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First Search for the Minimal Supersymmetric Model at HERA

H1 Collaboration

Abstract

Using data of e^+p collisions at centre of mass energies of 300 GeV at HERA a search for the production of the supersymmetric partners of the Standard Model electrons and quarks was performed. Within the Minimal Supersymmetric Model the decay of these selectrons ($\tilde{e}$) and squarks ($\tilde{q}$) involves the lightest supersymmetric particle χ_1^0 leading to signatures of missing energy and transverse momentum. No signal was found and bounds were derived excluding a new parameter region for masses of $M_{\tilde{e}} + M_{\tilde{q}} < 110$ GeV. In contrast to results from $p\bar{p}$ colliders the limits obtained here are independent of the gluino mass.

1 Introduction and Phenomenology

Supersymmetry [1, 2] is presently considered to be a promising candidate for a theory beyond the Standard Model (SM) of particle physics. Especially the Minimal Supersymmetric extension of the Standard Model (MSSM) is as compatible with all experimental data as the SM, but no direct evidence for the new particles predicted has been found yet.

A search for the single production of $\tilde{q}$ in models with broken R-parity was presented already earlier [3]. Here data obtained at the HERA ep-collider is used for the first time as a test for the MSSM with conserved R-parity, for which the dominant process is expected to be the t-channel exchange of neutralinos leading to a $\tilde{e}$-$\tilde{q}$ pair.

The signature under study is the subsequent decay into SM fermions and the lightest supersymmetric particle which is assumed to be a neutralino ($\tilde{e} \rightarrow e\chi_1^0$, $\tilde{q} \rightarrow q\chi_1^0$). Since in these models the χ_1^0 is stable and does not interact notably with ordinary matter this leads to events with missing momentum and a lack of transverse collinearity between electron and quark jet. These features make such events clearly distinct from SM deep inelastic scattering (DIS) which is the dominant source of background.

In this paper it is assumed that the masses of the left and right handed states of the $\tilde{e}$ are identical. The same holds for the $\tilde{q}$ states and degeneracy of masses is also assumed for the superpartners of the four lightest quark flavours.

The further independent MSSM parameters are the ratio of the two Higgs field vacuum expectation values ($\tan\beta$), the higgsino mixing parameter (μ) and the mass parameter for the SU_2 gauginos (M_2). In order to simplify the scan of the MSSM parameter space the corresponding value for the U_1 gauge group is taken as $M_1 = \frac{5}{3}M_2 \tan^2\Theta_W$ as suggested by Grand Unifying Theories (GUT). No other GUT relations are used. The above parameters specify completely all masses and couplings involved.

2 Data selection

The event sample was collected by the H1 experiment in 1994 during collisions of positrons and protons with 27.6 GeV and 820 GeV respectively and corresponds to an integrated luminosity of 3 pb^{-1}. A detailed description of the H1 detector is given in [4].

A first set of cuts was used to select events with an electron of high transverse momentum $P_{T,e}$ with respect to the beams and with hadronic activity.

- One electron must be found with a calorimetric energy deposition that complies with the one expected for electro-magnetic showers and with transverse momentum $P_{T,e} > 10$ GeV, the polar angle measured with respect to the proton beam momentum direction $\Theta_{electron}$ in the range $10° < \Theta_{electron} < 130°$ and isolation in a cone of pseudorapidity - azimuthal angle ϕ of radius 0.5,

- the sum of the total transverse energy flow E_T and missing transverse momentum $P_{T,miss}$ has to be greater than 40 GeV in order to be sensitive to events with high, as well as low, invisible energy,

- the jet angle Θ_{had} reconstructed from the total hadronic energy flow has to exceed $6°$ in order to avoid large effects from particles lost in the beam pipe,

- a vertex has to be constrained from measured charged tracks within the range expected from beam parameters and

- showers from cosmic muons and muons in the proton beam halo are rejected.

