\mu)\ \text{and}\ \sqrt{F}\,. \tag{2}$$

[1] In the following *electron* will be used to refer to both electron and positron unless explicitly otherwise stated.

[2] The coupling $\lambda'_{131}$ is not studied here because the production of a top quark together with a neutralino is suppressed due to the high top quark mass.

The parameter $\Lambda$ sets the overall mass scale for the SUSY particles, $M$ is the mass of the messenger particles, $N$ is the number of sets of messenger particles, $\tan\beta$ is the ratio of the Higgs vacuum expectation values and $\mathrm{sign}(\mu)$ is the sign of the Higgs sector mixing parameter $\mu$. The intrinsic SUSY breaking scale is $\sqrt{F}$, which also determines the $\tilde{G}$ mass according to $m_{\tilde{G}} \simeq 2.5 \cdot F/(100\ \mathrm{TeV})^2\,\mathrm{eV}$. Furthermore, $\sqrt{F}$ affects the neutralino decay rate according to $\Gamma(\tilde{\chi}_1^0 \to \gamma\tilde{G}) \sim 1/F^2$; low values of $\sqrt{F}$ thus suppress the $R\!\!\!/_p$ decays of the neutralino. In the SUSY parameter space considered here, the branching ratio $\mathrm{BR}(\tilde{\chi}_1^0 \to \gamma\tilde{G})$ exceeds $95\,\%$ if $\sqrt{F}$ lies in the range between the present experimental limit of $221\,\mathrm{GeV}$ [13] and $1\,\mathrm{TeV}$. Thus, $\sqrt{F}$ is not varied but it is assumed that the $R\!\!\!/_p$ decays of the neutralino do not contribute. In the range considered for $\sqrt{F}$ the neutralino lifetime is short enough to have no effect on the detection efficiency. The contributions of the heavier neutralinos $\tilde{\chi}_i^0$ $(i = 2, 3, 4)$ to the considered signal are small and thus neglected.

# 3 The H1 Detector

In the following the detector components most relevant for this analysis are briefly described. The main components of the tracking system are the central drift and proportional chambers which cover the polar angle[3] range $20^\circ < \theta < 160^\circ$ and a forward track detector ($7^\circ < \theta < 25^\circ$). The tracking system is surrounded by a finely segmented liquid argon (LAr) calorimeter [14] which covers the range $4^\circ < \theta < 154^\circ$ and which has an energy resolution of $\sigma_E/E \simeq 12\,\%/\sqrt{E(\mathrm{GeV})} \oplus 1\,\%$ for electrons and $\sigma_E/E \simeq 50\,\%/\sqrt{E(\mathrm{GeV})} \oplus 2\,\%$ for hadrons, as obtained in test beam measurements [15]. The tracking system and calorimeters are surrounded by a superconducting solenoid and its iron yoke instrumented with streamer tubes. The latter are used to detect hadronic showers which extend beyond the LAr and to identify muons. The luminosity is determined from the rate of Bethe-Heitler events ($ep \to ep\gamma$) measured in a luminosity monitor. A detailed description of the H1 experiment can be found in [16].

# 4 Event Simulation

In order to estimate the expected SM contributions to the signature under study and to determine the detection efficiencies for a possible SUSY signal, complete Monte Carlo (MC) simulations of the H1 detector response are performed. For each possible SM source a sample of MC events is used corresponding to a luminosity of more than 10 times that of the data. For the simulation of the charged and neutral current (CC and NC) DIS backgrounds, the DJANGO [17] event generator is used which includes first order QED radiation as modelled by HERACLES [18]. The parton densities in the proton are taken from the CTEQ5L [19] parameterisation. The direct and resolved photoproduction of light and heavy quark flavours is generated using the PYTHIA [20] program. The SM predictions for $ep \to eZX$ and $ep \to eW^\pm X$ are calculated using the leading order generator EPVEC [21] with the next-to-leading order QCD corrections implemented using a reweighting method [22].

[3]The polar angle $\theta$ is measured with respect to the proton beam direction.

