RECENT RESULTS IN PHYSICS BEYOND THE STANDARD MODEL AT HERA

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Recents results in Physics beyond the Standard Model at the e^+p collider HERA with the H1 and ZEUS detectors are presented. As no evidence for excited fermions or MSSM supersymmetric particles has been found using an integrated luminosity up to 20 pb^{-1}, new limits are derived. The status of events with an isolated high energy lepton and missing transverse momentum is also reported.

1 Introduction

Due to the lepton-quark initial state and the high centre of mass energy $\sqrt{s} = 300$ GeV, the e^+p collider HERA provides opportunities in searches for new Physics and complements those from LEP and TEVATRON.
Results presented concern the search of excited fermions using an integrated luminosity of 9.4 pb^{-1}. In a second part, preliminary results on the search of supersymmetric particles will be reported. Finally, a preliminary search for events with isolated leptons and missing transverse momentum from either ZEUS and H1 experiments will be discussed.

2 Search for excited fermions

The observation of excited states of quarks or leptons would be evidence for a new substructure of fermions as predicted in theories of compositeness. At HERA, single excited fermions are produced by the t channel exchange of a virtual gauge boson between the incoming positron and one quark of the proton, with masses up to 300 GeV. The process is $ep \to f^* X$, $f^* \to fV$, as shown in figure 1. The resonance f^* is searched for through its electroweak decay into a light fermion f and a gauge boson V.

To describe the excited fermion production and its decays, it is conventional to use the phenomenological model of Hagiwara, Komamiya and Zeppenfeld [1], extended to include excited quark production by Baur, Spira and Zerwas [2]. The effective Lagragian relating the transitions from spin $\frac{1}{2}$ excited state f^* into the ground state f is:

$$\mathcal{L}_{f^*f} = \frac{1}{\Lambda} f^* \sigma^{\mu\nu} [g f \frac{\tau}{2} W_{\mu\nu} + g' f' \frac{Y}{2} B_{\mu\nu} + g_s f_s \frac{\lambda}{2} G_{\mu\nu}] f + h.c \tag{1}$$

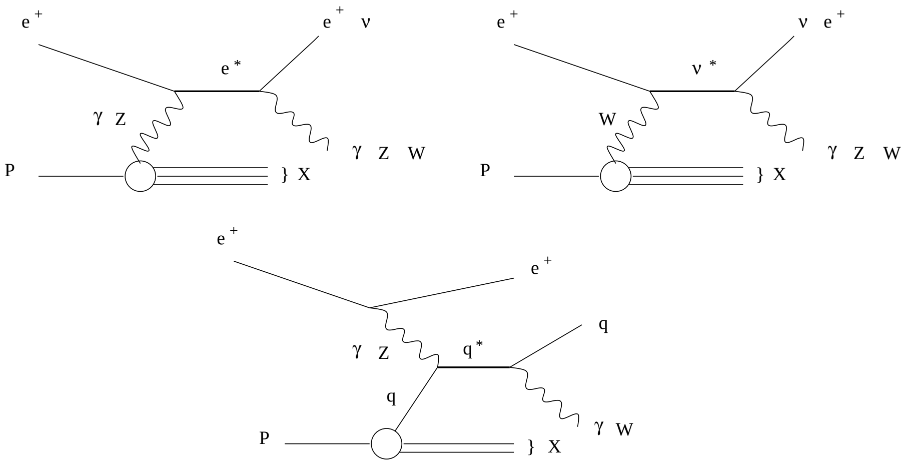

Figure 1: Production diagrams of excited electron, neutrino and quark at HERA. Only the decay modes considered in this search are represented.

where f, f' and f_s are the composite coupling constants associated to the gauge groups SU(2), U(1) and SU(3) respectively, and Λ is the compositeness scale.
The following assumptions are made to relate these unknown constants and reduce the cross-section dependance to a single parameter, f/Λ. For the excited electron and quark search, $f = f'$ is chosen, while for the excited neutrino, $f = -f'$ to allow the radiative decay. For the excited quark, f_s is set to 0, in order to explore electroweak production of such particles.
The ZEUS [3] search for excited fermions was performed using an integrated luminosity of 9.4 pb^{-1} through 11 decay channels listed in table 1. The H1 [4] collaboration also performed an excited fermion search with an integrated luminosity of 2.8 pb^{-1} .

	e^*			ν^*			q^*	
Final States	$e\gamma$	eZ^0 $\rightarrow eq\overline{q}$ $\rightarrow e\nu\overline{\nu}$	νW $\rightarrow \nu q\overline{q}'$ $\rightarrow \nu e\nu$	$\nu\gamma$	νZ^0 $\rightarrow \nu q\overline{q}$	eW $\rightarrow eq\overline{q}'$ $\rightarrow ee\nu$	$q\gamma$	qW $\rightarrow qe\nu$

Table 1: The decay modes and final states considered in the ZEUS search for excited fermions.

