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SEARCHES FOR SQUARKS WITH H1 AT HERA

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A search for squarks in R-parity violating supersymmetry is performed in $e^{\pm}p$ collisions at HERA using the H1 detector. The resonant production of squarks via a Yukawa coupling λ' is considered, taking into account direct and indirect R-parity violating decay modes. No evidence for squark production is found in the final state topologies investigated. Mass dependent limits on λ' are obtained in the framework of the Minimal Supersymmetric Standard Model.

The ep collider HERA is ideally suited to search for new particles coupling to electron[a]–quark pairs. In supersymmetric models (SUSY) with R-parity violation ($\not{R}_p$), squarks can couple to electrons and quarks via Yukawa couplings λ'. At HERA, squarks could be produced resonantly via the fusion of the incoming electron and a quark from the incoming proton. Squark masses up to the electron-proton centre-of-mass energy are kinematically accessible. The data were taken at $\sqrt{s} = 319\,\mathrm{GeV}$ and $\sqrt{s} = 301\,\mathrm{GeV}$ and correspond to an integrated luminosity of $105.8\,\mathrm{pb}^{-1}$ for e^+p collisions and $13.5\,\mathrm{pb}^{-1}$ for e^-p collisions.

In the most general supersymmetric theory that is renormalisable and gauge invariant with respect to the Standard Model (SM) gauge group, the R-parity $R_p = (-1)^{3B+L+2S}$, where B denotes the baryon number, L the lepton number and S the spin of a particle, is not conserved. Couplings between two ordinary fermions and a squark ($\tilde{q}$) or a slepton ($\tilde{l}$) are then allowed.

1 Search for squark production at HERA

The $\not{R}_p$ Yukawa couplings responsible for squark production at HERA are described in the superpotential by the terms $\lambda'_{ijk} L_i Q_j \overline{D}_k$, where i, j and k are family indices. L_i, Q_j and D_k are superfields, which contain the left-handed leptons, the left-handed quarks and the right-handed down quark, respectively, together with their SUSY partners $\tilde{l}^i_L$, $\tilde{q}^j_L$ and $\tilde{d}^k_R$. Non-vanishing couplings λ'_{1jk} allow the resonant production of squarks at HERA through eq fusion. The values of the couplings are not fixed by the theory. For simplicity, it is assumed here that one of the λ'_{1jk} dominates over all other possible trilinear couplings.

In $\not{R}_p$ SUSY squarks can decay via their Yukawa coupling λ' into SM fermions. The $\tilde{d}_R$-type squarks can decay either into $e^- + u^j$ or $\nu_e + d^j$, while the $\tilde{u}_L$-type squarks decay into $e^+ + d^k$ only. The $\not{R}_p$ squark decays proceed directly via the

[a] In the following, the term *electron* refers to both electrons and positrons if not stated otherwise.

couplings λ'_{11k} and λ'_{1j1}. Squarks can also decay via their usual R_p conserving gauge couplings. The $\tilde{u}_L$-type squarks can undergo a gauge decay into states involving a neutralino χ_i^0 $(i = 1 \ldots 4)$, a chargino χ_i^+ $(i = 1, 2)$ or a gluino $\tilde{g}$. In contrast, $\tilde{d}_R$-type squarks decay to χ_i^0 or $\tilde{g}$ only and decays into charginos are suppressed.

A version of the Minimal Supersymmetric Standard Model (MSSM) is considered where the masses of the neutralinos, charginos and gluinos, as well as the couplings between any two SUSY particles and a SM fermion/boson, are determined by the usual parameters. These are the "mass" term μ, which mixes the Higgs superfields, the SUSY soft-breaking mass parameters M_1, M_2 and M_3 and the ratio $\tan\beta$ of the vacuum expectation values of the two neutral scalar Higgs fields. The parameters are defined at the electroweak scale. The gaugino mass terms are assumed to unify at a Grand Unification (GUT) scale to a common value $m_{1/2}$. The sfermion masses are free parameters in this model.

In a search for the $\not{R}_p$ production of squarks in e^+p and e^-p collisions at HERA no significant deviation from the SM is observed in any of the final state topologies resulting from direct or indirect R_p violating squark decays. For details on the analysis see [1] and references therein. Mass dependent limits on the $\not{R}_p$ couplings λ'_{1jk} are derived within a phenomenological version of the MSSM. In order to investigate the dependence of the sensitivity on the MSSM parameters, a scan of the SUSY parameter space is performed. Squarks of all flavours with masses up to 275 GeV can be excluded at the 95% confidence level for a Yukawa coupling of electromagnetic strength. For a 100 times smaller coupling strength masses up to 220 GeV can be ruled out. As examples, in figure 1 the results for the direct production of squarks for λ'_{1j1} for $j = 1, 2$ and for λ'_{11k} for $k = 1, 2$ are compared with indirect limits from virtual squark exchange in low energy experiments. In addition, the results are interpreted in terms of constraints on the parameters of the minimal Supergravity model. The excluded regions in the $(m_0, m_{1/2})$ plane for $\lambda'_{1j1} = 0.3$ and $\lambda'_{11k} = 0.3$ are shown in figure 2.