The signal topology is simulated using the SUSYGEN generator [23]. The parton densities are evaluated at the scale of the Mandelstam variable $-t$. Efficiencies are determined by interpolation between calculations at different points in the parameter space, where the neutralino mass $m(\tilde{\chi}_1^0)$ is varied from $50\,\mathrm{GeV}$ to $140\,\mathrm{GeV}$ and the selectron mass $m(\tilde{e}_L)$ from $m(\tilde{\chi}_1^0)$ to $200\,\mathrm{GeV}$, both in steps of typically $15\,\mathrm{GeV}$.

# 5 Search for the Process $e^{\pm}q \rightarrow \tilde{\chi}_1^0 q' \rightarrow \gamma\tilde{G}q'$

## 5.1 Event Preselection

The process $e^{\pm}q \rightarrow \tilde{\chi}_1^0 q' \rightarrow \gamma\tilde{G}q'$ is characterised by missing transverse energy, a jet and an electromagnetic cluster in the calorimeter. The events used in this analysis are triggered by the LAr system with an efficiency of typically $95\,\%$ for the chosen kinematic region. Background events not related to $ep$ collisions are suppressed by requiring a primary interaction vertex reconstructed within $\pm 35\,\mathrm{cm}$ in $z$ of the nominal vertex position, by using topological filters against cosmic and proton-beam related background and by requiring an event time which is consistent with the bunch crossing time.

Events are selected if the missing transverse momentum determined from the energy deposits in the calorimeter is greater than $25\,\mathrm{GeV}$. The events are required to contain at least one hadronic jet in the range $10^{\circ} < \theta_{\mathrm{jet}} < 145^{\circ}$ and an identified photon with a polar angle $\theta_\gamma$ greater than $10^{\circ}$, both with transverse momenta greater than $5\,\mathrm{GeV}$. Hadronic jets are reconstructed from energy deposits in the calorimeter using a cone algorithm in the laboratory frame with a radius $\sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} = 1$, where $\eta = -\ln\tan\theta/2$ is the pseudorapidity and $\phi$ denotes the azimuthal angle.

Photons are identified using a shower shape analysis of energy deposits in the LAr calorimeter. For $\theta_\gamma > 20^{\circ}$ an electromagnetic cluster is only accepted as a photon candidate if it is not associated with a charged track in the central tracking system. In addition, the photon must not lie within the cone of any reconstructed jet with $p_{T,\mathrm{jet}} > 5\,\mathrm{GeV}$.

## 5.2 Systematic Uncertainties

The systematic errors on the SM background expectation are evaluated by considering the following uncertainties.

- The uncertainty on the electromagnetic energy scale of the calorimeter varies from $0.7\,\%$ to $3\,\%$ depending on the calorimeter region [24].
- For the jet transverse momenta selected in this analysis (typically above $20\,\mathrm{GeV}$) the uncertainty on the hadronic energy scale is $2\,\%$ [25].
- The uncertainty on the track reconstruction efficiency is $2\,\%$.

- An uncertainty of $10\,\%$ is attributed to the SM cross sections for CC and NC DIS as implemented in the MC simulation which arises mainly from the parton densities of the proton at high $x$.
- The measurement of the integrated luminosity has a precision of $1.5\,\%$.

Furthermore, the following uncertainties related to the modelling of the SUSY signal are taken into account.

- The theoretical uncertainty of the signal cross section due to the uncertainty of the parton densities, which is typically a few percent and does not exceed $7\,\%$ for $e^-p$ scattering or $17\,\%$ for $e^+p$ scattering anywhere in the parameter space studied.
- Choosing either the invariant mass of the final state particles or the transverse momentum of the final state quark instead of the square root of the Mandelstam variable $-t$ as the hard scale at which the parton distributions are evaluated yields an additional theoretical uncertainty of up to $10\,\%$ at large selectron and neutralino masses.
- A relative uncertainty of $10\,\%$ is attributed to the signal detection efficiencies, resulting mainly from the interpolation between the neutralino and selectron masses.

All systematic errors are added in quadrature separately for the signal and the background. The resulting uncertainties are between $11\,\%$ and $22\,\%$ in both cases.

