PROCEEDINGS

Search for R_p-violating SUSY and excited fermions at HERA

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Abstract: Recent results from searches for physics beyond the Standard Model (SM) in $e^{\pm}$-proton collisions at a center of mass energy of 300 – 318 GeV at HERA are presented. Searches for excitations of fermions and for the production of squarks in R-parity-violating Supersymmetry (SUSY) are reviewed.

1. Introduction

At the HERA collider, electrons (positrons) and protons collide at a center of mass energy of about $\sqrt{s} = 318$ GeV (300 GeV before 1998). Since 1994, integrated luminosities of about $\mathcal{L} = 110$ pb^{-1} in e^+p and $\mathcal{L} = 15$ pb^{-1} in e^-p scattering have been collected by each of the two experiments H1 and ZEUS. These data are used to search for new physics beyond the SM. Recent results on searches for excited fermions and for R-parity-violating SUSY are presented in this contribution.

2. Excited fermions

Fermionic substructure as predicted in compositeness models naturally leads to excitations of fermions. At HERA, such excited fermions could be singly produced via the t-channel exchange of a gauge boson, and would subsequently decay into a SM fermion and a boson. In the 1994–97/1999–2000 e^+p and the 1998–99 e^-p data, both collaborations have found no evidence for a deviation from the SM due to excited electron[1], neutrino or quark production, which decay into γ, Z or W and a SM fermion, followed by the subsequent decay of the boson into e, μ, ν or hadrons.

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[1]If not particularly emphasized, *electron* can mean either an electron or a positron.

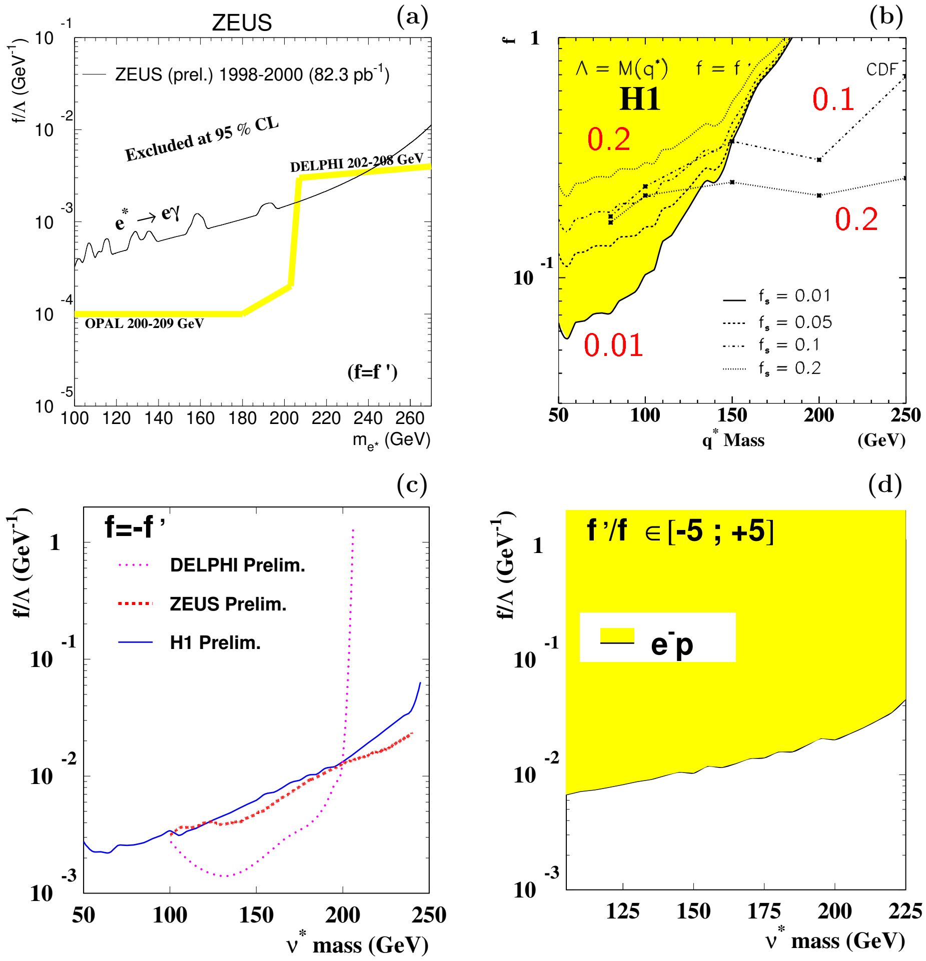

Figure 1: (a) ZEUS upper limits on f/Λ, under the assumption $f = f'$, as a function of the excited electron mass are compared to those from OPAL and DELPHI. (b) H1 upper limits on f, under the assumptions $f = f'$ and $\Lambda = M(q^*)$ for different values of f_s, as a function of the excited quark mass are compared to CDF results. (c) ZEUS and H1 upper limits on f/Λ, under the assumption $f = -f'$ as a function of the excited neutrino mass, are compared to those of DELPHI. (d) H1 upper limits on f/Λ, as a function of the excited neutrino mass, are presented for arbitrary ratios f'/f.

