SEARCHES FOR R-PARITY VIOLATING SUPERSYMMETRY AT HERA

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Searches for R-parity violating supersymmetry performed at the H1 experiment are presented. Emphasis is put on searches for squarks, which may be resonantly produced at the HERA ep collider in supersymmetry where R-parity is violated. The preliminary results presented here were obtained using data collected at a centre-of-mass energy of 320 GeV and corresponding to an integrated luminosity of 63 pb^{-1}.

1 Introduction

Searches for minimal supersymmetry (SUSY) at HERA with conservation of the so-called R-parity (R_p) have been performed by both the H1 and ZEUS experiments [1] at the HERA ep collider, looking for the production of a selectron-squark pair. HERA's sensitivity in such supersymmetric frameworks is however limited, when taking into account the mass range allowed by other experiments.

On the other hand, HERA is very well suited to search for squarks which possess R-parity violating ($\not{R}_p$) interactions. The resonant production of such squarks is adressed here, using H1 e^+p data collected in 1999-2000 and corresponding to an integrated luminosity of $\sim$ 63 pb^{-1}. Earlier squark searches performed using a lower statistics sample of H1 e^+p data collected at $\sqrt{s} =$ 300 GeV are published in [2].

2 Phenomenology of $\not{R}_p$ Supersymmetry at HERA

The most general SUSY theory which preserves the gauge invariance of the Standard Model (SM) allows for Yukawa couplings between two known SM fermions and a squark or a slepton. Such couplings do not conserve the R-parity, defined as $R_p = (-1)^{3B+L+2S}$ where S denotes the spin, B the baryon number and L the lepton number of the particles. The $\not\! R_p$ interactions which are the most relevant for HERA [3] allow the resonant production of $\tilde{u}_L^j$ and $\tilde{d}_R^k$, respectively the SUSY partners of the left-handed u^j and right-handed d^k quarks, where j and k denote generation indices. The relevant processes in e^+p collisions, $e^+d^k \to \tilde{u}_L^j$ and $e^+\bar{u}^j \to \tilde{d}_R^{k*}$, are mediated by the so-called λ'_{1jk} coupling. The sensitivity is thus highest for the $\tilde{u}_L^j$ production via λ'_{1j1}, due to the most favorable parton density.

Although the strength of the coupling λ'_{111} is severely constrained by the non-observation of neutrinoless double-beta decay, no such strong bounds exist on the other λ'_{1j1} couplings, allowing for potential large cross-sections at HERA. For example with $\lambda'_{1j1} = 0.3$ the production cross-section of a 290 GeV $\tilde{u}_L^j$ squark is ~ 0.2 pb for $\sqrt{s} = 320$ GeV. That is a factor of ~ 10 larger than the corresponding cross-section for $\sqrt{s} = 300$ GeV.

When the produced squark undergoes an $\not\! R_p$ decay the final state consists of a lepton and a quark. Final states with a larger multiplicity arise from R_p conserving decays of the squark into a quark and a neutralino, a chargino or a gluino. These gauginos, including the lightest one assumed to be the lightest supersymmetric particle (LSP), are not stable and decay either directly via $\not\! R_p$ into a lepton and two jets (mainly relevant for the LSP), or into lighter gauginos. The various decay chains lead to final states with several jets and one or several leptons.

3 Analysis

When the squark undergoes a $\not\! R_p$ decay into a quark and an electron, the final state is similar to that of high Q^2 Neutral Current (NC) Deep Inelastic Scattering (DIS), Q^2 denoting the square of the four-momentum carried by the exchanged boson. The characteristic angular distribution for the decay products of a scalar particle is used to reduce the DIS background. The invariant mass in the centre-of-mass of the hard-subprocess is reconstructed with a resolution of $3 - 6$ GeV for signal events. The observed invariant mass distribution does not show any resonant peak, and agrees well with the SM expectation up to the highest masses.

Final states resulting from an R_p conserving squark decay have been classified into several final states, depending on the number and nature of the final state lepton(s). As an example, Fig. 1 shows the observed and expected invariant mass distributions for events with an e^+ and several jets in the final state. Such final states might arise from the $\tilde{u}_L^j$ decay into a neutralino, followed by the $\not{R}_p$ decay of the latter into a positron and two jets. A good agreement is observed with the SM prediction. No striking event $e^+p \rightarrow e^- + \text{jets} + X$ showing an explicit violation of the lepton number (characteristic of $\not{R}_p$ induced by a λ' coupling) has been observed. The signal has also been looked for in channels with a neutrino and several jets, and with several leptons (ee, $e\mu$, $e\nu$, $\mu\nu$) and several jets. No discrepancy with the SM prediction has been observed.