### 5.3 Final Selection and Results

After the preselection, described in Section 5.1, 12 candidate events are selected in the complete $e^{\pm}p$ data sample and $11.5 \pm 1.5$ events are expected from SM background processes, predominantly from radiative CC DIS ($95\,\%$). The distributions of the polar angle $\theta_\gamma$ and the transverse momentum $p_{T,\gamma}$ of the photon candidates are shown in Fig. 2 (a) and (b), respectively. Fig. 2 (c) shows the transverse momentum $p_{T,h}$ calculated from the hadronic energy deposits in the calorimeter. The sum of the $E - p_z$ of all measured particles is presented in Fig. 2 (d). The distributions illustrate the good understanding of the SM processes. For comparison, a simulated SUSY signal for a $\tilde{\chi}_1^0$ mass of $125\,\mathrm{GeV}$ is also shown.

To reduce the CC DIS background, $p_{T,\gamma} > 15\,\mathrm{GeV}$ and $E - p_z > 15\,\mathrm{GeV}$ are required for the final selection. These cuts are also depicted in Fig. 2. No candidate event is found in the $e^+p$ data set, to be compared with $1.8 \pm 0.2$ expected from SM processes. In the $e^-p$ data sample, 1 candidate event is found while the SM prediction is $1.1 \pm 0.2$. The SM expectation arises predominantly from CC DIS ($90\,\%$) with small contributions from NC DIS and the production of $W$ and $Z$ bosons where the final state electron is misidentified as a photon. With all cuts applied, the final selection efficiency for the signal ranges between $10\,\%$ for low and $35\,\%$ for high neutralino masses. The largest contribution to the inefficiency arises from the missing transverse energy requirement.

Assuming that the massless gravitino is the only non-interacting particle in the event, its kinematics are reconstructed by exploiting the conservation of transverse momentum and the