In the absence of a positive signal for excited fermions in any of the channels studied, upper limits on the characteristics of the coupling f/Λ as a function of the excited fermion mass were derived at 95% confidence level (C.L).

Figure 3 shows these limits for e^*, ν^* and q^* production in each of the decay channels considered and using the assumptions described above. Stringent limits are given for the radiative decay $f^* \rightarrow f\gamma$ in each case.
For the ν^*, the limit from a previous ZEUS search in e^-p collisions with an integrated luminosity of 0.55 pb^{-1} is more stringent for ν^* masses above 130 GeV. This is because the ν^* production cross section in e^+p is heavily suppressed relative to e^-p. The 1998 e^-p beam runs will improve this limit.
Assuming $f/\Lambda = 1/M_{f^*}$, exclusion limits on the excited fermions masses can be determined. At 95% C.L excited electrons are excluded in the mass range between 30-200 GeV, excited neutrinos with masses in the range 40-96 GeV, and excited quarks with electroweak couplings over the range 40 to 196 GeV.
Figure 3 shows limits provided by LEP [5]. In e^+e^- collisions, excited leptons (e^*, μ^*, τ^*, ν^*) may be pair or single produced. At 95% C.L, any excited leptons with mass below 80 GeV have been excluded in pair production (independant of the couplings). In single production, this limit in terms of f/Λ is extended and shown in figure 3. The TEVATRON experiments [6] provided stringent limits on q^* production in $p\overline{p}$ collisions at $\sqrt{s} = 1800$ GeV. Excited quarks are excluded with masses between 80 and 760 GeV except for a window between 570-580 GeV. These limits are valid assuming strong couplings (excited quarks are produced in quark-gluon fusion).
Therefore, HERA extends the mass range well beyond the 170 GeV limits achieved at LEP and offers unique sensitivity for excited quarks electroweakly produced.

3 Search for selectrons and squarks

Supersymmetry is a promising theory beyond the Standard Model. Within the Minimal Supersymmetric Standard Model (MSSM), the R-parity is conserved. This implies that SUSY particles can only be produced in pairs and the lightest supersymmetric particle (LSP), the neutralino χ^0_1, is stable and as it weakly interacts, will escape detection.
At HERA, the dominant process is the production of a squark ($\tilde{\mathrm{q}}$) and a selectron ($\tilde{\mathrm{e}}$) in the t-channel exchange of a χ^0, $ep \rightarrow \tilde{\mathrm{e}}\tilde{\mathrm{q}}X$ as shown in the figure 2. Although the $\tilde{\mathrm{q}}$ and the $\tilde{\mathrm{e}}$ decay into their SM partner and any lighter gaugino, the cleanest signature involves both $\tilde{\mathrm{e}} \rightarrow \mathrm{e}\chi^0_1$ and $\tilde{\mathrm{q}} \rightarrow \mathrm{q}\chi^0_1$ and is considered for the search of these particles. The final experimental topology then consists of an electron which is acoplanar to the jet and missing transverse momentum.

H1 [7] published results with an integrated luminosity of 6,4 pb^{-1}. The ZEUS search [8], discussed here, uses an integrated luminosity of 20 pb^{-1}. No

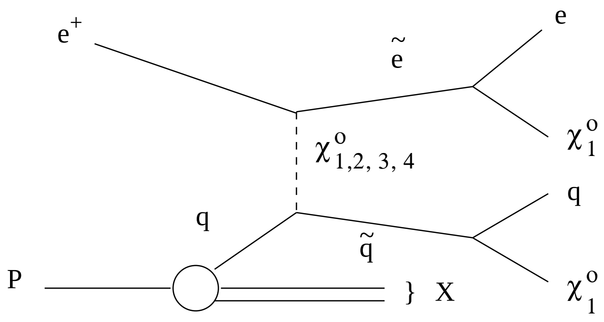

Figure 2: selectron and squark production via neutralino exchange and their decay into their SM partner and the LSP.