These cuts ensure trigger efficiencies close to one, but do not yet separate the signal from DIS background. This is seen in figure 1 where the remaining data sample of 1537 events is compared with the SM–DIS expectation [5]. The differential distribution of the missing transverse momentum is strongly peaked at small $P_{T,miss}$ which is indicative for the transverse energy containment and resolution of the detector. These observations are compared to the expectation for $\tilde{e}$-$\tilde{q}$ production with masses $M_{\tilde{e}}, M_{\tilde{q}} = 50$ GeV, $M_{\chi_1^0} = 35$ GeV showing how distinct the signal and the SM predictions are.

In order to enhance the signal and to reduce the SM background

- the missing transverse momentum has to exceed 5 GeV,

- the sum of the missing transverse momentum and the missing longitudinal momentum (Σ_{miss}) must exceed 20 GeV and

- the electron and the jet should not be collinear in the transverse plane, i.e. $|\phi_e - \phi_{had}| < 175°$.

After these cuts an efficiency of typically 40 – 60% for the signal is maintained for mass differences between the $\tilde{e}$ and the χ_1^0 of $M_{\tilde{e}} - M_{\chi_1^0} > 12$ GeV. For small mass differences less energy remains for the electron and the efficiency is reduced correspondingly. Based on a Monte-Carlo simulation of approximately fourfold data statistics no SM event is expected.

Also in the data no candidate events remain after these cuts.

2.1 Results

Taking into account constrains from the invisible width of the Z^0 and the fact that no decays of the Z^0 into sfermions or gauginos have been observed, the remaining MSSM parameter space not yet excluded was scanned in small steps. Altogether about 10000 parameter points have been evaluated. Particle masses and branching ratios of $\tilde{e}$ and $\tilde{q}$ into the χ_1^0 have been calculated using a modified version of the program ISASUSY [6]. Given the helicity amplitudes for the interference of the four neutralino exchange diagrams [7] the production cross section times branching ratios was determined at each parameter point [8]. After parton showers, fragmentation and decay [9] the resulting events were smeared for detector resolution and acceptance and detection efficiencies were derived.

The 95% confidence level exclusion limits in the M_2-μ plane for a fixed mass of $M_{\tilde{e}} + M_{\tilde{q}} = 100$ GeV and 110 GeV are shown in figure 2 for different values of $\tan\beta$ together with the existing bounds from Z^0 decays. Systematic uncertainties due to the luminosity measurement, the absolute normalization of the energy scales in the calorimeter and the choice of the quark density functions in the proton modify the cross section limits by 3%, 2% and 5% respectively leading to an uncertainty of the derived mass bounds of approximately 2 GeV.

The predicted cross section is highest for small $\tan\beta$ and μ making an as yet untested part of the MSSM parameter space accessible. For values of $\tan\beta > 3$ and positive μ

only small parts of the remaining parameter space can be excluded. The exclusion limits decrease rapidly when $M_{\tilde{e}} + M_{\tilde{q}}$ exceeds 110 GeV. Below this mass new limits in the supersymmetric parameter space are established.

Depending on M_2, μ and $\tan\beta$ masses of 45 – 55 GeV for $\tilde{e}$ and $\tilde{q}$ can be excluded thereby exceeding LEP and SLC bounds [2]. The CDF and D0 collaborations at Fermilab have also obtained bounds on $\tilde{q}$ masses [2]. These however depend strongly on the gluino mass and are more restrictive only in the case of small gluino masses. Further relations from GUT's have to be assumed in addition to the MSSM in order to compare the two results.

Acknowledgments

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Search for Supersymmetry at HERA