2 Search for bosonic stop decays at HERA

A complementary scenario is investigated (for details on the analysis see [2] and references therein), in which decays of the light squarks into neutralinos and charginos are kinematically not possible. It is moreover assumed that the sbottom quark $\tilde{b}$ is lighter than the lightest stop, such that the only possible decay modes are $\tilde{t} \to \tilde{b}W$ with $W \to f\bar{f}'$ and the $\not{R}_p$ decay into SM fermions, $\tilde{t} \to e^+d$. The stop quarks which are produced resonantly in e^+p collisions can decay bosonically into a sbottom quark and a W boson, $\tilde{t} \to \tilde{b}W$. The subsequent $\not{R}_p$ sbottom decay into SM particles, $\tilde{b} \to \bar{\nu}_e d$, and leptonic and hadronic W decays are investigated.

The R_p conserving bosonic stop decays lead to three final state topologies: the $je\not{P}_\perp$ channel, the $j\mu\not{P}_\perp$ channel and the $jjj\not{P}_\perp$ channel. R–parity violating direct stop decays have topologies similar to those of NC DIS processes. The analysis is particularly interesting following the observation of events with isolated electrons or muons and missing transverse momentum at H1 which have final state topologies similar to those of the $je\not{P}_\perp$ or $j\mu\not{P}_\perp$ channel. In the third generation large mixings between $\tilde{q}_L$ and $\tilde{q}_R$ are conceivable and therefore taken into account. Because of

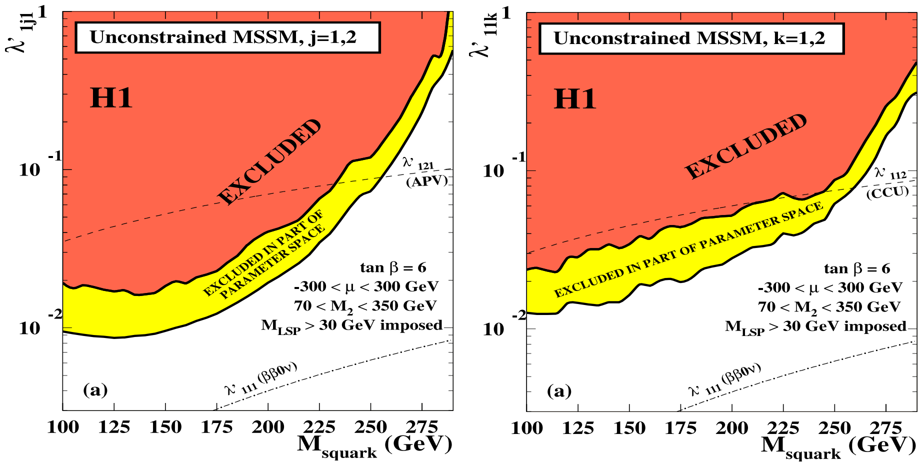

Figure 1. Exclusion limits (95 % CL) on λ'_{1j1} for $j = 1, 2$ (left) and on λ'_{11k} for $k = 1, 2$ (right) as a function of the squark mass from a scan of the MSSM parameter space as indicated in the figures. The two full curves indicate the strongest and the weakest limits on λ' in the parameter space investigated. Indirect limits from neutrinoless double beta decay experiments ($\beta\beta0\nu$) and atomic parity violation (APV) are also shown.

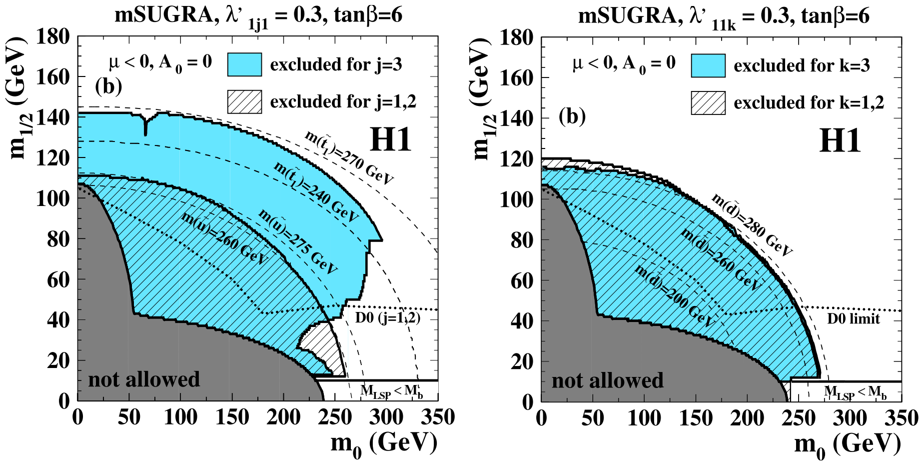

Figure 2. Excluded regions (95 % CL) in mSUGRA for $\tan\beta = 6$ with $\lambda'_{1j1} = 0.3$ (left) and $\lambda'_{11k} = 0.3$ (right). The region marked "not allowed" corresponds to values of the parameters where no REWSB solution is possible or where the LSP is a sfermion. The dashed lines indicate the curves of constant squark ($\tilde{u}_L$, $\tilde{t}_1$) mass. The limits from LEP and the Tevatron are given by the dotted lines.