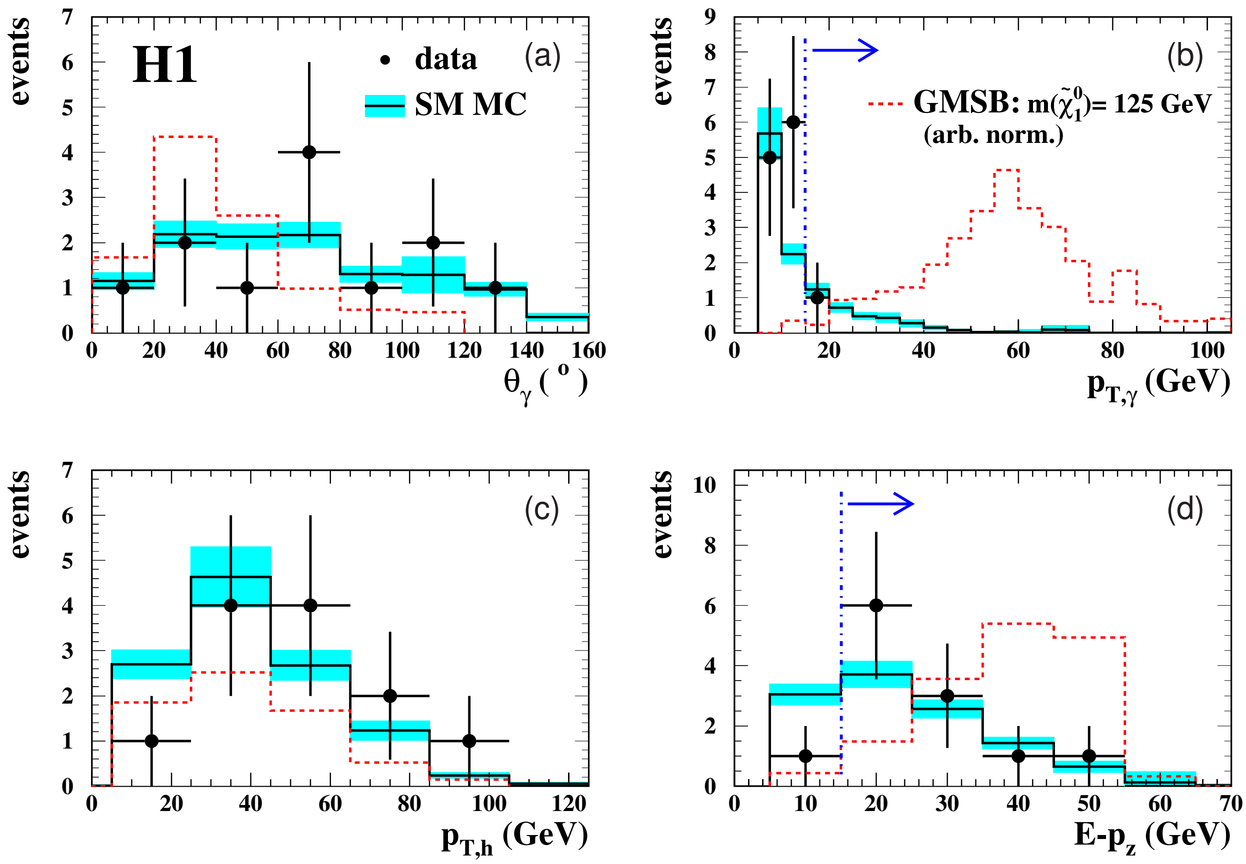


Figure 2: Distributions of the polar angle (a) and transverse momentum (b) of photon candidates, hadronic transverse momentum (c) and the sum of the $E - p_z$ of all measured particles (d) after preselection. The complete $e^{\pm}p$ data set is compared with the SM prediction. The signal expected for a neutralino with a mass of $125\,\mathrm{GeV}$ is shown with arbitrary normalisation (dashed histogram). The arrows indicate additional cuts applied on $p_{T,\gamma}$ and $E - p_z$ in the final selection.

constraint $(E-p_z)+(E_{\tilde{G}}-p_{z,\tilde{G}}) = 2E_e$. The four-vector of this particle is then added to that of the photon to reconstruct the invariant mass $m$ of the decaying neutralino. The data and the SM expectation for this distribution are shown in Fig. 3. From the simulation of the SUSY signal, also shown in Fig. 3, the mass resolution is determined to be around $10\,\mathrm{GeV}$. The candidate event has a reconstructed invariant neutralino mass of $36 \pm 4\,\mathrm{GeV}$.

# 6 GMSB Model Interpretations

As no significant deviation from the SM is observed, constraints on GMSB models at the $95\,\%$ confidence level (CL) are derived using a modified frequentist approach based on likelihood ratios, which takes statistical and systematic uncertainties into account [26]. For a given neutralino mass $m(\tilde{\chi}_1^0)$, the limits are obtained by counting the number of observed and expected events in a certain mass interval. In the investigated range of $50\,\mathrm{GeV} < m(\tilde{\chi}_1^0) < 140\,\mathrm{GeV}$,

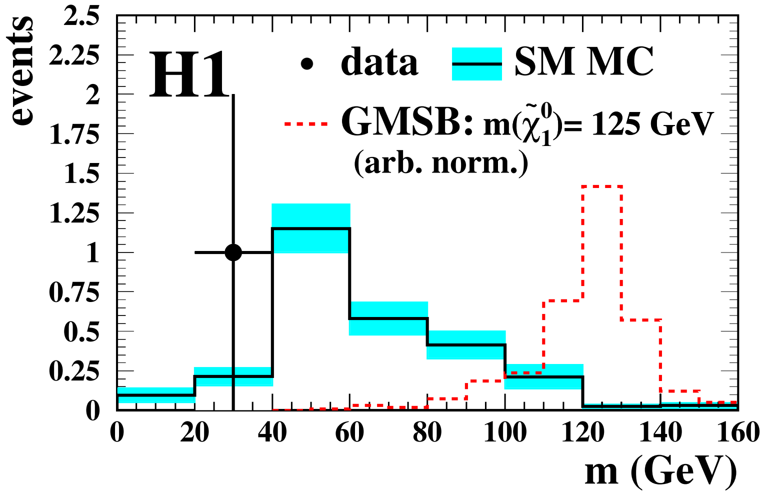


Figure 3: Distribution of the invariant mass of the photon candidate and the reconstructed missing particle in the final selection. The complete $e^{\pm}p$ data set is compared with the SM prediction. The signal expected for a neutralino with a mass of $125\,\mathrm{GeV}$ is shown with arbitrary normalisation (dashed histogram).

a mass interval of $\pm 2$ standard deviations, varying linearly between $\pm 16.5\,\mathrm{GeV}$ and $\pm 30\,\mathrm{GeV}$ around $m(\tilde{\chi}_1^0)$, is chosen.