H1

Preliminary

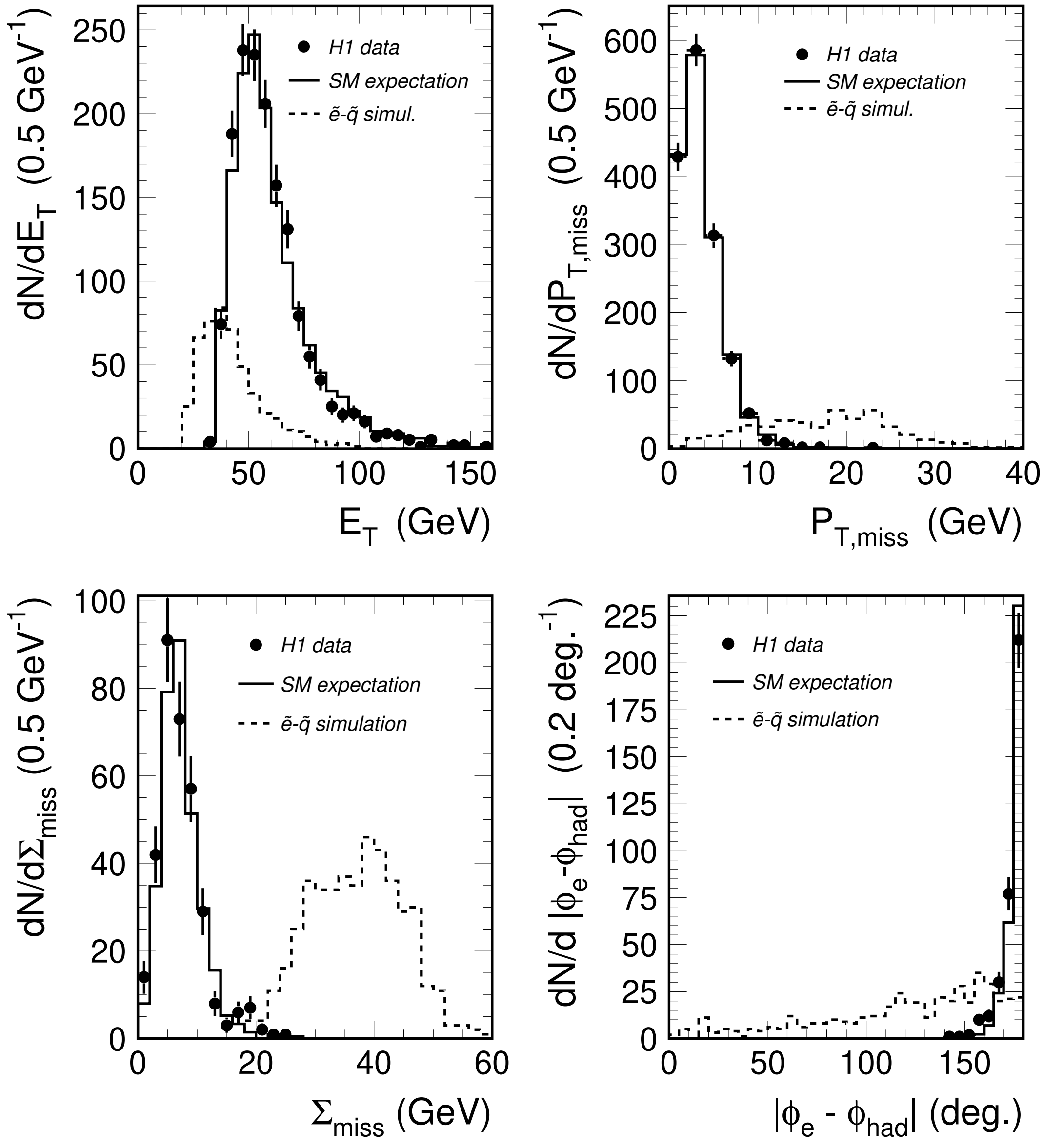

Figure 1: Distributions from data and SM expectation are shown in the variables E_T and $P_{T,miss}$ for the selected events with high P_T electrons and high $E_T + P_{T,miss}$. The simulation for $\tilde{e}$-$\tilde{q}$ production as described in the text is shown with arbitrary normalization by a dashed line. After the additional cut $P_{T,miss} > 5$ GeV the distributions of missing transverse plus longitudinal momentum Σ_{miss} and transverse collinearity of electron and jet $|\phi_e - \phi_{had}|$ in the lower two plots show good separation between signal and background. After the cuts $\Sigma_{miss} > 20$ GeV and $|\phi_e - \phi_{had}| < 175°$ no candidate events remain in data.