the structure of the squark mass matrices the stop and sbottom are the most likely candidates for the lightest squark states. The mixing angles $\theta_{\tilde{t}}$ and $\theta_{\tilde{b}}$ parameterise the mass eigenstates.

The interpretation of the results is performed within a MSSM in which the

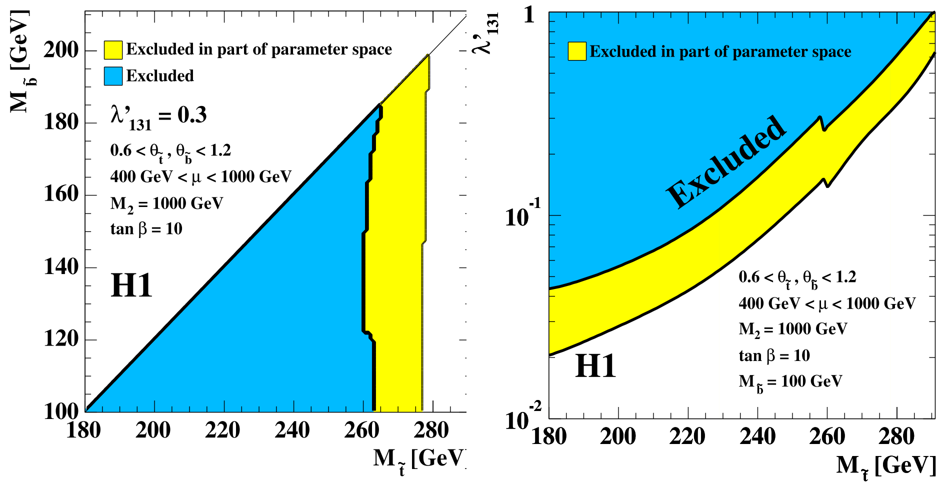

Figure 3. Exclusion limits at the 95% CL in the $(M_{\tilde{t}}, M_{\tilde{b}})$ plane for $\lambda'_{131} = 0.3$ (left) and on the $\not{R}_p$ coupling λ'_{131} as a function of the stop mass for $M_{\tilde{b}} = 100$ GeV (right). The limits are derived from a scan of the MSSM parameter space as indicated in the figures. The two full curves indicate the regions excluded in all (dark) or part (light) of the parameter space investigated.

masses of the neutralinos and charginos, as well as the couplings between any two SUSY particles and a standard model fermion/boson, are determined by the usual MSSM parameters. All squark masses as well as the squark mixings $\theta_{\tilde{t}}$ and $\theta_{\tilde{b}}$ are free parameters in this model.

In order to investigate the dependence of the sensitivity on the MSSM parameters, again a scan of the SUSY parameter space is performed. In the $j\mu\not{P}_\perp$ channel, a slight excess of events compared with the SM expectation is observed. Nevertheless, in e^+p collisions at HERA no evidence for stop production is found, since this excess is not supported by the other three final state topologies under consideration. The resulting limits obtained for $\tan\beta = 10$ are shown in figure 3 in the $(M_{\tilde{t}}, M_{\tilde{b}})$ plane for $\lambda'_{131} = 0.3$ (left) and in the $(M_{\tilde{t}}, \lambda'_{131})$ plane for $M_{\tilde{b}} = 100$ GeV (right). At $\lambda'_{131} = 0.3$ stop masses $M_{\tilde{t}} \lesssim 275$ GeV are excluded at a Yukawa coupling of electromagnetic strength, i.e. $\lambda'_{131} = 0.3$. For $M_{\tilde{t}} = 200$ GeV, couplings $\lambda'_{131} \gtrsim 0.03$ are ruled out and for $M_{\tilde{t}} = 275$ GeV the allowed domain is $\lambda'_{131} \lesssim 0.3$.

References

1. A. Aktas *et al.* [H1 Collaboration], “Search for Squark Production in R–Parity Violating Supersymmetry at HERA”, submitted to Eur. Phys. J. C, DESY-04-025, hep-ex/0403027.
2. A. Aktas *et al.* [H1 Collaboration], “Search for bosonic stop decays in R–parity violating supersymmetry in e^+p collisions at HERA”, submitted to Phys. Lett. B, DESY-04-084, hep-ex/0405070.