For the interpretation of the results, the GMSB parameters $\tan\beta$, $N$ and $\mathrm{sign}(\mu)$ are fixed. The neutralino mass is scanned by varying $\Lambda$ at fixed $M/\Lambda$, the masses being calculated using the SUSPECT program [27]. The mass of the supersymmetric partner of the left-handed electron is taken as a free parameter. All other sfermions are assumed to be heavy. Two example scenarios are considered. In the first, the masses considered correspond to a scan of the parameters in the range $30\,\mathrm{TeV} \leq \Lambda \leq 100\,\mathrm{TeV}$ taking $M/\Lambda = 2$ for $\tan\beta = 2$ and $N = 1$ with negative $\mu$. In the second scenario, $\tan\beta = 6$, $N = 2$, $\mu < 0$ and the parameter range is $20\,\mathrm{TeV} \leq \Lambda \leq 50\,\mathrm{TeV}$ with $M/\Lambda = 10^3$. For a given neutralino mass, a variation of $N$ has only a minor effect on the cross section, whereas the cross section decreases significantly with increasing $\tan\beta$.

In Fig. 4, upper limits on the cross sections are shown as a function of $m(\tilde{\chi}_1^0)$. The limits become less stringent at low neutralino masses due to the reduced signal detection efficiencies. The GMSB cross sections for different values of the couplings $\lambda'_{121}$ and $\lambda'_{112}$ are also shown for a mass difference $\Delta m = m(\tilde{e}_L) - m(\tilde{\chi}_1^0) = 10\,\mathrm{GeV}$.

In Fig. 5, excluded regions are presented in the plane spanned by $\Delta m$ and $m(\tilde{\chi}_1^0)$ using data from $e^+p$ and $e^-p$ collisions for various values of the respective $\not{R}_p$ coupling. The excluded domains, obtained for $\lambda'_{1j1}$ ($j = 2$) and $\lambda'_{11k}$ ($k = 2, 3$), conservatively apply also in the case of a $\lambda'_{111}$ coupling. For $\tan\beta = 2$, $N = 1$ and $\lambda'_{1j1} = 1.0$, the $e^+p$ results exclude neutralino masses up to $112\,\mathrm{GeV}$ for small $\Delta m$. For large $\Delta m$ and small neutralino masses, selectron masses up to $164\,\mathrm{GeV}$ are excluded. In $e^-p$ collisions, for $\tan\beta = 2$, $N = 1$ and $\lambda'_{11k} = 1.0$, neutralino masses up to $98\,\mathrm{GeV}$ for small $\Delta m$ and selectron masses up to $118\,\mathrm{GeV}$ for large $\Delta m$ are ruled out.