To determine the experimental sensitivity, the data have been interpreted in the framework of a compositeness model where the excited fermion f^* is a composite of a scalar and a spin $\frac{1}{2}$ constituent [1]. If f^* carries spin and isospin $\frac{1}{2}$, the effective Lagrangian reads [2]

$$\mathcal{L}_{eff} = \frac{1}{2\Lambda}\,\bar{F}^*_R\,\sigma^{\mu\nu}\,(\,gf\,\frac{\tau^a}{2}\,W^a_{\mu\nu} + g'f'\,\frac{Y}{2}\,B_{\mu\nu} + g_s f_s\,\frac{\lambda_a}{2}\,G^a_{\mu\nu}\,)\,F_L \quad + \quad h.c.\ , \qquad (2.1)$$

with the standard electroweak and strong couplings denoted by g, g' and g_s and the SM gauge field strength tensors $W^a_{\mu\nu}$ (SU(2)), $B_{\mu\nu}$ (U(1)) and $G^a_{\mu\nu}$ ($\mathrm{SU(3)_C}$). τ^a, Y and λ_a are the Pauli matrices, the weak hypercharge operator and the Gell-Mann matrices, respectively. The new couplings between the weak isodoublets F^*_R, F^*_L of the excited fermion fields and the SM fermion fields F_R, F_L are modified by f, f' and f_s. The compositeness scale is Λ. The coupling between e.g. a photon, an excited fermion and a SM fermion is given by $c_{\gamma f^* f} = \frac{1}{2}\ (f\ I_3 + f'\ \frac{Y}{2})$, where I_3 is the third component of the isospin of the fermion. Assuming relations between the new couplings, upper limits on f (or f/Λ) at the 95% confidence level (CL) have been obtained.

For excited electrons, the ZEUS upper limits have been improved recently by a factor of $2-3$ and are competitive with those from LEP for larger masses m_{e^*} [3] as can be inferred from Figure 1a. Figure 1b shows that, for small values of f_s, the H1 upper limits on f ($f = f'$; $\Lambda = M(q^*)$) for excited quarks are more restrictive than those of the TeVatron for not too large masses $M(q^*)$. The HERA results obtained on q^* production via the electroweak couplings f and f' are complementary to the results obtained at the TeVatron, where q^* production occurs via the strong coupling f_s.

From Figure 1c it can be seen that the H1 [4] and ZEUS [5] upper limits on f/Λ ($f = -f'$) for excited neutrinos deliver a unique sensitivity beyond the LEP center of mass energy.[2] In addition, H1 has obtained less model-dependent upper limits on f/Λ for arbitrary ratios f'/f [6]. This is presented in Figure 1d. Since ν^* results were obtained from a relatively small amount of e^-p [3] data, new e^-p luminosity from 2001 (see Section 4) will give substantially higher sensitivity to excited neutrinos and are expected to improve on the LEP limits, even for masses below 200 GeV.

3. Squarks in R-Parity-violating SUSY

In the Minimal Supersymmetric Standard Model (MSSM), there is a multiplicative quantum number called R-Parity which is defined by $R_p \equiv (-1)^{3B+L+2S}$, with the baryon number is denoted B, the lepton number L and the spin quantum number S. For SM particles (sparticles, the supersymmetric partners of the particles), this quantum number acquires the value $R_p = 1$ ($R_p = -1$). The R_p-conserving MSSM has been investigated at HERA in the associated $\widetilde{e}\,\widetilde{q}$ (selectron-squark) production [7].

However, the most general supersymmetric and gauge-invariant superpotential contains three R-Parity-violating Yukawa coupling terms, two operators mediating L violation and one B violation [8]. Of particular interest for HERA are the terms $\lambda'_{ijk} L_i Q_j \bar{D}_k$ with L_i (Q_j) the lepton (quark) $SU(2)_L$ doublet superfields and $\bar{D}_k$ the down-quark $SU(2)_L$ singlet superfields [9]. The R-Parity-violating dimensionless coupling constants are called λ'_{ijk} , where i, j, k denote the generation. For non-vanishing λ'_{1jk} , the resonant production of single squarks is possible in ep scattering. At HERA with an e^+ beam, predominantly the λ'_{1j1} couplings are probed.

Both H1 and ZEUS have searched for squark production using e^+p data from 1994–97 at a center-of-mass energy $\sqrt{s} = 300$ GeV distinguishing between R-Parity-violating ℓq ($\ell = e, \nu$) decays leading to lepton + jet topologies and decays into the superpartner of a gauge boson (gaugino) leading to lepton(s) + multi-jets topologies in the final state. The gaugino can decay to a lepton (e or ν_e) and two quarks with the same λ' coupling. It

[2] A similar picture can be found for the upper limits for excited quarks.

[3] In this case, e^-p scattering is superior to e^+p because the dominant valence quark interaction is helicity suppressed and has smaller parton densities in e^+p (d) compared to e^-p (u).