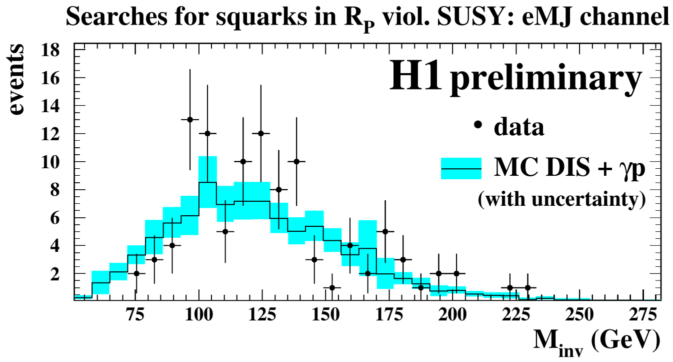

Figure 1: Distribution of the invariant mass of events with a positron and several jets in the final state.

4 Constraints on SUSY models

Upper bounds on the production cross-section of a $\tilde{u}_L^j$ are derived, combining all analyzed channels. In SUSY models[1] inspired from the Minimal Supersymmetric Standard Model (MSSM), the channels considered in this analysis cover $\sim$ 100% of the squark decay modes. These bounds are translated into constraints on the parameters of SUSY models.

Fig. 2 (left) shows upper limits on the Yukawa coupling λ'_{1j1} for $j = 1, 2$ as a function of the $\tilde{u}_L^j$ mass. These are obtained in a "phenomenological"

[1] More details about the models considered here can be found in [2] and references therein.

MSSM, where the gaugino masses are related to each other while the sfermion masses are free. A scan of the parameter space is performed, which shows that the obtained limits do not depend strongly on the model parameters. For a coupling of the electromagnetic strength ($\lambda' = 0.3$) squark masses up to ~ 280 GeV are excluded. Limits obtained on the coupling λ'_{121} extend beyond the bounds from low energy experiments. That is also the case for the coupling λ'_{131} (not shown), which could allow for resonant stop production at HERA.

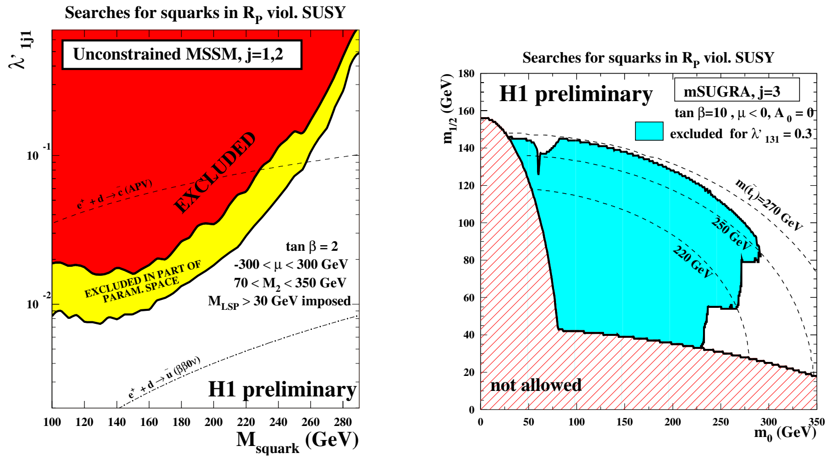

Figure 2: (left) Upper limits for the coupling λ'_{1j1} ($j = 1, 2$) as a function of the squark mass, in the "phenomenological" MSSM; (right) Constraints obtained in the mSUGRA model, assuming $\lambda'_{131} = 0.3$.

Example constraints obtained in the framework of the minimal Supergravity (mSUGRA) model are shown in Fig. 2 (right). Here, a common mass m_0 ($m_{1/2}$) is assumed for the scalars (gauginos) at the Grand Unification scale. Fig. 2 (right) shows the excluded domain in the ($m_{1/2}$, m_0) plane which is obtained assuming a coupling $\lambda'_{131} = 0.3$. Under this hypothesis stop masses up to ~ 270 GeV can be ruled out. The future sensitivity of the Tevatron experiments on light stop squarks might be around 200-250 GeV, depending on the main decay modes of the stop. A reasonably large coupling λ'_{131} would thus provide an interesting discovery potential for the stop at HERA, with the much larger integrated luminosity expected within the next years.

5 Other interesting topologies

In the results presented above solely fermionic decays of squarks were considered. In some SUSY models [4] where e.g. the sbottom is light, a resonantly produced stop might decay into a sbottom and a W boson, with cross-sections of ~ 1 pb being possible. This would be a source of events with a hard lepton, a hard jet and a large amount of missing transverse energy. A slight excess of such events is actually observed in the H1 experiment [5].

Other interesting events with several electrons in the final state have also been reported by H1 [6]. An interpretation of these events involving the $R\!\!\!/_p$ resonant production of a sneutrino ($ee \to \tilde{\nu}_{\mu,\tau} \to ee$) via $e\gamma$ collisions is unlikely taking into account LEP bounds on such a process.

6 Conclusions and Prospects

Stringent bounds on $\tilde{u}_L^j$ squarks with R-parity violating interactions have been set by the H1 experiment. The analysis of $e^- p$ data taken in 98-99 will bring complementary constraints on $\tilde{d}_R^k$ squarks. The seven to ten-fold increase of integrated luminosity expected by 2006 could offer a large discovery potential for stop squarks provided that the relevant $R\!\!\!/_p$ coupling is not too small.

References

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