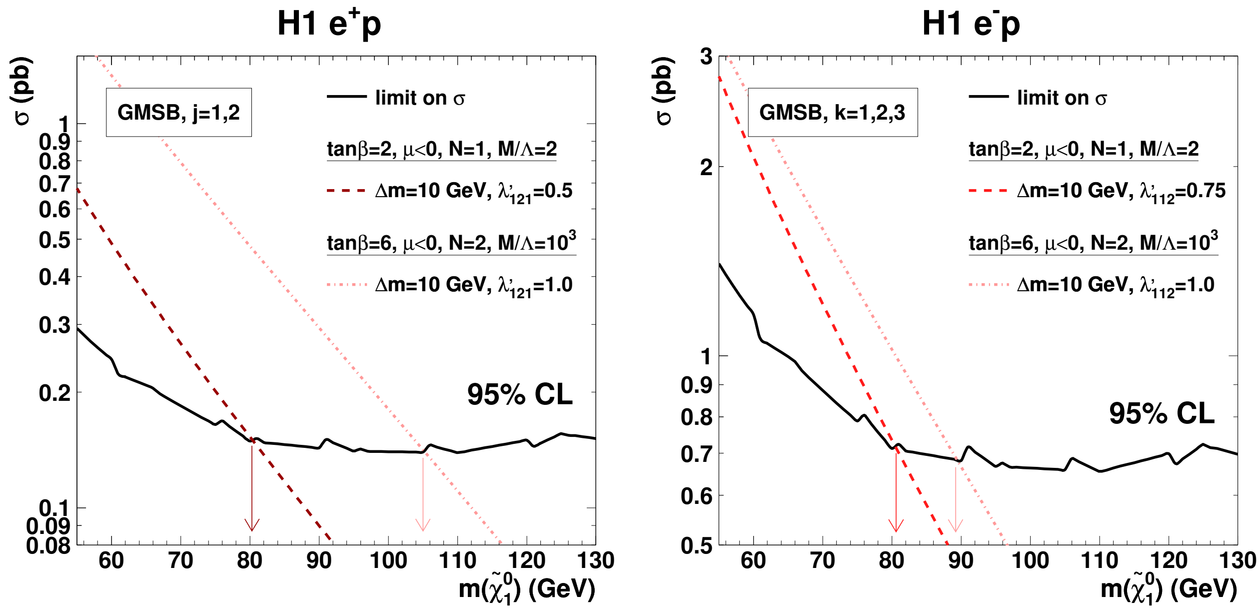


Figure 4: Upper limit at the 95 % CL on the cross section as a function of the neutralino mass for example GMSB scenarios (solid lines). For comparison, the GMSB cross sections for different $\not{R}_p$ couplings $\lambda'_{121}$ and $\lambda'_{112}$ are superimposed for a mass difference of $\Delta m = m(\tilde{e}_L) - m(\tilde{\chi}_1^0) = 10\,\mathrm{GeV}$ (dashed and dashed-dotted lines).

Apart from the coupling $\lambda'_{111}$, which is tightly constrained by searches for the neutrinoless double beta decay of nuclei [28], values of $\lambda'_{1jk} = 1$ $((j,k) \neq (1,1))$ are not excluded by indirect measurements when the squark masses are very high[4]. The limits on the $\lambda'_{121}$, $\lambda'_{112}$ and $\lambda'_{113}$ couplings obtained in this analysis are the first constraints which depend only on the slepton and neutralino masses. For instance, for masses of the $\tilde{\chi}_1^0$ and $\tilde{e}_L$ close to $55\,\mathrm{GeV}$, couplings $\lambda'_{1j1} > 0.3$ $(j = 1,2)$ and $\lambda'_{11k} > 0.5$ $(k = 1,2,3)$ are ruled out for $\tan\beta = 2$ and $N = 1$.

The range of neutralino masses which is excluded by this analysis for $\not{R}_p$ couplings of the order of one is comparable with that which is probed at the Tevatron [5] and at LEP [3]. It should be stressed, however, that our results are complementary to those derived at the Tevatron where the dominant contributions to the cross section are from the production of the lightest charginos ($\tilde{\chi}_1^+\tilde{\chi}_1^-$) and chargino-second neutralino pairs ($\tilde{\chi}_2^0\tilde{\chi}_1^\pm$). They are also complementary to those obtained at LEP since the process $e^+e^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0 \to \gamma\tilde{G}\gamma\tilde{G}$ is mainly sensitive to the supersymmetric partner of the right-handed electron.

# 7 Conclusions

Events containing a photon, a jet and large missing transverse momentum are analysed in data from $e^\pm p$ collisions at a centre-of-mass energy of $\sqrt{s} = 319\,\mathrm{GeV}$ using the H1 detector at HERA. Within the SM this topology is mainly produced by charged current processes with

[4] For example [29], searches for atomic parity violation allow couplings $\lambda'_{1jk} = 1$ if the supersymmetric partner of the left-handed up-type (right-handed down-type) quarks are heavier than $3.5\,\mathrm{TeV}$ ($5\,\mathrm{TeV}$).