signal was observed (2 events left for a SM expectation of 2.74 $\pm$ 0.47) and preliminary exclusion limits on $\tilde{\mathrm{e}}$ and $\tilde{\mathrm{q}}$ production were derived at 95% C.L. These limits are given as exclusion regions in MSSM parameter space. The parameters are the U(1) and SU(2) gaugino mass terms M_1 and M_2, the Higgs mass term μ and the ratio of the vacuum expectation values of the neutral Higgs fields $\tan\beta$.
Figure 4 shows the exclusion limits on M_2 versus μ, for $\tan\beta = 1.41$ and $M_2 = 2M_1$, good approximation of the relation $M_1 = \frac{5}{3}M_2 \tan^2\theta_W$. For $\mu \ll$0, the χ_1^0 is dominated by its photino component leading to couplings to the selectron and squark which are electromagnetic and allow for a sizable cross section. As $\mu \simeq 0$ the χ_1^0 is higgsino-like and the cross section becomes very small. ZEUS limits are compared to those from LEP [9] neutralino and chargino searches (dotted line on figure 4). HERA provides an improvement at low values of μ.
Figure 5 shows the excluded region in $M_{\tilde{\mathrm{e}}}$ versus $M_{\tilde{\mathrm{q}}}$ for differents values of the χ_1^0 mass and for $\tan\beta = 1.41$ and $\mu =$ -500 GeV. For $M_{\chi_1^o}$ =40 GeV, squarks with masses between 55 GeV and 89 GeV are excluded for $M_{\tilde{\mathrm{e}}}$ = 46 GeV, while selectrons having masses between 55 GeV and 92 GeV are excluded for $M_{\tilde{\mathrm{q}}}$ = 46 GeV. The LEP [10] limits are also indicated. HERA results exclude a further region at high selectron and low squark masses. The results also complement those from TEVATRON [11] because no assumption is made on the gluino mass.

4 Search for events with an isolated high energy lepton and missing transverse momentum

The H1 and ZEUS experiments have reported preliminary results concerning events with an isolated lepton of high energy and missing transverse momentum.
H1 [12] used an integrated luminosity of 25 pb^{-1}. The basic selection requiere-

ment is a missing transverse momentum greater than 25 GeV in the calorimetry [13] (inclusive selection). The search for an isolated lepton of high energy is based on the presence of an isolated track having a momentum greater than 10 GeV and matching an electromagnetic cluster or a muon. 5 events were left, 1 *electron*, 2 μ^+ and 2 μ^-.

The main process expected to yield a sizable rate of events with this kind of topology is the production and the decay of a $W^\pm$. The main contribution to the cross section is due to photoproduction interactions with radiation of a real $W^\pm$ from the quark line, followed by its leptonic decay ($ep \to eWX, W \to e^\pm\nu$ or $W \to \mu^\pm\nu$) with a total cross section of about 70 fb per channel and per charge. It is peaked at low values of the transverse momentum P_T^X of the recoil hadronic system X and shows a Jacobian peak at the W mass value in the lepton-neutrino transverse mass ($M_T^{\ell\nu}$) spectrum.

Figure 6 shows the expected distribution of W events in the (P_T^X,$M_T^{\ell\nu}$) variables. The corresponding values measured for the five events are indicated by ellipse contours. The muons events are accepted only when produced with a sizable P_T^X.

In total, 1.34$\pm$0.20 and 0.41$\pm$0.07 events are expected in the $e^\pm$ and $\mu^\pm$ channels respectively, while the other Standard Model contributions (heavy quarks and $\tau^+\tau^-$ pairs) are less than 0.05 events. Two of the five events are found in a region of phase space likely to be populated by $W^\pm$ production.

ZEUS has also performed a preliminary search for events with isolated lepton and missing transverse momentum using an integrated luminosity of 47 pb^{-1} (full 94-97 e^+p data). The selection requierements are divided into 2 parts: one to select electrons and the other one muons. The missing transverse momentum cut is lowered to 18 GeV. The isolated electron is defined by a track matching and electromagnetic cluster in the calorimeter while a muon is identified as a calorimeter minimum ionising particle and a track matching [14]. After this selection, 4 e^+ and no muon events where left.