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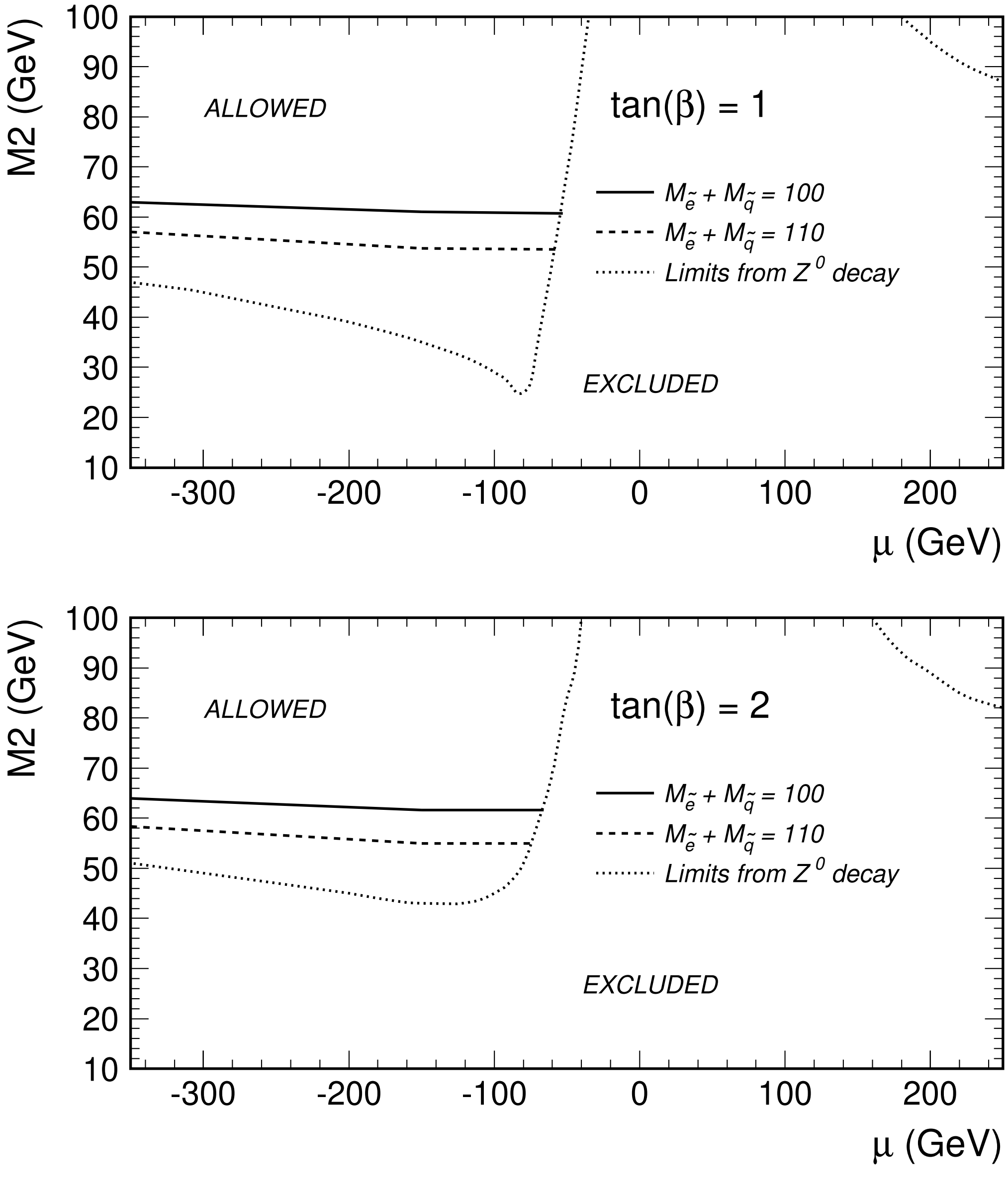

Figure 2: Domains in the M_2-μ plane excluded at 95% confidence level by our search for $\tilde{e}$-$\tilde{q}$ production at HERA. The limits are shown for two values of $\tan\beta$ and for masses $M_{\tilde{e}} + M_{\tilde{q}}$ of 100 GeV and 110 GeV. Within those mass constraints the bounds on M_2 and μ from Z^0 decays (shown by the dotted line) are improved. Conversely, a new domain for observation of MSSM particles is reached at HERA.