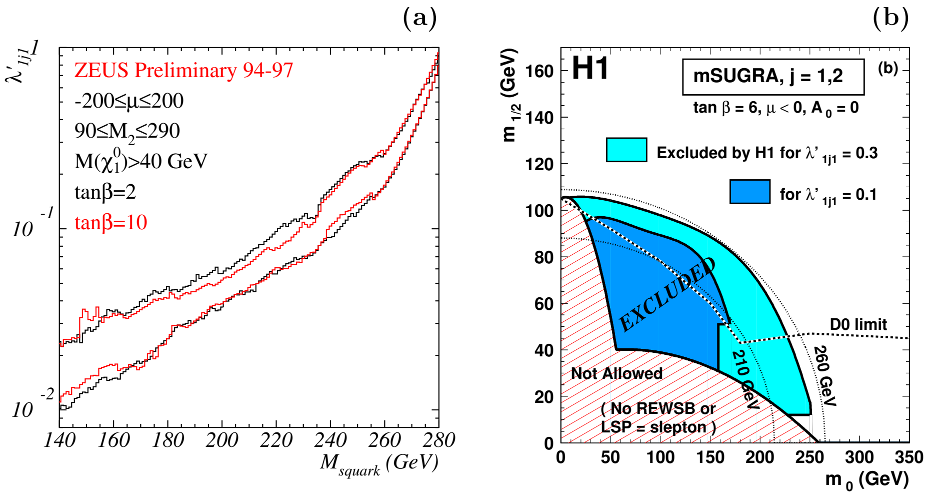

Figure 2: (a) as a function of the squark mass, for two values of $\tan\beta$, the upper and the lower curves give the maximal and minimal values for the upper limits on the R-Parity-violating SUSY coupling λ' (unconstrained MSSM) when varying μ and M_2. (b) for $\tan\beta = 6$ and two values of λ' (mSUGRA scheme), the excluded region in the (m_0,$m_{1/2}$) plane is depicted. The region below the dashed curve is ruled out by the D0 experiment. The contours for equal squark masses are also shown.

also can decay to a lighter gaugino and two fermions. H1 and ZEUS found no evidence for squark production. The results translate to constraints in SUSY parameter space in various scenarios.

Limits on R-Parity-violating couplings have been derived in the unconstrained MSSM where the sfermion and gaugino sector are assumed to be unrelated. The sfermion masses are free parameters. A scan in the SUSY parameter space (M_2,μ), M_2 being the soft SUSY breaking mass term and μ the mixing mass term for 2 Higgs doublets, has been performed for two different values of $\tan\beta$, the ratio of the vacuum expectation values of the two neutral scalar Higgs fields. As a result, Figure 2a presents the ZEUS upper limits on λ'_{1j1} as a function of the squark mass [10]. They are widely SUSY parameter independent. For $\widetilde{c}$ and $\widetilde{t}$ production the constraints on λ'_{1j1} are more stringent than the indirect bounds from atomic parity violation measurements [11, 12].

H1 also sets limits [12] in constrained models where the sfermion and gaugino sector are related at the GUT scale and evolved down to the electroweak scale by the Renormalization Group Equations. Minimal Supergravity (mSUGRA) models assume, in addition, that the electroweak symmetry breaking is driven by radiative corrections. This leads to 5 independent parameters: $\tan\beta$, the sign of μ, the common scalar mass m_0, the common gaugino mass $m_{1/2}$ and the common trilinear coupling at the GUT scale A_0. Figure 2b shows the H1 limits for fixed values of λ' and $\tan\beta$ in the (m_0,$m_{1/2}$) plane for $\widetilde{u}$, $\widetilde{c}$ production. Here, for reasonably large values of the Yukawa coupling (even as small as 0.1), H1 probes a domain which is not ruled out by the (λ' independent) TeVatron limits. For λ'_{1j1} values of the electromagnetic strength (≈ 0.3), squark masses below 260 GeV are ruled out. However, it should be noted that LEP has the highest sensitivity for $\widetilde{u}$, $\widetilde{c}$ production, while for $\widetilde{t}$ production for intermediate values of m_0 the H1 sensitivity is comparable with LEP. Note that the results are from 1994–97 data, and there are further data taken since 1998 at a higher center-of-mass energy, 318 GeV. There are also decays not yet investigated, for example $\widetilde{t} \to \widetilde{b} + W^+$, which can produce an event topology with an isolated lepton and missing transverse momentum, accompanied by a hadronic system with large transverse momentum. It is noteworthy that H1 observes an excess above the SM prediction in this topology [13].

4. Summary and prospects

In the HERA searches for R-Parity-violating SUSY and for excited fermions, no evidence for physics beyond the SM has been found. New constraints on squark production in R-Parity-violating SUSY and for excitations of electrons, neutrinos and quarks have been obtained. The HERA limits complement and are competitive with those of the LEP and TeVatron searches. After the HERA detector and luminosity upgrade in autumn 2001, HERA2 will accumulate approximately 1 fb^{-1} of luminosity. Thus, a remarkably enhanced discovery potential will be available for the analyses presented here. In particular, the polarized $e^\pm$ beams will lead to an increased squark production cross section and sensitivity.

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