Figure 7 shows the expected distribution of W events in the (P_T^X,$M_T^{\ell\nu}$) plane for the electron case. The Standard Model expectation is 3.46$\pm$0.35 events (2.22$\pm$0.02 events from W and 1.24$\pm$0.35 events from Neutral and Charged Current and e^+e^- pairs). For the muon case, this expectation is 1.30$\pm$0.23 events (0.46$\pm$0.02 event for W and 0.84$\pm$0.23 from Charged Current, $\mu^+\mu^-$ and $\tau^+\tau^-$ pairs).

As the SM expectation is compatible with the number of observed events, ZEUS derived upper limits on the total W cross section at 95% confidence level: $\sigma_{ep\to eW^\pm X}$ is greater than 3.9 pb in the electron case and above 2 pb in the muon case for a transverse hadron momentum greater than 20 GeV.

5 Conclusion

The ZEUS and H1 experiments have found no evidence for excited fermions or supersymmetric particles using an integrated luminosity up to 20 pb^{-1}. Upper limits at 95% confidence level were derived on excited electron and neutrino masses which are more stringent than the current limits from LEP. For the excited quark produced via electroweak mecanism, the limits complement those from TEVATRON where the strong production is assumed. New limits have also been established on SUSY particle production within the MSSM model. The observation of events having an isolated high energy lepton and missing transverse momentum in both experiments leads to interesting results. H1 observes 4 muons events which are not compatible with W expectation while ZEUS reports 4 positrons events compatible with W expectation. Further investigations are needed to conclude on the nature of these events.

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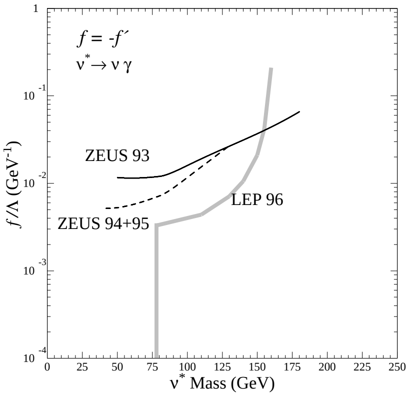
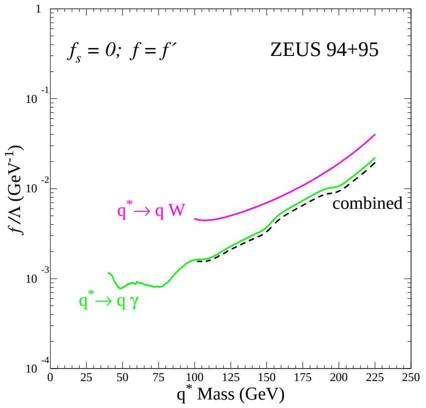
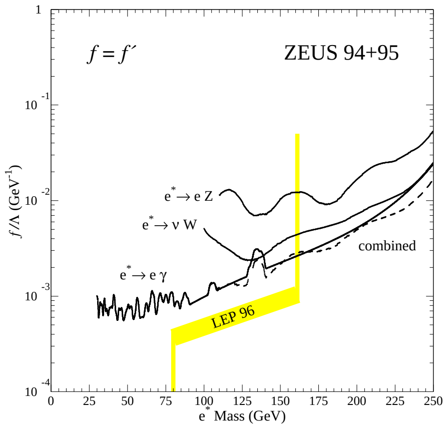


(a)



(b)



(c)

Figure 3: Limits on the characteristic coupling f/Λ as function of the excited fermion mass for ν^* (a), q^* (b) and e^* (c). Regions above the curves are excluded at 95% C.L. Limits from LEP are also reported with centre of mass energy up to 161 GeV.

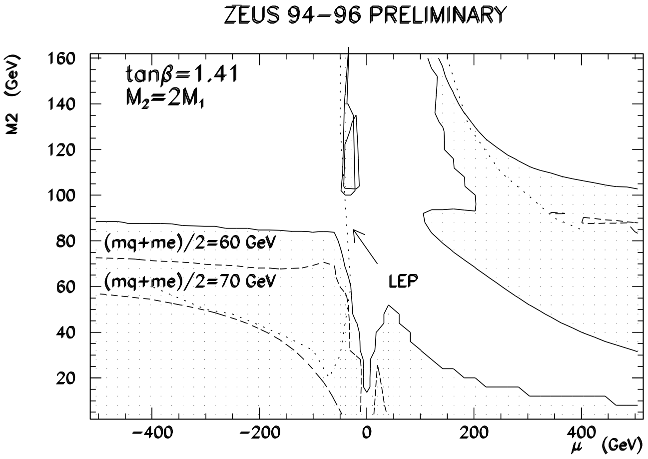


Figure 4: Excluded region at 95% C.L in the M_2 vs. μ plane for $\tan\beta$ = 1.41 and for $M_{\tilde{e}} = M_{\tilde{q}}$ = 60 GeV (full line) and 70 GeV (dashed). The region below the dotted line is excluded by LEP.