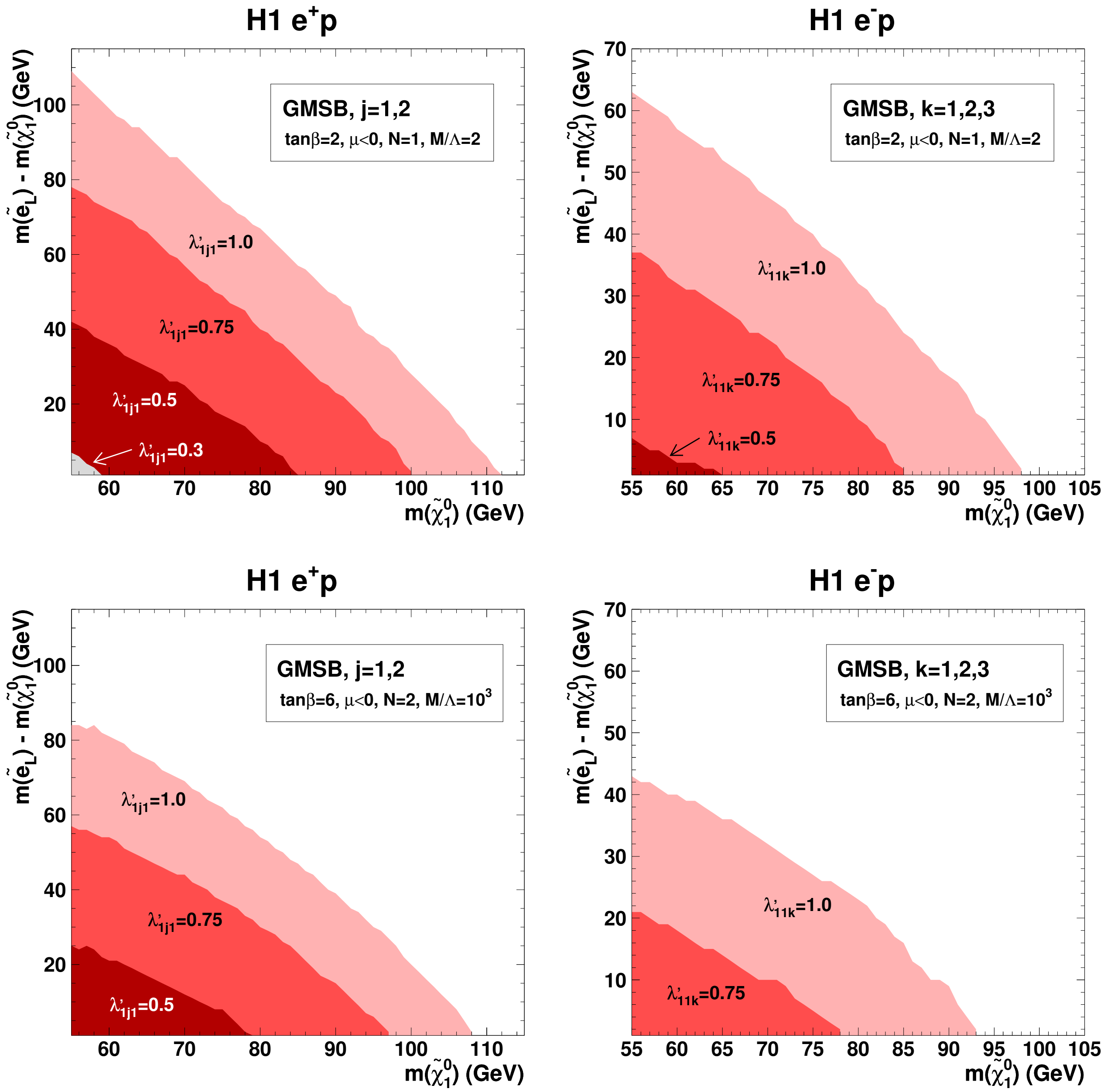


Figure 5: Excluded regions at the $95\,\%$ CL in the $\Delta m = m(\tilde{e}_L) - m(\tilde{\chi}_1^0)$ and $m(\tilde{\chi}_1^0)$ plane for various values of $\lambda'_{1j1}$ $(j = 1, 2)$ and $\lambda'_{11k}$ $(k = 1, 2, 3)$.

photon radiation. Such events also arise in gauge mediated SUSY breaking models with $R$-parity violation ($\not{R}_p$). The data analysis reveals no deviation from the SM. Constraints on GMSB models are derived for different values of the $\not{R}_p$ coupling. For small mass differences between the neutralino $\tilde{\chi}_1^0$ and the supersymmetric partner of the left-handed electron $\tilde{e}_L$, neutralinos with $m(\tilde{\chi}_1^0)$ up to $112\,\mathrm{GeV}$ are ruled out at the $95\,\%$ CL for $\not{R}_p$ couplings $\lambda' = 1$. Similarly, for large mass differences, masses $m(\tilde{e}_L)$ up to $164\,\mathrm{GeV}$ are excluded. For masses $m(\tilde{\chi}_1^0)$ and $m(\tilde{e}_L)$ close to $55\,\mathrm{GeV}$, $\lambda'_{1j1}$ Yukawa couplings of electromagnetic strength are excluded. These are the first constraints from HERA on SUSY models which are independent of the squark sector.

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