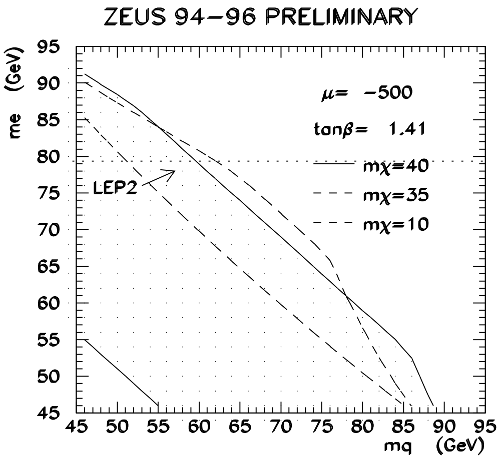


Figure 5: Excluded region at 95% C.L in the selectron mass vs. squark mass plane for fixed values of the neutralino mass, $M_{\chi_1^0}$ = 10 GeV (dash-dotted), 35 GeV (dashed), 40 GeV (full line) and for $\tan\beta$ = 1.41 and μ = -500 GeV. The selectron mass limit from LEP is also shown.

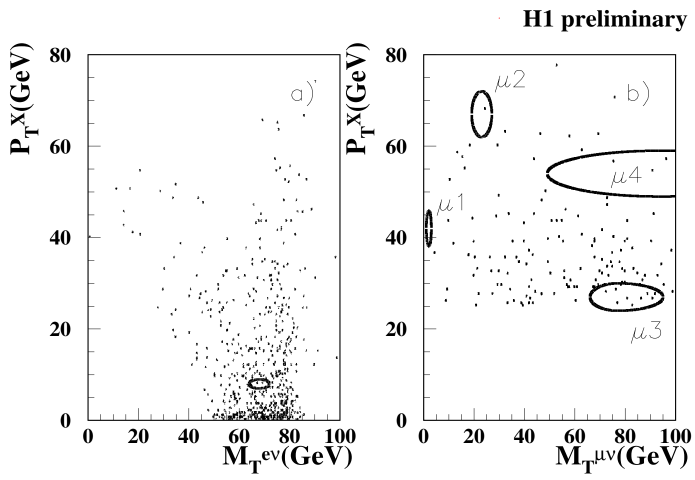


Figure 6: Distribution of the five H1 events (ellipses) in P_T^X and $M_T^{\ell\nu}$, a) electron channel and b) muon channel. The ellipse contours corresponds to the 1-sigma uncertainty on the measured parameters of each event. The points show the Standard Model expectation for W production and for an accumulated luminosity a factor 500 higher than in the data.

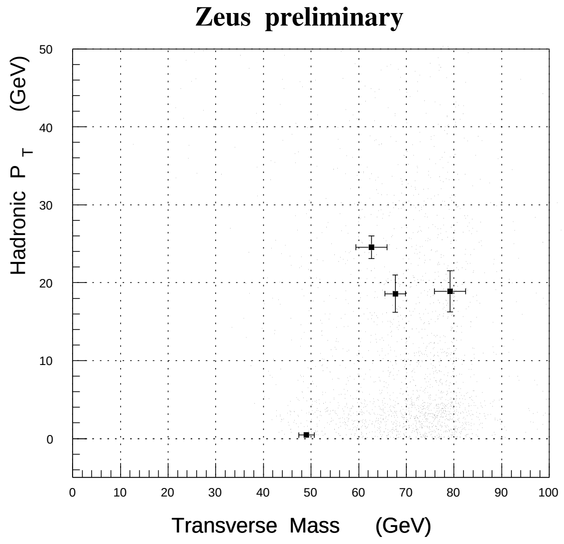


Figure 7: Distribution of the 4 e^+ ZEUS events in P_T^X vs. $M_T^{e\nu}$ plane. The points show the Standard Model expectation for W production and for an accumulated luminosity a factor 1000 higher than in the data.